# Systems Supporting Production Engineering

WYDAWNICTWO
P.A.NOVA

**Editor**
***Jan KAŹMIERCZAK***

# Systems Supporting Production Engineering

**GLIWICE 2013**

REVIEWERS:

| | |
|---|---|
| Prof. dr hab. inż. Barbara BIAŁECKA | Central Mining Institute |
| Doc. RNDr. Zdeněk BOHÁČ CSc. | VSB-TU Ostrava |
| Dr hab. inż. Mariusz LIGARSKI | Silesian University of Technology |

All articles have been double peer-reviewed by researchers having large and acknowledge domestic and international experience.

Every author is responsible for typographical layout and translation of article.

Covers project: Elżbieta MILEWSKA

ISBN 978-83-937845-0-9


ul. Górnych Wałów 42, 44-100 GLIWICE, POLAND
tel. +4832 400 41 02
fax. +4832 400 41 10



Gliwice 2013

# CONTENTS

# 1

# CHALLENGES FOR ERGONOMICS AND IMPROVEMENT OF WORKING CONDITIONS DURING SURGERIES WITH USE OF LAPAROSCOPIC TOOLS

## 1.1 INTRODUCTION

Surgical procedures are performed in the specific conditions of working environment. On the one hand, they have to ensure patient safety keeping the correctness of medical procedures and specified sanitary regimen, on the other hand, the work conditions should ensure the effectiveness in performing operations by surgeons.

The observed development of medical methods and techniques is focused on increasing the effectiveness of patient treatment. Together with this development increases the degree of complexity of medical equipment and with it changes in such areas as work organization in the operating room and requirements for the exploitation of the equipment. The results of these changes are certainly positive for a patient, but may raise specific problems for medical staff.

Firstly, there is a need to continuously improving the competencies of medical professionals in the field of computer science and engineering that are not normally taught in the path of training surgeons and nurses, as already has been signaled in [1, 2]. This need is caused by the necessity to handle complex medical devices which are based on up to date achievements in science and robotics. Secondly, complex medical equipment brings problems in the shaping of working conditions and ergonomics. They mainly refer to:

- deployment of extended medical devices with auxiliary equipment, such as cables, pipes, which reduce the effective working area [3],
- construction of surgical instruments and medical devices that determines the specific, often awkward surgeons' postures while performing by them surgical procedures,
- changes in a way of doing works from the dynamic, characterized by the free maneuvers of the surgeon, to the static with restricted mobility, as is the case by laparoscopic surgeries.

It can be hypothesized that the problems mentioned above are caused by lack of sufficient ergonomics awareness and poor preparation of contemporary medical staff and management staff in range of how to create ergonomic working conditions. This problem, however, is not a new problem. Already in the early 20th century Frank B. Gilberth, one of the precursors of the scientific approach to the work management, drew attention to the fact

that: „…surgeons could learn more about motion study, time study, waste elimination, and scientific management from industries than the industries could learn from hospitals” [4].

The considerations signaled above have become a background to take in-depth reflection on ergonomics in the field of surgery, especially laparoscopic surgery.

The Aim of the paper is to present the results of preliminary studies on ergonomic needs within performing laparoscopic procedures, which will be the basis for the development of vocational training in range of: creating work conditions in the operating room and ergonomic handling of laparoscopic tools.

Preliminary studies were carried out on the basis of five hospitals, where are normally performed laparoscopic procedures. Research methods are survey research, where questionnaire was developed by the Instituto de Biomecánica de Valencia in Spain, the coordinator of the project "Vocational Training Online course on laparoscopy's ergonomics for surgeons and laparoscopic instruments' designers”, as well as free interviews, direct observation and analysis of the literature.

## 1.2 CHALLENGING AREAS OF CREATING WORK CONDITIONS IN LAPAROSCOPIC SURGERIES

Laparoscopic surgery is one of the rapidly developing fields of minimally invasive surgery and is now used in all areas of general surgery [5].

The set used for laparoscopy include: trocars (tools for putting instruments into abdominal cavity), insufflator, visual track, which includes: video processor, light source, TV monitor, head, in addition diathermy and surgical tools to perform the surgery.

The popularity of laparoscopic methods is because of numerous benefits for patients. These are as follows:

- reduced post-operative complications, such as fever or infection,
- less pain,
- shortnes hospitalization,
- faster recovery time,
- faster and less problematic healing of surgical wounds, better cosmetic results.

Despite the undeniable benefits for patients, laparoscopic surgery has brought certain negative consequences for surgeons, formulating in effect the ergonomic challenges in this area. These challenges can be located in five areas:

- the first area is the ergonomics in posture while performing laparoscopic procedures,
- the second area is the ergonomics of working conditions and work organization in operating room,
- the third area concerns the improvement of ergonomic laparoscopic instruments,
- fourth area affects the mental aspects of the surgeons performing laparoscopic procedures,
- the fifth area is the design of ergonomic specific products supporting the work of the laparoscopic surgeons.

### The first area

Laparoscopic surgery has changed the way of surgeons interactions in the operating

field, what is revealed by a change in their posture and movements of the upper limbs. Laparoscopic surgeons tend to maintain a more upright posture with limited range of motion and fewer moves of back when compared to the surgeons performing open surgeries [6].

The characteristic factors that may simultaneously contribute to creating pain in musculoskeletal system is uncomfortable, repetitive movements of the upper limbs, as well as long-term static and awkward position of the head and back [7].

In most cases, surgeons performing laparoscopic procedures take the standing position, which carries the risk of loss of stability. Surgeons have in fact a limited ability to change their body weight, they have to perform manual maneuvers in precisely way standing often on one leg and using the foot pedal to operate the laparoscopic equipment [5, 6, 8].

Based on laparoscopic procedures observations and interviews conducted with surgeons it can be concluded that the way of taking body position depends mainly on where the surgeon is located in relation to a patient. Surgeon postures will be different when the surgeon is on the left or right side of the patient or when the place of surgeon staying is between the patient's legs. In addition, an important aspect influencing the manner of operating of the upper limbs is the location of incisions for insertion the laparoscopic instruments inside abdominal. If the incisions are too close then laparoscopic tools are parallel to each other, and thus the movements of the surgeon's limbs have a smaller range causing more static loads. Besides, performing the surgical procedure is more difficult. If, however, the both incisions are away, the result is more easily maneuvering of the upper limbs, reducing static burden and facilitating work in the surgical field of abdomen cavity.

## The second area

Another, very important and indicated by the surgeons, aspect influencing the overall body posture is to organize the work conditions in the operating room, especially the layout of laparoscopic tools and auxiliary equipment, particularly a monitor.

The problem of the organization of work in the operating room by laparoscopic surgery is associated with previously unforeseen and totally different manner of work when compared to traditional open surgery, furthermore the need for visual interaction with the monitor (and not with the patient as previous), more remote than reality the operation field, or other types of experiences like tactile feedback and force transmission described in [9].

Changing the manner of performing surgeries from the open to minimally invasive with use of specific tools have not led to changes in the organization of the work space in operating rooms. The advances in the field of laparoscopy, such as the development of optics video with higher resolution and improved operational instruments on the one hand allowed doctors to perform more advanced laparoscopic surgeries. On the other hand, this progress has not been accompanied by changes in the design of operating rooms and setting up the monitor which would alleviate the fatigue musculoskeletal system of laparoscopic surgeons [5].

There is recommended the specific location of the monitor [10, 11]:

– In horizontal level the monitor should be positioned in a straight line along the forarm-motor instrument for each person taking part in the operation. This location will avoid axial rotation of the spine.

- In the sagittal plane the monitor should be placed just below eye level to avoid neck strain.

The location of the monitor presented above, is associated with two problematic consequences: firstly, each additional monitor increases the cost of purchasing a laparoscopic equipment (cost of monitor for laparoscopic procedures is about 20 to 30 times higher than a traditional monitor), secondly the layout of the monitors in a specific position, especially below the line of sight causes huge changes in the organization of the whole workplace. Traditionally, the monitor is located above the equipment due to the concentration of people and devices at the operating table.

## The third area

The manner of performing laparoscopic procedures depends on the design of surgical instruments, especially on the shape of the handgrip and the tool length.

There were observed unergonomic patterns of tool grips that are not adapted to the shape and size of the hand and the motor abilities of surgeons' upper limbs, what leads to fatigue, discomfort and paresthesia of hands [12].

The shape of the laparoscopic instruments and the way of using them determine the unusual positions of arms, hands and fingers. There are available different types of handles for use in minimally invasive surgery indeed. However, the principle of using them is similar, based on the positioning tools maneuvering hands and fingers which may lead to the local pressure and the injuries or nerve irritation [13].

Few studies have been conducted in the frame of designing and validation of correctness of usage of ergonomic laparoscopic instruments. An example might be a prototype of the gripper tool that was designed basing on the analysis and evaluation of current tools in combination with the opinion of the surgeons. There was developed a special survey containing questions identifying problems related to using traditional instruments, and questions evaluating ergonomics of prototype tool. The illustrations of the prototype as well as the detailed results of the study are presented in [14]. Another example is an ergonomically designed grasper described in details in [15].

## The fourth area

Laparoscopic surgery enforces certain patterns of behavior of doctors. They are often associated with psychological stress and mental fatigue. The factors causing this phenomena are:

- activities under pressure of effectiveness and speed while performing the surgery which should be transformed to reduction of procedure cost [12],
- increase of the technical complexity of the surgical equipment and a high degree of difficulties of even simple procedures, resulting the necessity of increased attention while whole surgery and the severity of pain and fatigue by medical staff [16, 17, 18],
- remote access and changing in the observation of the operating field which enforces unnatural behavior of surgeons in a sense that they do not direct the vision on the patient (which is a natural behavior and for longtime practitioners the subconscious impulse) but

on the monitor where the operating field (on a flat screen) in various degrees of resolution and picture quality is displayed.

According to studies, psychological burden of surgeons performing laparoscopic procedures is much higher in comparison to open surgical techniques [8].

### The fifth area

Laparoscopic procedures are characterized by limited mobility and surgeons' high static load during the operations. These circumstances require new technologies and solutions for how to perform procedures that could enhance the comfort of the surgeon. One of such solutions is the auxiliary equipment for surgeons working in the field of minimally invasive treatments such as ergonomic surgical chairs. There was identified only a few propositions in this field.

One of them is an operating chair so called ETHOS platform of ETHOS Surgical enterprise, USA used for laparoscopic surgery [19].

The chair consists of the an integrated seat with adjustable support for the chest. It also includes two individually adjustable armrests and footrests. There was carried out a clinical evaluation of the chair which was clearly positive and indicates that the chair may help minimize the mental and physical stress for the surgeon [20].

Another solution is a chair which allows the surgeon to maintain partly standing and partly sitting position during the operation. As in the previous case, the chair is integrated with the pedals which are comparable to the pedal in the car. Adjustment of the height of chair is driven by electric motors, controlled by a special footswitch. Initial clinical examination of usefulness of the chair indicates that its application reduces fatigue and effectively support the surgeon during long endoscopic procedures [21].

There is proposed by Medisign a similar support construction for both open and minimally invasive procedures. The prototype was evaluated based on seven surgical procedures. In addition a method for electromyography (EMG) to assess muscle activation in back and legs at an experimental setting was used. Results: Six of the seven doctors participated in the experiment indicated that the supported body position is comfortable, safe, and the chair is easy-to-use. EMG results show that the support construction effectively reduces the activity of the muscles [22].

## 1.3 DISCUSSION ABOUT THE ERGONOMIC LEVEL IN LAPAROSCOPIC PROCEDURES – PRELIMINARY RESULTS OF EMPIRICAL STUDIES

There was summarized the preliminary results of empirical research in the field of ergonomics in laparoscopic procedures. The summary has become the basis for the discussion on the role of ergonomics in laparoscopic surgery, as well as the surgeons' ergonomic awareness and finally training needs for improvement in this area. The discussion is mainly based on the answers of 41 laparoscopic surgeons obtained through the survey research (see p. 1). Wherein, the questionnaire was divided into six major areas: personal data, experience in laparoscopic surgery, course features, level of knowledge, problems of ergonomics and training needs. The surveys were complemented by unstructured interviews touching the issues raised in the questionnaire and observations of two laparoscopic procedures.

The average length of professional experience of the respondents was 12,71 years, which means that the answers are crucial for achieving the objective of research. The vast majority of laparoscopic surgeons are men (70 per cent of respondents). Most of the questioned persons are above 36 years old. This fact is related to a small number of young doctors particularly residents, i.e. people who actually specialize in a certain field of medicine. A specialization in general surgery is not a popular specialization among young people because of the high degree of difficulty. General surgery, including laparoscopic surgery requires from the surgeon an extraordinary concentration during the entire procedure and the necessity of making unforeseen decisions. In contrast to other kind of surgeries, like orthopedic surgery where the surgical procedures are performed in a schematic way and the result of the treatment depends on the mechanical accuracy of surgical activities, in general surgery many times is not possible to work according to strict schemas.

Surgeons spend on average from 1 to 2 hours a day doing laparoscopic procedures. The most commonly performed laparoscopic procedures among surveyed doctors are treatments in the inframesocolic area, including cholecystectomy, i.e. removal of the gallbladder.

Laparoscopy is a rapidly expanding field of medicine, and the same execution of procedure requires a solid and reliable preparation. According to the respondents the most important factors impacting on perfecting skills in laparoscopic surgery are:

- performing as many procedures as possible,
- the possibility of practical training based on working with medical simulators,
- access to laparoscopic instruments allowing perform the staged procedures.

Furthermore the doctors paid attention to such aspects improving the professional skills as the exchange of experience and support from teammates side.

Almost all of surveyed surgeons took part in training in laparoscopy, where most of them assess them as the good and very good. However, these trainings usually applied only to the clinical issues. Unfortunately, in most cases, they have not been and are not related to aspects of ergonomics. Most of the surgeons have not participated in training activities to improve working conditions at laparoscopic surgery. This has negative consequences in unergonomic performing the procedures by them. Wherein, the way of surgery is a result of the components: activities resulting from a certain medical procedure, as well as activities related to the preparation of a patient for surgery, and the organization of working conditions in an operating room. A mode of action of surgeons, including a way of adopting a specific body position, a way of moving, manner of communication, is shaped and fusing over many years of practice. There is a high probability that the change in technology, such as the ability of adjustment the height of operating beds to patient, mobility of devices, will not lead to changing the way of performing the surgery, which after many years has become routine for an experienced surgeon. There is therefore the necessity to educate the surgeons in the field of ergonomics and forming working conditions as quickly as possible i.e. already within medical studies and in the beginning of surgical practice. For experienced surgeons it is suggested to make attempts of changing their habits towards pro-ergonomic behavior and use of ancillary equipment to enforce an ergonomic way of acting.

Lack of knowledge of ergonomics (only less than 15 per cent of the respondents declared their competence in this area) and a specific way of performing laparoscopic

operations by most respondents result overload in muscles of the back, shoulders and neck. Among other identified negative effects are: numbness and loss of feeling in the fingers, calluses on the thumbs, pain in the musculoskeletal system and the overall physical and mental fatigue.

The indicated musculoskeletal fatigue and overall burden is caused mainly by the body position while surgery. According to the respondents the main factors contributing to the adopting a specific body position during surgery are:

- patient positioning,
- position and the adjustment ranges of the table,
- a type of laparoscopic surgery,
- position of the monitor,
- the necessity of using pedals for controlling diathermy systems.

It is worth to note that all of the factors identified above, apart from the type of laparoscopic procedure, are ergonomic factors and therefore those that can be shaped and improved. In turn, to the main factors that directly affect the physical fatigue belong:

- duration of surgery,
- awkward postures,
- position of the monitor,
- the instruments grip design.

The preliminary results of the survey clearly indicate that knowledge of surgeons in the ergonomic design of work can help to reduce the burden during laparoscopic procedures. An optimistic aspect is that all surgeons participating in the research are open to the possibility of conducting training in range of ergonomics. However, the main factors motivating to participate in such training is professional development, by knowing new techniques, furthemore by gaining knowledge of reducing the aches and pains caused by surgical practice and expand general knowledge of ergonomics. Important elements here are also increasing new skills, exchange knowledge with other professionals and gaining knowledge of the proper selection of laparoscopic instruments.

It is suggested that training was mainly a practical dimension. For most respondents, the most appropriate form of training is a mixed form i.e. partially online and partially in the form of traditional classes. A very important aspect for the medical staff is the duration of training. The most indicated length is to 20 hours.

Taking into account such time rigor, the important aspect is to formulate appropriate training structure, corresponding to the real training needs.

According to the opinions of respondents, the most important topics in potential training are:

- ergonomics in the field of laparoscopic surgery,
- ergonomics related to laparoscopic surgical instruments,
- surgeon postural ergonomics,
- ergonomic related to the type of laparoscopic surgery.

Simultaneously the specified areas are those, in which the majority of questioned laparoscopic surgeons would take part.

## CONCLUSIONS

Laparoscopy is an opportunity for patients to less pain and faster recovery. It is also a completely different field of surgery when compared to the open surgical procedures and requires specific conditions and new skills of surgeons. First of all, surgeons must operate with a continuous concentration during the whole procedure. An additional factor increasing stress is unnatural operative field presented in the form of visualization on the screen, thus forcing the surgeon to visual contact with the device, and no longer directly with the patient. The serious problem are the somatic relations in antropotechnical system while the surgery, characterized by a long-term static position causing overload and pain in musculoskeletal system. Problematic are also the operations with using handle tools, which are often not adapted to the shape of the operator's hand, causing numbness and lack of sensation of the upper limbs or calluses on thumbs.

The ergonomic problems indicated in the article while using the laparoscopic instruments can be mitigated in two ways. The first way is to educate surgeons in the principles of ergonomic proceedings. Wherein the a good idea seems to be an integrated training by the subconsciously shaping pro-ergonomic behavior e.g. learning how to perform laparoscopic surgery on ergonomically correct training place. The second way is to provide designers of surgical tools information on these aspects of the tool construction that should be improved in respect of ergonomic.

## Acknowledgments

This article was prepared by participating in the project: Online Vocational Training course on laparoscopy's ergonomics for surgeons and laparoscopic instruments' designers, conducted in frame of Lifelong Learning Program: Leonardo da Vinci Multilaternal Projects for Development of Innovation, Agreement number: 2012-3649/001-001, financed by National Agency for Lifelong Learning Programme Organismo Autónomo Programas Educativos Europeos (OAPEE). The author would like to thank the project coordinator the Instituto de Biomecánica de Valencia in Spain for the cooperation and initiation of research and to all of the hospitals, the doctors and the decision makers who have agreed to participate in the study. The author also thanks the Silesian University of Technology that allowed the realization of the work in range of exploitation of surgical instruments within the statutory research, work symbol BK 249/ROZ3/2012.

## REFERENCES

1. Bartnicka J.: Uwarunkowania procesu absorpcji wiedzy technicznej personelu szpitalnego na przykładzie eksploatacji narzędzi chirurgicznych, w: (red.) Knosala R.: Innowacje w Zarządzaniu i Inżynierii Produkcji. Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole 2013.
2. Bartnicka J, Dąbrowski D.: Method of surgical staff competence improvement using the augmented reality technology, w: Systems supporting production engineering. Monograph. Eds: Biały W., Kaźmierczak J., Gliwice: Wydaw. Pracowni Komputerowej Jacka Skalmierskiego, 2012.

3. Berguer R.: Ergonomics in the Operation Room, The American Journal of Surgery, 1996, 171, pp. 385-386.
4. Gilberth F. B.: Motion study in surgery, Canadian Journal of Medicine and Surgery 1916, 40, pp. 22-31; thanks to: Berguer R.: Ergonomics in the Operation Room, The American Journal of Surgery, 1996, 171, pp. 385-386.
5. Nguyen N. T., Ho H. S., Smith W. D., Philipps C., Lewis C., De Vera R. M., Berguer R.: An ergonomic evaluation of surgeons' axial skeletal and upper extremity movements during laparoscopic and open surgery, The American Journal of Surgery, 2001, 182, pp. 720-724.
6. Berguer R., Rab G. T., Abu-Ghaida H., Alarcon A., Chung J. A.: A comparison of surgeons' posture during laparoscopic and open surgical procedures, Surgical Endoscopy, 1997, 11, pp. 139-142.
7. Berguer R.: Surgery and ergonomics, Archives of Surgery, 1999, 134, pp. 1011-1016.
8. Gofrit O. N., Mikahail A. A., Zorn K. C., Zagaja G. P., Steinberg G. D., Shalhav A. L.: Surgeons' Perceptions and Injuries During and After Urologic Laparoscopic Surgery, Urology 2008, 71 (3), 404-407.
9. Sukthankar S. M., Reddy N. P.: Force feedhack issues in minimally invasive surgery, in: Satava R. M. , Morgan K. , Siehurg H. B., Mattheus R., Christensen J. P. eds.: Interactive Technolgy and the New Paradigm for Healthcare, Studies in Health Technology and Informatics, lOS Press, 1995, 375-379, thanks to: Berguer R.: Ergonomics in the Operation Room, The American Journal of Surgery, 1996, 171, pp. 385-386.
10. Van Det M. J., Meijerink W. J. H .J., Hoff C., Totté E. R., Pierie J. P. E. N.: Optimal ergonomics for laparoscopic surgery in minimally invasive surgery suites: a review and guidelines, Surgical Endoscopy, 2009, 23, pp. 1279-1285.
11. Xiao D. J., Jakimowicz J. J., Albayrak A., Goossens R. H. M.: Ergonomic factors on task performance in laparoscopic surgery training, Applied Ergonomics, 2012, 43, pp. 548-553.
12. Berguer R.: Surgical technology and the ergonomics of laparoscopic instruments, Surgical Endoscopy, 1998, 12, pp. 458-462.
13. Matern U., Eichenlaub M., Waller P., Ruckauer K.: MIS instruments. An experimental comparison of various ergonomic handles and their design, Surgical Endoscopy, 1999, 13, pp. 756-762.
14. Trejo A. E., Doné K. N., DiMartino A. A., Oleynikov D., Hallbeck M. S.: Articulating vs. conventional laparoscopic grasping tools – surgeons' opinions, International Journal of Industrial Ergonomics, 2006 36 (1), pp. 25-35.
15. Trejo A. E., Jung M.-Ch., Oleynikov D., HallbeckM. S.: Effect of handle design and target location on insertion and aim with a laparoscopic surgical tool, Applied Ergonomics, 2007, 38, pp. 745-753.
16. Berguer R., Chen J., Smith W. D.: A comparison of the physical effort required for laparoscopic and open surgical techniques, Archives of Surgery, 2003, 138, pp. 967-970
17. Berguer R., Forkey D. L., Smith W. D.: Ergonomic problems associated with laparoscopic surgery, Surgical Endoscopy, 1999, 13, pp. 466-468.

18. Berguer R., Smith W. D., Chung Y. H.: Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery, Surgical Endoscopy, 2001, 15, pp. 1204-1207.
19. http://www.ethos-surgical.com/ethos-surgical-platform/ethos-surgical-platform.html
20. Rassweiler J. J., Goezen A. S., Jalal A. A., Schulze M., Pansadoro V., Pini G., Kim F., Turner C.: A New Platform Improving the Ergonomics of Laparoscopic Surgery: Initial Clinical Evaluation of the Prototype, European Urology, 2012, 61 (1), pp. 226-229.
21. Schurr M. O., Buess G. F., Wieth F., Saile H.-J., Botsch M.: Ergonomic surgeon's chair for use during minimally invasive surgery, Surgical Laparoscopy Endoscopy & Percutaneous Techniques, 1999, 4, pp. 244-247, thanks to: Rassweiler J. J., Goezen A. S., Jalal A. A., Schulze M., Pansadoro V., Pini G., Kim F., Turner C.: A New Platform Improving the Ergonomics of Laparoscopic Surgery: Initial Clinical Evaluation of the Prototype, European Urology, 2012, 61 (1), pp. 226-229.
22. Albayrak A., van Veelen M. A., Prins J. F., Snijders C. J., de Ridder H., Kazemir G.: A newly designed ergonomic body support for surgeons, Surgical Endoscopy, 2007, 21, pp. 1835-1840, thanks to: Rassweiler J. J., Goezen A. S., Jalal A. A., Schulze M., Pansadoro V., Pini G., Kim F., Turner C.: A New Platform Improving the Ergonomics of Laparoscopic Surgery: Initial Clinical Evaluation of the Prototype, European Urology, 2012, 61 (1), pp. 226-229.

# CHALLENGES FOR ERGONOMICS AND IMPROVEMENT OF WORKING CONDITIONS DURING SURGERIES WITH USE OF LAPAROSCOPIC TOOLS

**Abstract:** *The aim of the article is to present the preliminary results of research into diagnosis of needs for shaping ergonomic work conditions of surgeons performing laparoscopic surgeries.*
*In particular these needs have been diagnosed thanks to such methods as: surveys, interviews, direct observations and literature analysis. Identified ergonomic needs are the base for training preparation the aim of which should be shaping ergonomic awareness of present and future laparoscopic surgeons, manifesting itself in such aspects of activities as selection and further use of surgical instruments, the organization of work and the optimal layout of workplace equipment.*
*The ergonomic needs of surgeons should be transferable to the ground of design process of laparoscopic instruments and are the basis for supporting the work of surgical tools designers.*
*The participation of international project "Online Vocational Training course on laparoscopy's ergonomics for surgeons and laparoscopic instruments' designers" of Lifelong Learning Program: Leonardo da Vinci Multilaternal Projects for Development of Innovation, was the direct circumstance for undertaking the research. In addition, the content of the article touches aspects of an exploitation of surgical instruments what is related to the current statutory research of Institute of Production Engineering and the task "Management of innovations in processes of surgical tools exploitation with using ICT".*

**Key words:** *ergonomics, shaping of work conditions, surgical tools, e-learning, laparoscopic surgeons*

# WYZWANIA W ZAKRESIE ERGONOMII I DOSKONALENIA WARUNKÓW PRACY PRZY ZABIEGACH CHIRURGICZNYCH Z UŻYCIEM NARZĘDZI LAPAROSKOPOWYCH

**Streszczenie:** *W artykule przedstawiono wstępne wyniki badań nad rozpoznaniem potrzeb w zakresie kształtowania ergonomicznych warunków pracy chirurgów wykonujących zabiegi laparoskopowe. W szczególności potrzeby te diagnozowane są za pomocą metody badań ankietowych, wywiadów, obserwacji i analizy literatury. Zidentyfikowane potrzeby ergonomiczne są bazą do opracowania szkolenia, którego celem ma być kształtowanie świadomości ergonomicznej obecnych i przyszłych chirurgów laparoskopowych, ujawniającej się w takich aspektach działań, jak dobór i późniejszy sposób posługiwania się narzędziami chirurgicznymi, czy też organizacja pracy i optymalne rozmieszczenie elementów wyposażenia na stanowisku pracy. Potrzeby ergonomiczne chirurgów są przenaszalne na grunt procesu projektowo-konstrukcyjnego narzędzi laparoskopowych i stanowią podstawę do wspomagania pracy projektantów narzędzi chirurgicznych.*
*Bezpośrednią przesłanką podjęcia badań w zakresie ergonomii zabiegów laparoskopowych jest realizacja projektu międzynarodowego Online Vocational Training course on laparoscopy's ergonomics for surgeons and laparoscopic instruments' designers) w ramach programu Lifelong Learning: Leonardo da Vinci Multilaternal Projects for Development of Innovation, Treści artykułu dotykają aspektu użytkowania narzędzi chirurgicznych wpisując się tym samym również w ramy obecnie prowadzonych badań statutowych Instytutu inżynierii produkcji i zadania nt. Zarządzanie innowacjami w procesie eksploatacji narzędzi chirurgicznych z zastosowaniem technologii ICT.*

**Słowa kluczowe:** *ergonomia, kształtowanie warunków pracy, narzędzia chirurgiczne, e-learning, zabiegi laparoskopowe*

dr inż. Joanna BARTNICKA
Silesian University of Technology, Faculty of Organization and Management
Institute of Production Engineering
ul. Roosevelta 26, 41-800 Zabrze
e-mail: Joanna.Bartnicka@polsl.pl

# 2

# THE INFLUENCE OF TYPICAL SOURCES OF TRAFFIC NOISE MODELLING METHOD ON THE ACCURACY OF CALCULATIONS OF ACOUSTICS EMISSION

## 2.1 INTRODUCTION

The evaluation of acoustic influence of road noise sources within strategic acoustic maps or other expert studies is connected with the necessity to model the noise source properly and to calculate its acoustic emission in accordance with the assumed computational model. However, acoustic emission modelling is quite a complex issue due to the possibility of various road geometry modelling (number of roadways, number of lanes, etc.) as well as due to the possibility to apply different computational methods. These factors exert a significant influence on the obtained results' accuracy.

This article presents results of a research experiment the purpose of which was to analyze the influence of different methods of road noise sources modelling as well as the influence of the applied computational method on accuracy of the acoustic emission calculations.

## 2.2 RESEARCH PROBLEM IDENTIFICATION

In accordance with the Polish legislation, while preparing road models for the purposes of strategic acoustic maps' creation, one uses the road networks layer available from the city's geodetic resources (SIT/SIP) and represented in the form of road axes. It shall be one axis in case of a single carriageway road and two axes in case of dual carriageway road. Therefore, the way of road modelling regardless of the number of lanes in each direction is here clearly imposed by the existing GIS model (GIS – Geographic Information System). For example, figure 2.1 presents various ways of a modelling of a road having one roadway and 4 lanes. In the city's GIS model the road is described by one axis (a) of traffic volume accumulated to 1 axis. However, this road may be modelled in a much more precise way, e.g. as a system of two directions i.e. two axes (b) and a system corresponding to reality where each lane is represented by a separate line source (axis) and specified by the traffic volume resulting from vehicles which actually move along this lane (c).

Thanks to our experience we know that the method of road modelling shall influence the calculations result. Yet, we do not know how big the influence will be. The conducted research experiment attempts to answer this question.

The experiment also focused on analysis of the results obtained while using the same method of road modelling but obtained with the use of various computational methods. The following five most popular computational methods were analyzed:

- French NMPB,
- German RLS-90,
- British CRTN,
- Scandinavian Statens Planverk 48
- Swiss STL-86.

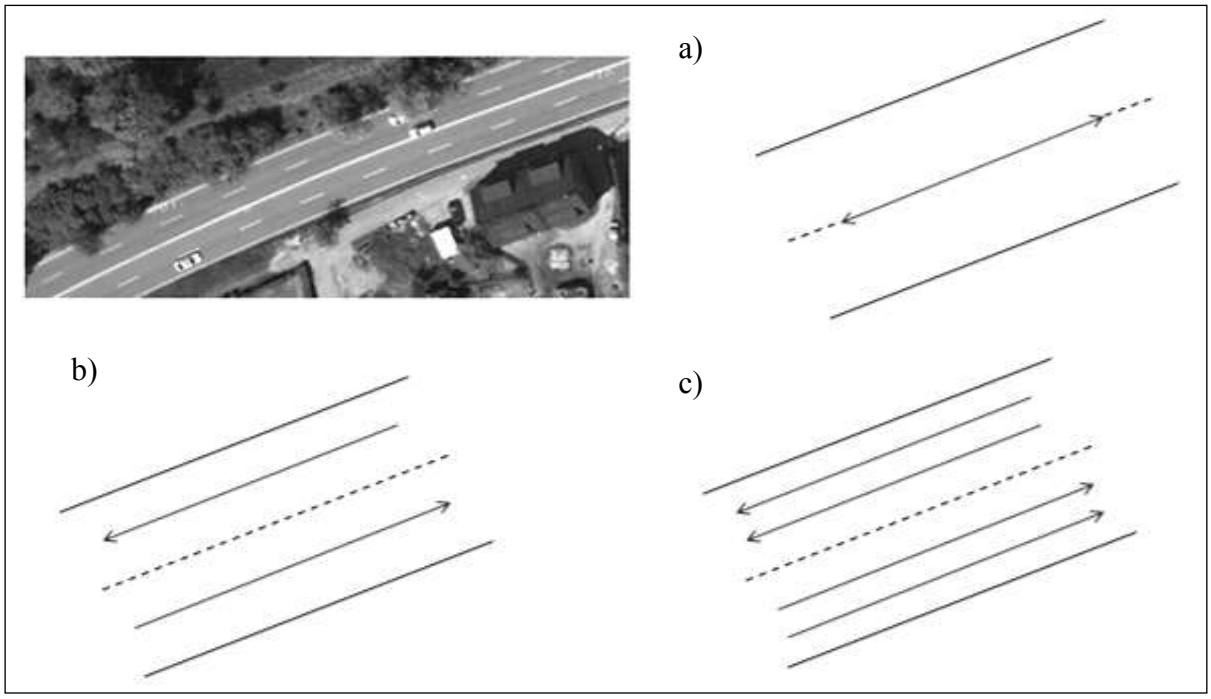



**Fig. 2.1 Various models of one type of road:**
**a) one roadway as the total of all lanes, b) each direction modelled separately,**
**c) all lanes modelled separately**

The method recommended by the 2002/49/EC Directive for road noise calculation is the French method NMPB Routes 96 (SETRA-CERTU-LCPC-CSTB), specified in „Arrêté du 5 mai 1995 relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1995, art. 6" and by French standard "XPS 31-133".

## 2.3 COURSE OF THE RESEARCH EXPERIMENT

The research experiment conducted consisted in selecting homogeneous, in respect of traffic volume, various types of roads and making very precise measurements of traffic volume and equivalent level of noise in a particular measurement point. While selecting measurement points special attention was paid to the necessity of ensuring low level of the background noise during measurements. Then the roads were subjected to acoustic modelling in CadnaA computational system, using various modelling techniques and various computational methods, and the obtained results were presented in the form of diagrams and tables.

### 2.3.1 Selection of road sections and measurement points

The determinant of selection of roads where measurement points were situated was the road type (highway, national road, local road), the number of roadways, the number of lanes, traffic homogeneity and lack of disturbance from other sources. Thanks to the variety of roads it was possible to make a more detailed analysis of modelling ways of road noise sources' acoustic emission. The measurement points were located near four different types of roads:

- **Point PP1** – A4 highway – two roadways with three lanes each, the section between Wspólna junction and Wirek junction,
- **Point PP2** – national road no. 88 – one roadway with two lanes in each direction, the section between Gliwice and Zabrze,
- **Point PP3** – district road – dual carriageway road with two lanes each way, Bytomska Street, Zabrze,
- **Point PP4** – district road – single carriageway road with one lane each way, Kujawska Street, Gliwice.

### 2.3.2 Field measurements of sound levels

Field measurements of the levels of sound emitted by motor vehicles were made in measurement points located near four types of roads. Each measurement point was located 20 metres away from the external edge of the road at the height of 4±0.1 metres above the ground level.

The measurements were made on working days from Monday to Friday, which was connected with lower traffic on weekends. The measurements were taken during good and stable weather conditions, i.e. when it was neither rainy nor windy.

In case of each type of read the measurements of sound levels as well as measurements of traffic volume were taken at the same time, i.e. between 3pm and 4pm, that is at the time when the traffic was relatively high, however, in each case the traffic was smooth (no traffic jams). Results of measurements regarding the equivalent level of noise in each of the measurement points have been presented in table 2.1.

**Table 2.1 Results of traffic noise measurements**

| ID | Sound level, dB | | | |
|---|---|---|---|---|
| | $L_{Amin}$ | $L_{Amax}$ | $L_{Aeq}$ | SEL |
| PP1 | 61.9 | 86.9 | **76.1** | 111.7 |
| PP2 | 50.0 | 86.6 | **67.9** | 103.5 |
| PP3 | 43.1 | 84.5 | **64.0** | 99.5 |
| PP4 | 41.4 | 83.1 | **63.8** | 99.4 |

An acoustic parameter taken into consideration in further studies is obviously the equivalent noise level ($L_{Aeq}$). It is used for comparison of the results of acoustic calculations, made with the use of CadnaA software on the basis of analysis of particular models of road noise sources, with the results of acoustic measurements.

### 2.3.3 Traffic volume and traffic structure measurements

The results of traffic volume measurements constitute the basis for calculating the

source's acoustic emission by means of computational methods implemented in CadnaA software produced by DataKustik. GmbH. That is why the main assumption of the research experiment was a very detailed analysis of the road traffic volume measurements and identification of the traffic structure. Traffic volume measurements were made exactly for the time when the measurement of road noise was made. Vehicles were counted for each lane separately dividing them into lightweight vehicles (passenger cars, delivery vans) and heavyweight vehicles (cars above 3.5 tons – trucks, buses, tractors and motorcycles). Figure 2.2 represents the road (measurement point) with marked measurement sections where traffic volume measurements were taken, whereas table 2.2 presents the results of traffic volume measurements for measurement point PP3.

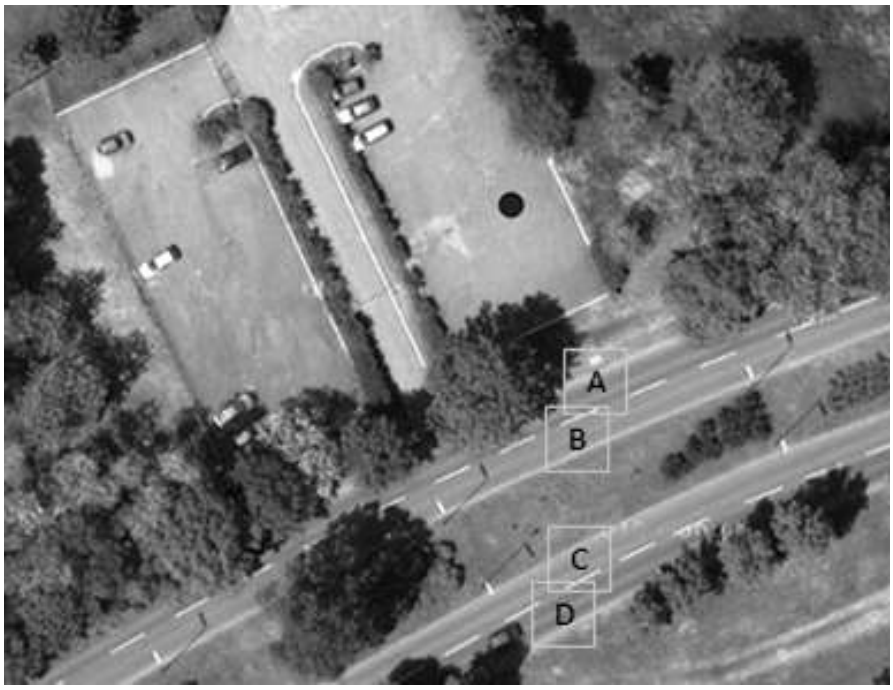



**Fig. 2.2 PP3 measurement point together with the marked measurement sections**

**Table 2.2 The results of traffic volume measurements – point PP3**

| Section | Number of lightweight vehicles | Number of heavyweight vehicles | Total | Heavyweight vehicles share [%] |
|---|---|---|---|---|
| A | 396 | 10 | 406 | 2.5 |
| B | 70 | 1 | 71 | 1.4 |
| C | 73 | 0 | 73 | 0.0 |
| D | 315 | 9 | 324 | 2.8 |

### 2.3.4 The method of road noise sources modelling

CadnaA software was used for the preparation of geometric and computational models of the examined sources of road noise. It was assumed that each of the road would first be modelled in a simplified manner thus it would be represented by one linear source (axis) and described by the total traffic volume on the road. Subsequent models would take more and more details into account, consequently, they would be more and more accurate. An example of the models created for a dual carriageway road (Bytomska Street in Zabrze- point PP3) has

been presented in figure 2.3.

Models similar to the ones presented in figure 2.3 were prepared for the remaining roads analysed in the research experiment.

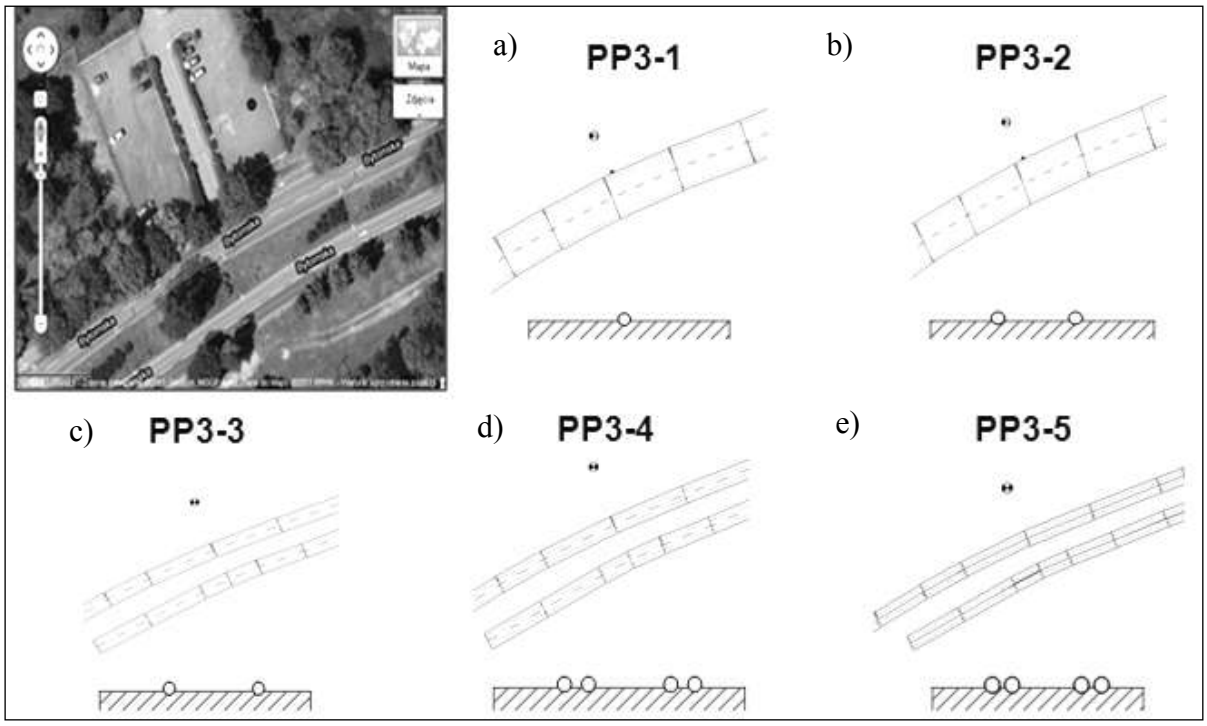



**Fig. 2.3 Exemplary models of the noise source for a dual carriageway road (point PP3):**
**a) model of one roadway as the total of all lanes,**
**b) model of one roadway with the "*Calculate both external lanes separately*" function on,**
**c) each of the roadways (traffic directions) modelled separately,**
**d) as above with the "*Calculate both external lanes separately*" function on,**
**e) each of the lanes modelled separately**

### 2.3.5 Computational determination of selected roads' acoustic emission by means of various modelling ways

In order to determine the sound level in measurement points by means of computational methods, each of the created geometric models of roads had to be supplemented with detailed data connected with traffic parameters, road parameters, etc. Input data for the use of computational methods from CadnaA software were as follows:

– traffic volume with the percentage share of heavyweight vehicles

Depending on the method of a selected type of road's modelling, the volume of traffic was specified for each lane separately or was accumulated for each of the roadways. Moreover, most of the computational methods used includes the "*Calculate both external lanes separately*" option. In case when this option is on, the program divides the total traffic volume of one roadway equally for two lanes.

– admissible speed limits for lightweight and heavyweight vehicles

Different speed limits are admissible for lightweight and heavyweight vehicles in case

of the various types of roads analysed. Article 20 of the Traffic Code contains information regarding admissible speed of vehicles on various road types. Admissible speed limits of vehicles on the analysed roads are as follows:

**PP1 –** A4 highway – admissible speed: 140 km/h; for heavyweight vehicles: 80 km/h**,**

**PP2 –** national road no. 88 – admissible speed: 100 km/h, for heavyweight vehicles: 80 km/h,

**PP3 –** reduced speed limits on the basis of vertical signs – 70 km/h,

**PP4 –** built-up area from 5am until 11pm – admissible speed limit 50 km/h.

– type of surface of the analyzed road type

Computational methods used for the calculation of the level of noise emitted from various types of roads include the option of selecting road surface. The surface of all the analyzed types of roads is made of smooth asphalt and their condition is good. Figure 2.4 presents an example of a dialogue box "Roads" of the CadnaA software which allows to enter the data specified above.

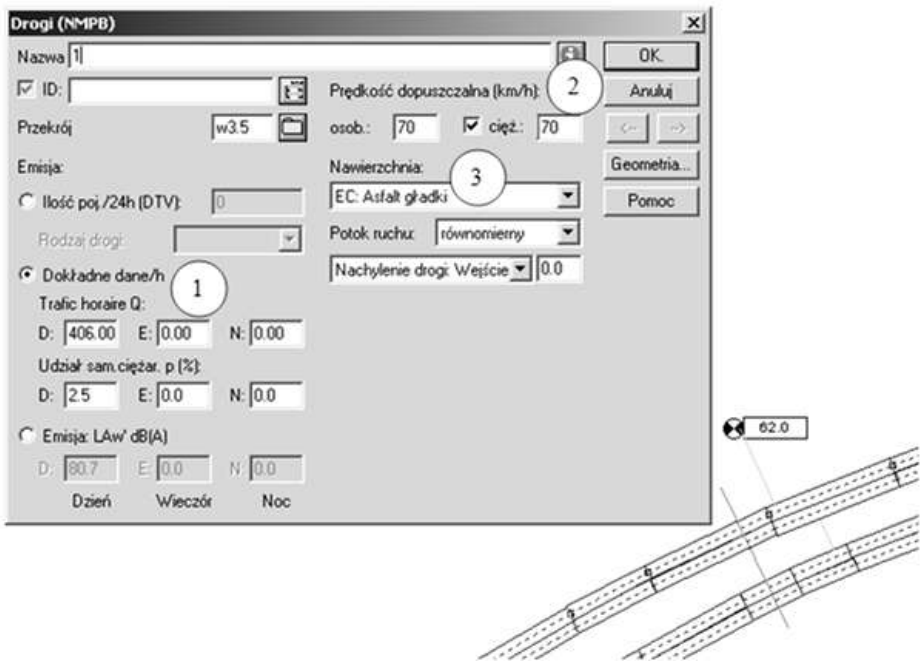



**Fig. 2.4 "Roads" dialogue box with data entered regarding:**
**1) traffic volume, 2) admissible speed limits, 3) type of surface**

After one has entered all the data and made calculations using the "Calculate" command, the field next to the receptor displayed the value of noise level expressed in [dB] for the selected road model. Determination of the equivalent level of noise A in the assumed measurement points for the models created for each of the types of roads was carried out by means of five computational methods:

– french method – NMPB,
– german method – RLS 90,
– british method – CRTN,
– scandinavian method – Statens Planverk 48,
– swiss method – STL86.

## 2.3 COMPARISON OF THE MEASUREMENTS' RESULTS AND MODEL CALCULATIONS' RESULTS

The comparison of acoustic measurements' results and model calculations' results consisted in calculating the difference between the calculations' result, by means of particular computational method, and the result of the actual measurement of the sound level. Selection of the most accurate computational method and the most accurate modelling way for a particular type of road was based on finding the smallest difference between the calculations' result and the result of measurement for a particular model.

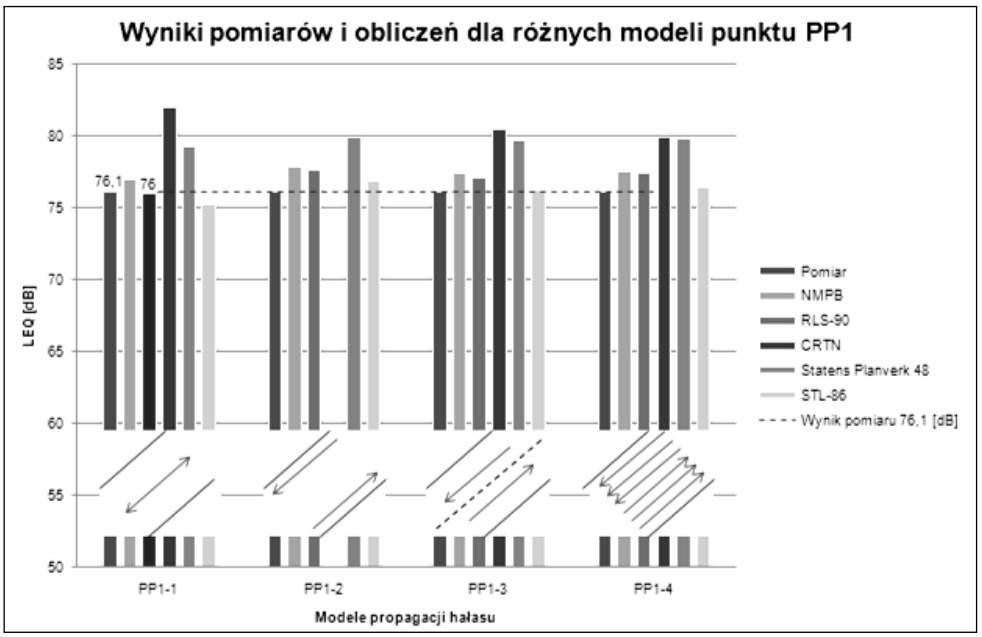



**Fig. 2.5 Comparison of measurements' results and model calculations' results of noise emission from A4 highway (point PP1)**

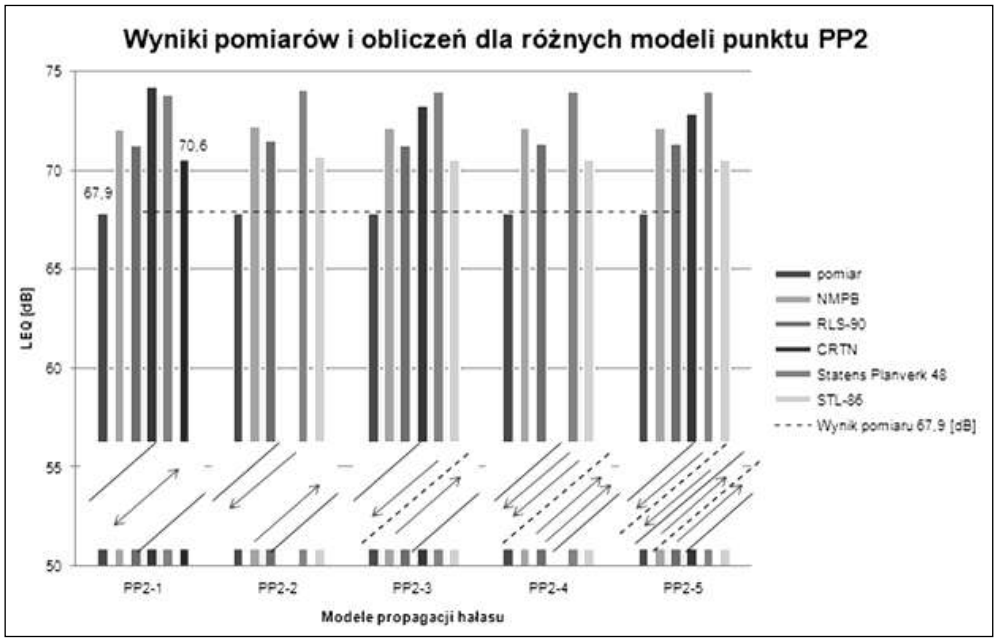



**Fig. 2.6 Comparison of measurements' results and model calculations' results of noise emission from the national road no. 88 (point PP2)**

Figures 2.5-2.8 present diagrams depicting the results of measurements and calculations made for various models of road noise sources and various models of noise propagation, for all types of the analyzed roads respectively. Red dashed line was used to represent the noise level corresponding to the measurement result. Red column in each of the diagrams represents the value of sound level for the most accurate computational method for a particular type of road.

Cumulative list of the recommended models as well as road noise computational methods for the four types of roads, which were the subject of the research experiment, have been presented in Table 2.3 on the basis of analysis of the results shown in figures 2.5-2.8.

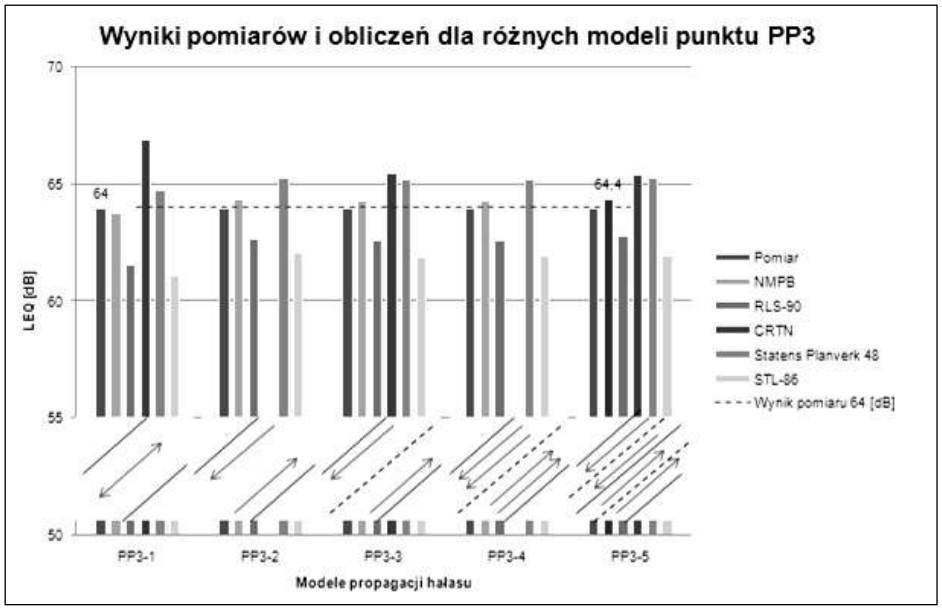



**Fig. 2.7 Comparison of measurements' results and model calculations' results of noise emission from a district dual carriageway road (point PP3)**

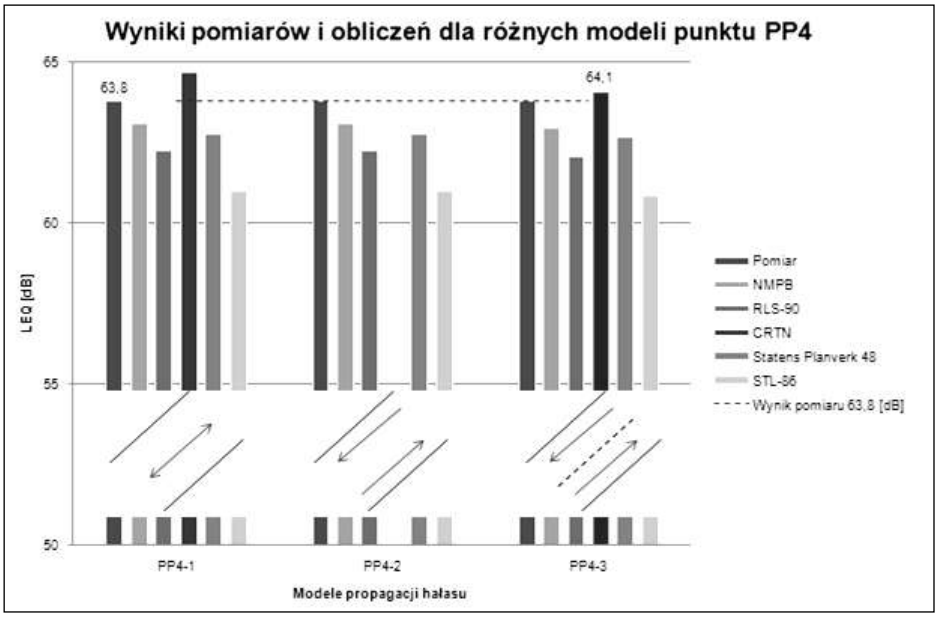
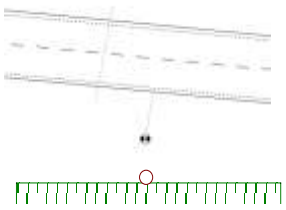
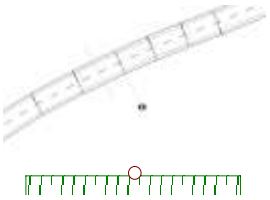
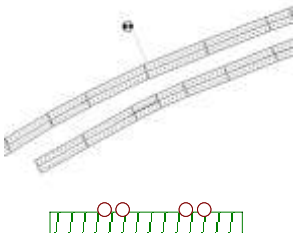
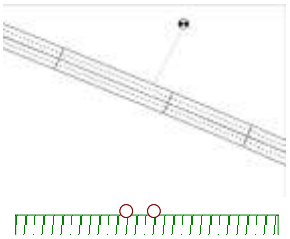



**Fig. 2.8 Comparison of measurements' results and model calculations' results of noise emission from a district single carriageway road (point PP4)**

Table 2.3 includes the most accurate geometric models of roads as well as computational methods for each of the analyzed types of roads. As it may be noticed, the results of calculations made in points PP1, PP3 and PP4 are slightly different from the results of measurements, whereas in case of point PP2 the difference is 2.7 dB.

**Table 2.3 Cumulative list of the recommended geometric models and computational methods for various types of roads**

| ID | Recommended model | | Recommended computational method | Measurement result [dB] | Calculations result [dB] | Difference [dB] |
|---|---|---|---|---|---|---|
| | Model number | Scheme | | | | |
| PP1 | PP1-1 |  | RLS-90 | 76,1 | 76,0 | -0,1 |
| PP2 | PP2-1 |  | STL-86 | 67,9 | 70,6 | 2,7 |
| PP3 | PP3-5 |  | NMPB | 64,0 | 64,4 | 0,4 |
| PP4 | PP4-3 |  | CRTN | 63,8 | 64,1 | 0,3 |

## CONCLUSIONS

The conducted research experiment as well as the analysis of the obtained results allowed to draw the following conclusions regarding the correct method of acoustic emission modelling of road noise sources:

– Computational determination of road noise emission in CadnaA program is based on data regarding the volume of traffic (including the percentage share of heavyweight vehicles),

admissible speed limit and the type of the road surface. That is why, before the modelling commencement, great emphasis should be put on credibility of the data collected .

- In case of modelling, in CadnaA program, of roads of high traffic volume and a great number of lanes (e.g. highways), the program raises too high the results of noise emission calculations in comparison to the measurement result. Methods RLS-90 and STL-86 in the model which is theoretically the least accurate constitute an exception where the results of calculations are slightly lower than the measurement result.
- When modelling local roads having significantly lower traffic volume than in case of highways, CadnaA program results of noise emission calculations are lower in comparison to the measurement result.
- When considering roads of high traffic volume and a great number of lanes (in this case a highway and a national road), the most accurate modelling way turned out to be the modelling of one roadway as the total of all the lanes and introducing for this roadway an accumulated traffic of vehicles from all the lanes. In this case the source of noise emission is situated in the central part of the modelled roadway, i.e. on its axis.
- In case of local roads where the traffic volume is significantly lower than in case of highways, the most accurate model included the modelling of each of the roadways separately and introducing traffic volume for each of the roadways separately. In such a case there are a few sources of noise emission (depending on the number of lanes) located on the axis of each of the lanes.
- Methods RLS-90 and STL-86 are the recommended road noise computational methods for roads of high traffic volume and a great number of lanes. In case of RLS-90 method, for the recommended method of point PP1 modelling (highway) the difference between the measurement result and calculations result was only 0.1 dB. Whereas in case of STL-86 method this difference for point PP2 was 2.7 dB. However, it is worth mentioning that calculations' results obtained by means of STL-86 method changed slightly, withdrawing from the recommended modelling way. In case of RLS-90 method, the change of the modelling way from the recommended into a different one resulted in a increase of the difference between the measurement result and the calculations' result.
- In case of local roads of low traffic volume, NMPB and CRTN turned out to be the most accurate computational methods. As for the NMPB method, recommended by the EU Directive, the difference between the calculations' result and the measurement result for the recommended way of point PP3 modelling was 0.4 dB. It is worth noticing that that the CRTN method became more and more accurate proportionally to the decrease of traffic volume on the examined roads and proportionally to the increase of the model's theoretical accuracy (modelling each of the roadways separately). In case of PP4 point (local road of low traffic volume) the difference between the measurement result and the calculations' result was as low as 0.3 dB. One may also notice that the STL-86 computational method, which turned out to be the most accurate in case of roads of high traffic volume, was the least accurate for points PP3 and PP4 (local roads).
- The "*Calculate both external lanes separately*" option available in CadnaA software exerted a small influence on the calculations' results or increased the results in comparison to the measurement result. This option divides the total traffic volume of one

roadway equally for two lanes and it constitutes some kind of a simplification (it is well known that more vehicles move on the external lanes). Nonetheless, as it has already been mentioned, this simplification did not have a significant influence on the calculations' results or raised them too high, that is why it is not recommended to use this option for modelling processes.

- Method NMPB recommended by the EU Directive for traffic noise calculation turned out to be the most accurate in case of modelling local roads having moderate or low traffic volume.
- The obtained results indicate to the necessity of conducting large-scale research in order to confirm the obtained results and conclusions.

*This article was written within development project no. 14 0001 06/2009: "Network model of consulting in the processes of creation and exploitation of strategic acoustic maps" funded by the National Centre for Research and Development*.

**REFERENCES**

1. Boczkowski, A., Koźlik, G. *Weryfikacja dokładności obliczeń emisji akustycznej źródeł hałasu drogowego w zależności od przyjętego sposobu modelowania źródła.* Materiały XL Zimowej Szkoły Zwalczania Zagrożeń Wibroakustycznych. Gliwice-Szczyrk 27.02-02.03.2012. Str. 17-29. (2012).
2. Boczkowski A.: *Zarządzanie klimatem akustycznym miasta z wykorzystaniem cyfrowych map akustycznych*. Ekonomika i Organizacja Przedsiębiorstwa. Nr 7. Lipiec 2006.
3. Boczkowski A., Komoniewski M.: *Wykorzystanie cyfrowych map akustycznych do realizacji zadań z zakresu ochrony środowiska przed hałasem*. Materiały XXXIV Zimowej Szkoły Zwalczania Zagrożeń Wibroakustycznych. Gliwice-Ustroń 27.02-3.03.2006. Str. 231-237.
4. Poradnik dla pracowników samorządowych uczestniczących w tworzeniu i użytkowaniu strategicznych map akustycznych. Praca zbiorowa pod redakcją prof. Jan Kaźmierczaka. Główny Instytut Górnictwa, Katowice 2008.

# THE INFLUENCE OF TYPICAL SOURCES OF TRAFFIC NOISE MODELLING METHOD ON THE ACCURACY OF CALCULATIONS OF ACOUSTICS EMISSION

**Abstract:** *The implementation of the strategic acoustic maps or evaluation of traffic investments interactions entails the necessity of modelling the traffic noise sources and calculating the emission of acoustic source. The modelling of the traffic noise seems to be the complex matter owing to different methods of modelling the road geometry (e.g. the number of roads and lines) and the possibility of application different methods of calculation. Mentioned factors significantly affect the accuracy in received results. The article below presents the course and the results of the scientific experiment, which main aim was analyzing the impact of different ways of modelling the traffic noise sources and the influence of the applied method of calculation on the accuracy in calculations of road acoustic emission. With particular precision there were explored the results obtained with the use of French calculating method NMPB Routes 96 recommended by The Directive 2002/49/WE for traffic noise calculations*.

**Key words:** *strategic acoustics maps, traffic noise, modelling the traffic noise sources, accuracy of the acoustic calculation, French calculating method NMPB Routes 96*

# WPŁYW SPOSOBU MODELOWANIA TYPOWYCH ŹRÓDEŁ HAŁASU DROGOWEGO NA DOKŁADNOŚĆ OBLICZEŃ EMISJI AKUSTYCZNEJ

**Streszczenie:** *Realizacja strategicznych map akustycznych miast lub ocen oddziaływania inwestycji drogowych na klimat akustyczny, wiąże się koniecznością modelowania źródeł hałasu drogowego oraz obliczaniem emisji akustycznej źródła. Modelowanie hałasu drogowego stanowi dość złożony problem, z uwagi na różne sposoby modelowania geometrii dróg (tj. liczby jezdni, liczby pasów ruchu, itp.) oraz możliwość zastosowania różnych metod obliczeniowych. Czynniki te wpływają w istotny sposób na dokładność uzyskiwanych wyników. W artykule przedstawiono przebieg i wyniki eksperymentu badawczego, którego celem było zbadanie wpływu różnego sposobu modelowania źródeł hałasu drogowego oraz wpływu zastosowanej metody obliczeniowej na dokładność obliczeń emisji akustycznej dróg. Szczególnie dokładnie przeanalizowano zbadano wyniki uzyskane przy zastosowaniu francuskiej metody obliczeniowej NMPB Routes 96 zalecanej do obliczeń hałasu drogowego przez Dyrektywę 2002/49/WE.*

**Słowa kluczowe:** *strategiczne mapy akustyczne, hałas drogowy, modelowanie źródeł hałasu drogowego, dokładność obliczeń akustycznych, francuska metoda obliczeniowa NMPB Routes 96*

dr inż. Arkadiusz BOCZKOWSKI, Grzegorz KOŹLIK
Silesian University of Technology, Faculty of Organization and Management
Institute of Production Engineering
ul. Roosevelta 26, 41-800 Zabrze
e-mail: Arkadiusz.Boczkowski@polsl.pl

# 3

# EVALUATION OF INNOVATIVE POSSIBILITIES OF PRODUCTION PROCESS IN THE ROLLING MILL

## 3.1 INTRODUCTION

Each company, even if achieves success in the market, with time has to think about making changes or introducing innovations. They are essential in a competitiveness in the market.

The word innovation in Latin "Innovare" means creating something new. Therefore, innovation can be defined as the process of transforming the existing possibilities in new ideas and introducing them into practical use [1].

Innovation can be seen as scientific or technical fact, which aims to develop innovative capacity. Because innovation is needed for the company growth. Made invention is an innovation as long as in the practice new, previously non-existent solution is used in this field [2].

An important type of innovation is the innovation of the process. These are all changes involving improvements to new or significantly improved production methods, including how to arrive with the product to customers.

It is important that the introduced innovation has brought tangible results, so it should be well planned and carefully implemented. Therefore, authors decided to conduct a research connected with the possible effects of innovations in the selected company.

## 3.2 RESEARCH METHOD

The aim of the research is to evaluate the factors influencing the development of the concept of the production process in the selected company on the basis of the employee opinion. The authors of the study decided to use one of questions from the BOST methods.

The BOST method, that is Toyota's management principles in the questions, is an innovative surveyed method which investigates intangible resources of the company. It was created in Institute of Production Engineering, Faculty of Management, Czestochowa University of Technology by Multi Professor Eng. Stanislaw Borkowski. It is the result of years of research. This method was described in papers [3, 4, 5].

The BOST method has a form of a survey. This survey occurs in two versions: for the employees and for their superiors.

With the answers it is possible to evaluate importance in areas such as enterprise mission, quality, standardization, visual control, manufacturing process, etc. So it is very comprehensive research tool [6].

In the article 1st Toyota's management principle, which is "Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals" [7], was chosen. The employees were supposed to answer the question: What factors decide on development concept of your company ?, thinking about the company in which they work for. They had to evaluate the individual factors of innovation introduction on a scale 1-7 (where 1 – the least important, 7 – the most important factor). The factors listed in the question are following [8]:

- Customer's interest (DK),
- Innovativeness of a product (IP),
- Cooperation with partners (WK),
- Confidence in relations with employees (ZP),
- Independence and responsibility of employees (SP),
- Development of technology (RT),
- Preservation of culture in the enterprise (PR).

The survey was conducted among the employees of one of the Polish rolling mills. The research included 30 production workers of that rolling mill.

### 3.3 CHARACTERISTIC OF THE RESEARCH COMPANY

The research steelwork is a modern company with a stable production process, organizational system, friendly for the surrounding environment. The mission of the company is to strengthen the company's position in Poland and abroad as the most efficient producer of long steel products with high quality.

The rolling mill of the research company is a continuous average type of rolling mill. It was launched in 1999. At the beginning its assortment included rounds flat steel bars, round steel bars and reinforced bars.

The research rolling mill is equipped with a devices from the company Danieli Morgardshammar. It is one of the most modern rolling mills in Europe, and the most modern in Central and Eastern Europe. In this rolling mill it is possible to implement the stringent requirements of designers connected with engineers or technical parameters and quality of ribbed bars, for both domestic and foreign market. This rolling mill is still modernized in order to meet the requirements of the customers [9].

### 3.4 CHARACTERISTIC OF RESPONDENTS

The survey was conducted among 30 production workers of the rolling mill in one of the Polish steelworks. In table 3.1 it is shown the general characteristics of the respondents (demographics of the survey). However, in table 3.2 the characteristics of surveyed employees were presented. The research characteristics of the respondents are following:

- gender (MK),
- education (WE),
- age (WI),
- job seniority (SC) – that is experience,
- mobility (MR) – that is which place of work,
- mode of the employment (TR).

**Table 3.1 Features of respondents. Characteristic**

| Symbol | Features' marking and their characteristic | | | | | |
|---|---|---|---|---|---|---|
| | MK | WE | WI | SC | MR | TR |
| 1 | Men | High school | < 30 | < 5 | 1 | Regular |
| 2 | Women | Professional | 31 - 40 | 6 do 10 | 2 | Transfer |
| 3 | | Secondary | 41 - 50 | 11 do 15 | 3 | Finance |
| 4 | | Higher | 51 - 55 | 15 do 20 | 4 | |
| 5 | | | 56 - 60 | 21 do 25 | 5 | |
| 6 | | | 61 - 65 | 26 do 30 | 6 | |
| 7 | | | > 66 | 31 do 35 | | |
| 8 | | | | > 36 | | |

Source: own study

**Table 3.2 Features of respondents. Percentage characteristic**

| Symbol | Features' marking and their rate characteristic | | | | | |
|---|---|---|---|---|---|---|
| | MK | WE | WI | SC | MR | TR |
| 1 | 90 | 7 | 17 | 23 | 43 | 63 |
| 2 | 10 | 17 | 23 | 10 | 33 | 20 |
| 3 | | 47 | 33 | 20 | 0 | 17 |
| 4 | | 30 | 10 | 23 | 10 | |
| 5 | | | 10 | 7 | 7 | |
| 6 | | | 7 | 7 | 7 | |
| 7 | | | 0 | 10 | | |
| 8 | | | | 0 | | |

Source: own study

Like in every company, also in the research rolling mill it was noted high diversity of the surveyed employees. Among the surveyed production employees 90% are men. It is important to remember that the rolling mill, where the working conditions are very difficult, is the research company. Almost 50% of employees have secondary education, 30% higher education. Over 30% are people who are 41-40, with 11-15 or 15-20 job seniority (experience). In the company over 66 year-old people do not work (pension age). For most of the employees the research rolling mill is 1st or 2nd place of work, what means that the managers of the rolling mill steelwork think about experienced staff, and they know how much the employees training costs the company. Over 60% of people got their work in the research rolling mill in regular mode of the employment.

## 3.5 RESULTS OF THE RESEARCH

The results obtained by the various factors listed in the question are presented in figure 3.1 in a form of a circular graphs.

Analising figure 3.1 it was seen that:

- Factor customer's interest (DK) by 23.3% of respondents were evaluated at 7, and only 1.6% gave an evaluation 1 (fig. 3.1a).
- Factor innovativeness of a product (IP) received 20% of the evaluation 7, and only 3.3% of 1 and 6.7% of 2 (fig. 3.1b).

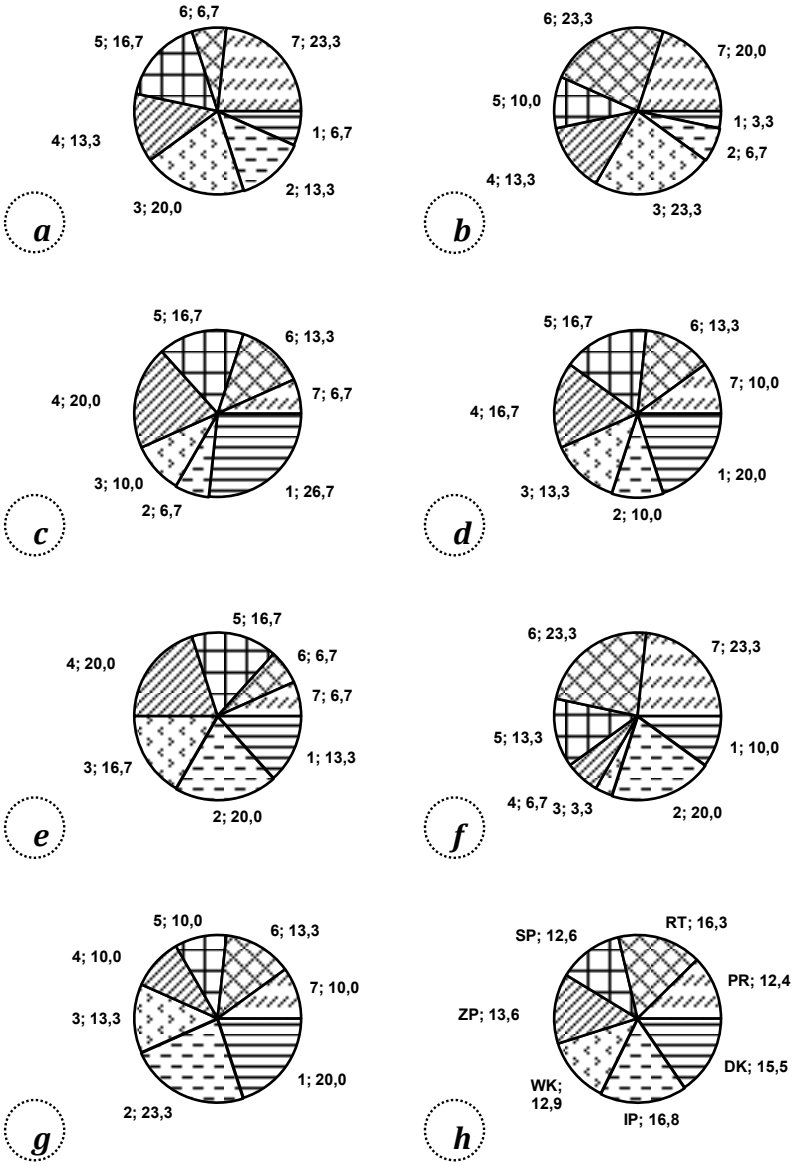



**Fig. 3.1 Principle 1. Circular graphs - evaluation structure of the factors' importance for E2 area:**
**a) DK, b) IP, c) WK, d) ZP, e) SP, f) RT, g) PR, h) average**

Source: own study

- Factor cooperation with partners (WK) mostly was evaluated by the respondents (26.6%) at 1, and the least often (6.7%) as 7 (fig. 3.1c). This factor was not too important for the employees.
- Factor confidence in relations with employees (ZP) the most often received the evaluation 1 (20% of responses). It is a factor with a great diversity of responses (fig. 3.1d).
- Factor independence and responsibility of employees (SP) mostly was evaluated at 2 and 4 (20% of responses), and the least often at 6 and 7 (6.7% of responses) (fig. 3.1e).
- Factor development of technology (RT) was usually evaluated at 6 and 2 (respectively 23.3 and 20% of responses). That is wide variation in the responses, and probably a large asymmetry of the distribution (fig. 3.1f).

– Factor preservation of culture in the enterprise (PR) received 23.3% of the evaluation 2 and 20% of 1. 7 was granted to this factor only in 10% (fig. 3.1g).
– On average, the highest score was given to factor innovativeness of a product (IP) – 16.8% and development of technology (RT) – 16.3%. It means that these factors affect, according to the employees, the concept of the development of the research rolling mill (fig. 3.1h).

To provide distribution of quartiles a box-and-whisker plot was used. Schematic version of box-and-whisker plot is presented in figure 3.2.

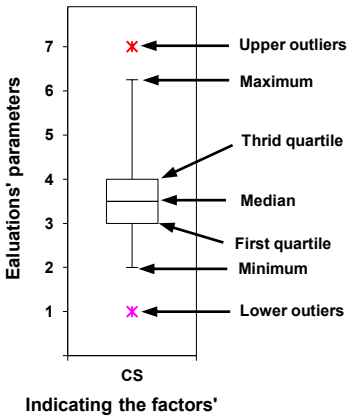



**Fig. 3.2 Box-and-whisker plot – characteristic**

Source: own study

A box-and-whisker plot provides a wealth of information on the empirical distribution. The location of the box in relation to the numerical axis is the location of the distribution, the vertical line separates them into two sets is a central tendency. On the other hand, the length of the box representing the difference between the first and third quartile, shows the diversity of characteristics for 50% of the central unit.

A vertical line representing the median divides the whole box into two parts, covering 25% of the observations. Depending on the location of the median in the box it indicates skewness in the central part of the distribution.

Complementary part of the plot are "whiskers" located outside of the box. When the whiskers are of equal length, they prove about the symmetry of the distribution. Longer right whisker than the left one shows the positive skewness (asymmetry). Longer left whisker than the right one shows the presence of a negative asymmetry across the distribution.

Correct image of the skewness on the basis of the box-and-whisker plot may be disturbed when some observations "stand out" from the rest, they are denoted with x * (x of "star").

In figure 3.3 the box-and-whiskers plot for all factors of the research area is presented.

Analysing the box-and-whisker plot (figure 3.3a for individual factors of 1$^{st}$ principle it is possible to see lack of symmetry of quartiles in all cases, apart from the factor independence and responsibility of employees (SP). In this case, both the box that is divided into two equal parts (fig. 3.3b and 3.3c), and both whiskers, which have the equal length (fig. 3.3d), have an impact on the symmetry of the distribution of quartiles.

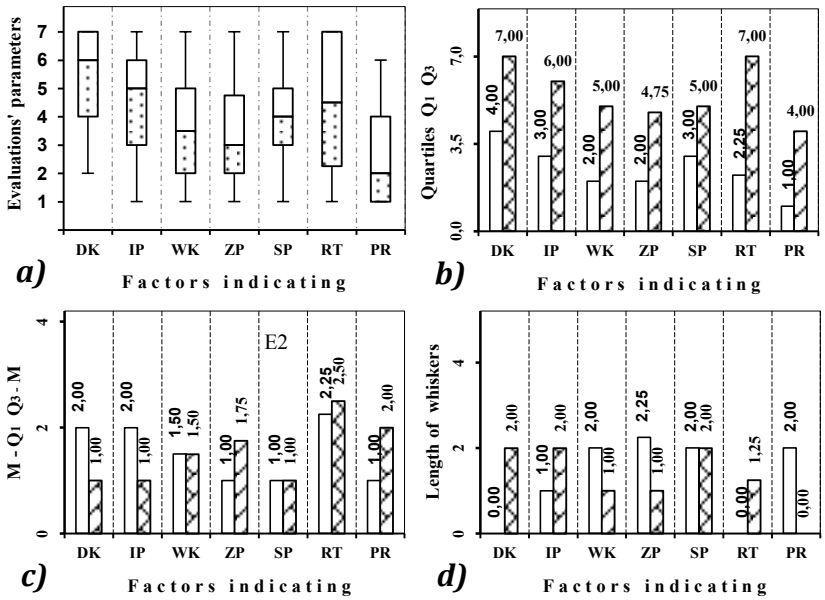



**Fig. 3.3 Improvement power. Box-and-whisker plots and its elements: a) basic graphs, b) Q1 Q2 quartiles, c) M – Q1, Q2 – M suitably, d) length of whiskers: upper (without filling), lower (with filling) for factors in E2 area**

Source: own study

In case of the factors cooperation with partners (WK), confidence in relations with employees (ZP), preservation of culture in the enterprise (PR) positive asymmetry was noticed. These factors were evaluated as less important by employees.

While in case of the factors customer's interest (DK), innovativeness of a product (IP) and development of technology (RT) negative asymmetry was found. These factors received higher evaluations given by the surveyed employees.

An analysis of the correlation between the characteristics of respondents and the evaluations given to individual factors was conducted. The results of the analysis are presented in the form of a bubble chart (figure 3.4). Three different levels of significance were taken into consideration ($\alpha = 0.2$, $\alpha = 0{,}1$ and $\alpha = 0.05$). In figure 3.4 1 indicates a positive correlation, while 2 means negative correlation.

Analysing figure 3.4a it is possibile to see that there is correlation betweeen gender (MK) and customer's interest (DK) with significance level $\alpha = 0.2$, also between gender (MK) and confidence in relations with employees (ZP) with $\alpha = 0.2$ and $\alpha = 0.1$, gender (MK) and independence and responsibility of employees (SP) with $\alpha = 0.2$, $\alpha = 0.1$ and $\alpha = 0.05$. In case of the correlation between gender (MK) and confidence in relations with employees (ZP), negative relation was observed, what means that for women this factor was less important.

In case of education (WE) (fig. 3.4b) there was observed negative correlation with development of technology (RT) with significance level $\alpha = 0.2$. For the person with higher education level this factor was less important.

Observing the age (WI) of employees (fig. 3.4c) it was noted negative correlation with innovativeness of a product (IP) and cooperation with partners (WK) with significance level $\alpha = 0.2$. For older employees these factors were less important.

From figure 4d it results that there is negative correlation between job seniority (SC) and innovativeness of a product (IP) with significance level $\alpha = 0.2$.

In case of mobility (MR) (fig. 3.4e) there is negative relation with innovativeness of a product (IP) with significance level $\alpha = 0.2$ and positive correlation with development of technology (RT) with $\alpha = 0.1$ i $\alpha = 0.05$. People who change their place of work more often evaluated development of technology (RT) higher. Maybe it is connected with their experience which they took from other place of work.

From figure 3.4f it results that there is negative correlation between mode of the employment (TR) and independence and responsibility of employees (SP) with $\alpha = 0.2$ and also positive correlation of this characteristic with preservation of culture in the enterprise (PR) with all significance levels.

In other cases, the correlation was not significant, which means that there was no link between the characteristics of respondents and the evaluation of those factors.

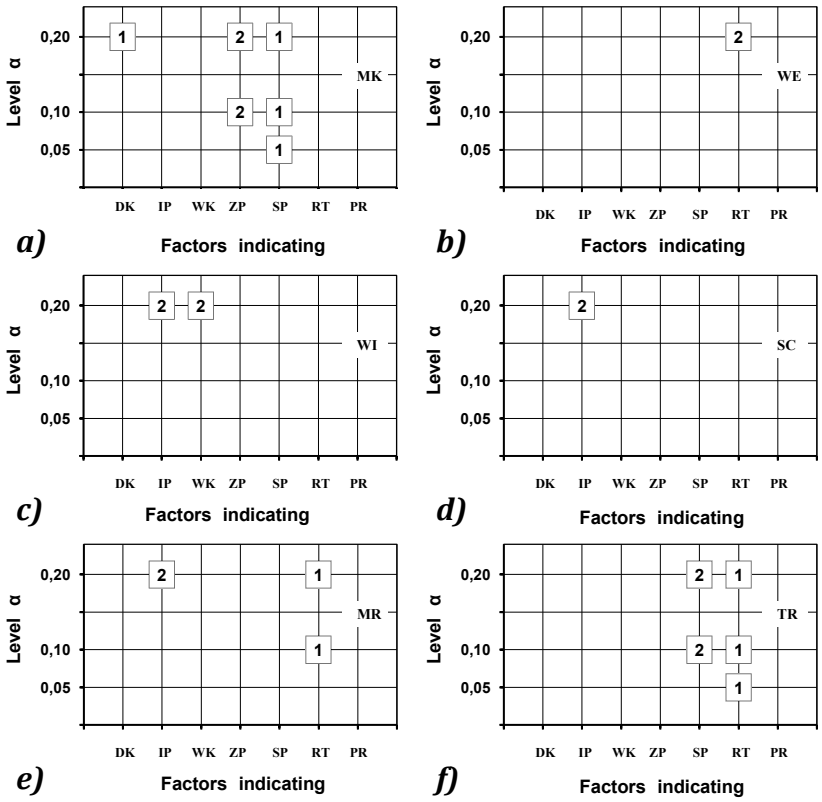



**Fig. 3.4 Principle 1. An identification of statistically significant influence of respondents features: a) gender, b) education, c) age, d) job seniority, e) mobility, f) mode of the employment and significance level of importance evaluation factors for E2 area. 1 – positive correlation, 2 – negative correlation**

Source: own study

## SUMMARY

The dominant feature of the companies operating in countries with a market economy is a constant search for new solutions, appreciating the human potential, his work and activity,

sustained commitment to improving the organization. Consistent implementation of the company management is a guarantee of the success.

The starting point to make changes in the company is the evaluation of the existing state. Such states are the best known by the employees of the company. The aim of this study was to draw the conclusions about the evaluations of factors decide on development concept of the production process in the chosen company.

30 production workers of the rolling mill in the Polish steelworks were asked to answer the questions in the survey. The BOST method was used as the research method. The results can be used by making-decision department.

Average the highest score was given to two factors determining the development concept in the company, i.e. innovativeness of a product (IP) – 16.8% and development of technology (RT) – 16.3%. This means that these factors are the best evaluated by employees. According to them this factors are the most important in the development concept in the rolling mill where they work.

They claim that the company should develop its technology or invest in new one to meet the rigorous requirements of the market. It is also important the product innovation, which determines the competitiveness of the company among others companies available on the market.

It should be noted, however, that all factors of 1st Toyota's management principle form one unit (in proportion) and it is not allowed to skip any of them in own activities.

## REFERENCES

1. Słownik Języka Polskiego; www.sjp.pl (dnia 1.03.2013)
2. Penc J.: Innowacje i zmiany w firmie. Transformacja i sterowanie rozwojem przedsiębiorstwa. Agencja Wydawnicza „Placet", Warszawa 1999, s. 5
3. Borkowski S.: Toyotaryzm. Wyniki badań BOST. Wyd. PTM, Warszawa 2012
4. Borkowski S.: Zasady zarządzania Toyoty w pytaniach. Wyniki badań BOST. Wyd. PTM, Warszawa 2012
5. Borkowski S. Dokumenty zawierające wymyślony termin (Toyotaryzm) oraz zawierające nazwę i strukturę opracowanej metody (BOST). Potwierdzenie daty. „AAK" Kancelaria Patentowa s.c. Częstochowa
6. Konstanciak M., Borkowski S., Jagusiak M. Supervisors' Assessment According to BOST Method in Chosen Polish Company. Communications, Nr 4, 2011 s. 58-62
7. Liker J.K.: Droga Toyoty – 4 zasad zarządzania wiodącej firmy produkcyjnej świata**.** Wyd. MT Biznes, Warszawa 2005
8. Borkowski S., Klimecka-Tatar D. Selejdak J.: Characteristics of Immaterial Stores in the Company Producing Steel Constructions. Forum Manazera Nr 1, 2012, s. 5-9
9. Dyja H., Mróz S., Sygut P., Sygut M.: Technologia i modelowanie procesu walcowania prętów okrągłych o zawężonej tolerancji wymiarowej. Wydawnictwo Wydziału Inżynierii Procesowej, Materiałowej i Fizyki Stosowanej Politechniki Częstochowskiej, Seria: Monografie Nr 27, Częstochowa 2012.

# EVALUATION OF INNOVATIVE POSSIBILITIES OF PRODUCTION PROCESS IN THE ROLLING MILL

**Abstract:** *The dominant feature of the companies operating in countries with a market economy is a constant search for new solutions, appreciating the human potential, his work and activity, sustained commitment to improving the organization. Consistent implementation of the company management is a guarantee of the success. The aim of the research is to evaluate the factors influencing the development of the concept of the production process in the selected company on the basis of the employee opinion. The authors of the study decided to use one of questions from the BOST methods. The results can be used by the management of the research company to make innovative decision.*

**Key words:** *The production process, the method of BOST, Toyota's management principle*

# OCENA MOŻLIWOŚCI INNOWACYJNYCH PROCESU PRODUKCYJNEGO WALCOWNI

**Streszczenie:** *Dominującą cechą przedsiębiorstw działających w krajach z gospodarka rynkową jest ciągłe poszukiwanie nowych rozwiązań, docenianie potencjału ludzkiego, jego twórczości i aktywności, trwałe zaangażowanie w proces doskonalenia organizacji. Konsekwentne realizowanie przedsiębiorczości w zarządzaniu stanowi gwarancje sukcesu. Celem badań jest dokonanie oceny czynników decydujących o koncepcji rozwoju procesu produkcyjnego wybranego przedsiębiorstwa na podstawie opinii pracowników. Autorzy do badań postanowili wykorzystać metodę BOST, czy zasady zarządzania Toyoty w pytaniach. Wyniki badań mogą być wykorzystane przez kierownictwo badanego przedsiębiorstwa w podejmowaniu decyzji innowacyjnych.*

**Słowa kluczowe***: proces produkcyjny, metoda BOST, zasada zarządzania Toyoty*

prof. n tech. i n. ekon. dr hab. inż. Stanisław BORKOWSKI
dr inż. Manuela INGALDI, mgr inż. Marta JAGUSIAK-KOCIK
Czestochowa University of Technology, Faculty of Management
Institute of Production Engineering
al. Armii Krajowej 19b, 42-201 Częstochowa
tel. +4834 3250 399, e-mail: bork@zim.pcz.pl; manuela@gazeta.pl; jmarti@go2.pl

# 4

# MEANING OF THE QUALITY IN THE PRODUCTION OF MEDICAL PRODUCTS

## 4.1 INTRODUCTION

Each enterprise in contemporary world seeks the methods that help survive in the market and be successful. Vast variety and range of goods offered to customers cause that their quality, apart from price and timeliness, is becoming the main factor of competitiveness in enterprises.

The concept of the quality (Greek *poiotes*) has been present in humanity since Ancient times. Plato, a prominent Greek philosopher, defined quality as 'a kind of perfection'. When a Latin term was being promoted to reflect the Greek concept, Cicero introduced *qualitas*, which started to be used in many languages e.g. in English.

The contemporary concept of quality is defined as meeting or exceeding customer expectations. An important factor in using the above definition is increasing competition and growing richness of a particular part of society.

Quality exists in a number of aspects and approaches [6]:

- quality in value-based approach: humans expect that what they do should be good i.e. should have a particular value. This means that quality is connected with the value, while the value is connected with evaluation. In order to ensure adequate evaluation, one needs the criteria and the basis for criteria are particular reasons,
- quality in market approach – degree of consistency of the properties of the product with customer expectations. The attempts of balancing demand and supply occurs through quality,
- quality in systematic approach, considered much wider than merely at the level of the enterprise,
- quality in process approach: a process is regarded as an ordered and interrelated chain of events which transform inputs into the final products. With this approach, quality is not a single act but it results from different activities which caused that the obtained effect matches the expectations.

## 4.2 CHARACTERISTICS OF ENTERPRISE

The enterprise analysed in the study was established in 1988 and is a leading supplier of solutions in the sector of manufacturing wheelchairs for the disabled. The enterprise deals with production of parts and assembly of a lightweight version of wheelchairs.

The wheelchairs are used by patients who are unable to move independently or partially

independently with the help of another person. The modular structure of the wheelchairs and wide range of optional equipment offered (the basic version is equipped in fleece seats, cane holder, support for lower extremities after amputations) allow for adaptation of wheelchairs to the persons with limited opportunities of moving or persons with the lack of these chances due to degeneration and deformation of body parts, contractures and joint diseases, muscle and nerve damage, balance disturbances or human body emaciation due to cancer, lost limbs or paralysis.

In the case of individual orders, the following factors should be considered: body size and weight, physical and psychical condition, age of the patient and their housing and environmental conditions.

The wheelchairs are manufactured in the enterprise studied according to the requirements of the Directive 93/42/EWG that concerns medical products. According to the classificatory criteria for medical products, these wheelchairs were classified as class one. This means that the wheelchairs manufactured by the enterprise ensure a high level of utility and safety.

## 4.3 DESCRIPTION OF THE RESEARCH SUBJECT

The product analysed in the study is a wheelchair presented in figure 4.1. It features an aluminium frame, which ensures that its weight is relatively low. It is easy to fold and has a wide range of optional equipment.

**Fig. 4.1 Wheelchair**

Source: Material provided by the analysed enterprise

With high quality of the parts used and modular construction, the wheelchair can be adjusted to individual needs and preferences of customers. The model presented in the study

is dedicated to more active users due to the material and constructional solutions which reduce its weight and allow for an independent moving and active enjoying the life.

Technical specifications of the wheelchair:

1. seat width: 40.5 - 48 cm,
2. depth of the seat: 40 - 46 cm (original setting: 43 cm),
3. back height: 42.5 cm (possible change to 47.5 cm),
4. weight: from ca. 15 kg,
5. maximum load: 125 kg.

## 4.4 RESEARCH METHODOLOGY

BOST questionnaire (principles of Toyota management in questions) was created by Prof. Stanisław Borkowski, director in the Institute for Production Engineering in the Faculty of Management in the Częstochowa University of Technology and is based on the principles of Toyota manufacturing system. The name BOST comes from the first initial letters of the professor's first name and surname and is a proprietary name [1, 2, 3]. The questionnaire is universal and can be used in both manufacturing and service-providing enterprises (e.g. banks, hospitals, schools, shops).

The BOST questionnaire is dedicated to both managers and employees and the questions correspond to the Toyota's principles and the Toyota house roof [4]. Furthermore, the questionnaire allows for the evaluation of the managers according to the Toyota's principles, respondent's profile and specification of the enterprise's/institution's activities.

The BOST questionnaire is comprised of 12 sets of factors. The version for the employees includes a set of factors which determine the elements of the Toyota house roof and the principles 1, 2, 3, 4, 6, 7 and 14, whereas the version for the employers includes a set of factors that describe all the principles of management in Toyota and the elements of the Toyota house roof. The questionnaire contains a ranking of importance and the respondents evaluate the importance of each factor on a particular scale.

The first set of factors in the questionnaire for employees (area E1) represents Toyota house roof (quality, costs, lead time, work safety, employees' motivation) and respondents evaluate, on a scale of 1 to 5, which of the factors are the most important in the enterprise studied. Another group of factors (customer's good, independence and responsibility of employees, innovativeness of product, development of technology, cooperation with partners, care for the enterprise's culture, trust in relationships with employees) is denoted as the area E2 and relates to the principle 1 of Toyota ("Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals") - the respondent evaluate, on a scale of 1 to 7, which of the factors they regarded as decisive in the concept of development in the enterprise.

The area E3, connected with the principle 2 of Toyota management ("Create a continuous process flow to bring problems to the surface"), concerns the factors which, according to the respondents, are the most important to the production process. The respondents can chose from the following factors: continuous system of detecting problems, stopping production after detection of the quality problem, standard tasks, processes and documents, delegating authority, using only reliable technologies, using visual control (on a

scale of 1 to 6).

Another set of factors is a set regarded as the area E4 and connected with the principle 3 of Toyota management ("Use the pull systems to avoid overproduction") and the respondent, on a scale of 1 to 4, evaluated which of the factors (production to order of customers, rational utilization of machines, people, generation of the product stock, short lead times) is ensured during organization of the manufacturing system.

The principle 4 of the Toyota management, i.e. "Level out the workload (heijunka)" is connected with another set of factors (equal workload for employees, equal load to machines, short series of products, regularity of deliveries) i.e. the area E5. The employees answer to the question of: Which factors are the most important to the production process? The above factors are evaluated on a scale of 1 to 4.

The area E6, which is comprised of such factors as time for performance of a single time, process, three-part warehouses, documents, training, flow of information or employment, is connected with the principle 6 of Toyota management ("Standardized tasks and processes are the foundation for continuous improvement and employee empowerment"). The respondents were asked to choose from the above set of factors and answer to the following question: Which type of standardization is the most important in ensuring continuous improvement of the processes in your enterprise (scale of 1 to 7) ?

Another set of factors relates to the principle 7 of Toyota management ("Use visual control so no problems are hidden"), denoted as E7. The respondents answered to the question: "Which factor is the most important to visual control". They used a scale of 1 to 6 and chose from the following factors: cleanliness, order, flow, information boards, participation in production places, monitoring, graphical presentation of the results.

The BOST questionnaire was carried out in the enterprise studied (wheelchair manufacturer) among the employees. The last set of factors (area E8), which related to the principle 14 of the Toyota management was also analysed in detail. ("Become a learning organization through relentless reflection (hansei) and continuous improvement (Kaizen).") and it included such factors as: the employment of workers – ZT, relations between employees and bosses – RE, motivation system – SM, documentation – DA, technology portfolio – PT, information flow – PN, quality – JK, cooperation with customers – WS, maintenance – UM, cooperation with suppliers and partners – WD. The employees in the enterprise studied focused on the above factors and responded using a scale of 1 to 10 to the question: Which area will produce best effects after its improvement ? [5].

In addition area E8, an analysis of the respondents structure, denoted as area E12 area was done. In BOST questionnaire we have six features of respondents: gender – MK, education level – WK, age – WI, job seniority – SC, mobility – MR, type of employment – TR) in order to determine the structure of human resources in the organizations studied.

## 4.5 ANALYSIS OF THE RESULTS

Table 4.1 and figure 4.2 present the respondents characteristics in the company studied (area E12 in the BOST questionnaire), which manufactures wheelchairs, divided into:

- gender (MK) – 1 – Man, 2 – Woman,
- education level (WE) – 1 – basic, 2 – professional, 3 – secondary, 4 – higher,

**Table 4.1 Features of respondents. Number characteristic. It concerns enterprise, which produces wheelchairs**

| Symbol | Features' marking and their numerical characteristic | | | | | |
|---|---|---|---|---|---|---|
| | MK | WE | WI | SC | MR | TR |
| 1 | 23 | 1 | 4 | 9 | 2 | 19 |
| 2 | 7 | 3 | 13 | 13 | 8 | 4 |
| 3 | | 9 | 6 | 1 | 10 | 7 |
| 4 | | 17 | 4 | 2 | 6 | |
| 5 | | | 3 | 2 | 3 | |
| 6 | | | 0 | 1 | 1 | |
| 7 | | | 0 | 2 | | |
| 8 | | | | 0 | | |

Source: own study

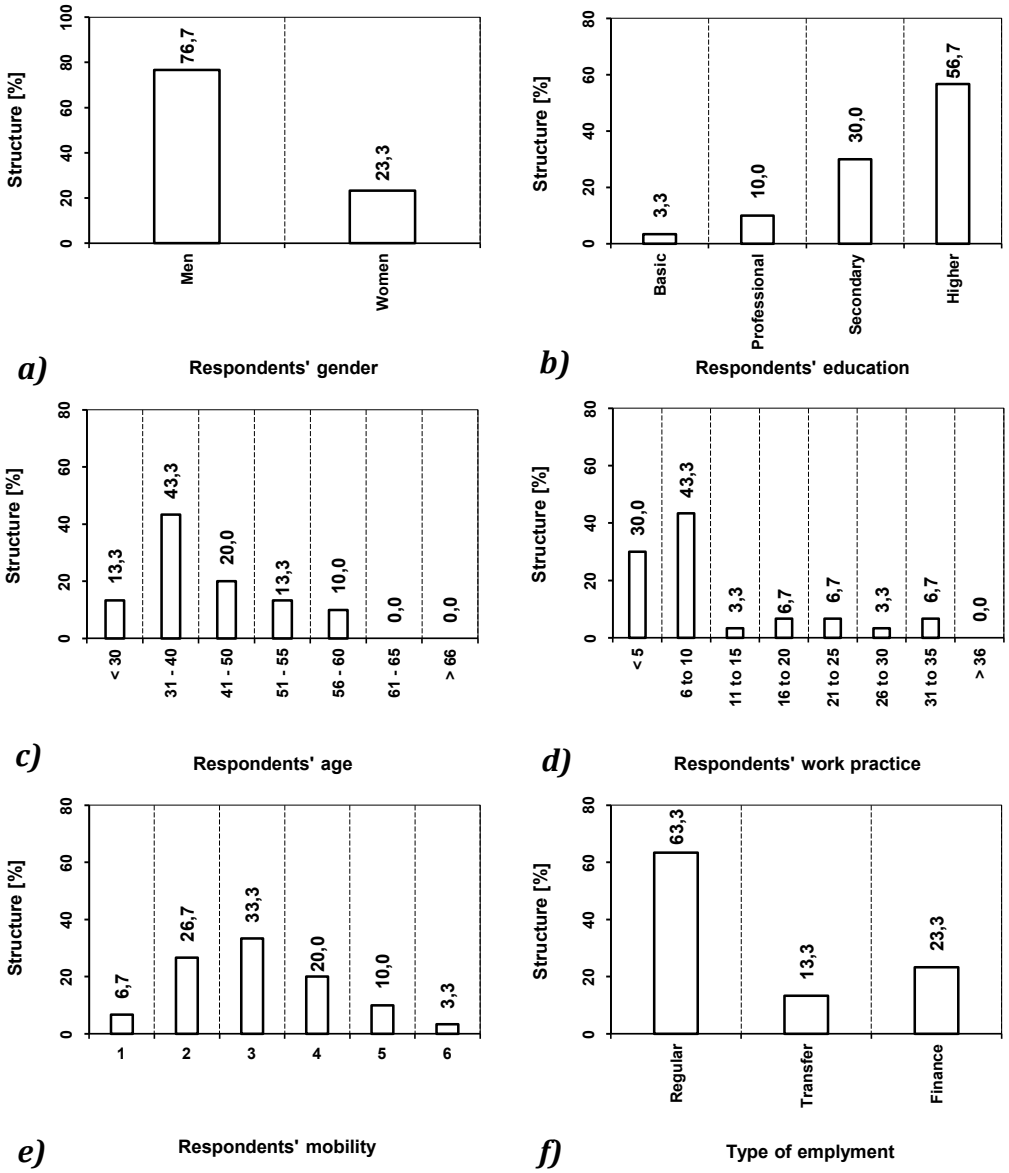



**Fig. 4.2 Histograms. Respondents characteristic with consideration of: a) gender, b) education, c) age, d) job seniority, e) mobility, f) type of employment. It concerns enterprise, which produces wheelchairs**

Source: own study

- age (WI) – 1 – to 30 years, 2 – 31 to 40 years, 3 – 41 to 50 years, 4 – 51 to 55 years, 5 – 56 to 60 years, 6 – 61 to 65 years, 7 – more than 66 years,
- job seniority (SC) – 1 – to 5 years, 2 – 6 to 10 years, 3 – 11 to 15 years, 4 – 16 to 20 years, 5 – 21 to 25 years, 6 – 26 to 30 years, 7 – 31÷35 years, 8 – 36 years and more,
- mobility (MZ) – current employment is: 1 – the first, 2 – second, 3 – third, 4 – fourth, 5 – fifth, 6 – further place of work,
- type of employment (TR) – 1 – in the regular mode, 2 – on the basis of the transfer, 3 – due to better financial conditions.
- table 4.1 and figure 4.2 shows that the majority of the respondents in the enterprise studied are men (76.7% i.e. 23 people). Regarding the education level (WE), the most of the employees have higher education level, which means 17 people (56.7%) and secondary education level (9 people, 30%). With respect to age (WI), the majority of the employees surveyed are those aged 31 to 40 years and from 41 to 50 years. This group includes 19 respondents, which constitutes 63.3% of the whole group. Job seniority (SC) in over 70% or the respondents is 5 to 10 years and, for 24 employees the enterprise represents the second, third and fourth workplace (MR). The most of the employees who participated in the survey i.e. 19 people (63.3%) were employed (TR) in the regular mode.
- another set of factors (E8) in BOST questionnaire, which was analysed in detail in the enterprise studied contains the areas which were supposed to be evaluated by the respondents in terms of the effects obtained after improvement. One of these factors is quality (JK).
- the numerical comparison of the scores for the factors from the area E8 is presented in the form of a table (see table 4.2) and bar charts (fig. 4.3).

**Table 4.2 Principle 14. Numerical combination of the factors' importance evaluation for E8 area. It concerns enterprise, which produces wheelchairs**

| Evaluation | Factors indicating | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ZT | SM | PT | JK | UM | RE | DA | PN | WS | WD |
| 1 | *12* | *1* | *3* | *1* | *2* | *3* | *3* | *3* | *2* | *0* |
| 2 | *7* | *3* | *3* | *0* | *4* | *4* | *2* | *2* | *1* | *4* |
| 3 | *3* | *8* | *1* | *2* | *2* | *2* | *2* | *4* | *3* | *3* |
| 4 | *0* | *3* | *2* | *0* | *5* | *3* | *4* | *3* | *6* | *4* |
| 5 | *4* | *0* | *2* | *2* | *2* | *5* | *4* | *4* | *6* | *1* |
| 6 | *2* | *5* | *3* | *2* | *2* | *5* | *4* | *1* | *2* | *4* |
| 7 | *1* | *1* | *6* | *2* | *3* | *3* | *4* | *5* | *2* | *3* |
| 8 | *1* | *8* | *6* | *2* | *3* | *3* | *4* | *1* | *0* | *2* |
| 9 | *0* | *1* | *2* | *13* | *3* | *1* | *3* | *1* | *5* | *1* |
| 10 | *0* | *0* | *2* | *6* | *4* | *1* | *0* | *6* | *3* | *8* |

Source: own study

Table 4.2 and figure 4.3 demonstrate that the employees in the enterprise studied, who are expected to generate the highest effects after improvement, pointed to the area which concerned the quality factor (JK). This factor was given the scores 9 and 10 by 19 respondents, which means that nearly 63% of the employees regards this factor as the factor which should be improved first. The importance of this factor is even higher since none of

other factors in the E8 area scored more than 50% of 9 and 10 points. Furthermore, the above table and the figure demonstrate that the group of factors which were given higher scores (7, 8, 9 and 10) contains the factor concerning technology profile (PT) – 16 respondents evaluated this factor with 7, 8, 9 and 10 scores, of which only 4 people used 9 and 10 points, and the factor related to cooperation with suppliers and partners (WD) – 8 respondents gave the highest score (10) to this factor.

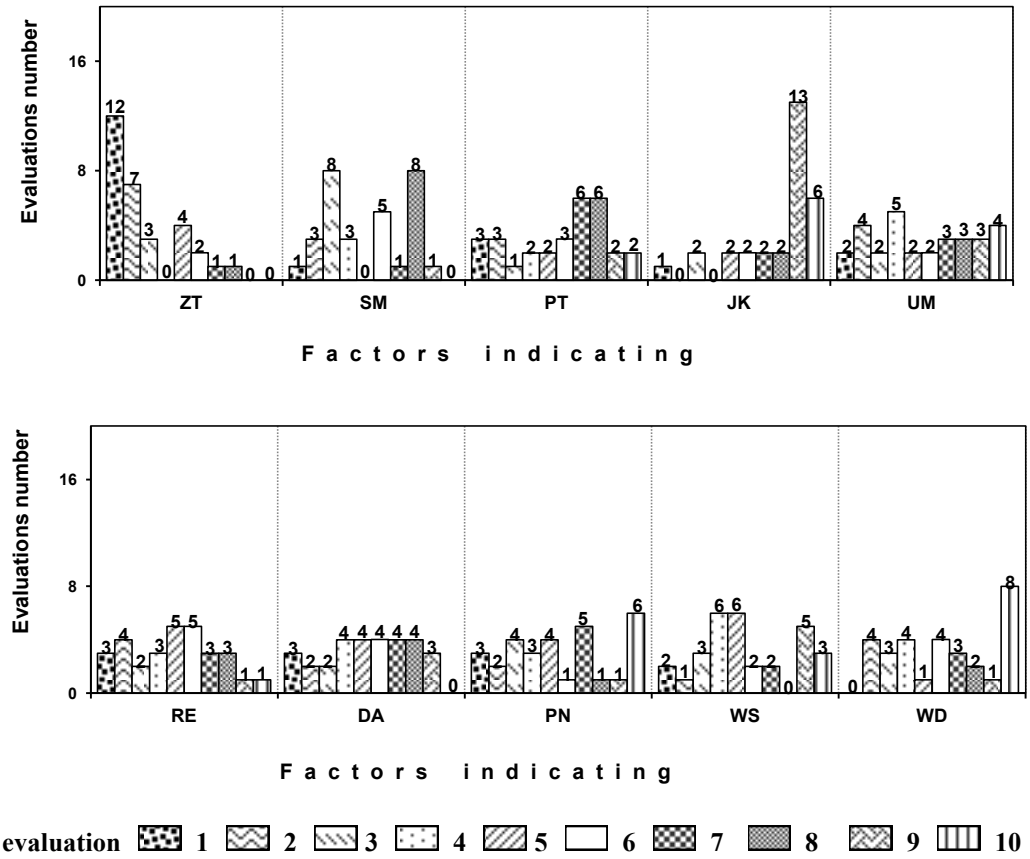



**Fig. 4.3 Principle 14. Distribution analysis of evaluations E8 area factors. It concerns enterprise, which produces wheelchairs**

Source: own study

The factor which was evaluated as a factor which does not produce or might produce the lowest effects after improvement is employment (ZT). Compared to the quality factor, an opposite pattern can be observed: 19 employees (63% of the respondents) gave this factor the lowest scores (1 and 2).

Another figure 4.4 shows Pareto-Lorenz diagrams that represent the importance of the factors from the area E8 for individual scores.

As results from the Pareto-Lorenz diagrams presented in figure 4.4, the quality factor (JK) takes the first place in the ranking of importance for the score 9 (over 40% of the scores) and the second place in the ranking of importance for the score 10 (20% of the scores). On the other hand, the factor of cooperation with suppliers and partners, was given the first place in the ranking of importance for the score 10 (over 20% of these scores), but the penultimate ($9^{th}$) place for the score 9. It is noticeable that the factor of technology portfolio was given the

first place in the ranking of importance for the score 7, the second place in the ranking of

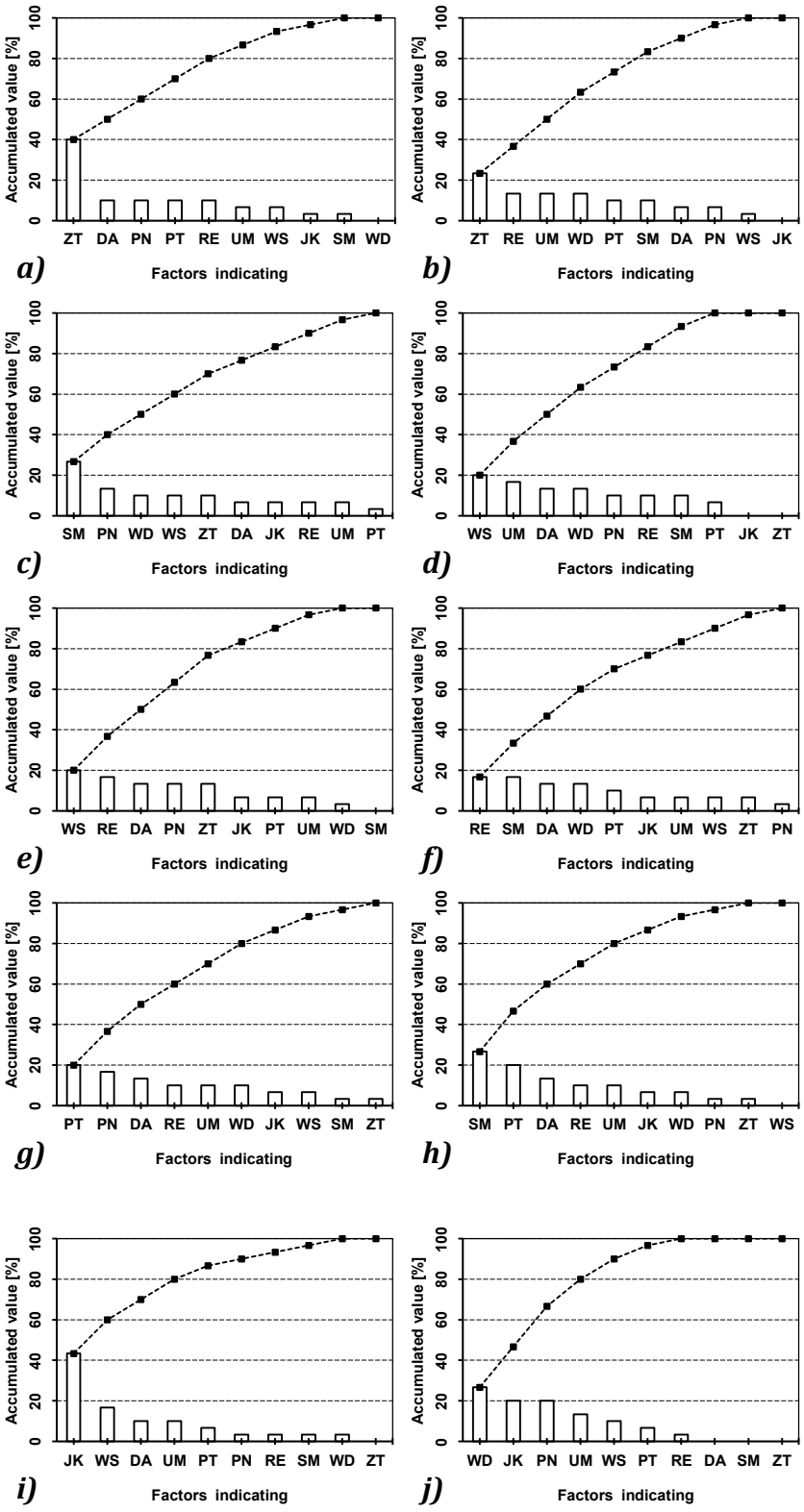



**Fig. 4.4 Principle 14. Pareto-Lorenz diagrams of the factors' importance E8 area for evaluations:**
**a) „1", b) „2", c) „3", d) „4", e) „5", f) „6", g) „7", h) „8", i) „9", j) „10".**
**It concerns enterprise, which produces wheelchairs**

Source: own study

importance for the score 8 but, in the case of the highest scores (9 and 10), it was given further places in the ranking of importance (the fifth place for the score "9" and 6th place for "10"). The first place in the ranking of importance for the lowest scores (1 and 2) was taken by the factor connected with employment.

## SUMMARY

As results from the presented analysis, the employees who responded to the BOST questionnaire pointed to the quality as the area which is likely to produce the highest effects after improvement. Over 60% of the respondents assigned 9 and 10 scores to this factor, which demonstrates the importance of this factor. Quality, which is meeting customer expectations and even exceeding these expectations in the enterprise studied (wheelchairs), is given the first place in the enterprise. Improvement in the product quality (wheelchairs) is likely to help increase the patient's comfort and adjust wheelchairs to their individual needs. It is essential when manufacturing wheelchairs to be oriented toward production of high-quality parts, which in effect allows for long, maintenance-free, safe and convenient use of the wheelchairs by the disabled people.

## REFERENCES

1. BORKOWSKI S. *Dokumenty zawierające wymyślony termin (TOYOTARYZM) oraz zawierające nazwę i strukturę opracowanej metody (BOST). Potwierdzenie daty.* Częstochowa: „AAK" KANCELARIA PATENTOWA s.c. 2012.
2. BORKOWSKI S. *Toyotaryzm. Wyniki badań BOST.* Warszawa: Wydawnictwo Menedżerskie PTM. 2012.
3. BORKOWSKI S. *Zasady zarządzania Toyoty w pytaniach. Wyniki badań BOST.* Warszawa: Wydawnictwo Menedżerskie PTM. 2012.
4. LIKER J. K. *Droga Toyoty – 14 zasad zarządzania wiodącej firmy produkcyjnej świata.* Warszawa: Wydawnictwo MT Biznes. 2005.
5. BORKOWSKI S., SYGUT P. JAGUSIAK-KOCIK M. *14 Toyota's Management Principle Basis of Process Improvement in the Baking Industry.* Chapter 6. [In:] *Toyotarity. Improvement of Production/Service Processes*. Monography. Editing and Scientific Elaboration BORKOWSKI S., SYGUT P. Celje: Faculty of Logistics, University of Maribor. 2012.
6. SŁOWINSKI B. *Zarządzanie i inżynieria jakości*. Wydawnictwo Uczelniane Politechniki Koszalińskiej, Koszalin. 2011.

## MEANING OF THE QUALITY IN THE PRODUCTION OF MEDICAL PRODUCTS

**Abstract:** *This chapter presents the definition of the quality and basic concepts of quality. An enterprise which manufactures the lightweight wheelchairs of the disabled was analysed. The methodology used in the study was BOST questionnaire – their principles of Toyota management in questions. The chapter contains a detailed analysis of the two selected areas of BOST questionnaire: the area E8, connected with the 14th principle of Toyota management and the area E12, i.e. respondent's characteristics. It was found that the quality in the enterprise studied is considered as an area in the enterprise which might produce the greatest effects if it is improved. The analysis used bar charts and Pareto-Lorenz diagrams.*

**Key words:** *BOST poll and, Toyota's management principle, diagram Pareto-Lorenz*

## ZNACZENIE JAKOŚCI W PRODUKCJI WYROBÓW MEDYCZNYCH

**Streszczenie:** *W rozdziale zaprezentowano definicję jakości oraz podstawowe ujęcia jakości. Przedstawiono przedsiębiorstwo zajmujące się produkcją lekkich wózków inwalidzkich. Metodyka badań to charakterystyka ankiety BOST – zasad zarządzania Toyoty w pytaniach. W rozdziale dokonano szczegółowej analizy dwóch wybranych obszarów ankiety BOST- obszaru E8, związanego z zasadą 14 zarządzania Toyoty i obszaru E12 czyli charakterystyki respondenta. Stwierdzono, że w badanym przedsiębiorstwie jakość postrzegana jest jako obszar przedsiębiorstwa, który może przynieść największe efekty po udoskonaleniu. Do analizy użyto wykresów słupkowych i diagramów Pareto-Lorenza.*

**Słowa kluczowe***: ankieta BOST, zasada zarządzania Toyoty, diagram Pareto-Lorenza*

prof. n tech. i n. ekon. dr hab. inż. Stanisław BORKOWSKI
dr inż. Manuela INGALDI, mgr inż. Marta JAGUSIAK-KOCIK
Czestochowa University of Technology, Faculty of Management
Institute of Production Engineering
al. Armii Krajowej 19b, 42-201 Częstochowa
tel. +4834 3250 399, e-mail: bork@zim.pcz.pl; manuela@gazeta.pl; jmarti@go2.pl

# 5

# ISSUE OF MULTIPLE-LAYER WINDING OF ROPES ON DRUMS OF MINE-SHAFT HOISTINGS

## 5.1 INTRODUCTION

Multi-layer winding of ropes on cylindrical drums of hoisting machines, which are used in the shaft hoists, presently is widely used in many countries around the world (Republic of South Africa, Canada, England, Russia, Ukraine, Germany, etc.) in stationary deep hoisting devices and in winders for shaft sinking and in auxiliary emergency-rescue shafts. In Poland, the Mining Mechanization Center KOMAG in Gliwice, and Shaft Sinking Company in Bytom, already in the 70's of last century, have concentrated on issue of the multi-layer winding of ropes on drums of the mining winders [1, 5, 9, 13, 14, 15]. Currently in Poland, after decades of interruption, again there began to new shaft sinking or to shafts sinking to a depth of 1200 m of shafts, existing in coal mining. Therefore, there have appeared some problems connected with kinematics of winding and ropes' wear during their multi-layer winding.

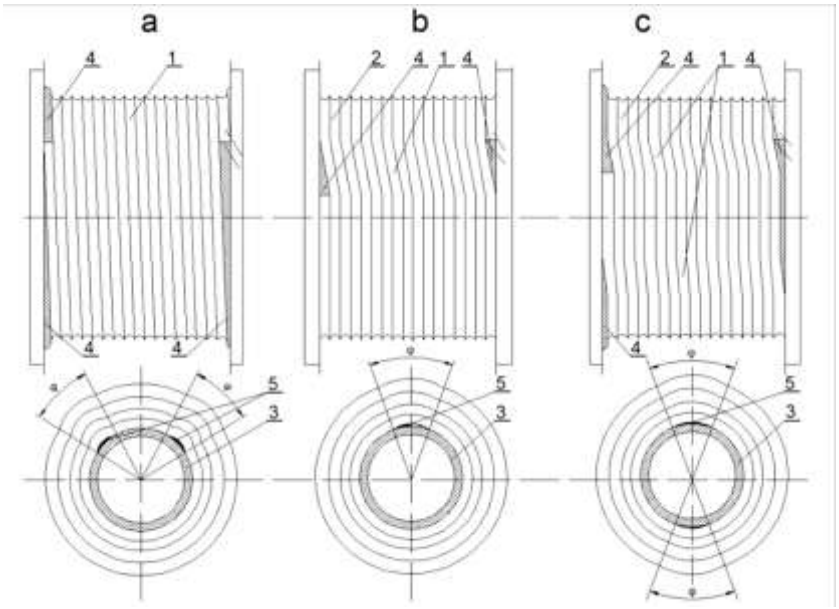



**Fig. 5.1 Types of grooving the lining of cylindrical drums** [14]**:**
**a – helical grooves, b – parallel grooves with single skew transition,**
**c – LeBus method, parallel grooves with double skew transitions;**
**1 – skew grooves, 2 – parallel grooves, 3 – drum shell 4 – leading or filling wedges,**
**5 – crossing zones of rope transition from one layer to subsequent layer,**
**φ - wrapping angle of the crossing zones**

In the country, a multi-layer winding of ropes was used and is still using, mainly in the winders for shaft sinking and in auxiliary, emergency, rescue and inspection shafts. In practice, multi-layer winding of ropes is applied on smooth-faced drums (abandoned in mine-shaft hoists) or in drums with the lining in which grooves are made. There is also applied direct grooving of drum shells. There can be distinguished three basic types of drums grooving and winding of ropes, fig. 5.1: helical, parallel with the single skew transition, and parallel LeBus method with double skew transitions. In the LeBus method one can distinguish LeBus synchronous and LeBus asynchronous grooving.

Helical grooving consists of the continuous spiral, which assure continuous winding at the one layer of rope, fig. 5.1a. Formerly, this type of grooving was also applied to multi-layer winding. However, due to a number of adverse effects, such as: wedging of the rope at the rims of a drum, disordered winding, seizure of rope, causing dangerous dynamic forces within the rope and its destruction, presently it is used exceptionally and only there, where parallel winding cannot not be applied *e.g.* in machines with grooves incised in the drum shell. Therefore, helical grooving is used only for one-layer or two-layer winding, however practically it is used in the winding of few layers.

Parallel grooving consists of grooves made parallel to the rims with one zone of skew grooves (fig. 5.1b), where the rope displaces by one pitch of winding corresponding to $(d+\varepsilon)$, where $d$ – diameter of the rope, $\varepsilon$ – slit between the coils of rope. In order to improve the rope transitions to next layer, there are placed directing-uplifting wedges in that zone.

The necessary condition for satisfactory operation of machine with multi-layer winding of rope on a drum is regular smooth compact and ordered winding of rope, both in the first, as in the subsequent layers. If the winding is irregular, there is a possibility of breakdown of rope through the already wound layer and placement on the lower improper layer, as well as the possibility of wedging of the rope at the rim of the drum, what causes an occurrence of strong jerks in the rope, transmitting on the mining vessel and causing its vibrations.

As a result of wedging the rope and vibrations caused by transition of rope from layer to layer and from coil to coil, the durability of the rope decreases, as the result of wear and cracking of wires. It should be noted, that the compact and ordered rope winding in the first layer of lining grooves influences on proper winding of the next layers, and simultaneously for the safe exploitation of the shaft hoists. The problem of multi-layer winding of ropes on drums of winders includes three issues:

- strength of the drums during multi-layer winding,
- kinematics (behavior) of rope during winding,
- durability and wearing of the hoisting rope, related to the selection of the rope lay.

In this paper, based on literature, methods of ropes winding, particularly LeBus method, are presented.

## 5.2 ROPE WINDING IN THE HELICAL GROOVES

One methods of multi-layer winding of rope is its winding on the drums, which are equipped with lining of grooves incised according to helical (screw) line.

The first layer of rope on the surface of cylindrical drum with incises grooves, according to helical line winds fluently and regularly. This type of winding lasts until the

penultimate coil inclusive, until the last line of coil will not encounter to the gap having wedge's shape created by rims' wall of drum, and the penultimate coil, fig. 5.2. In this, so-called critical place of drum rope gradually picks up on the second layer of winding. Rope, to get in the state of equilibrium, abandons the critical place of a drum and places between the coils of first layer, *i.e.* between the penultimate and adjacent, remaining there until it comes up again to a critical place of the drum [3, 13].

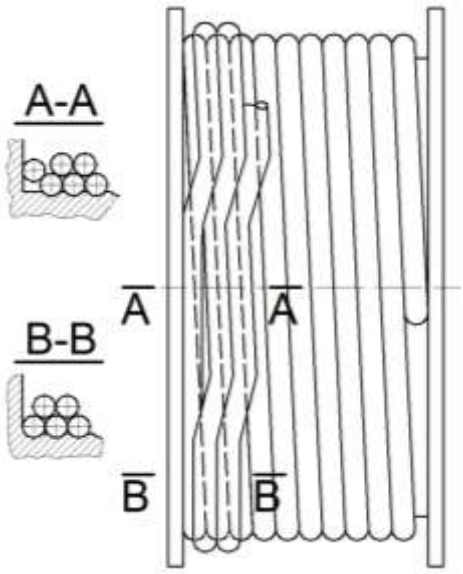



**Fig. 5.2 Two-layer winding of rope on cylindrical drum with lining with helical grooves** [13]

Then rope again rises from the groove formed by two adjacent coils and performs the second pitch displacement along the drum's generatrix. Such continual, pitch displacement of rope on the second layer of winding is done twice during in each rotation of the drum, fig. 5.3 [7].

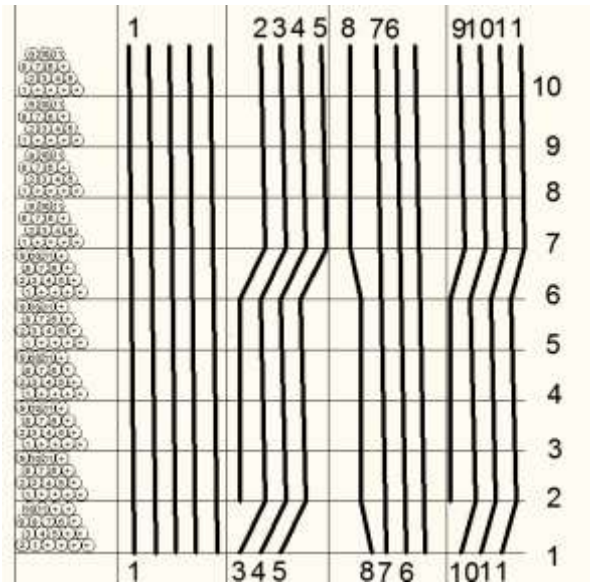



**Fig. 5.3 Development of surface of the winding of drum lining with spiral grooves** [4]

On the spiral grooves in the range of multi-layer winding, the coils of odd layers are laid according to the helical line, and in the even layers rope does the double pitch of displacement from coil to coil, during each rotation of a drum. In critical places next to the rims of drum wedging of the rope and disordered winding of rope occurs, contributing to cause dangerous dynamic forces in the rope. It has very negative influence on a durability of rope and may also cause damage of drum rims. Due to safety reasons, rope transition from layer to the next layer, must occur with limited or reduced winding speed.

Rope in the first layer is laid in a groove with fixed inclination angle γ related to the plane perpendicular to the axis of the drum. This angle determines the dependences, fig. 5.4 [10, 11]:

$$\tan\gamma = \frac{d+t}{2\pi R} \tag{5.1}$$

where:
$t$ – slit between coils of rope winding,
$R$ – radius of winding rope (drum radius)
$d$ – diameter of rope

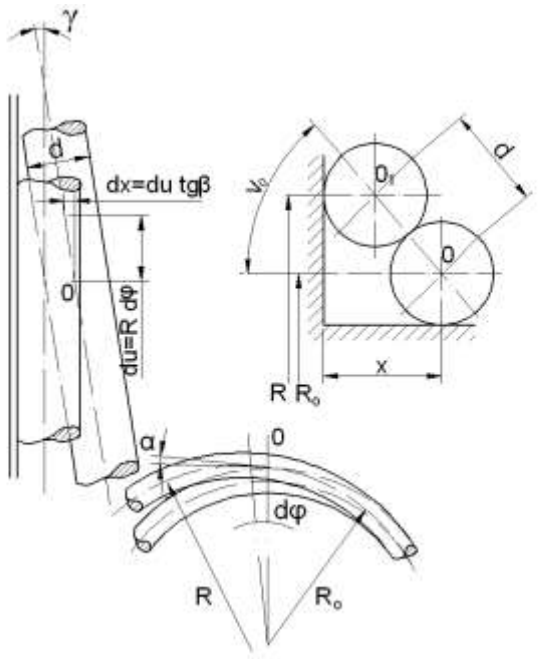



**Fig. 5.4 Two-layer winding of rope on a cylindrical drum with helical grooves** [4]

Assuming that the cross-section of the rope has a circular shape and do not deform, a change in winding radius during the transition from the first layer to the second, is defined by the dependences (fig. 5.4):

$$R_i = R + d \cdot V \tag{5.2}$$

where:
$V$ – angle determining the position of the cross-section of rope coil at any critical point of the drum.

This angle in the literature is determined as coordinating angle and connected with adequate angle of drum's rotation $\varphi$. To calculate the parameters $\varphi$ and $R_1$ the dependence

according to [11] can be used:

$$\varphi = 2\pi \frac{d}{d+\varepsilon}(1 - \cos w)$$

and:

$$R_i = R + d \cdot \sqrt{1 - \left(1 - \frac{d+t}{d} \cdot \frac{\varphi}{2\pi}\right)^2} \tag{5.3}$$

This way of rope arranging in a critical position of drum can occur only in a case when the fleet angle equals zero. Then rope is in the state of equilibrium, if the angle $V = \pi/2$, or if the rope winds itself, or is laid in groove formed by two adjacent rope coils of the first layer. In reality, in the mine-shaft hoists with drum machines, such position of the rope never occurs, because during the winding of rope fleet angles are inevitable. Therefore, the rope to be in the state of equilibrium leaves the critical place of the drum earlier than its boundary (interval) passing to the second winding layer. This pitch rope displacement along a generatrix of drum is called first transition of rope, cross-section I-I, in fig. 5.5. During the further winding of rope, if deviation angles are not excessive (in opposite case a break of coil of winding rope occurs), rope is laid in the groove created by two adjacent coils of the first layer (penultimate and the on placed close to it), until the rope will not pass the critical place of drum again from beginning. It is there again pulled out from the groove formed by two adjacent coils of winding and performs a second pitch displacement called second transition ($\varphi_p$ – angle of transition) in the second layer of rope, position II-II, fig. 5.5. It results that, during each rotation of a drum, rope in the second layer performs two pitch displacements [11].

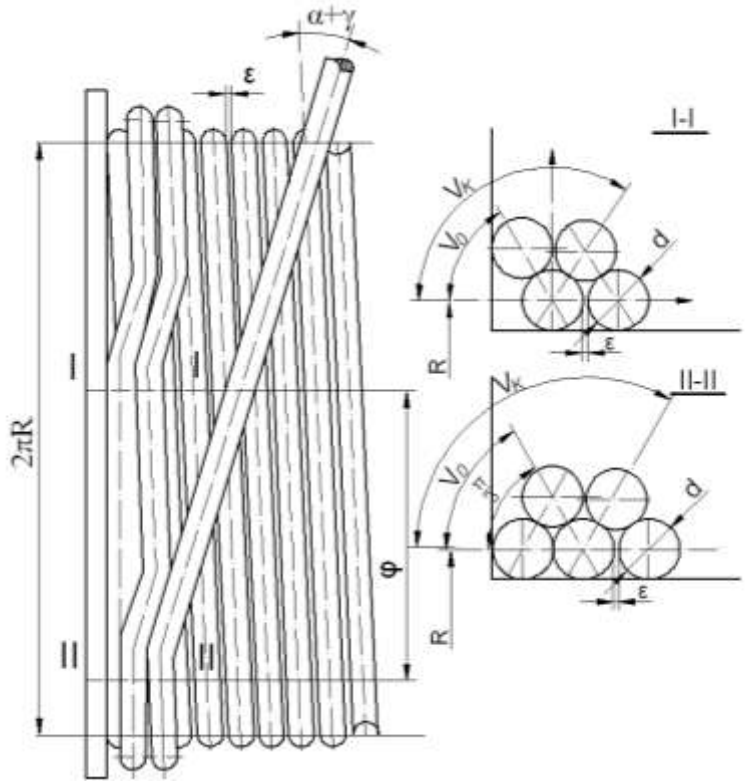



**Fig. 5.5 Diagram of the rope transition from coil to coil during multi-layer winding on cylindrical drum with helical grooves** [7], **I-I the first transition (the first pitch), II-II – second rope transition (the second pitch)**

Behavior of rope during the transition in the second layer of winding (and in the subsequent layers) is characteristic for multi-layer winding, particularly the two-layer winding.

## 5.3 WINDING OF THE ROPE IN PARALLEL GROOVES

Properly multi-layer winding is possible, only with a parallel arrangement of the rope on the drum rims in incised parallel grooves in the lining or shell drum, or after the appropriate formation of the first layer of coils on a smooth drum shell. Fundamental condition for the correctly multi-layer winding is adherence of terminal coils of rope to rims of drum, that there not exists a possibility of side movement in layers. Irregular layering is caused by absence of proper side support of rope, which is caused by the incorrect winding width of drum.

Under these conditions, rope has the possibility to perform side movements, wedging and goes through the lower layer. The incision of parallel grooves in the lining or in the shell of drum with appropriate width gives the possibility to avoid the rope wedging at the rim of the drum and also to achieve the proper arrangement of the rope in the winding process at the rim and in the other coils [13].

In parallel grooved drums, rope performs one pitch in the transition from coil to coil during each rotation of the drum, both in the first, and in the last layer. To obtain the more smooth arrangement of the rope in the subsequent layers in the parallel grooves, purposeful is to make in lining or in the shell of drum, the skew grooves in places of transition from one coil to next, in which the rope moves along the drum of one diameter of the rope.

Cross-section of wound layers and developed traces of ropes are shown in fig. 5.6. Analysis of the rope transition from the first layer to the second shows that the rope moves up and inside, along the generatrix of the drum, by a half diameter of the rope. The nearest subsequent coil moves also toward the drum interior, but by the full diameter of rope.

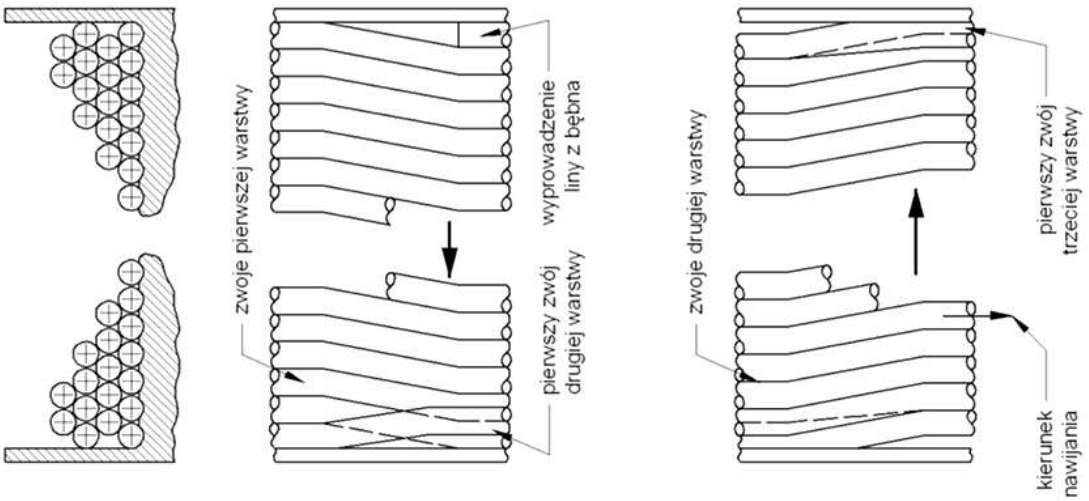



**Fig. 5.6 Multi-layer winding of rope on cylindrical drum with lining with parallel** [7]

The first movement of the first coil of the second layer is departing from the rims of the drum, leaving the free space equal to a half diameter of the rope.

During the winding of the second coil of the second layer, the rope goes partially

through the cross shifting of the first coil, and then through the two coils in the lower layer. At the end of the second layer, during the transition to the third layer, rope moves up and toward the rim of drum, by a half of diameter of rope to the position at the rim, above the gap equal to a half of diameter of rope at the end of second layer. The next coil of third layer moves toward the interior of a drum by a full diameter of rope. Proper shiftings of rope by a half of diameter at the rims of drum are in the same direction, whereas shiftings by a full diameter of rope occur in opposite direction. In further layers winding of rope will go in the same manner, *i.e.* in the odd layers as in the first one, and in the even layers as in the second one.

The cross-section which is presented in fig. 5.6 shows, that the even number of layers contain one coil less than the odd layers. It is caused by a gap equal to a half of diameter of rope between the terminal coils of the even layer and rims of drum [13].

In each layer the same number of coils can be obtained, when the transition of rope from layer to layer at the left rim of the drum will be equivalent to transition at the right rim. It can be fulfilled, when rope during the transition from the last coil of previous layer to the first coil of next layer will made a pitch equal to half diameter of rope towards the and will adhere to it. This is achieved by the termination of coils of the first layer at a distance equals to a half diameter of the rope from the rims of the drum. Each layer starts at the rim of the drum and it is terminated by upwards movement and displacement in the rim direction, to form the first coil of the next layer. Coils arrangement is the same as in the previous pattern [13, 14].

5.3a *The multi-layer winding of rope in parallel grooves with one transition of skew grooves in the circumference*

In this method of winding, the coil of rope winds parallel to rims and during each rotation of the drum makes a singular skew displacement of one pitch to next rope's groove. Uplift of rope to the next layer with simultaneous recurrence takes place during directing of rope from the rim to the middle of wounding zone (fig. 5.7).

For this type of winding requirements are as follows [7, 13, 14]:

a. The pitch of rope grooves, $t$, can equals up to 1.1 of the diameter of rope, $d$, and the depth of groove, $h$, minimum 0.25 of the diameter of rope,
b. Introduction of rope from drum is distant from the right or left rim by a pitch of rope grooves measuring from the edge to the axis of rope, and is located directly behind the skew grooves towards the direction of wounding. Gap equal to a half of diameter of rope between the rim and the first coil has to be filled by insert to the height of winding diameter of the second layer.
c. Winding width of drum $B$ (spacing between rims) has to be selected according to total number of rope coils, $z$, in the layer increased by a half of coil. In the new drums there has to be selected proper winding width on the stage of design. In the operating drums or at the replacement to the rope of different diameter matching is performed by the putting the filling inserts at the rims or at one of rim to the height at least of 1.5 of diameter of rope above the axis of rope of last layer.
d. Experimentally it was established, that the length of the skew grooves, $l$, measured at the circumference of the drum, parallel to the rims, should equals to about 2/3 $d^2$. In respect of

implementation, recommended length of skew grooves should equal to multiplicity of lining's width rounded up.

e. Directing wedges are made for rationatization of rope transition to subsequent layer. There are placed at rims in the zone of skew grooves. Height of wedge with scarf of 15° angle has to be equal to at least 1.5 of diameter of rope above the geometrical axis of rope of last layer. Edges of wedges can be cut, and sharp edges should be blunted.

f. Filling inserts are placed in the zone of skew grooves at the rim opposite to rope exit from the drum and they uplift rope from the first layer into the second one. Height of the inserts changes from the level of first layer to the level of the second layer. Inserts in the zone of skew grooves at the exit of rope from the drum and inserts in the zone of parallel grooves support the coils of second layer. Inserts can be made totally with drum linings, properlu shaping the lining at the rims or as segements. Filling inserts and directing wedges are made of hard wood, aliminium, textolit, plastics or steel. Depending on the material used, they are fixed to the rim, linings or to the shell of drum, by screws, tap bolts, and steel one can be welded.

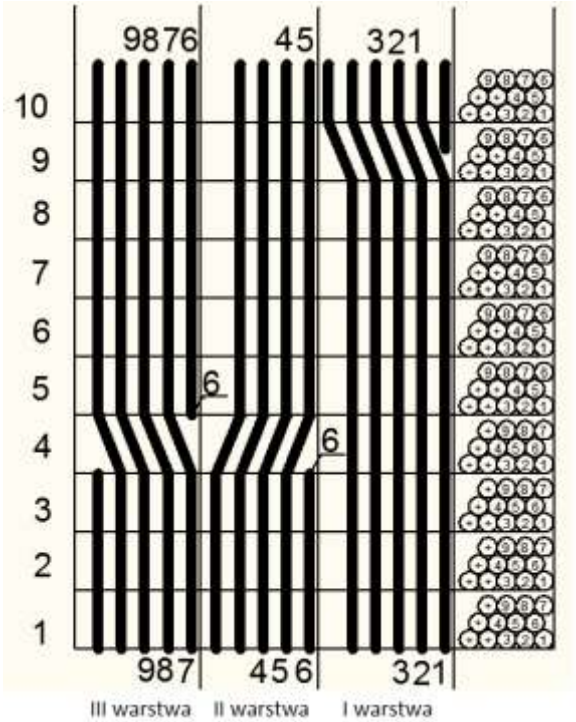



**Fig. 5.7 Development of surfaces of winding of drum's lining with parallel grooves and one skew transition** [14]

5.3b *Multi-layer winding of ropes in parallel grooves with two transitions of skew grooves in circumstance of the drum using lebus method*

In 1937, Frank LeBus patented the idea of a special grooving of drum lining, which properly guided the rope during its winding on a drum. This method was developed in 1950, and in technology it bears the name of the method LeBus. Frank LeBus was a producer of drilling rigs for the oil mining in Texas. The experiences with difficulties which occurred during winding multiple layers of rope on drums of drilling rigs, led to patent the new LeBus

method, which started to be applied also in other types of winders including mining shaft hoisting. In mines in USA and South Africa, there began to use the LeBus grooving method during the winding multiple layers of ropes on cylindrical drums since 1962 [2, 4, 8, 12, 16].

In LeBus method grooves (fig. 5.1c, and 5.8) are made parallel to the rims and the displacement of coils along the drum by one pitch is obtained by performing skew grooves in two zones on the circumference of the drum, shifted from each other by 180°. With such grooved rope moves by a half pitch in one zone, thereby reducing the hitting of rope in the place of crossing and the possibility of excessive vibrations. Such grooving of LeBus method called synchronous is particularly useful for winding of mining vessels with a high speed, during multi-layer winding of more than three layers. Currently this way of grooving, LeBus synchronous, is the most popular method. To avoid synchronization of rope's jerks and vibrations during rotation of the drum, and to reduce the amplitude of harmonic vibrations (resonance of rope), there was done modification of the LeBus method (fig. 5.8b). It involves change in the displacement angle $\varphi$ of skew grooves from 180° to (150° and 210°), (163° and 197°), or any other combination, which gives the sum of 360°. This method of grooving of lining was called LeBus asynchronous, and it is also widely used (fig. 5.8b).

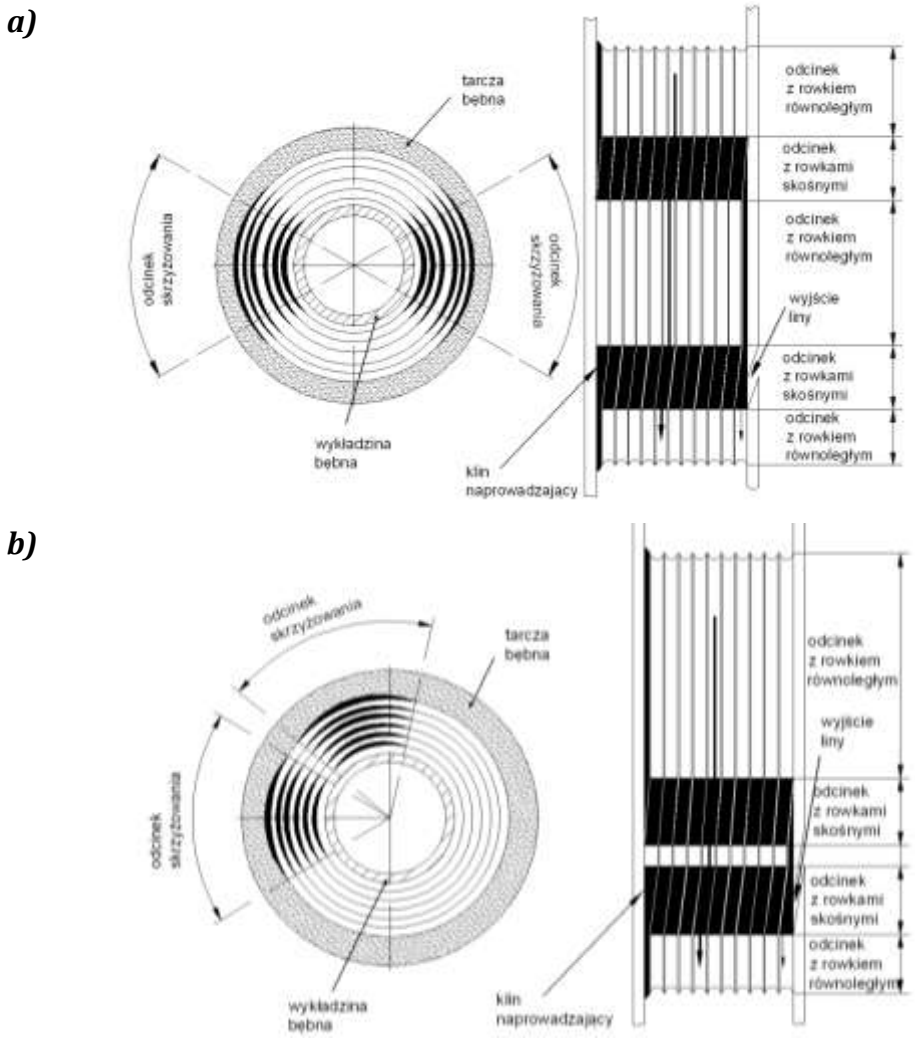



**Fig. 5.8 Schemes of multi-layer winding of ropes on the drums of LeBus method** [14]**: a) synchronous, b) asynchronous**

A necessary condition for satisfactory operation of the machine with multi-layer winding of ropes on drum is regular, smooth, compact and ordered winding of rope, both in the first and in subsequent layers. If the winding is irregular, then there is a possibility that rope will break through the wound layer and will place on lower improper layer. Also there is possibility of rope wedging at the rims of drum, what causes in rope occurrence of strong jerks, transmitting on the mining vessel, and causes its vibrations.

As a result of rope wedging and vibrations caused by transition of rope from layer to layer and from coil to coil, the durability of the rope decreases, as the result of wearing and cracking of wire. It should be noted, that compact and ordered winding of the first layer of rope in lining grooves influences on the proper winding of the subsequent layers, and thereby for the safe exploitation of the shaft hoisting.

### 5.3c *Parallel winding with two skew transitions in circumstance of the drum using synchronous LeBus method*

In the LeBus method coils of rope wind parallel to the rims and during each rotation of the drum perform double skew displacement of a half pitch *t* to next rope's groove. Uplift of rope to the next layer take place in a zone of skew grooves situated next to the exit of rope from a drum. Return of rope from the rim to the middle of wound zone (without uplift the rope) takes place in second zone of skew grooves.

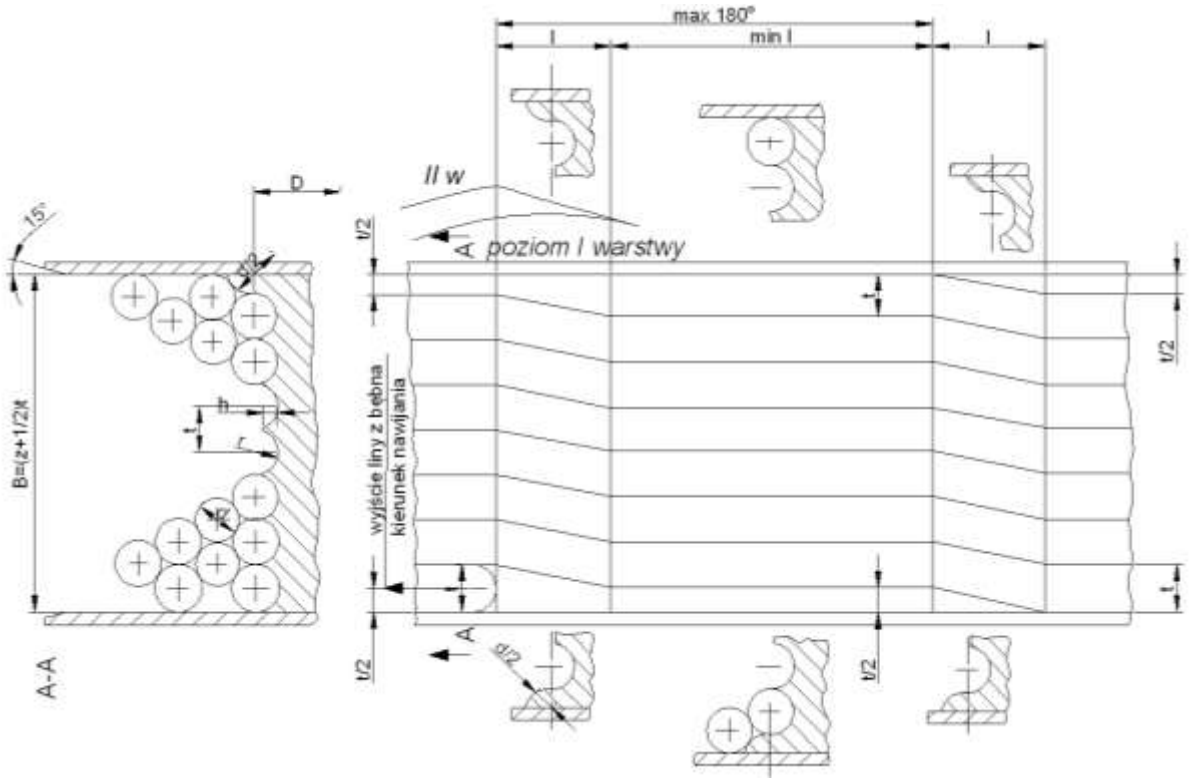



**Fig. 5.9 Winding, using the synchronous LeBus method** [4]

In zone of skew grooves situated next to the exit of rope from the drum, next to the opposite rim, inserts uplift the rope from the first to the second layer, and height of these inserts is changeable from the level of first layer to the level of second layer. However, inserts

situated next to rim of the rope's exit from the drum, have changeable height from the level of second layer, to the level of third layer. Inserts situated in a second skew zone having an equivalent height, equals the level of second layer. Inserts can be made as complete with the lining of drum or in the form of segments [14].

In a fig. 5.9, there is presented a cross-section through a wound layer and the development of a drum. The grooves which are parallel to the rims, are made on the entirely circumstance of drum, with the exception of already mentioned two areas of the skew grooves. The skew grooves joint the parallel grooves situated shifted each other by a half pitch of groove *(d+ε)/2*.

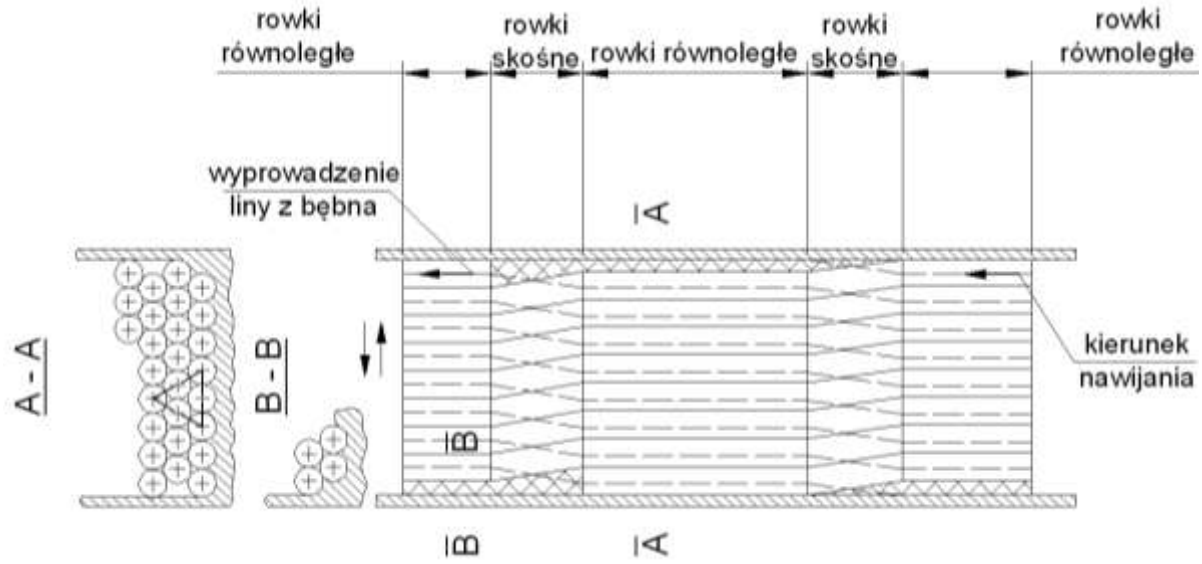



**Fig. 5.10 The development of rope marks and cross-section of wound layers in LeBus synchronous method** [4]

Directly at the rims of the drum there are situated filling inserts, which are used to support the extreme coils of the second layer, as indicated in a fig. 5.10 by a double hatching. Grooves are connected with filling inserts by mild transitions made in the same circumstance of drum as the skew grooves. Filling inserts reach a maximum height in the area of parallel grooves. During one rotation of a drum, rope will move twice about the half of rope diameter, so totally about one diameter. During the first skew displacement of the first coil of each layer, rope departs from the rim of the drum and when the last skew displacement of the last coil of each layer coming to the rim, then rope places parallel and adheres to the rim. Cross-section through the layers shows, that rope arranges in a pyramid-shaped columns, which ensures rope stability during the winding and the absence of side movements.

From the literature review it concludes, that the rope grooves (fig. 5.9) should be made according to following rules:

a. The total pitch of grooves *t* can equal to maximum 1.1 diameter of rope *d*, and depth of groove, *h*, minimum 0.25 of rope diameter.
b. Winding width of drum B (spacing between rims) has to be selected according to total number of rope coils, *z*, in the layer increased by a half of coil. In the new drums there has to be selected proper winding width on the stage of design. In the working drums or at the

replacement to the rope of different diameter matching is performed by the putting the filling inserts at the rims or at one of rim to the height at least of 1.5 of diameter of rope above the axis of rope of last layer

c. Output of rope from the drum is located at the left or right rim, that a rope adheres to the rim. The output of rope is located directly behind the skew grooves which uplift the rope to the next layer towards the winding of rope. Gap equal to half of diameter of rope (exactly half of pitch of rope groove) between the opposite rims and the last coil of first layer is filled with an insert at the height of level of second layer. In the second zone of parallel grooves gap, equal to half of diameter of rope, is laid near the rim of exist of rope from the drum, *i.e.* opposite than in the first zone.
d. Company LeBus states, that the length of the parallel grooves should be equal to about 80% of the circumference of a drum, and the total length of the skew grooves to about 20%.
e. Filling inserts are placed in a zone of parallel grooves to support the extreme coils of the second layer. Height of these inserts equals to the level of second layer.
f. The filling inserts are placed in the skew grooves area next to rim of the opposite output of rope from the drum and uplift the rope from the first to the second layer. The height of wraps is changing from level of the first layer to level of second layer. Inserts in the zone of skew grooves at the output of rope from the drum and inserts in the zone of parallel grooves support coils of second layer.
g. In order to obtain a good winding of rope, during an installation of rope it should be winded on the drum with an initial tension corresponding to 2% of force breaking the rope or with a tension corresponding to 10% of rope exploitation load.
h. Fleet angles of rope to the rope pulley should equals from $0.3^{o}$ to $1.5^{o}$.
i. In the LeBus method high requirements are given regarding the geometrical dimensions of grooves and tolerance of diameter of rope.

## SUMMARY

From the literature review it results, that the most profitable of all the methods of multi-layer winding of ropes on drum, due to the durability of a rope, its compact laying, and reduction of vibrations, is the synchronous LeBus method, or its modification, LeBus asynchronous.

At this moment these methods of multi-layer winding of ropes are widely used in global technique. Beside the rock and oil mining, there are used also in other domains *e.g.* cranes, transport machines in harbors, ships, offshore drilling platforms.

## REFERENCES

1. Antoniak J., Carbogno A.: Trzywarstwowe nawijanie liny z nabiegami miedzywarstwowymi. Opinia Instytutu Mechanizacji Górnictwa Politechniki Śląskiej. Gliwice 1976.
2. Clark R., Porter C.: A study of hoist drum grooving. International Conference on Hoisting of Men, Materials and Minerals. Toronto-Kanada 1998.

3. Coulshead A. J. G.: Mobile Winding Engines and Multi-Layer Rope Spooling. The Mining Engineer nr 91, 1961.
4. Das LeBus – Seilrillensystem wirkt ausgleichend und regulierend. Internationale Seilbahn – Rundschau, Heft 4/1963.
5. Hudzik M.: Wielowarstwowe nawijanie liny. Wzorcowa dokumentacja elementów prowadzenia liny. Opinia atestacyjna Nr 12/85. CMG-KOMAG Gliwice, 1985.
6. Najdienko J. S., Sołomienciev A. J., Mieliksietov S. S., Markov A. A.: Mnogosłojnaja navivka kanatov na barabany prochodčeskich podjemnych mašin. Šachtnoje stroitielstvo No. 11, 1972.
7. Niesterov P. P., Počtovienko Ju. E.: O profilirovanii kanavok barabanov rudničnych pod'emnych mašin pri mnogosłojnoj navivkie kanatov. IVUZ Gornyj Żurnał No 3 1967.
8. Oakden H.: Methods of controlling coiling of multiple layers of wire rope on cylindrical drums with particular reference to the LeBus system. International Conference on Hoisting – Men, Materials, Minerals. Johannesburg, September 2007, 1973.
9. Opis patentowy 127747 „Bęben linowy". Zmyslowski T., Grzechowiak A., Wrzeszcz M. i inni. CK-TMG „KOMAG". Gliwice, 1985.
10. Počtovienko Ju. E.: Skorosti i uskorienija kanata pri mnogosłojnoj navivkie. Viestnik mašinostrojenia No 10, 1966.
11. Praca zbiorowa. Teorija i praktika podjema. Izd. Naukova Dumka. Kiev, 1975.
12. Seidenather C.: Keeping it smooth itd. International Cranes and Specialized Transport, 2007.
13. Stajer F.: Wielowarstwowe nawijanie lin na bębny. Mechanizacja i Automatyzacja Górnictwa, Nr 10 (71), 1974.
14. Stajer F.: Wielowarstwowe nawijanie lin na bębny maszyn wyciągowych. Maszyny Górnicze. CMG KOMAG, Nr 15, Gliwice, 1987.
15. Stajer F., Zmysłowski F.: Wielowarstwowe nawijanie lin w wyciągach szybowych. Mechanizacja i Automatyzacja Górnictwa. Nr 5, 1979.
16. http://www.lebus-help.com.

# ISSUE OF MULTIPLE-LAYER WINDING OF ROPES ON DRUMS OF MINE-SHAFT HOISTINGS

**Abstract:** *In paper development of methods of multi-layer winding of ropes on cylindrical drums of mine hoisting machines (winders) was presented. Methods of winding ropes on smooth drums and drums with grooved linings were discussed. There was presented helical and parallel winding of ropes, and the most preferred in global technique of winding of ropes on drums with LeBus lining in synchronous LeBus version, and asynchronous LeBus version, in which the grooves are incise on sections, as parallel and skew grooves. Based on the literature review and experience in use of different methods of multi-layer winding of ropes, especially of LeBus method, abroad and in country, general requirements for their use are presented*.

**Key words:** *winding of ropes, LeBus method, testing of wire ropes*

# ZAGADNIENIE WIELOWARSTWOWEGO NAWIJANIE LIN NA BĘBNY GÓRNICZYCH WYCIĄGÓW SZYBOWYCH

**Streszczenie:** *W opracowaniu przedstawiono rozwój metod wielowarstwowego nawijania lin na bębny cylindryczne maszyn górniczych urządzeń wyciągowych. Omówiono metody nawijania lin na bębny gładkie i bębny z wykładzinami rowkowanymi. Przedstawiono nawijanie lin spiralne, nawijanie równoległe oraz najbardziej preferowane w technice światowej nawijanie lin na bębny z wykładziną LeBus w wariancie LeBus synchroniczny i LeBus asynchroniczny, w których rowki są nacięte odcinkowo jako rowki równoległe i skośne. Na podstawie przeglądu literatury oraz doświadczeń w stosowaniu różnych metod wielowarstwowego nawijania lin za granicą i w kraju, szczególnie metody LeBus przedstawiono ogólne wymagania co do ich stosowania.*

**Słowa kluczowe:** *nawijanie lin, metoda LeBus, badanie lin stalowych*

dr hab. inż. Jarosław BRODNY, prof. nzw. w Pol. Śl., dr inż. Marcel ŻOŁNIERZ
Silesian University of Technology, Faculty of Mining and Geology
Institute of Mining Mechanisation
ul. Akademicka 2A, 44-100 Gliwice
e-mail. Marcel.Zolnierz@polsl.pl; Jarosław.Brodny@polsl.pl

# 6

# MANUFACTURING DATA ACQUISITION IN NON-AUTOMATED PRODUCTION SYSTEMS

## 6.1 INTRODUCTION

In a competitive and globalized economy, data acquisition from production systems is becoming a more important issue because it is a means to improve the company's performance through the integration of the business and manufacturing company layers. The management of the company should obtain updated information on the situation in the production system – the execution of production orders, effectiveness of machinery and equipment, circulation of materials, semi-finished and finished products, activities performed by employees, quality of products, etc. This information should be relayed to the management of the company and to information systems supporting the company operation and its resource planning (ERP), either directly or via middleware – Manufacturing Execution Systems (MES).

Integration of company layers, realized by middleware systems (MES) is well described and standardized in ANSI/ISA-95. This standard, however, focuses on collaboration between MES and ERP systems, leaving unresolved communication issues between the physical production process and MES systems. Solutions described in the standard mainly concern the acquisition of data from production systems in which most of the technological processes are automated. This implies the need to systematize and develop methods to obtain information on production from the companies in which the degree of automation of technological processes is low. This is the case in companies where the majority of operations are performed using simple equipment and tools, or completely manually. There may be some other hurdles for data capture, such as the movement of workers and machines over a large area, unstable and variable technological processes, the multi-assortment manufacturing of small quantities of products.

## 6.2 DATA ACQUISITION IN VARIOUS PRODUCTION SYSTEMS

Solving the problem of data acquisition for the purposes of management requires, in the first instance, the classification of production systems due to the characteristics that affect the availability of the data. The basic criterion for this classification may be the degree of automation of the technological processes. This is due to the fact that the introduction of automatic process control requires the installation of the sensors and measuring devices closing the feedback control loop. The data obtained from these devices can be extracted and used as well for tasks that are not directly connected with the control of the process.

Due to the criteria of the degree of technological processes automation, it is possible to specify the following types of production systems:

- automated systems using modern control devices, equipped with a network interface, using contemporary programming and communication standards,
- automated systems using older or less sophisticated types of control devices, without communication interfaces,
- mechanized systems, in which no means of automation are used,
- systems in which most of operations are performed manually or using simple equipment and tools.

The analysis of the needs of ERP and MES systems, used as modern enterprise management tools, results in the following list of types of information to be obtained from the production system [11]:

- information about the usage and state of machinery and equipment,
- information about the production tasks performed in the system,
- data on flow of materials, parts, work in progress, and finished products through the manufacturing system,
- information about the activities of employees,
- data on the quality of the products.

The data obtained from the control system, intended originally for the purpose of process control often do not carry all the information needed to assist in the management of production processes. In this case, there is a need to use different solutions to fill in the missing information.

In the companies characterized by a predominance of processes performed manually the basis of information retrieval is the method referred to as the manual acquisition.

Manual acquisition is based on direct communication between employees at different levels of the hierarchy of management. It can be verbal or conducted by various forms and reports filled in by staff. This solution has many drawbacks, first of all, it is inefficient in the context of modern industrial systems. Manual acquisition is often associated with the appearance of errors and delays. There is a risk that important information will be transmitted with a delay or even suppressed, as there is a lack of efficient mechanisms to verify the information entered [1]. Also removal of workers from their primary tasks in order to keep records is unwanted and reduces their overall productivity.

The requirements of modern management support systems (ERP, MES) make it necessary to use solutions that are more reliable and faster. This leads to the definition of the acquisition method, referred to as semi-automatic acquisition (otherwise called assisted manual acquisition). Figure 6.1 shows the proposed classification of methods of data acquisition for the purpose of the company management.

Automatic acquisition means retrieval of data from technological processes automatic control systems that take place without human intervention. The data comes from sensors, industrial controllers, CNC machines and other sources. A SCADA (Supervisory Control and Data Acquisition) system often plays a role of a link, that allow integration with the upper layers of the company [10, 18].

The problems associated with manual data acquisition has led to the development of a

variety of solutions that can be described as semi-automatic or assisted manual acquisition. In these methods, operator intervention may be required, but it is minimized, and the actions of the employee are supported with hardware and software solutions, that enable the reduction of the error rate of data acquisition and increase its speed.

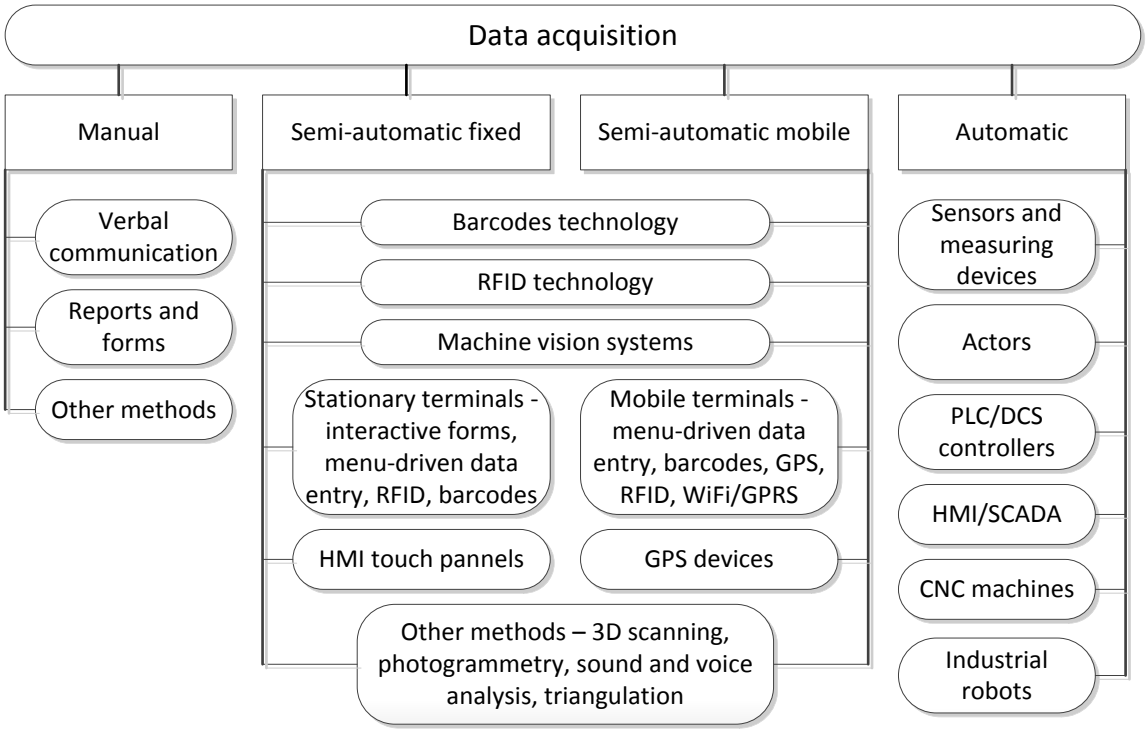



**Fig. 6.1 Classification of methods of data acquisition from production systems**

Technology of automatic identification of objects is the basis of these solutions. The use of different types of automatic identification systems has become a necessity due to the increase in the number and variety of manufactured products. The first applications of automatic identification were introduced in storage systems. With the improvement of technology and the introduction of information systems for different areas of the company business, the importance of automatic identification systems continues to grow. Solutions of this type allow the acquisition of information for management purposes, from non-automated and semi-automated production systems. Semi-automatic acquisition can be carried out using fixed or mobile devices.

Currently, there are many methods used in the automatic identification of objects. They can be based on: barcodes (optical reading), magnetic track, radio frequency (RFID), the analysis of voice (audio), image, etc [6].

The following chapters present the characteristics of manual, automatic and semi-automatic solutions of data acquisition for the purposes of production management.

## 6.3 MANUAL DATA ACQUISITION

Despite the trend towards reducing the human role in the manufacturing process, it is still not possible to completely eliminate it. Automation, robotics and mechanization allows the significant reduction in human participation in the production process, but still there are

processes that are not automated, mainly due to insufficient profitability. Supervision of automated devices is still necessary. Moreover, support and maintenance processes in industry are rarely the subject of automation.

Depending on the specifics of the production process, the employee may act as:

- The performer of manual operations – perform tasks manually or with the use of simple tools. An additional difficulty in the acquisition of data is a situation where the employee performs his duties in locations far away from the main area of a company or in a large area. Often, the employee must be mobile in the production halls or in the open field. Information is required on employee activity – the degree of realization of contracted tasks, materials used and problems encountered.
- Warehouse worker – responsibilities of warehouse workers usually involves accepting deliveries, issuing materials, completion of shipments, etc. Warehousemen activities should be recorded, but there is no need to report their exact location.
- The operator of machinery, equipment, means of transport – it is necessary to obtain information about the activity of the worker, the task stage, the problems encountered, machine location, the estimated time of completion of the tasks, etc.

Information obtained from these groups of workers are often put into the management support systems by mid-level supervisory staff or data entry operators. Data can be entered directly into the business layer systems. Often, the common practice is the entry of the data into various types of document templates in a standard word processor or spreadsheet. These documents go via e-mail to people who put it into the ERP system. Delays and errors may appear at each stage of the transmission of information. You can also not rule out the possibility of hiding information from senior management by subordinates.

The results of research, and practice, indicates that the employee is not a reliable source of information, forwarding it with considerable delay and errors resulting from subjectivity, negligence or malice [3]. The most commonly used method of manual data acquisition is the acquisition from employees during conversation (direct or phone) or by filling in forms and reports. These methods are not sufficient in the modern enterprise, and it is necessary to create alternative, more reliable methods.

## 6.4 AUTOMATIC DATA ACQUISITION

Automatic data acquisition for the purpose of management is possible in automated production systems. These solutions cover most of the needs for the data acquisition from part of the production system, covered by the automatic control [6, 19]. Data acquisition for the purposes of control is usually realized automatically, without the involvement of employees. Data acquired for control purposes can be simultaneously used for management purposes after pre-processing. Often it is necessary to create the appropriate interfaces.

The list of elements of industrial automation systems that can be a source of data to ERP systems include:

- control and measurement devices installed on machines and equipment - measuring instruments (sensors, transducers, etc.), equipment used in quality control,
- actuators for industrial automation – solenoid valves, servo drives, frequency inverters, metering pumps etc.,

- control devices: PLCs, industrial computers, operator panels (HMI), distributed control systems (DCS),
- human-machine interface/supervisory control and data acquisition systems (HMI/SCADA),
- machinery and equipment carrying out processes: machines, CNC machine tools, industrial robots, transport systems, palletizing systems and other devices.

The above devices, as a data source, can be divided into two categories: primary and secondary. Typical primary sources are sensors and measuring devices, directly responding to changes in the physical process. Devices such as industrial controllers (PLC, DCS), CNC control systems and industrial robots can be regarded as a secondary source, because they relay signal from primary sources. At the same time they generate new data resulting from the operation of control algorithms processing original data from primary sources.

SCADA systems are also secondary sources, integrating data from different types of sources. At the same time SCADA systems can also collect data from process operators or supervisors (commands and data entered manually) or generate it, thanks to implemented master control algorithms [16].

Data obtained from the control systems must be sent to the systems in the upper layers of enterprise through appropriate interfaces, enabling the integration of these systems, both at the hardware and software levels. There are a lot of problems arising from high fragmentation on the market of automation systems – there are many competing standards and solutions promoted by the various hardware and software manufacturers. This applies to both the control systems and industrial communication networks.

This situation is the cause of attempts to introduce uniform standards and communication protocols, allowing access to data in control systems from different manufacturers. Examples of such solutions are the OPC standard (created for access to various types of industrial controllers) [22] and MTConnect (communication interface for CNC machines) [5]. Software installed in the upper layers of a company, compatible with these standards, may obtain the required data from the control systems through the interface servers.

## 6.5 SEMI-AUTOMATIC DATA ACQUISITION

The use of semi-automated data acquisition methods in companies stem from the necessity of solutions that are more efficient and reliable than the manual acquisition. The easiest way to improve the manual acquisition is to provide lower-level employees with access to computer terminals equipped with software supporting data entry. The terminal can be fixed or mobile, and programs designed to input data should be written in such a way as to facilitate data entry and simultaneously reduce the risk of errors. This is accomplished through easy-to-use graphical interfaces and the implementation of mechanisms to verify the data and to prevent the introduction of incorrect information. A standard PC can be used as a terminal, although HMI touch panels are more suitable for use in harsh industrial environments.

This solution still requires the employee to use up valuable time for the cumbersome typing of long strings of characters. This problem can be solved by the use of automatic

identification systems. These systems usually use a label with coded information and corresponding readers, allowing fast and reliable reading, and, in some cases, writing or editing of data [4]. These labels are not readable without proper equipment. The most widely used automatic identification systems are barcode technology and RFID technology. This category may also include vision systems, which are different from previous methods because of a lack of the need for labels, but also a slightly different range of applications. Each of these technologies has a number of advantages, but also disadvantages that limit its use in certain situations.

## Automatic identification systems

The expansion of automatic identification systems, and barcode technology in particular, began with storage and logistics applications. Storage facilities were the basis for the development of MRP. In practice, this means that the automatic identification systems are often directly connected to the business systems (ERP/MRP/MRP2). Automatic identification can also be directly integrated with the process control systems. For vision systems, this is often the standard mode of operation.

The most commonly used method of the automatic identification is **barcode technology**, which is a source of data mainly for warehouse management systems [17, 21]. The most important advantage that has influenced the popularity of barcode technology is the low price of the labels and reading equipment, and the quick read time. The advantages of this technology make it the primary method of identification used in production systems, logistics and warehousing. Deployment of barcode scanners at many points of the production system and thoughtful, design allows us to get information about the objects (materials, semi-finished or finished products and equipment) movements. The limitation is that the barcodes have little information capacity, so serve only as an object identifier. The rest of the data is stored in the system database, and so in the absence of access to this database, the codes are useless because they do not carry any information, such as the product genealogy. Barcodes printed on paper are not resistant to harsh industrial environmental conditions, but it is possible to use a more robust material or print a barcode directly on the objects surface.

**RFID systems** (Radio Frequency Identification) are based on the wireless transmission of data between the tag and the reader [12, 24]. This technology is newer than barcodes and can solve a number of problems related to low barcode label durability, small information capacity and the need of the scanner to have direct visibility of the label. The RFID labels (tags) are compact in size, may be resistant to certain environmental factors (heat, cold, dirt, mechanical damage, moisture and chemicals) and have longer operating range (from a few millimeters to several meters). It is possible to detect and identify objects from a distance, regardless of their orientation, which eliminates the need for manipulation of objects, and thus facilitates automatic data acquisition. RFID R/W (read/write) tags allows us to write and edit the data. In industrial applications RFID technology is primarily used to control the flow of products at various stages of the manufacturing process and storage. In a situation where transponders may be reused or applied to labeling objects of great value, the higher price of tags is practically of no importance [8].

**Machine vision technologies** play different roles in data acquisition from production systems than barcodes and RFID technologies. They are usually strongly associated with the

technological process, performing the function of a sensory system, directly controlling the process or a part of it. Vision systems used for quality control or sorting can provide direct access to information about the number of manufactured components or production quality [9]. A typical operation mode of the vision system is inspection triggered by control systems. Machine vision systems may also work in a continuous mode, monitoring the changes in a scene (for example, in security and surveillance systems). Efforts are also made to use machine vision systems for monitoring the progress of construction work (to measure the degree of work completion based on image analysis and comparison with the CAD model of the structure) or a visual analysis of the activity of employees (often in combination with the data from the position sensors and movement sensors) [20]. Vision systems can also be used for monitoring and controlling of mobile robots or analyzing the flow of large products (e.g. tanks, wagons, etc.) through the stages of the production process, which takes place over a wide area, often outside the production hall [2].

### Other methods of data acquisition

When a standard automatic identification systems are not sufficient it may be necessary to use other solutions. This applies especially to those companies where employees or equipment are moving around a vast area and there are no typical production lines. A combination of different techniques of acquisition like barcodes, RFID, vision systems, GPS, 3D scanning, etc., can provide more possibilities of data acquisition in difficult conditions [15].

A possible solution to the problems of acquisition of information in such cases is the use of mobile devices, such as industrial data collectors, portable computers, PDAs (Personal Digital Assistants), smartphones or tablets [7]. Such devices equipped with appropriate software allow you to enter data in field conditions, have wireless connection modules and, often, GPS receivers. Most also allow you to prepare photographic or film documentation and can read bar codes or RFID tags.

In industrial applications, the most commonly used devices (data collectors) are designed for operation in harsh environments, but recently the use of consumer electronic devices, such as smartphones and tablets has become more common practice. These devices are controlled by operating systems (Windows Mobile, Android, iOS), which allows the easy design of applications. Applications usually allow simple data entry through menu systems and incorporate information from sensors built into the device (e.g. camera acting as a barcode scanner, GPS and RFID-NFC systems) and wireless communication with databases. These devices are often owned by employees – a BYOD (Bring Your Own Device) model.

There are also attempts to use sound analysis and speech recognition for data acquisition from workers, to avoid distracting them from their main work [13].

### Acquisition of data about the location of objects

In many cases it is necessary to obtain information about the location of objects and workers within the production system. RFID readers and barcode scanners are installed in specific spots and cover a small area, so the RFID and bar codes do not provide continuous information on the location of labeled objects. Data is only available for the transition of the object with the tag or label through the scanning area, but there is no information about what is going on with it until the next scanner detects the object.

In the case of work carried out in a large area, positioning methods based on GPS (Global Positioning Systems) working with Geographic Information Systems (GIS) are often useful [14]. Location systems based on GPS provide continuous information in the open field, but do not work inside buildings. When the data about the position of objects shielded from the GPS signal is needed, other solutions, such as triangulation of the signals of different types (radio, optical) may be used.

Often there is a need to combine several technologies in order to obtain satisfactory results. In the most difficult cases, the common practice is to use a combination of techniques like RFID, barcodes, 3D laser scanning, photogrammetry, GPS and mobile devices with the possibility of wireless data transmission. To automatically determine the activity of mobile machines and vehicles, load sensors and accelerometers can be used. For vehicles equipped with modern CANBUS control systems, direct download of data is possible.

## 6.6 A PRACTICAL EXAMPLE OF ACQUISITION OF PRODUCTION DATA

Data acquisition can be a problem mainly in companies where manufacturing processes are non-automated. An example would be a company which manufactures large products (such as tanks for liquefied gases), individually or in small quantities according to the customer order. The plant do not use automated production equipment, majority of production operations are long-term operations performed manually carried out using simple tools and machines. The products are characterized by their large dimensions (typical tank: length of about 18 m, diameter of up to 3 m) and weight (14-15 tons). Within a week, the plant is capable of producing 5-10 tanks. The main techniques used in the production process is welding, machining, cutting and shaping metal sheets. Some parts are made by subcontractors. The tank assembly is long process, some operations take more than 10 hours.

In the described system acquisition of information about the tasks of production and movement of materials and finished products within the production hall is necessary.

In the business layer the ERP system – SAP R/3 SPRINT is used to support company management. This system generates orders of production operations, a printout include also a barcode, allowing worker or manager to confirm the operation execution. Initially, confirmation of the operation was carried out by the production plant manager, who collected data on the operations performed from foremen and entered it into the SAP system at the end of the production shift. It was a typical example of the manual acquisition, where the information appeared in the ERP system with a significant delay, frequently with errors and glitches.

Registration of production material flow is supported by the dedicated SAP module, but only release of materials for the production from material warehouse and the arrival of a finished products to the products warehouse are considered – there is no information about the intermediate stages of the production of tanks.

The unsatisfactory state of data acquisition in the company has led to the development of solution, that currently include tracking of production operations performed by the employees. In the later stages of development it is planned to include also materials and products flow in the reporting system.

## Production data acquisition system

The main role in the production data processing system covers the *Mistrz*, which is the link between ERP (SAP) and production hall and plays role of two way interface. Scheme of the *Mistrz* is presented in figure 6.2. The *Mistrz* operation is based on production orders, imported from SAP. SAP generates a code allowing to confirm the operation in the form of a barcode. The data on ordered operations is copied to the separate the *Mistrz* SQL database.

The main source of production data are portable data collectors Datalogic Viper, equipped with barcode scanner, touch screen, keyboard, and WiFi wireless interface. Application installed on data collectors is responsible for communication with master system, allowing easy and quick data entry using barcode scanner and keyboard.

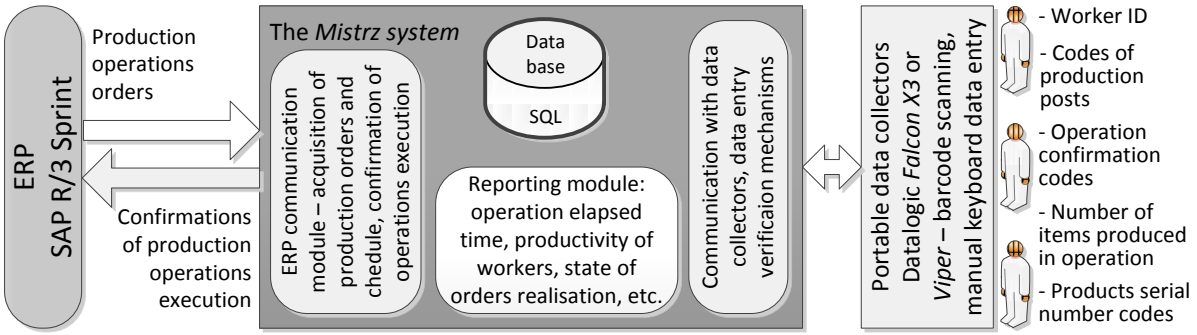



**Fig. 6.2 Data acquisition in *Mistrz* system**

Data collectors are placed in the data acquisition cells in separate areas of the production hall, common for a few production posts. There are three types of charts available in the data acquisition cells, each containing description and corresponding barcode. First type of charts contain codes of production posts – it allows worker to specify on which production post he was working (or will work). Second type of charts contain codes of operations confirmation in different production orders, allowing worker to confirm execution of specific operation, generated in the SAP system. The third type of charts are lists and barcodes of product serial numbers. Each employee has a badge with a personal barcode.

Before starting work, the employee should log on to work at a given post, scanning his personal badge barcode and code of the post. The worker performs operation ordered by his foreman or production manager, but there is no record on it in the *Mistrz* system. After completion of the operation or at the end of the production shift, worker goes to data acquisition cell, re-scans his personal code and confirmation code of the operation he performed. Then worker can determine degree of realization of the operation. Possibilities are: complete execution of the operation order, partial execution (e.g. employee finished 5 of 20 ordered items) or the zero-execution (the employee performed an operation, but failed to complete a single piece, due to the fact that the execution time exceeded the production shift time). If worker performed operation on a final product (with a serial number assigned), serial number barcode should be also scanned.

Employees usually leave the confirmation of orders at the end of their shift, often entering confirmation of several different operations performed during shift.

The data input is checked in real time, among others the following attributes are

verified:

- worker personal code compliance with list of employees present that day at work,
- correctness of confirmation code of operation order – only codes of operations that are partially completed or not entirely completed previously are allowed,
- compliance of the number of completed items with the number specified in the order,
- correctness of serial number.

Data verification procedures introduction was forced because of large number of errors in the initial period of system functioning (workers scanned incorrect codes).

The *Mistrz* system is responsible for communication with data collectors, verification of data entry, importing of production orders from SAP, confirmation of executed orders into SAP and reporting according to the certain criteria. All required and collected data is stored in local SQL database. The *Mistrz* system administrators are responsible for the entered data, processing and export information to SAP. Those administrators have also high access privileges in SAP system, which allows correction of errors occurring despite of data verification. Production manager, his deputy and members of company management have also access to the *Mistrz* system. These people have the ability to generate reports on production orders and employee productivity. Worker productivity is determined basing on the difference between the operation execution time expected in SAP and the elapsed operation time, even though elapsed time is not measured precisely.

## Further modifications for improvement of data acquisition system

The main problems with the production data acquisition system in described company are associated with the lack of information on the circulation of materials. Current data acquisition system covers only raw material issuing from the materials warehouse (in the SAP system) and introduction of the finished products into the appropriate warehouse. There is no information about the elements (parts) used to build the product. These elements do not have own serial numbers, although are produced in separate technological processes. It is proposed to introduce the serial numbers for these components and their precise evidence storage. Full evidence of the circulation of materials and semi-finished products can be achieved using a barcode labels printed on durable material or applied on the part itself (e.g. laser tagging). Also RFID tags in a durable enclosure can be used, but it require change of data collectors. Set of mid-range RFID fixed scanners, installed at production stations can automatically capture data from tags fixed to semi-finished products and parts, allowing automatic (without involvement of workers) capture of the data on objects flow.

Another problem is the delay in entering information about the execution (total or partial) of manufacturing operations and the lack of information about which production order and operation an employee performs until it will be reported at the end of the shift. There are cases of workers forgetting to confirm the operation or entering of incorrect data, despite of the data verification mechanisms. Data acquisition requires attention and diligence from ordinary employees who have been burdened with additional responsibilities. It is proposed to extend the set of data to be entered at the beginning of the shift by worker with the information about the production order and operation, assigned to a particular employee. Confirmation of orders should be made immediately after worker complete the operation, before taking other jobs.

Described problems require modification in the *Mistrz* system and data collectors software. All proposed modifications are shown in figure 6.3.

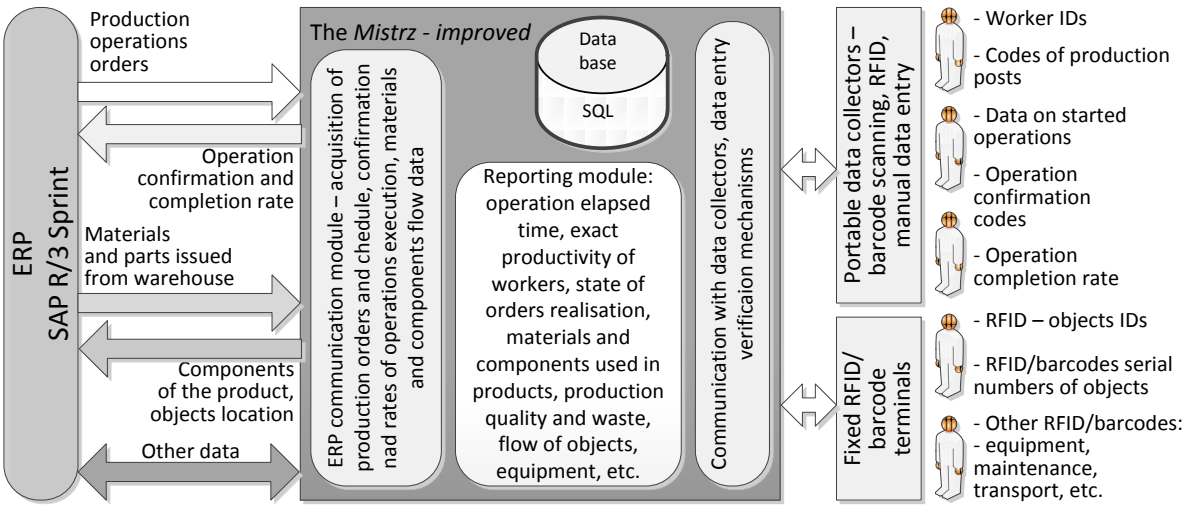



**Fig. 6.3 Proposed modifications in the data acquisition system**

## SUMMARY

Data acquisition in non-automated production systems is much more difficult than in automated ones. In particular, it is difficult to obtain data on employees activity and circulation of materials in the production system. The standard solution for this situation is the use of automatic identification systems, but in the harsh operating conditions of the production system, hardware (data collectors) and labels resistant to these conditions should be selected.

Various types of automatic identification systems play a particular role in the enterprise, allowing the acquisition of data that is not collected with elements of industrial automation and control systems. Automatic identification systems can be seen as a data source parallel to the control system or the primary source of data.

It is necessary to create a middleware between the business and data sources layers, responsible, among other things, for the verification of entered data. In practice, there are often problems resulting from the accidental scanning of wrong labels.

Semi-automatic data acquisition systems should be user-friendly, allowing the worker to input the required data easily and quickly. Data acquisition system elements (scanners and labels) should be resistant to adverse environmental conditions (high temperatures, moisture, aggressive chemicals, weld spatter) and mechanical damage. Installation of systems identifying objects from a distance, without the need for activity from the employees (e.g. long-range RFID tags and stationary scanners in production posts) should be considered. This will allow automatic collection of data on material and production flow.

## REFERENCES

1. Alqarni A. A., Pardede E.: Integration of Data Warehouse and Unstructured Business Documents. Network-Based Information Systems (NBiS), 2012 15th International Conference on, pp. 32-37.

2. Bowden, R., KaewTraKulPong P.: Towards automated wide area visual surveillance: tracking objects between spatially-separated, uncalibrated views. Vision, Image and Signal Processing, IEE Proceedings, Vol. 152, no.2, 2005, pp. 213-223.
3. Boyd M. A., Abou Khalil A., Herrin S. A.: Real-Time Automated Diagnosis for Human-Computer Based Monitoring and Control Systems. Reliability and Maintainability Symposium, 1997 Proceedings, pp. 355-360.
4. Cohen J.: Automatic identification and data collection systems. McGraw-Hill Book Company, 1994.
5. Eckert K., Frank T., Hadlich T., Fay A., Vogel-Heuser B.: Typical Automation Functions and Their Distribution in Automation Systems. Emerging Technologies & Factory Automation (ETFA), 2011 IEEE 16th Conference on, 2011, pp. 1-8.
6. El-Omari S., Moselhi O.: Integrating automated data acquisition technologies for progress reporting of construction projects. Automation in Construction 20 (2011), pp. 699-705.
7. El-Omari S., Moselhi O.: Integrating automated data acquisition technologies for progress reporting of construction projects. Automation in Construction 20 (2011), pp. 699-705.
8. Ferrer G., Heath S. K., Dew N.: An RFID application in large job shop remanufacturing operations. Int. J. Production Economics 133(2011), pp. 612-621.
9. Golnabi H., Asadpour A.: Design and application of industrial machine vision systems. Robotics and Computer-Integrated Manufacturing, 23/2007, pp. 630-637.
10. Kaczmarczyk M., Kalinowski K., Ćwikła G.: Zastosowanie oprogramowania HMI/SCADA Proficy iFIX w sterowaniu zautomatyzowaną linią montażową. Komputerowo Zintegrowane Zarządzanie, Zbiór Prac, Tom I. Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole 2009, str. 471-480.
11. Kletti J. (ed.): Manufacturing Execution Systems – MES. Springer-Verlag Berlin Heidelberg 2007.
12. Li Zhekun, Rajit Gadh, Prabhu B. S.: Applications of RFID technology and smart parts in manufacturing. Proceedings of DETC'04: ASME 2004 Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Paper no. DETC2004-57662, pp. 123-129.
13. Ming-Kuan Tsai, Jyh-Bin Yang, Chang-Yu Lin: Integrating wireless and speech technologies for synchronous on-site data collection. Automation in Construction 16 (2007), pp. 378-391.
14. Min-Yuan Cheng, Jiann-Chyun Chen: Integrating barcode and GIS for monitoring construction progress. Automation in Construction, 11 (2002), pp. 23-33.
15. Navon R., Goldschmidt E.: Monitoring labor inputs: automated-data-collection model and enabling technologies. Automation in Construction 12 (2002), pp. 185-199.
16. Qian Wang, Qingquan Qian: Design and analysis of communication network for distributed SCADA system. Power Engineering Society Winter Meeting, 2000, IEEE Vol. 3, pp. 2062-2065.

17. Sherin M. Youssef, Rana M. Salem: Automated barcode recognition for smart identification and inspection automation. Expert Systems with Applications 33 (2007), pp. 968-977.
18. Supervisory Control and Data Acquisition (SCADA) Systems. National Communication Systems, Technical Information Bulletin 04-1. http://www.ncs.gov/library/tech_bulletins/2004/tib_04-1.pdf, 15.10.2009.
19. Świder J., Hetmańczyk M.: Hardware and Software Integration of Mechatronic Systems for an Example Measurement Path for Temperature Sensors. Solid State Phenomena, Trans-tech Publications, vol. 147-149, 2009, pp. 676-681.
20. Tavakoli S., Mousavi A.: Adopting user interacted mobile node data to the Flexible Data Input Layer Architecture. Intelligent Sensors, Sensor Networks and Information Processing, 2008. ISSNIP 2008. International Conference on, 2008, pp. 533-538.
21. Wang Daxi, Wu Liangqi, Wei Zengpei, Zhu Haiwei: Application Research of Monitoring for Logistics Information Based on Intelligent Barcode. Computer Application and System Modeling (ICCASM 2010), International Conference on, pp. 632-636.
22. Yang Chuanying, Li He, Liu Zhihong: Implementation of Migrations from Class OPC to OPC UA for Data Acquisition System. System Science and Engineering (ICSSE), 2012 International Conference on, 2012, pp. 588-592.
23. Yang Musheng, Zhang Yu, Li Aijun: Research on wireless process data acquisition technology based on Agent in remote manufacturing. Wireless Communications, Networking and Mobile Computing, 2009. WiCom '09. 5th International Conference on, pp. 1-4.
24. Yan-hong Wang; Guan-jin He; Li-xin Kong: Research on collection of process data based on RFID technology for job-shop. Logistics Systems and Intelligent Management, 2010 International Conference on, Vol. 1, pp. 451-455.

# MANUFACTURING DATA ACQUISITION IN NON-AUTOMATED PRODUCTION SYSTEMS

**Abstract:** *This paper presents the problem of acquisition of production information from the companies in which technological processes are mostly non-automated. Data acquisition for company management is essential for the integration of the business and manufacturing layers of the company, providing access to current data on production tasks. Most of the problems with the acquisition of data from automated systems is solved, while the lack of automated systems is an obstacle in obtaining information. The paper presents and organizes the issues of methods and means of data acquisition in companies, in which the majority of manufacturing operations is performed manually.*

**Key words:** *manufacturing data acquisition, MES, barcodes, RFID, machine vision*

# AKWIZYCJA INFORMACJI DLA POTRZEB ZARZĄDZANIA W NIEZAUTOMATYZOWANYCH SYSTEMACH PRODUKCYJNYCH

**Streszczenie:** *W artykule przedstawiono problematykę akwizycji informacji produkcyjnych z przedsiębiorstw, w których procesy technologiczne nie są zautomatyzowane. Akwizycja danych dla potrzeb wspomagania zarządzania jest konieczna dla integracji warstwy biznesowej i produkcyjnej przedsiębiorstwa, zapewniając dostęp do bieżących danych o realizacji zadań produkcyjnych. Większość problemów z akwizycją danych z systemów zautomatyzowanych jest rozwiązana, podczas gdy brak systemów automatycznych jest przeszkodą w pozyskiwaniu informacji. W pracy przedstawiono metody i środki akwizycji danych z przedsiębiorstw, w których większość operacji produkcyjnych jest wykonywana manualnie.*

**Słowa kluczowe:** *akwizycja danych produkcyjnych, MES, kody paskowe, RFID, systemy wizyjne*

dr inż. Grzegorz ĆWIKŁA
Silesian University of Technology, Faculty of Mechanical Engineering
Institute of Engineering Processes Automation and Integrated Manufacturing Systems
ul. Konarskiego 18a, 44-100 Gliwice
tel. +4832 237 25 45; e-mail: grzegorz.cwikla@polsl.pl

# 7

# IMPROVING THE EFFICIENCY OF LIME PRODUCTION PROCESS USING FLOCCULANT

## 7.1 INTRODUCTION

In the Limestone Production Plant "Trzuskawica" the process of pipeline transport of lime slurry is carried. Limestone slurry flows by turbulent traffic and is usually accompanied by a moving bottom sediment. Limestone slurry is directed to the settling tank (natural reservoir), in which the solid-phase fraction sediments and the excess water, through the transfer system, is recycled back to the process of hydrotransport. This method is very wasteful, since sedimentation tanks are located at a considerable distance from the plant, which increases costs of transport. Moreover, expensive and technically complex is remove of waste material from the sedimentation tank. Also, the amount of the recovered water from settler tank is not satisfactory. For these causes, it is reasonable to use a different technology that allows to shorten the distance of transported hydromixture and recover more water from the hydrotransport process. This will be possible when the solid-phase is separated from hydromixture, which will be stored in the plant on the heaps [6, 7].

Sedimentation is often used mechanical method of purifying water from suspended substances. It consists in sinking denser, dispersed solid phase in a mixture of two phases to the bottom under the influence of gravity force, which allows their separation. The limitations of the sedimentation usually occurs when we are dealing with very small diameters of the particles and the sedimentation velocity (terminal velocity) is low, which increases the time of clarifying [5].

On the process of sedimentation occurrence affect many factors, including: the solid phase concentration, the viscosity and density of the solid phase and the carrier, the type of used coagulant (flocculant), the nature of the resulting flocks or agglomeration abilities, the type of traffic hydromixture – laminar, turbulent, the type of removed slurry and the colloidal substances, the process of diffusion, etc. [3].

## 7.2 DIAGNOSIS OF THE HYDROTRANSPORT PROBLEMS IN THE PLANT

In the analyzed case decanted from the precipitate water is recycled back into the process, and collected in the bottom of the tank sludge is periodically removed. This waste material is characterized by high fragmentation and strong hydration, which is why it is not used economically. Waste is deposited on the waste disposal site located at the area of the plant. This method of waste disposal is time-consuming and burdensome. It forces, among other things, the need of downtime in devices, manual or mechanical removal of waste

material, which have a high specific gravity (about 2 kg/dm$^3$). This entails the growth of costs of functioning of the plant.

Another problem is the high consumption of water. It is estimated that in the whole process at all stages of production, from raw material feed applications from the mine through the successive stages of crushing and breaking, screening and washing, the amount of consumed water is equivalent to 400 m$^3$/h. This water comes from its own shots in Sitkówka. Until now, water after pre-purifying from the smallest fraction was discharged into the Bobrza river.

The solution to the problems associated with water purification from fine particles of silty phase with diameters not exceeding the 0.0875 mm is the use of flocculants dispensing station in the system. The functioning of the installation rests on adding to the contaminated water production (hydromixture) the solution of flocculant, chemical accelerating the clarification. Synthetic polymeric substances (called flocculants) cause the flocculation process in which are forming the flocks in a layer maintained in a suspended state. The fine particles are bound in large flocs, which then fall by the gravity to the bottom of the settler tank. The clarified water is directed back to the process, while the concentrated sludge at the bottom of the tank can be deposited on the plant`s waste disposal site.

## 7.3 THE MECHANISM OF FLOCCULATION

To flocculation occurred must appear direct collisions between suspended particles, therefore must be defeated the forces of repulsion. The energy of these forces depends of the mutual distance between particles and becomes important at very small distances. These distances can be defeated by using the so-called "Brownian motion", the chaotic motion of particles in the fluid caused by collisions of slurry with the molecules of the liquid. Brownian motion is observed for the microscopic, smaller than a micrometer particles of slurry, regardless of their type. The molecules move constantly and their movement is unabated. Speed of movement is greater for smaller particles and higher temperature. Flocculation based on this phenomenon is called "perykinetics flocculation ". However, if the movement of the solution is enforced, eg by mixing, then we speak about the "orthokinetic flocculation" [4].

During the flocculation process occurs, between particles are created bridges. Great-chain-molecules of typically synthetic polymers are absorbed on the surfaces of the particles causing them to crosslinking. The possibility of bridges formation is dependent on both the number of free polymer groups remaining at the disposal as well as the degree of filling the particles of the polymer. There is an optimal concentration of the polymer, below which due to the shortage and above which because of the availability to adsorption on the particles, the cross-linking is incomplete [1].

Transport resulting from different particles velocity is also based on different sizes of flocks, which results in significant differences in the rate of subsidence during the sedimentation. They cause additional collisions and therefore an increase in flocks, which leads to the formation of faster falling aggregates [5].

However, the formation of flocks in the pipes due to the possible speed of movement for each pipe diameter has its limits, at which on the one hand there are deposits of thickened sludge, on the other hand take place the destroying of flocks [2].

## 7.4 THE MECHANICAL PROCESS OF SEDIMENTATION USING A FLOCCULANT

The sedimentation process with using a flocculant in this production enterprise is limited by the conditions resulting from technical parameters of installation and human factor. Diagram of radial AquaCycle sedimentation tank installed on the premises of the ZPW Trzuskawica is shown in the figure 7.1.

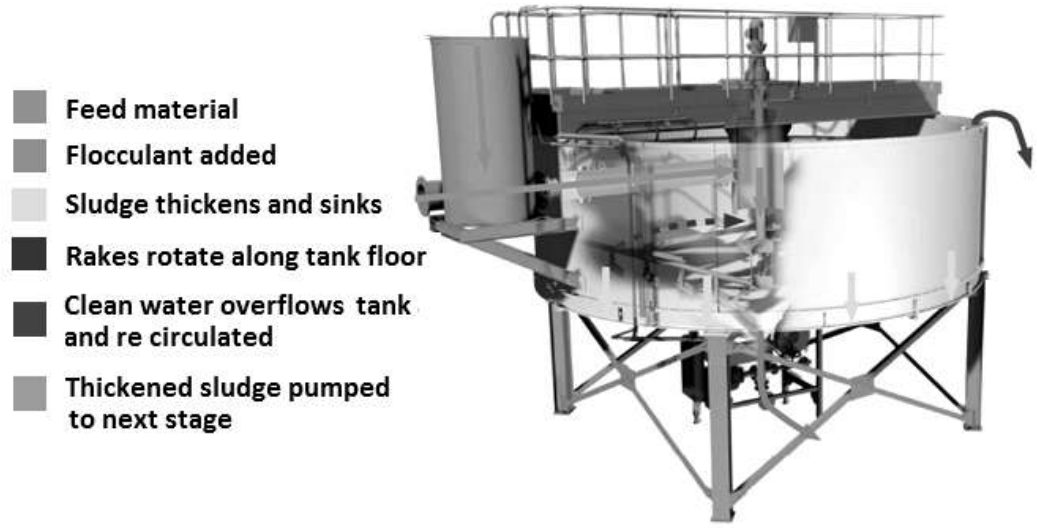



**Fig. 7.1 Scheme of radial settler tank with coagulation chamber**

Source: AQUACYCLE Brochure: Water Treatment System. /www.cdeglobal.com/

The process of preparing flocculant must last enough long because of the maturing of flocculant for 45 minutes at 20 centigrade degrees. Pre-mixing of flocculant occurs in the closed pipeline connecting the flocculant dosing station with a settler tank. Flocs are formed in the central circular chamber of the sedimentation tank equipped with a stirrer and the stators, of which the water flows radially outwards. The peripheral speed of the stirrer amounts about (0.5-1.5) m/s. Uniform distribution of the coagulant throughout all the volume of the tank provides to maintain the homogeneous system. In the sedimentation tank thickening of sludge occurs in a continuous manner, which means that there is a constant supply of raw sewage sludge with continuous discharge of supernatant liquid and the sludge. Efficiency of the tank, shown in the figure 1, is 400 $m^3$/h. Other specifications of the tank are: internal diameter: 10.5m, depth 4.4m, weight of the drum: 20t, total weight of the tank: 200t.

## 7.5 RESEARCH METHODOLOGY

The study aimed to determine the optimal dose of flocculant, the addition of which, in possible short time occurs the sedimentation of solid particles in hydromixture. The results were also analyzed in terms of cost-effectiveness of the application of flocculant in continuous motion of installation. The tested material is limestone mixtures with a density of 2720 kg/$m^3$, which mostly constitute the particles of dust fraction (76.55%) with diameters in the range (2-50) um. The percentage content of clay fraction having an average particle diameter of less than 2 microns is 16.4%, while the phase of the sand with a diameter of grains in the range greater than 50 microns is 7.05% of all particles.

The analysis of chemical composition of the solid particles was performed. In terms of the chemical, tested sediment consists mostly of calcium oxide (CaO – 73.64%) and silicon dioxide ($SiO_2$ – 13%). Other chemical compounds included in solid particles constitute a small share, and are as follows: MgO – 0.61%, $Fe_2O_3$ – 0.32%, $Al_2O_3$ – 1.11% and $SO_3$ – 0.28%. Humidity of tested samples was 96.67%.

Before starting the measurements of sediment, resulting from the sedimentation process of adding a flocculant, it was necessary to determine the mass concentration of hydromixture (Cm). It specifies the percentage content of solids (sludge mass) in total weight of the hydromixture, as shown in equation (1).

$$C_m = \frac{m_s}{m_s + m_l} \cdot 100\% \tag{7.1}$$

where:

$C_m$ – mass concentration (%)

$m_s$ – mass of the solid phase (kg)

$m_l$ – mass of the liquid phase (kg)

Sampling of material, required for examine the mass concentration, took place by collecting and drying the three sample volumes up 100ml to obtain the average value. However, appropriate measurements of the sedimentation process using flocculant held for samples with a volume of 250 ml.

## 7.6 RESULTS OF RESEARCH

Figure 7.2 presents summarizes the time of sludge sedimentation for different doses of flocculant at three mixing times (tm) – 15s, 30s, 45s and the mass concentration of hydromixture $C_m$ = 9.3%.

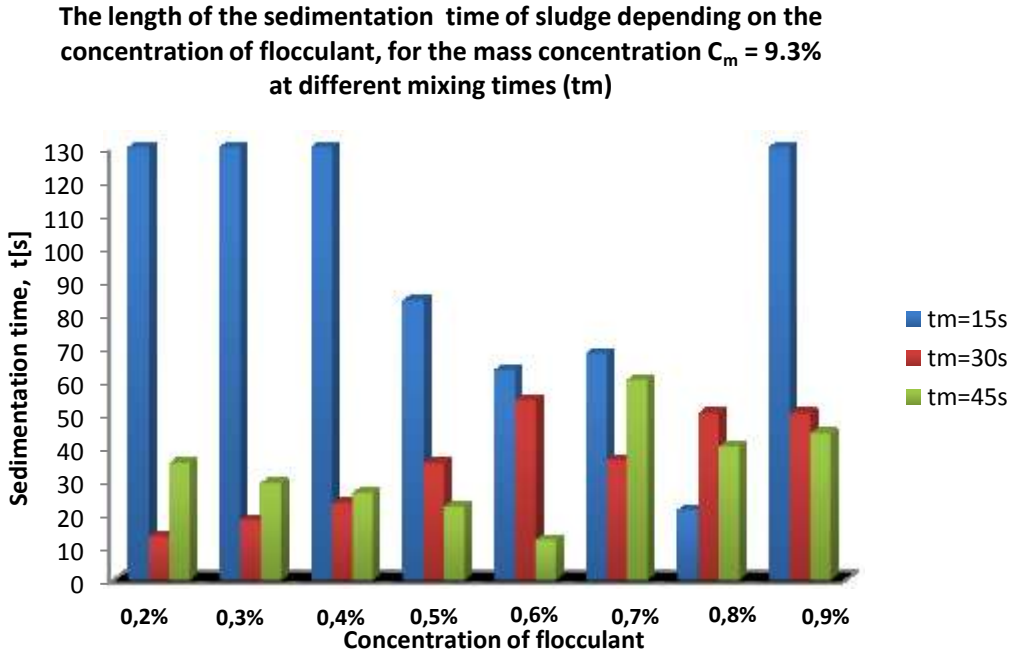



**Fig. 7.2 Time dependence of sedimentation sludge from concentration of added flocculant**

Source: own study

It can be seen that for the time of mixing t = 30s was obtained the fastest settling time of approx 13s, at a dose of 0.2% flocculant. For this dose of flocculant, from the beginning of the process of sedimentation, in a vessel appeared a clear separation between the liquid limit and the suspension. In measured time, counted from the time of addition the flocculant to hydromixture, the level of the suspension lowered and the sludge at the bottom grew to the point where the process of gravitational sedimentation of particles ended. In a further step, sludge was compacted obtaining the smallest porosity from observed in these conditions. For the time of sedimentation equals 13s and the flocculant mass concentration of 0.2%, the height of sediment was only 29mm.

For other flocculant concentrations above 0.2% was achieved much longer time of sedimentation and less desirable form of sedimented sludge. For example, for the higher dose of flocculant equals 0.6% and with a longer mixing time of 45s, obtained more than three times higher sediment. This height is about 72 mm, which mainly resulted from its form. The sludge was characterized by high porosity (figure 7.3).

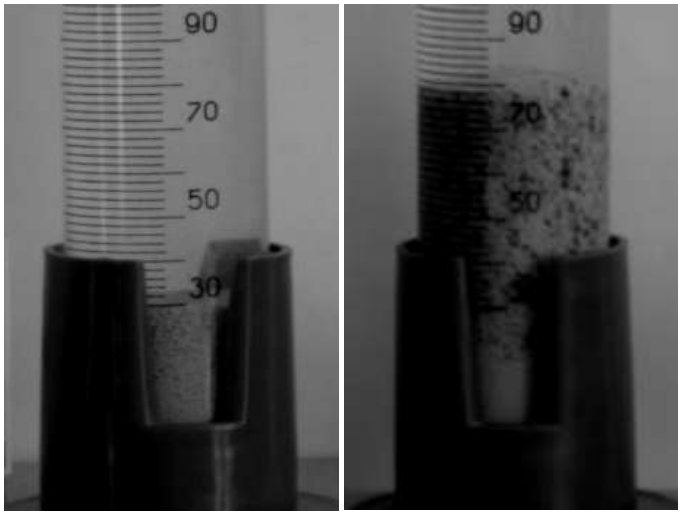



**Fig. 7.3 The character of sediment after the addition of flocculant dose concentration of 0.2% (picture left) and 0.6% (picture right) to hydromixture with mass concentration $C_m$ = 9.3%**

Source: own study

Figure 7.4 shows a summary of the different doses of flocculant in one stirring time of hydromixture for the mass concentration of solid phase $C_m$ = 9.3%.

Figure 7.4 shows the dependence of the height of sludge arisen in the sedimentation process, in function of sedimentation time, for selected concentrations of flocculant in the range from 0.2% to 1%. The presented experimental data relate to the use of constant time of stirring the samples equals 30s. As it is apparent from the figure, for solid phase concentration of $C_m$ = 9.3% the optimum dose of flocculant is 0.2%. It results from the fact that the resulting sludge is characterized by a minimum porosity that is obtainable in these conditions, with an acceptable sedimentation time of about 13s. At higher than the optimal concentrations of flocculant, the process of sludge sedimentation in hydromixture occurs relatively quickly but the height of sludge is greater, and the consistency of sludge is porous and fluffy, because of which it occupies a larger volume.

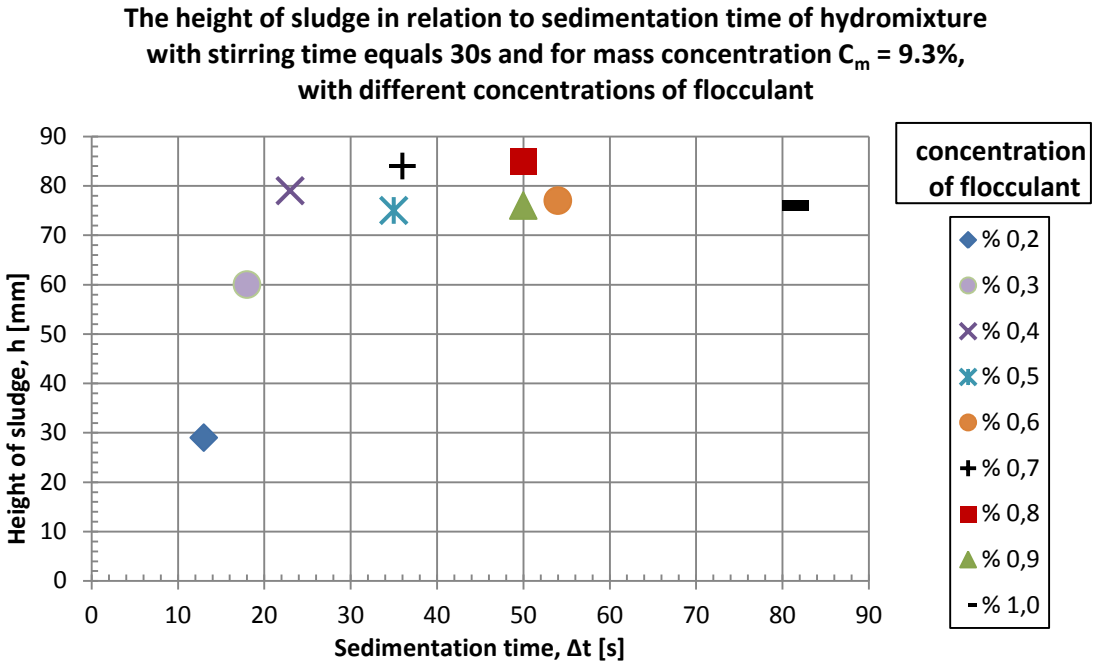



**Fig. 7.4 Dependence the height of sludge in relation to the time of sedimentation at different concentrations of added dose of flocculant**

Source: own study

The presented results are a part of the analysis that leads to the conclusion that the optimal dose of flocculant should be selected depending on the percentage of dry matter in hydromixture. It shows an increasing tendency connected with the growth of the mass concentration. But at higher concentrations of added flocculant than optimal, process occurs relatively quickly but leads to getting the undesirable form from the production point of view (high porosity, high hydration, a large volume of sludge).

## THE RESULTS OF ANALYSIS AND SUMMARY

The use of sedimentation supported by flocculant as a method for separation the water and suspended therein fine solid phase can increase the degree of separation of solid particles in the clarification phase and obtain a sludge with possibly high content of solid in densification phase. It is estimated that as a result of spontaneous sedimentation of water in the settler tank, in normal production process of limestone without the use of flocculant, the degree of contamination of the process water is at least 0.25% of its volume. By applying flocculant, mineral slurry precipitates out from the water in greater extent and settles at the bottom of clarifier. Depending on the used flocculating agent, so purified water may characterized the degree of contamination on the level of only 0.006% its volume.

Application of installation using a flocculant for accelerating the sedimentation process in the production of limestone affects the growth of the efficiency of the recovery solid phase from hydromixture. Nearly 400m$^3$ of technological water characterized by high clarity is recirculated for re-use. From a technical point of view, the use of the flocculating system reduces the laborious and time-consuming of handling associated with sludge disposal. In the traditional system of waste management, select it from the settlers was very burdensome and

often involve the need of manually select it from the tank. Using the presented installation whole process of water purification is automatic. Sludge formed in the process of sedimentation using flocculants is characterized by humidity less than about 8%. In addition, after extra compression it in a hydraulic press, is almost completely devoid of water so that it can be easily reloaded, transported and stored.

The average concentration of added flocculant in analyzed process maintains on the level of 0.2%. This quantity results from the percentage conversion of the added amount of flocculant in solid form in relation to dry solids content of sludge, remaining after the evaporation of water from the predetermined volume of hydromixture (2g of the powder would be added/1kg of dry weight). The amount of flocculant consumed in the process is estimated at 25 kg/day at a price of 13zł/kg. Monthly would be consumed the amount corresponding to 800 kg of the substance.

Performed experiments indicate that the use of flocculant, leading to the creation of well aggregating flocks at the bottom of the settler tank, is the right direction of change the existing technology. Carried out preliminary tests have shown that the sedimentation process can be greatly accelerated when the flocculant is pre-dissolved in water and added in a solution form to hydromixture. Tested flocculant belongs to a group of complex substances, reo-unstable, which requires more detailed tests to determine the dependence of shear stress on shear rate for the variable concentration of the solid phase in hydromixture and a variable concentration of flocculant in hydromixture.

## REFERENCES

1. Einslauer J., Horn D.: Flockungschemikalien: organische Stoffe. DVGW Schriftenreihe Wasser Bd. 42, 1984, p. 59-72.
2. Grohmann A.: Über die Anwendung der Flockenbildung In Rohren zur Wasserreinhaltung Und Phosphorelimination. Z-Wasser- u. Abwasserforschung 14. 1981. p. 104-109.
3. Maciejewski M.: Hydraulika systemów oczyszczania wody i ścieków oraz zbiorników wodociągowych. Instytut Meteorologii i Gospodarki Wodnej. Warszawa 1999, p. 48-52.
4. Orzechowski Z., Prywer J., Zarzycki R.: Mechanika płynów w inżynierii i ochronie środowiska. Wydawnictwa Naukowo-Techniczne. Warszawa 2009, p. 392-397.
5. The collective work under the red. Gimbela R., Jekela M. i Lieβfelda R.: Podstawy i technologie uzdatniania wody. Tom I. Oficyna Wydawnicza PROJPRZEMEKO. Bydgoszcz 2008, p. 88, 102.
6. Shook C., Bartosik A.: The pseudohomogeneous flow approximation for dispersed two-phase systems. Proceed. 22nd Int. Symp. Fine Particles Soc., Los Angeles, CA., also: *Particulate Science and Technology*, 1991, vol. 9, p. 119-134, Hemisphere Publ. Corp.
7. Shook C.A., Roco M. C.: Slurry Flow: Principles and Practice. Butterworth-Heinemann, Boston, 1991.

# IMPROVING THE EFFICIENCY OF LIME PRODUCTION PROCESS USING FLOCCULANT

**Abstract:** *Inseparable element of the lime production process is pipeline transport of hydromixture which arises from rinsing of stones. Such hydromixture is a finely-granular solid phase and the water that serves as a carrier of the solid phase. At the end of the transporting process the water is recovered in order to recycle it for re-circulation, and the solid phase is deposited in dumps or in the sludge tanks. Hydromixture clarification process through the process of sedimentation, is difficult due to the large amount of solid particles with a diameter less than 2 μm. In order to improve the efficiency of sedimentation process we added polymer additives called flocculants. They allow the formation of flocs by binding together fine particles into larger agglomerates, which are under the influence of gravity and fall intensively to the bottom of settler tank.*
*This paper presents the results of experimental studies on the use of flocculant to accelerate sedimentation process and get back water for further use. Significant reduction of sedimentation time using the opti*mal *dose of the flocculant, which was determined in an experimental way was demonstrated.*

**Key words:** *hydraulic mixtures pumps, experimental studies, flocculant, efficient use of water*

# POPRAWA EFEKTYWNOŚCI PROCESU PRODUKCJI WAPNA POPRZEZ ZASTOSOWANIE FLOKULANTA

**Streszczenie:** *Nierozłącznym elementem procesu produkcji wapna jest transport hydromieszaniny popłuczkowej. Hydromieszaninę popłuczkową stanowi drobno-ziarnista faza stała i woda służąca jako nośnik fazy stałej. Na końcu procesu transportu woda odzyskiwana jest w celu zawrócenia jej do ponownego obiegu, natomiast faza stała deponowana jest na hałdach lub w zbiornikach osadowych. Proces klarowania hydromieszaniny, poprzez proces sedymentacji, jest utrudniony ze względu na dużą ilość cząstek stałych o średnicach poniżej 2* μm*. W celu poprawy efektywności procesu sedymentacji dodawane są polimerowe dodatki zwane flokulantami. Umożliwiają one tworzenie się kłaczków (flocs) poprzez wiązanie ze sobą drobnych cząstek w większe aglomeraty, które pod wpływem grawitacji intensywnie opadają na dno osadnika.*
*W artykule przedstawiono wyniki badań eksperymentalnych nad zastosowaniem flokulanta, który poprawia ekonomię efektywnego wykorzystania wody w procesie hydrotransportu i rozdział fazy stałej od fazy ciekłej. Wykazano istotne skrócenie czasu sedymentacji przy zastosowaniu optymalnej dawki flokulanta, którą określono w sposób eksperymentalny.*

**Słowa kluczowe:** *hydromieszanina, badania eksperymentalne, flokulant, efektywne wykorzystanie wody*

mgr inż. Beata JAWORSKA, dr hab. inż. Artur BARTOSIK, prof. PŚk
Kielce University of Technology, Faculty of Management and Computer Modelling
Department of Production Engineering
Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce
e-mail: artur.bartosik@tu.kielce.pl; b.jaworska@tu.kielce.pl

# 8

# IDENTIFICATION AND MODELING OF EMISSION SOUND SOURCES AT WORK STATIONS

## 8.1 INTRODUCTION

A period of a dynamic industrialization of Upper Silesia and, being its direct consequence, a long-term domination of the mining industry interfered greatly with the structure of the environment – by means of physical, biological and chemical degradation. These changes lower a potential ability of the land to gain maximum and stable harvest in terms of agriculture and forestry, but they also have an influence on unfavorable distortion of the landscape. In Silesia there are 5705 ha of degraded and devastated terrains, which include, among others, green wasteland, production sites, mining landfill sites, brownfields located in built-up areas, unused water tanks [5].

## 8.2 THE CONSEQUENCES OF LAND DEGRADATION

Among the visible consequences, what comes to the fore, is the degradation of the surface. It is conditioned by various factors, such as kind of extraction techniques, intensity of extraction, geological form of bedded deposits, which manifests by the subsidence of earth's surface, horizontal ground movement or inclination. Apart from distortion of the surface, it translates directly into destruction or damages to the buildings located in the degraded area. Thickening development of industrial areas over the years, as well as intensified exploitation, also built-up areas directly under densely containing monumental buildings (e.g. churches), have led to numerous architectural damages and building disasters.

Subsidence of earth's surface, the consequence of underground mining, often leads to formation of characteristic elements of industrial and post-industrial landscapes – fens or inundation encompassing agricultural terrains, forests or settlement terrains[6]. A fen is an accumulation of water on a lowered part of the terrain while inundation means a process leading to excessive water accumulation on the lowered terrain [6]. The negative effects of inundations are primarily:

- soil degradation,
- losses in crops and tree stand,
- destruction of natural environment of plants.

Pond created in the result of land descent shows figure 8.1.

Degradation of the surface includes also the use of the terrain for landfills which are a result of extraction of ores and their processing, the so-called heaps and slime separators which consist of coal slurry of a low calorific value. Example of dumping ground with post-

mining waste shows figure 8.2, and example of coal slurry shows figure 8.3.

**Fig. 8.1 Example of a pond created in the result of land descent**

Source: author's photograph

**Fig. 8.2 Example of dumping ground with post-mining waste**

Source: author's photograph

**Fig. 8.3 Example of coal slurry**

Source: author's photograph

Mining landfills have a definitely negative influence on the aesthetics of the landscape, but primarily they constitute a source which allows harmful substances to get to the environment – these are substances that get filtered into water as well as the emission of gaseous and dusty pollution. The phenomenon of spontaneous combustion, which is particularly dangerous, occurs rather on older heaps where waste less separated from coal is stored.

Degradation is also reflected in the change of water relations. It is possible to specify two groups of factors: directly influencing the change of water circulation, and a group of factors which indirectly contribute to the change of water relations. Direct factors include [9]:

- water collection and discharges,
- discharges of deep mining water to watercourses,
- water transfers between river basins,
- drainage and intensive, long-lasting exploitation of underground waters.

Indirect factors are, among others [9]:

- meliorative works,
- regulation of watercourse and development of watercourse beds,
- change of land use.

In addition to the environment, the next main recipient of negative effects of industrial activity is the man. Apart from damages which may be defined as "hard" (e.g. destruction of a residential building) there are a number of subtle factors, which cannot be measured but still significantly lower the quality of life e.g.:

- ugly view of a damaged landscape,
- unpleasant odor of the landfill,
- hopelessness of life in a chaotic environment etc.

## 8.3 DEVELOPMENT AND REVITALIZATION OF DEGRADED LANDS

Currently there are over 30 coal mines functioning which produce annually about 30 million tons of waste. Increasing legal rigor, referring to the influence of extraction on the environment (in terms of natural and social relations), unfortunately is not able to stop further negative impact on environment. Neighborhood of power plants as well as steelworks and plants which use solid fuels as a basic medium of energy also causes an increase in the pollution of environment by other heavy metals [3]. Nowadays, Silesian industry is mainly based on coal extraction and its use as a fuel, and therefore the highest concentration of heavy metals, including mercury, occurs in the area of such plants [1]. Thus, degradation may embrace forest, agricultural as well as built-up areas.

Due to the liquidation of many mining centers, the areas which until recently have been subjected to strong influence of extractive economy, are now becoming the so-called post-mining sites. Their dominant visual features include ruined post-mining buildings, water-filled hollows and hills of heap site. Appropriate development of those post-mining areas will restore them or add to their environmental, economic or social attractiveness.

Obviously, development or revitalization of the post-industrial areas have been implemented for many years now, but unfortunately they embrace only a small percentage of all degraded areas. Development is to give the terrain its natural shape, to bring back the natural balance of soil ingredients in order to give the terrain environmental or economic value. Revitalization is about giving the degraded terrain other function and use.

In practice, dealing with the consequences of mining activities means:

- development of post-mining sites (heaps and slime separators),
- extinguishing of fired heaps and possibly their subsequent land use, mine subsidence repair,
- revitalization of historic mining buildings.

## 8.4 THE OBJECTIVES OF THE DEVELOPMENT OF DEGRADED LANDS

The objectives of land development degraded by mining may be divided into three basic groups, corresponding to the pillars of sustainable development:

- environmental objectives,
- economic objectives,
- social objectives.

Protection or development of natural environment is a basic environmental objective of land development. It happens very often that, for instance, the ecosystem which has self-developed in the water tank in the hollow includes extremely valuable elements of fauna and flora. An important issue here is to decide if such enclave should be preserved or if one should bring back the original layout of the area with its characteristic assemblage of plants and animals. Thus, shaping of the post-industrial landscape can manifest itself through protection activities such as creation of reserves or nature and landscape parks. Protection of the landscape is the realm of ideas and activities aiming at preserving the objects of nature in their original form as well as protection of environment aiming at its preservation in a state that guarantees the continuity of the most important processes in the biosphere and optimal conditions of human existence [4].

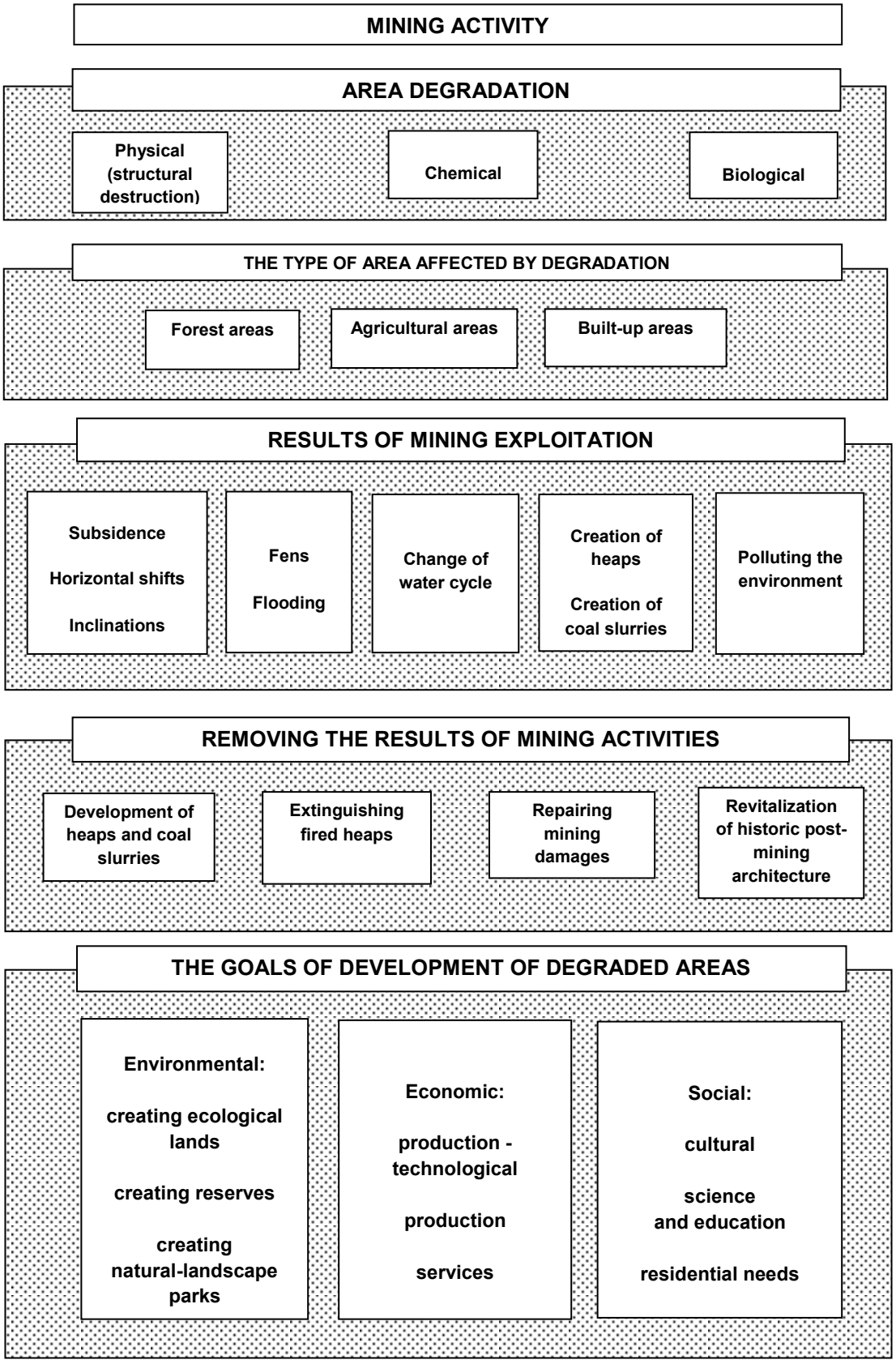



**Fig. 8.4 Synthesis of results of mining activity and directions for developing the post-mining areas**

Source: own work based on [9]

Development of the heaps which are no longer thermally active consists of sowing them with grass and after some reasonable time, their afforestation.

Environmental, economic and social objectives often interact with each other and the elements of one stimulate elements of the others. Land development within the area of production and technology, production or service constitutes basic directions of economic objectives. Production and technological function includes among others transportation, storage, industrial as well as scientific and technological parks. Service development is often focused around trade and services downtown, catering, entertainment centers as well as services connected with business etc. Social objectives embrace broadly understood cultural, scientific and educational activities, extended to activities related to housing needs.

In the late XIX century and early XX century, in the age of the so-called "industrialization", in a close neighborhood of emerging extraction and processing plants, deliberately planned housing areas were built for workers and their families, which consisted of multi-family houses, schools and often hospitals. Such working-class housing estates are a valuable architectural heritage of the past years, being additionally a witness of the concept of planning at those times. Unfortunately, a vast majority of such colonies is neglected and inhabited by the poor but still alive, because it continuously performs its housing function.

Some of such housing areas, at the beginning discovered by artist, photographers and filmmakers for their own use, were finally fortunate, supported by adequate promotion, to occur in collective awareness as a valuable, characteristic for that region type of constructions. Chosen architectural objects or their groups – monumental housing buildings or post-mining buildings – according to the above mentioned possibility of revitalization, may begin to fulfill completely different functions, realizing particular social objectives. Properly prepared inferiors may become exhibition centers, theatres, may serve as a gallery or educational and scientific centers. Separate buildings or their groups can be also prepared in order to give them the functions of museums or open-air museums of technology.

Synthesis of results of mining activity and directions for developing the post-mining areas shows figure 8.4.

## 8.5 EDUCATION OF SPECIALISTS

A requirement for elaborating an adequate conception of land development is its natural, geological-mining and social-environmental recognition. Land assessment may be only conducted by professional personnel. Figure 8.5 shows schematic representation of stages of converting devastated areas.

The cycles of lectures and workshop, being a basis of specialists' training, should be supported by trips to chosen terrains, representative from the point of view of development. On such lands, similarly to a lens, there is the whole range of problems concentrated which often appear where the mining industry used to be a centre of functioning. Training the professional personnel allows to increase the significance and attractiveness of such lands efficiently and effectively due to their development. Revitalization proceeded in a proper way provides benefits in various aspects for local councils, municipalities and residents of the developed lands, for example creating new work places. Aspects creating attractiveness of the area transformer according to the guidelines of sustainable development shows figure 8.6.

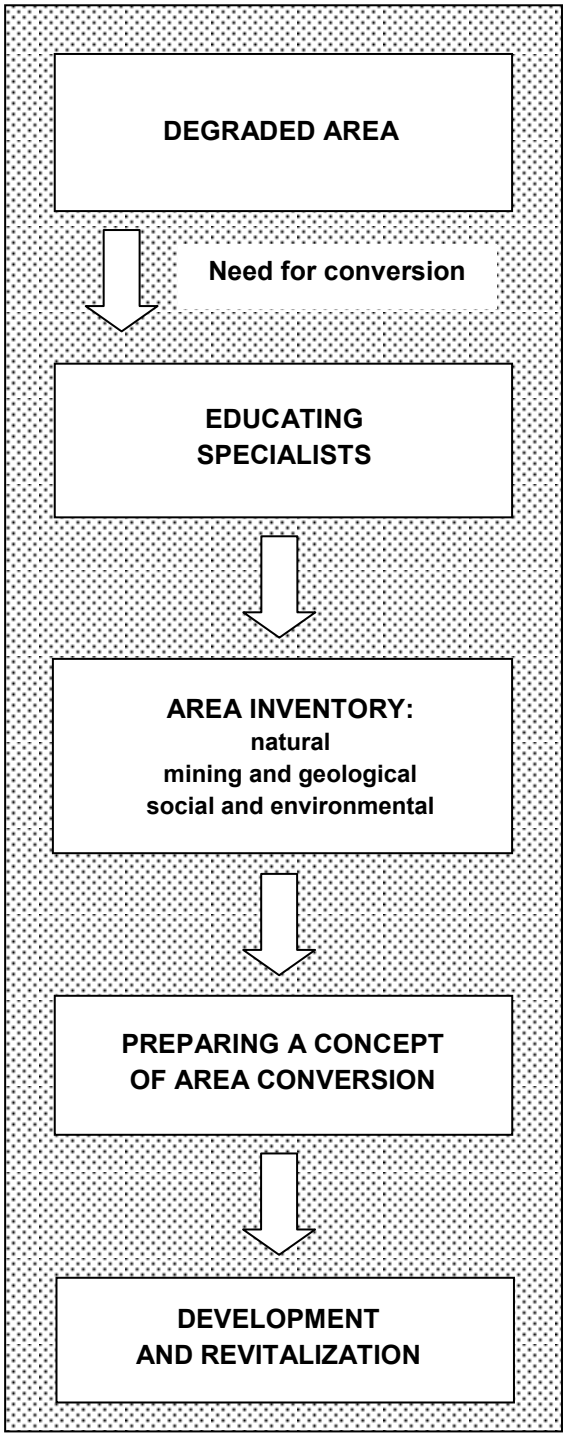



**Fig. 8.5 Schematic representation of stages of converting devastated areas**

Source: own work

The basic problem in Poland, including Silesian Province, is not sufficient information about post-industrial lands, therefore the data about the selected area must be created almost from the basis. However, it is worth to confront the research and search query results with the data gathered in Regional Spatial Information System [7], grounding on data provided by city, municipal councils and county offices. Full and reliable data constitute valuable information sources for potential investors as well, thus they may contribute to supporting changes on commercial rules [8].

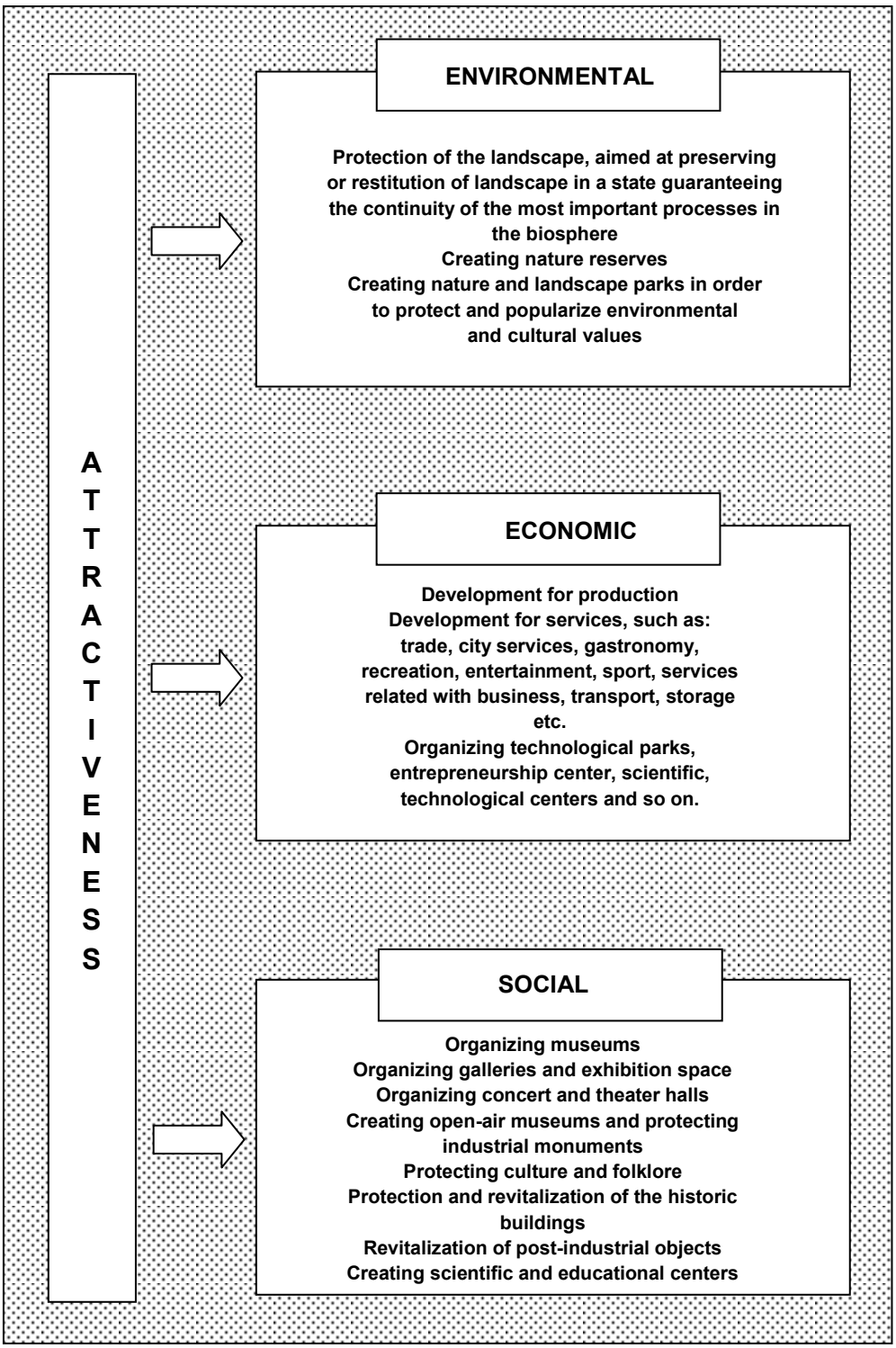



**Fig. 8.6 Aspects creating attractiveness of the area transformer according to the guidelines of sustainable development**

Source: own work based on [9]

A restraint of revitalization processes of the lands that stopped to serve economic functions is their unregulated legal-owner status. There is a lack of legal foundations visible necessary for engaging local governments and administration on a province level [8].

Efficient conduction of revitalization, next to support by a developed information base, should be characteristic for activity and cooperation of local governments and administration

of different levels, cooperation of local governments with scientific-research centers and also exchange of experiences of European Union countries which have successfully implemented interesting solutions. A significant transfer channel of development conceptions concerning borderland areas is trans-border cooperation [2]. It gains a special meaning in case of elaborating ways of revitalization in post-mining terrains; this may considerably affect the qualitative change of post-industrial landscape – landscape in a holistic understanding, related to esthetic and natural aspects as well as to the quality of life of societies connected with the land. Although areas being in the borders of other countries are specific for various legal regulations, the way of exploitation or organization culture contra these factors influenced on a different degree or character of conversions of similar areas in terms of geology, geography or nature. Consequently, disseminating good practice may find its use not only in revitalization or development of lands that bear the effects of mining activity but also when implementing a wide range of actions of preceding character.

## CONCLUSIONS

The area of Silesian province, Upper-Silesian Industrial Basin and Rybnicki Coal Basin in specific constitute the most devastated areas in the scale of the whole country. Intensive exploitation and processing of mineral resources have contributed to this situation as it was conducted with a lack of consciousness about its impact on environment and with poor management of waste accompanying the mining and processing activity. Despite a progressive process of mines liquidation, the results of negative conversion and environment pollution are still noticed [1]. One of the ways of retrieving or providing environmental, economic and social attractiveness for such areas is their complex development. Educating competent personnel is extremely important who could conduct a necessary natural, geological-mining and social-environmental cataloging in the selected area. Next, there should be conceptions of their conversion elaborated from environmental, economic and social point of view.

## REFERENCES

1. Michalska A.: Analiza zanieczyszczenia środowiska rtęcią na terenie województwa śląskiego. Journal Of Ecology and Heath, nr 4 2010, str.165-168, Górnośląska Wyższa Szkoła Pedagogiczna im. Kardynała Augusta Hlonda oraz Wyższa Szkoła Ekonomii i Administracji, Mysłowice 2010
2. Szadkowska E.: Pojęcie współpracy transgranicznej, rozdział w „Współpraca transgraniczna. Aspekty prawno-ekonomiczne" pod red. Perkowskiego M, Fundacja Prawo i Partnerstwo, Białystok 2010
3. Wojnar K., Wisz J.: Rtęć w polskiej energetyce., Energetyka, kwiecień 2006
4. Studium zagospodarowania przestrzennego pasma Odry i studium zagospodarowania przestrzennego dorzecza Wisły – opracowanie wykonane przez konsorcjum utworzone przez: Pracownię Urbanistyki i Architektury ŁAD sp. z o. o. w Katowicach i Główny Instytut Górnictwa w Katowicach, generalny projektant studium: Adamczyk A.
5. http://www.slaskie.pl/wpo/wpo_4.htm
6. http://www.slaskie.pl/przest_plan/ekofiz/13

7. http://www.rcas.slaskie.pl
8. http://ing.org.pl/files/content
9. Materiały konferencyjne konferencji „Edukacja specjalistów z zakresu zarządzania terenami pogórniczymi na pograniczu polsko-czeskim", zorganizowanej w Rybniku w dniach 24-25 kwietnia 2013 r.

## CONVERSION OF THE LANDS DEVASTATED BY MINING ACTIVITY

**Abstract:** *Mining activity in Silesian province contributed and still contributes to changes in natural environment, also concerning social and economic relations in a significant area. Such lands undergo a conversion, also their land morphology changes, vegetation is devastated and residential process is halted as well.*

*In order to provide or retrieve natural, economic and social attractiveness of such lands it is necessary to develop them properly. Therefore, it becomes important to train competent specialists who will elaborate adequate conceptions of using post-mining areas, profitable from environmental, economic and social view.*

**Key words:** *Devastated post-mining lands, land development, revitalization, conversion*.

## PRZEKSZTAŁCANIE TERENÓW ZNISZCZONYCH DZIAŁALNOŚCIĄ GÓRNICZĄ

**Streszczenie:** *Na znacznym obszarze województwa śląskiego dają się zauważyć zmiany w środowisku naturalnym, a także w stosunkach społecznych i gospodarczych, spowodowane działalnością górniczą. Obszary te ulegają przekształceniom, zmienia się morfologia ich powierzchni, degradacji ulega szata roślinna, zahamowany zostaje również rozwój osadniczy.*

*Przywrócenie lub nadanie atrakcyjności środowiskowej, gospodarczą i społeczną tych terenów możliwe jest poprzez ich właściwe zagospodarowanie. Kwestią o dużym znaczeniu, zatem, jest wykształcenie kompetentnych specjalistów, potrafiących opracować korzystne z punktu widzenia środowiskowego, gospodarczego i społecznego, koncepcje wykorzystania terenów pogórniczych.*

**Słowa kluczowe:** *Zdegradowany teren pogórniczy, rekultywacja, rewitalizacja, przekształcanie terenu*

dr inż. Krzysztof MICHALSKI
Silesian University of Technology, Faculty of Organization and Management
Institute of Production Engineering
ul. Roosevelta 26, 41-800 Zabrze
e-mail: Krzysztof. Michalski@polsl.pl

# 9

# IDENTIFICATION AND MODELING OF EMISSION SOUND SOURCES AT WORK STATIONS

## 9.1 INTRODUCTION

The research done in the area of analysis and assessment of noise threatened working place concentrate in the first chase on identification of sources of sound. In order to perform the assessment of noise threat in the examined space, there is a need to gather additional information, among others about the construction features of the place, its equipment, etc. The process of selection of used ways and methods is highly determined by the acoustic parameters of the sources of sound, their characteristics and localizations. The information related to geometric models of the places as well as material features of the barriers create a set of complimentary parameters – necessary for proper selection of noise reducing methods,

Due to variety of application of methods of modeling the acoustic fields it was stated, that each of them has limited applicability in the research because of the shape of the place and characteristics of the field. Its main simplification is related to the assumption of stability of acoustic parameters of the field in the domain of time simultaneously excluding the wave phenomena.

This article is an attempt to identify the sources of sound as the emitters of acoustic energy in the working place. In this approach, the sources are treated as either points or areas emitting acoustic energy. The analysis of flow of acoustic energy may be treated as examination of propagation of waves from the sources of sound. Taking into account the energy-related results caused by the flow of acoustic wave creates the new possibilities in the research on identification of sound sources in small rooms. The analysis of flow of acoustic energy in small rooms is of the greatest importance because of existence of wave phenomena such as: radiation, absorption, refraction and dispersion of an acoustic wave. Taking into account the wave phenomena in assessment of noise threat in the working environment enables to identify the meaning of their emergence in the energy-related description of an acoustic field.

Energy-related approach to acoustic field allows to perform a more detailed analysis of ways of transmission and dispersion of acoustic energy directly from the source in the examined environment. In particular, thanks to such a description of the field, it is possible to analyze the variability of the shape of the waves and streams of energy in the frequency domain. Application of advanced graphical methods and visualization of flows of acoustic energy in relation with the measurement methods allows to shape the noise threatened working place according to the requirements of ergonomics.

## 9.2 EVALUATING NOISE THREAT USING GEOMETRIC METHODS

### 9.2.1 Noise exposure model

The proposed model using geometric methods of noise simulation applies in particular to stationary noise sources and ergodic stationary signals (the mean value and the autocorrelation function are independent of time). The sound intensity parameter for any number of sound beam reflections can be expressed by means of the following generalized formula:

$$I_{ki} = \frac{N_i}{\Omega_i \cdot R_{ki}^{\,2}} \Pi(1-\alpha_k)^{N}_{k=1} \tag{9.1}$$

where:

$N_i$ – acoustic power of the j-th sound source,

$R_{ki}$ – the distance of the sound beam from the i-th source to the k-th point,

$\Omega_i$ – $_i$- solid angle of the radiation of the i-th sound source,

$\alpha_k$ – sound absorption coefficients for the model surfaces.

Isolating the attributes of acoustic parameters from (9.1), an $a_{ik}$ coefficient is introduced, which describes the following relationship:

$$a_{ik} = \frac{(1-\alpha_k)}{\Omega_i \cdot R_{ki}^{\,2}} \tag{9.2}$$

After converting the (9.2) equation to a matrix form we receive the following:

$$|I| = |N| \cdot |A| \tag{9.3}$$

where:

$I$ – sound intensity vector

$N$ – vector of acoustic sound sources,

$A$ – coefficients matrix

With the matrix representation of equation (9.3) – it takes the following detailed form:

$$\begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ \dots \\ I_n \end{vmatrix} = |N_1 N_2 N_3 \dots N_n| \cdot \begin{vmatrix} a_{11} a_{12} a_{13} \dots a_{1m} \\ a_{21} a_{22} a_{23} \dots a_{2m} \\ a_{31} a_{32} a_{33} \dots a_{3m} \\ \dots \\ a_{n1} a_{n2} a_{n3} \dots a_{nm} \end{vmatrix} \tag{9.4}$$

The (theoretical) component values of sound intensity coming from the individual sound sources can be obtained through a sound simulation post-process, using N = 1[W] as acoustic power values for the sources. In this case the sound intensity vector includes the theoretical values of acoustic parameters at reception points.

In order to determine the real acoustic power values of the sound sources for the calculated sound intensity values at reception points, the operation of reversing the coefficients matrix [A] must be performed. This matrix contains a description of the geometric and acoustic parameters of the system discussed here.

The essence of the proposed model consists in determining the inverse matrix [A], which includes the spatial relationships of geometric position in the source-receiver

relationship as well as the geometry of the room, and takes into consideration the properties of the model's surface material.

$$\left|N\right| = \left|N_1 N_2 N_3 ... N_n\right| = \left|A\right|^{-1} \begin{vmatrix} I_1 \\ I_2 \\ I_3 \\ ... \\ I_n \end{vmatrix} \tag{9.5}$$

The real values of acoustic power of sound sources on the basis of the values obtained for the intensity vector at reception points is determined using equation (9.5).

For potential acoustic situations with 3 sound sources the noise exposure model using geometric methods of sound simulation takes the following form for the determined real values of acoustic power:

$$\begin{vmatrix} I_1 \\ I_2 \\ I_3 \end{vmatrix} = \left|N_1 N_2 N_3\right| \cdot \begin{vmatrix} a_{11} a_{12} a_{13} \\ a_{21} a_{22} a_{23} \\ a_{31} a_{32} a_{33} \end{vmatrix} \tag{9.6}$$

The obtained set of relationships of acoustic situations caused by the sources (9.3) for the simulated acoustic field in a room is described by an approximated noise exposure risk matrix model.

### 9.2.2 The analysis of the results of sound simulation in a model room

A theoretical model room was prepared for the purpose of a computer simulation with the following dimensions: 3.2[m]x2.2[m]x2.7[m] (fig. 9.1). The model room was designed as an ideal echo-free chamber with 3 spherical sources and 14 reception points situated at the height of 1 [m]; the α = 1 coefficient was used for all the walls. It was decided that sources $P_1$ and $P_2$ will be situated at the height of 0.5 [m] and source $P_3$ at the height of 1 [m].

The simulation parameters for the calculations were 5000 beams of sound from each source and 2000 reflections. According to equation (4) presented below equal acoustic power levels $L_N$ of 120 dB (A) were used for all the sources.

$$L_N = \left|120 \quad 120 \quad 120\right| \left[dB(A)\right]$$

Following the sound simulation the sound levels coming from the respective sources $P_1$, $P_2$, $P_3$. were obtained for 3 selected reception points (1, 2, 3).

The following values were obtained from source $P_1$ at 3 reception points:

$$P_1 = \begin{bmatrix} 101{,}5 \\ 102{,}6 \\ 103 \end{bmatrix} \left[dB(A)\right]$$

The following values were obtained from source $P_2$ at 3 reception points:

$$P_2 = \begin{bmatrix} 103 \\ 102{,}6 \\ 101{,}5 \end{bmatrix} \left[dB(A)\right]$$

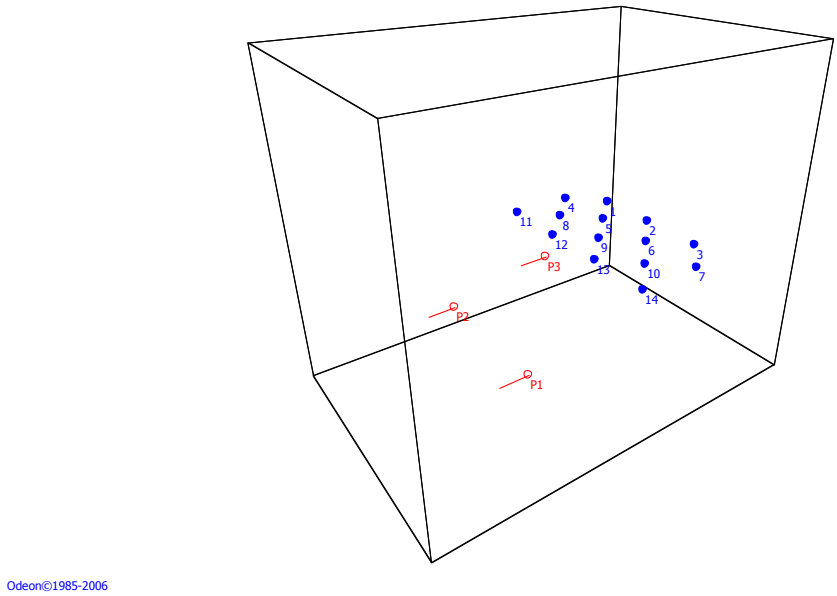



**Fig. 9.1 Simulation model of the room**

The following values were obtained from source $P_3$ at 3 reception points:

$$P_3 = \begin{bmatrix} 106 \\ 107 \\ 106 \end{bmatrix} [dB(A)]$$

Using the above and converting the units in matrix [A], the matrix was then inverted:

$$|A|^{-1} = \begin{vmatrix} 10{,}922 & 182{,}530 & -70{,}238 \\ -153{,}665 & -153{,}655 & 131{,}537 \\ 182{,}530 & 10{,}922 & -70{,}238 \end{vmatrix} \left[ {}^{1}\!/_{m^2} \right]$$

After converting the units appropriately and substituting them in equation (9.6) and after multiplication total values of intensity vector in the individual points coming from sources $P_1$, $P_2$, $P_3$ are obtained.

$$|I| = \begin{vmatrix} 0{,}073 \\ 0{,}086 \\ 0{,}073 \end{vmatrix} \left[ {}^{W}\!/_{m^2} \right]$$

The model can be verified by determining the value of acoustic power levels of the sources on the basis of the obtained results of the sound level at the same reception points in the model. The sound simulation yielded the following values of sound level at 3 reception points – successively from sources $P_1$, $P_2$, $P_3$:

$$P_1 = \begin{bmatrix} 63{,}5 \\ 64{,}6 \\ 65 \end{bmatrix} [dB(A)], \; P_2 = \begin{bmatrix} 65 \\ 64{,}6 \\ 63{,}5 \end{bmatrix} [dB(A)], \; P_3 = \begin{bmatrix} 63 \\ 64 \\ 63 \end{bmatrix} [dB(A)]$$

The total values of the intensity vector in the examined points are:

$$|I| = \begin{vmatrix} 0{,}000158 \\ 0{,}0000158 \\ 0{,}0000501 \end{vmatrix} \left[ W/m^2 \right]$$

After substituting them in equation (9.5), multiplying the matrix and converting the units, acoustic power values of sources $P_1$, $P_2$, $P_3$ are obtained.

$$L_N = |80 \quad 80 \quad 75| \left[ dB(A) \right]$$

The verification of the proposed matrix model confirmed that the levels of acoustic power of the sources used for the simulation were correct.

After substituting them in equation (9.5) the values of acoustic power $L_N$ for the 3 reception points were calculated taking into account various acoustic situations of the source activity.

**Table 9.1 Sound power level values in pending television receiving equipment points**

| Acoustic situations | $L_{N1}$ [dB(A)] | $L_{N2}$ [dB(A)] | $L_{N3}$ [dB(A)] |
|---|---|---|---|
| $P_1$ | 80 | 0 | 0 |
| $P_2$ | 0 | 80 | 0 |
| $P_3$ | 0 | 0 | 75 |
| $P_1,P_2$ | 79.89 | 79.89 | 62 |
| $P_2,P_3$ | 67.74 | 79.97 | 74.67 |
| $P_1,P_3$ | 79.97 | 67.74 | 74.67 |
| $P_1,P_2,P_3$ | 80.67 | 80.67 | 72.44 |

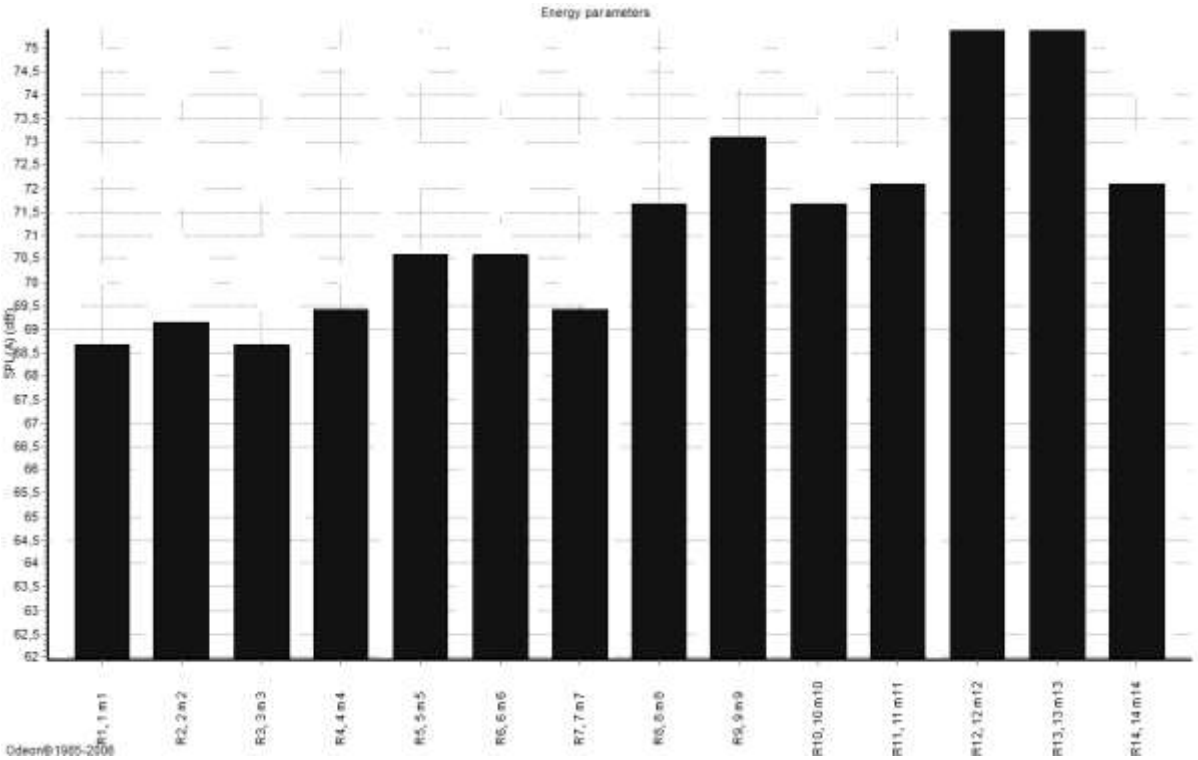



**Fig. 9.2 Sound level distribution map at the height of source $P_3$ in the model room**

**In the simulation the sound level values were different at the reception points due to theirposition in space** (Figure 9.3)

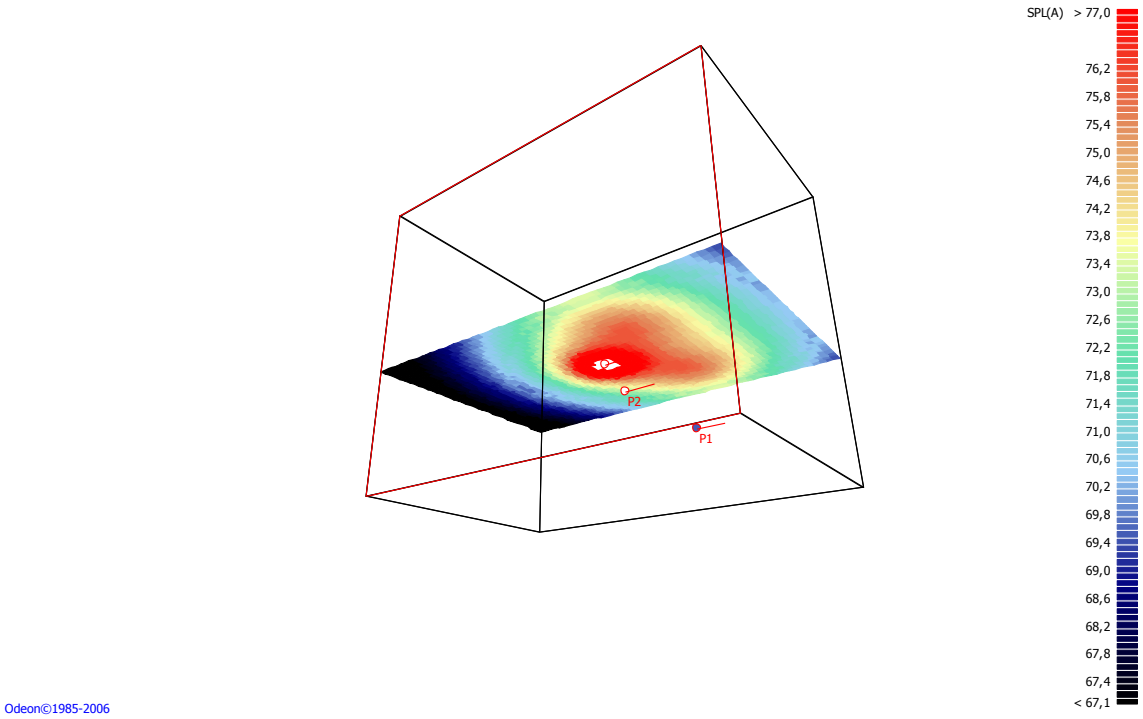



**Fig. 9.3 Sound level distribution at reception points**

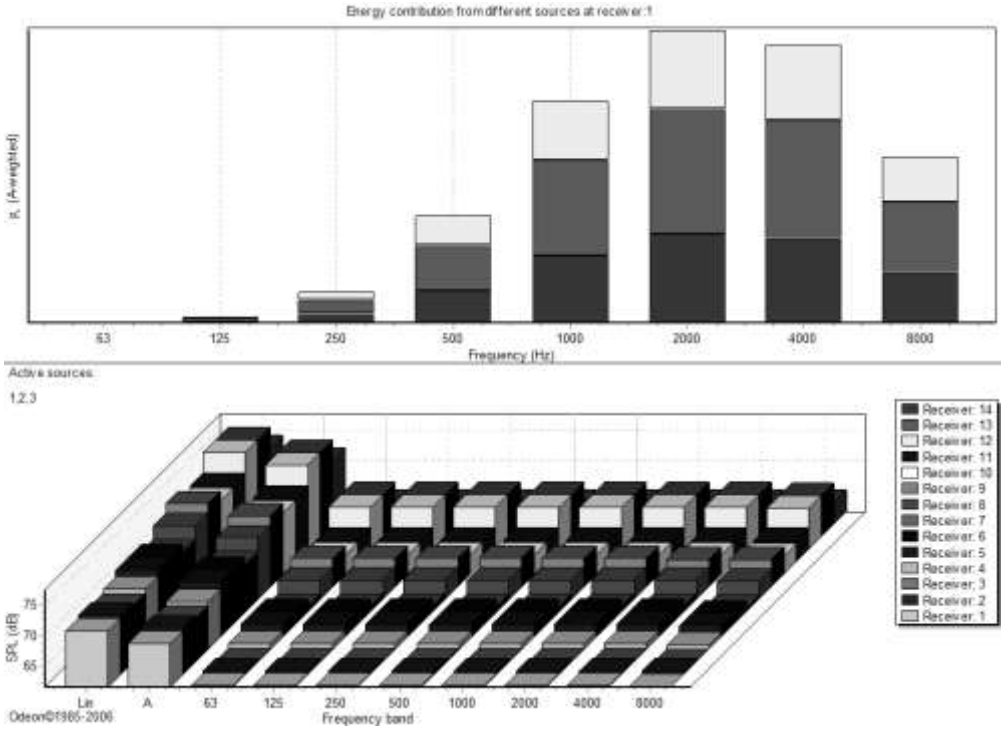



**Fig. 9.4 The share of source energy in point 1 and sound level distribution at reception points for octave frequency bands**

The values of acoustic power obtained for the reception points in question for the alternatives of two and three active sources (table 9.1) are similar to the values of the respective sources. However, in these acoustic situations there are sound level values from sources, which should yield zero values. An analysis of the results of the acoustic parameters simulation for the selected alternative of the operation of sources $P_1$, $P_2$, $P_3$ was carried out

using the *Odeon 8.5* software.

The sound level value distribution at reception points in octave frequencies does not show variability (fig. 9.2). The simulation results show that the largest energetic share of the sources in 1 reception point occurs at the 2000 [Hz] frequency.

## 9.3 THE ANALYSIS OF THE PHENOMENA OF INTERFERENCE OF SOUND SOURCES FOR THE PURPOSE OF NOISE THREAT EVALUATION

The results obtained from the simulation (table 9.1) at the reception points for the proposed noise threat evaluation model show some discrepancies. This is caused by the dimensions of the room and the limitations of the geometric simulation methods used. The distribution of acoustic energy from the sound sources in limited spaces mainly depends on the shape and the ratio between the room dimensions and the length of the emitted waves. In the case in question the room dimensions are relatively small in relation to the wavelengths.

Additionally, in small rooms wave phenomena occur which are not accounted for in the geometric simulation methods. The aspects described above may result in discrepancies in the results of the analysis of the acoustic situations of the sound sources.

### 9.3.1 The analysis of the interference of the sources using a sound intensity vector

The problem to be subjected to further research consists in preparing a noise threat evaluation model which will account for the phenomenon of the interference of sound sources. It will be important to determine the impact of the occurrence of interference of the sources on the results of noise threat evaluation in small rooms.

The research which has already been completed in this area [1, 2], which uses intensity methods, proves to be more effective in terms of the results of the analysis of acoustic phenomena in small rooms compared to the methods based on the distribution of acoustic pressures.

The sound intensity vector represented by the methods listed above includes component values of intensity in three perpendicular directions. This makes it possible to perform an analysis of the interactions of the sources and to analyze their energetic wave effects (e.g. an analysis of phase relations between sound source signals).

The theoretical models used in the techniques of acoustic field distribution in small rooms contain certain limitations. They mainly consist in that a set of acoustic phenomena often occurs in the analyzed system, such as: interference of reflected and scattered waves, absorption, diffraction, the formation of standing waves. Each of the phenomena listed above is known in its theory and described as a discrete phenomenon. The problem which describes the synthesis of acoustic phenomena in small rooms is complex enough for a representation of such theoretical model not yet to be known.

### 9.3.2 Using sound simulation methods in noise threat evaluation

The significance of the interference of sound sources for the evaluation of noise threat can be analyzed using computerized ‘idealized’ room models. Such models should: describe the parameters of the sources and the receivers, the walls of all the surfaces should be ideally

absorptive and should not contain any partitions. Performing a sound simulation in such a model will help analyze interference.

An energetic approach is proposed for carrying out analyses of interference. In this approach energetic interactions of an acoustic wave taking place between the sources will be analyzed. Research on the propagation of acoustic energies in rooms, taking into account wave phenomena and using numerical methods are described in detail in [3].

It is suggested that further research should consist in carrying out a sound simulation on a model (fig. 1) using tools to analyze wave phenomena. For this purpose it is proposed that FEM/BEM methods be used for the needs of numerical modeling of acoustic radiation issues and the description of the reactions of the structures triggered by the energy of the traveling acoustic wave. The research should focus on the vector distribution of acoustic field, accounting for the interferential effects of the active sources in relation to phase relations and frequency bands.

## CONCLUSIONS

- The proposed noise exposure matrix model can be used to evaluate the level of acoustic powers of the sources on the basis of the acoustic parameter values at the reception points. Another important element of the model is the coefficient matrix [A] of the analyzed room, which refers to the adopted relations: source-receiver and their invariable geometric and acoustic properties. This model was used in the formula to describe geometric methods of sound simulation, which are not sufficient in the case of the analyzed room due to the limited applicability of the method. The results obtained in the model analysis indicate certain discrepancies when acoustic alternatives of several active sources were analyzed.
- It is proposed that FEM/BEM numerical methods should be used in sound simulation when studying the interference of the sources in small rooms. The analysis of the interference of the sources in terms of frequency and effects will make it possible to evaluate a precise impact this phenomenon has on noise threat. For this purpose, it is planned that such analyses should first be performed on the analyzed model of the room (fig. 1) and comparing the results obtained by geometric methods with FEM/BEM.
- Further research will be connected with creating simulation models of rooms representing real-life systems for which the sound simulation analyses will be verified by means of measurement methods. When the measurement values verify the simulation results a way can be elaborated to evaluate the impact of interference of the sources on noise threat.

## REFERENCES

1. Zmysłowski A., Kuboszek A.: Estymacja źródeł dźwięku i symulacja dyfuzyjnego pola akustycznego. *Materiały XXVII Szkoły Zimowej Zwalczania Zagrożeń Wibroakustycznych* Gliwice-Ustroń, 1999.pp 261-266.
2. Atelier scientifiques franco-polonais sur le: ”Uwarunkowania przydatności systemów informatycznych wspomagających zarządzanie w przedsiębiorstwie produkcyjnym i handlowym w warunkach transformacji gospodarczej” ENSM.SE, France 2000.
3. Weyna S.: *Rozpływ energii akustycznych źródeł rzeczywistych*. WNT, Warszawa, 2005.

# IDENTIFICATION AND MODELING OF EMISSION SOUND SOURCES AT WORK STATIONS

**Abstract:** *The research done in the area of analysis and assessment of noise threatened working place concentrate in the first chase on identification of sources of sound. In order to perform the assessment of noise threat in the examined space, there is a need to gather additional information, among others about the construction features of the place, its equipment, etc. The information related to geometric models of the places as well as material features of the barriers create a set of complimentary parameters – necessary for proper selection of noise reducing methods.*
*The analysis of flow of acoustic energy in small rooms is of the greatest importance because of existence of wave phenomena such as: radiation, absorption, refraction and dispersion of an acoustic wave. Taking into account the wave phenomena in assessment of noise threat in the working environment enables to identify the meaning of their emergence in the energy related description of an acoustic field.*
*This article is an attempt to identify the sources of sound as the emitters of acoustic energy in the working place. In this approach, the sources are treated as either points or areas emitting acoustic energy. The analysis of flow of acoustic energy may be treated as examination of propagation of waves from the sources of sound. Taking into account the energy-related results caused by the flow of acoustic wave creates the new possibilities in the research on identification of sound sources in small rooms.*

**Key words:** *acoustic energy, flows of acoustic energy, noise threat*

# IDENTYFIKACJI I MODELOWANIE EMISJI ŹRÓDEŁ DŹWIĘKU NA STANOWISKACH PRACY

**Streszczenie:** *Badania przeprowadzone w zakresie analizy i oceny hałasu zagrażającego miejscom pracy koncentrują się w pierwszym rzędzie na identyfikacji źródeł dźwięku. W celu przeprowadzenia oceny zagrożenia hałasem w badanej przestrzeni, istnieje potrzeba zebrania dodatkowych informacji, m.in. o cechach konstrukcyjnych pomieszczenia, jego wyposażenia, itp. Informacje niezbędne do modelowania, reprezentowane przez miejsca położenia oraz cechy materiałowe barier akustycznych tworzą zbiór parametrów, niezbędnych do prawidłowego doboru metod redukcji poziomu hałasu.*
*Analiza przepływu energii akustycznej w małych pomieszczeniach ma duże znaczenie z powodu występowania zjawisk falowych, takich jak: promieniowanie, absorpcja, załamanie i rozproszenie fali akustycznej. Uwzględnienie występowania zjawisk falowych w ocenie zagrożenia hałasem w środowisku pracy pozwala zidentyfikować znaczenie ich występowania w energetycznym opisie pola akustycznego.*
*Niniejszy artykuł opisuje sposób zidentyfikowania źródeł dźwięku jak emiterów energii akustycznej w miejscu pracy. W tym podejściu, źródła traktowane są jako punkty, elementy liniowe, bądź powierzchniowe emitujące energię akustyczną. Analiza przepływu energii akustycznej traktowana może być jako badanie propagacji fal od źródeł dźwięku. Dotychczasowe wyniki badań nad przepływem energii związanym z propagacją fali akustycznej pozwalają określić nowe kierunki w badaniach nad identyfikacją cech źródeł dźwięku w małych pomieszczeniach.*

**Słowa kluczowe:** *energia akustyczna, przepływy energii akustycznej, zagrożenie hałasem*

dr inż. Waldemar PASZKOWSKI, dr inż. Artur KUBOSZEK
Silesian University of Technology, Department of Organization and Management
Institute of Production Engineering
ul. Roosevelta 26, 41-800 Zabrze
e-mail: Waldemar.Paszkowski@polsl.pl; Artur.Kuboszek@polsl.pl

# 10

# APPLICATION OF COMPUTATIONAL INTELLIGENCE METHODS IN CONTROL AND DIAGNOSIS OF PRODUCTION PROCESSES

## 10.1 INTRODUCTION

It is a well known fact that manufacturing costs, along costs of materials, are the main cost components of products. As the quality of manufacturing has become a decisive factor in competing in a global market, a proper control of production processes, especially related to process fault management, has become one of the key issues in a plant operation. It has been a subject of extensive research and development for many years. This concerns both the discrete processes, characteristic of the parts industries such as electronics, cars, aircrafts, household products etc. and to the process industries such as chemical, textile, food etc, in which the continuous processes are typical. As indicated in [25], a fault or problem in a process does not have to be the result of a failure of an equipment component, or even involve specific hardware. A problem might be defined as non-optimal operation or off-spec product. For example, in a process plant, root causes of non-optimal operation might be hardware failures, but problems might also be caused by poor choice of operating targets, poor feedstock quality, poor controller tuning, sensor calibration errors, human errors etc.

The process fault management includes fault detection, its diagnosis, i.e. finding the root causes of the fault and fixing it. The right control procedures of a production process should support the prevention of the faults as well as provide the means for necessary corrections.

The process control procedures and the hardware controllers often utilize data-driven (empirical) models correlating the process inputs with the outputs. Many advanced techniques are currently employed in research and new developments in this field. The applications based on Data Mining (DM) become commonly used. Apart from statistical tools, the learning systems such as Artificial Neural Networks (ANNs), Decision Trees (DTs), various logic rule systems and other methods of Computational Intelligence (CI) are engaged. They can be applied in the control and fault diagnosis of hardware elements or systems, utilized in many areas including manufacturing (e.g. neuro-fuzzy controllers), as well as in the control and fault diagnosis of the production process treated as a whole, which is the scope of the present work.

The rest of this paper is organized as follows. In the next section the main types of control systems and fault diagnosis are briefly reviewed, together with the actual applications of the CI-based and advanced statistical techniques in these areas. In Section 3 the

methodologies of significance analysis of process parameters, useful in building the data-driven models for process control as well for the fault diagnosis, based on the previous works of the present authors, are discussed. In Section 4 we present some evaluations of predictive capabilities offered by the time-series analysis from the standpoint of some industrial process control. In Section 5 the results of research aimed at evaluation of learning systems capabilities to detect out-of-control patterns of points observed in process run charts, are presented.

## 10.2 CONTROL AND FAULT DIAGNOSIS SYSTEMS USING ADVANCED DATA-DRIVEN METHODS

### 10.2.1 Types of control systems used in manufacturing industries

There are two main approaches to control of manufacturing processes: Statistical Process Control (SPC) and Engineering Process Control (EPC). Quality engineers employ SPC techniques to monitor the processes, whereas control engineers utilize EPC techniques to regulate them. Originally, SPC was first applied in the parts industry whereas EPC comes form the process industry. However, the discrepancies between these industries and the methods of controlling process variables are becoming smaller. Both control strategies are aimed at reduction of process variability, however, they seek to accomplish this objective in different ways [14]. SPC assumes that the process output can be described by statistically independent observations fluctuating around a constant mean and is intended to detect signals which represent the special (assignable) causes of external disturbances increasing the process variation. EPC actively counteracts the process disturbances by making adjustments to process variables in order to keep the output quality parameter on target. The output may shift or drift away from the desired quality target due to disturbances. These disturbances are usually not a white noise but exhibit a dependence on past values, i.e. they are auto-correlated. Hence, it is possible to anticipate the process behavior based on past observations and to control the process and outputs by adjusting the input variables [8].

To make an appropriate selection between the two approaches in practice, it is important to identify disturbance structures and strengths of the two control methods to influence the process. In the in-depth study [8] the following recommendations are made. If a process is not correlated, there is no need to employ EPC schemes and traditional and SPC control charts should be used for identifying assignable cause variations. When data are correlated, the possibility of employing EPC techniques should be examined. If appropriate controllers are available, EPC control schemes can be employed to compensate for the auto-correlated disturbance. To identify and understand the cause of process changes, a unified control framework should be applied to regulate a process using feedback control while using the diagnostic capability of SPC to detect unexpected disturbances to the process.

An example of such integrated approach is the Run-to-Run (R2R) or Lot-to-Lot control system [8]. The controller provides recipes (inputs) based on post-process measurements at the beginning of each run, updates the process model according to the measurements at the end of the run, and provides new recipes for the next run of the process. The R2R control originates from semiconductor industry where obtaining real-time information during a run is difficult and frequent changes of inputs to the process may increase the variability of the

process outputs.

It should be noticed that application of EPC combined with SPC can cause some problems as the EPC feedback compensation mechanism affects out-of-control detection by SPC and degrades the output quality once suddenly assignable causes are removed. Further discussion on integration of the two control approaches can be found in [4].

### 10.2.2 The role of CI and advanced statistical methods in process control and fault diagnosis

The most important SPC tools are control charts, widely and successfully used for detection of appearance of unexpected abnormalities of the process in the form of excessive variations of quality characteristics of the products. However, they are not capable of identifying the root causes of the process instability and to provide the means for optimum control of the process.

Various types of models linking the potential causes with the process outputs, particularly the product characteristics, can be used for that purposes. Qualitative models, such as the well known Cause-and-Effect diagrams (also known as Ishikawa or "Fishbone" diagrams) are widely used. However, because of the obviously limited capabilities of the qualitative models, various quantitative data-driven models, based on DM approach and utilizing CI methods, become more common in industrial practice. Since the year 2000 a vast growth of various applications, aimed at supporting and improvement of manufacturing processes, has been observed. Some important reviews or systemic approaches can be found in [3, 9, 10, 11, 16, 24, 28, 29, 30].

SPC control charts assume that the process is not auto-correlated, i.e. the current observation does not depend on the previous observations. The presence of auto-correlation, e.g. the process mean's trend, makes it difficult either to recognize a state of statistical control or to identify departures from the in-control state [8]. To avoid this, the Special Cause Charts (SCC) have been proposed and developed [32]. The idea is to apply the time-series analysis to the original auto-correlated data (for example the ARIMA model), remove the trends and periodicity components and plot the control chart (SCC) using the residual data.

Application of control charts is based on finding characteristic patterns of points, indicating that the process variation is due to a special cause. Usually seven typical sequences of points are distinguished, which can be interpreted in terms of probable type of the special cause or probable further behavior of the process (see, e.g. [26]). Searching for the patterns is usually made 'manually', however, the advanced learning systems can be also useful for quick finding typical sequences, identifying more complex or subtle out-of-control cases or application of control charts for the auto-correlated processes (see, e.g. [2, 6, 7, 22, 33]). Some assessments of ANNs and DTs capabilities to detect these typical patterns of points, made by the current authors, are presented in Section 5.

In manufacturing industry the most commonly used type of EPC is probably the feedback control. It uses deviations of the output from the target to calculate the amount of adjustment. EPC always requires a process model in a form of input-output relationship which, for the feedback control, can utilize the time-series analysis tools (see, e.g. [8]). Predictive capabilities of the time-series models based on regression modeling of residual

data, applied to some foundry processes by the present authors, are presented in Section 4.

Building the above mentioned qualitative and quantitative models used for identifying the root causes of the process instability as well application of EPC requires a careful selection of the process input variables. Therefore, a significance analysis of these variables, made from the viewpoint of the process output, would be of great interest since selection only significant variables allows quality engineers to obtain relatively simple and valuable models. In general, those variables which are found to be the most significant for a given process fault, e.g. increasing percent of defective parts, could be regarded as the first candidates for root causes of the fault. Finding the most significant input variables also allows selecting them as the most efficient process inputs in EPC, i.e. having the largest gain coefficients, being a measure of the impact of input control to process outputs. Identification of the most significant process variables can also facilitate establishing optimal inspection procedures in the manufacturing process, enabling engineers to concentrate on selected process variables and thus avoiding unnecessary costs. Various examples of the use of significance analysis for manufacturing process parameters can be found in a number of works, e.g. [1, 5, 12, 15, 21, 23, 29, 31].

Relative significances of process input variables can be found using different approaches, which assume different definitions of the significance and using various tools, including CI methods. In Section 3, the summary of the present authors' research on the methodologies utilized in the significance analysis of process variables, will be presented.

### 10.2.3 Examples of company systems

In this section two examples of company systems using CI tools in control and fault diagnosis of manufacturing processes are presented. The first example is a complete quality improvement system which expands traditional SPC capabilities through DM techniques [24]. The study is based on data which represent discrete and correlated process. The second example shows how useful ANNs can be in the process diagnosis, especially when conventional methods are difficult to apply [27]. In this case, a continuous production process was considered.

In the exhaustive study [24] the Continuous Quality Improvement System developed and tested in a LED packaging company was described. LED (Light Emitting Diode) is a very popular electric component used in a wide range of products from automobiles through computers to cell phones. Several facts indicate that traditional SPC methods are not an optimal tool for quality control and management in this case. Large lot sizes, high level of automation and fast production are characteristic for the LED packaging process. The process cannot be stopped due to effectiveness decrease so all potential problems should be detected, diagnosed and fixed during production, which cannot be achieved with the conventional approach. Data related to LED packaging operations are accumulated with high speed. From the quality control and improvement perspectives it is crucial to discover knowledge in this fast growing database. Furthermore, LED packaging process includes a set of operations which final goal is to bond the dice with PCB (Printed Circuit Board) and to enclose it in an epoxy compound. This should be treated as a discontinuous material flow. Every step may affect quality on the next stage. For that reason, the whole process and its parameters are

strongly correlated, which makes a serious constraint in application of traditional SPC techniques. DM provides tools and methods which are used to expand SPC capabilities.

The first step in every process analysis is a description and parameterization. In this particular case, the complete list of all kinds of quality issues was made. The potential defects were assigned to related technology operations. It was discovered that for each step in this process a parameter which is critical to quality can be determined. A product dimension, which is specific for different operations, was accepted as a control factor. Through measurement of this parameter, yield rate and defect rate are monitored and controlled both for single operation and for the process overall. Predefined CTQ (Critical-To-Quality) dimensions are tracked with a SPC control chart. Every out-of-control signal is a trigger for DM analysis. A large-scale defect database and process data warehouse are considered as a source of rules and knowledge and DM methods are used to extract it. It is important to highlight that each result is certified whether it is reasonable or not before application. DM techniques allow to identify the root cause of out-of-control signal in a short time.

Rapid adjustments are essential in continuous quality control and improvement system. A SPC chart is re-applied after correction. Fig. 10.1 describes the model of continuous quality improvement system with central position of the data warehouse. Historical data and real time data are used to control and improve the quality. Efficiency measures are process yield and defect rate.

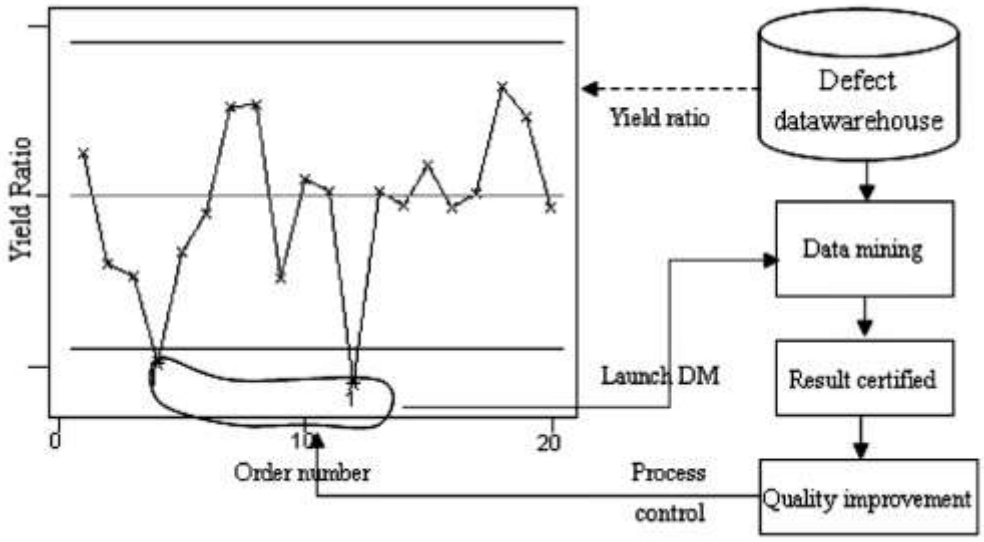



**Fig. 10.1 Scheme of continuous quality improvement system** [24]

A well-designed system should be helpful to the whole operating personnel. It should also collect data needed to identify the batch and include all the factors which are related to the production process. Not only parameters of each technological operation are taken into account but also an environment, understood as a machines, operators, materials and environment status. In this task, the large-scale data warehouse is used which contains all the information related to material flow as well as an additional part dedicated to defect description, if any occurred. The infrastructure of the system consists of three layers responsible for different tasks and connected to each other, shown in fig. 10.2.

The first layer is responsible for data collecting and is dedicated for operators. With the use of that initial layer it is possible to prepare daily reports and simple queries. The second layer is essential for quality management and continuous improvement. In this layer data from all the sources (process and data warehouse) are analyzed. Quality engineers may use that layer as a source of all kinds of information. Traditional SPC techniques, like control charts, are expanded by DM techniques (DT) to create a comprehensive quality management tool. This layer is responsible for on-line process control, diagnostic, and knowledge discovery necessary to continuous quality improvement. The third layer is dedicated to top managers to support a decision-making process. Reports created at this level visualize overall production efficiency.

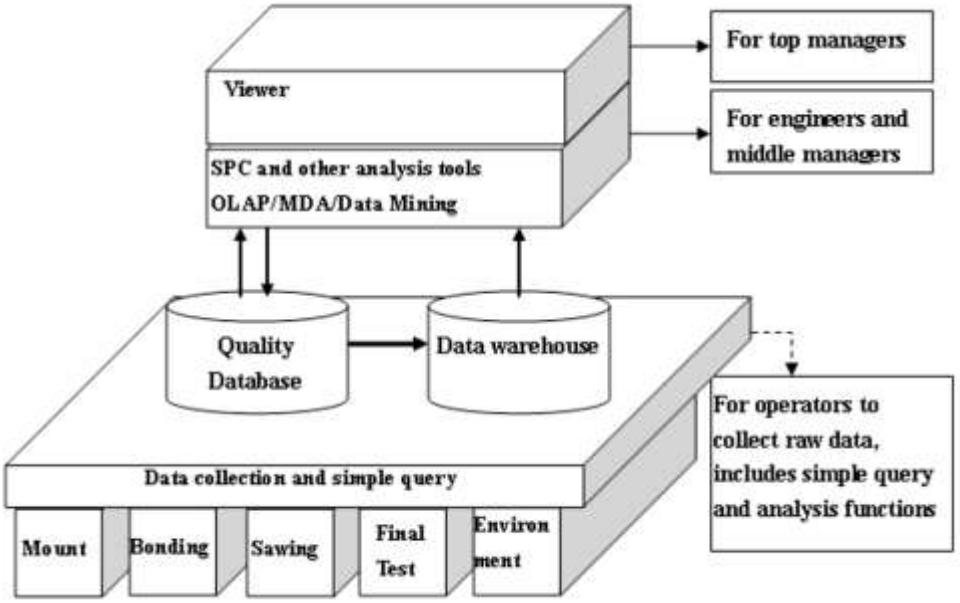



**Fig. 10.2 Three-layer system infrastructure** [24]

The parallel control of multiple parameters allows to apply three dimension SPC. The first element is a control chart which monitors the CTQ factor within the operation. At the same time, this operation yield is controlled by the other chart. The same system monitors the overall production efficiency. In that way it is possible to establish easily each disturbance on manufacturing process outcome.

The whole system was found to be useful and helpful in the process control and allows a continuous quality improvement.

The second example concerns multi-stage continuous process applied in the chemical industry [27]. In such conditions traditional statistical methods are ineffective, but combined with DM techniques may create a valuable tool for production control and management. This unique tool development was an answer to unexplained fluctuations in defect measurements observed in a chemical processing plant. The system objectives were to take full advantage of the site infrastructure and to increase production efficiency by quality control. In order to complete that task, a model capable of predicting defects and identifying casual relations within the process has to be developed. A production process should be reflected in

measurable parameters. Then, those factors should be analyzed to detect potential defects just by observation of conditions in the plant. From the range of DM techniques and methods, ANNs of MLP type have been chosen. In this particular case, production involves a number of large capacity stages responsible for mixing and processing of the liquid product. Material flow is continuous, there are no batches, raw materials are delivered and the final product is collected incessantly. The production system runs twenty-four hours a day, 365 days a year. Routine maintenance operations are conducted without breaks and so fast that it is considered unlikely for them to have significant impact on production parameters. The quality control is based on laboratory measurements of selected parameters taken at regular time intervals.

Throughout the process more than four hundred sensors are installed and utilized for measurements of standard parameters like temperature and pressure. It is worth noticing that due to continuous material flow and frequent mixing operations there is no possibility to track exact raw material distribution in the production system. The authors of the system had access to almost all the data related to the production but some of them were not available because of their confidential character. A network design team also received information about operators and shift assignments. However, a traditional statistic approach indicated no impact of the human factor on a defect rate.

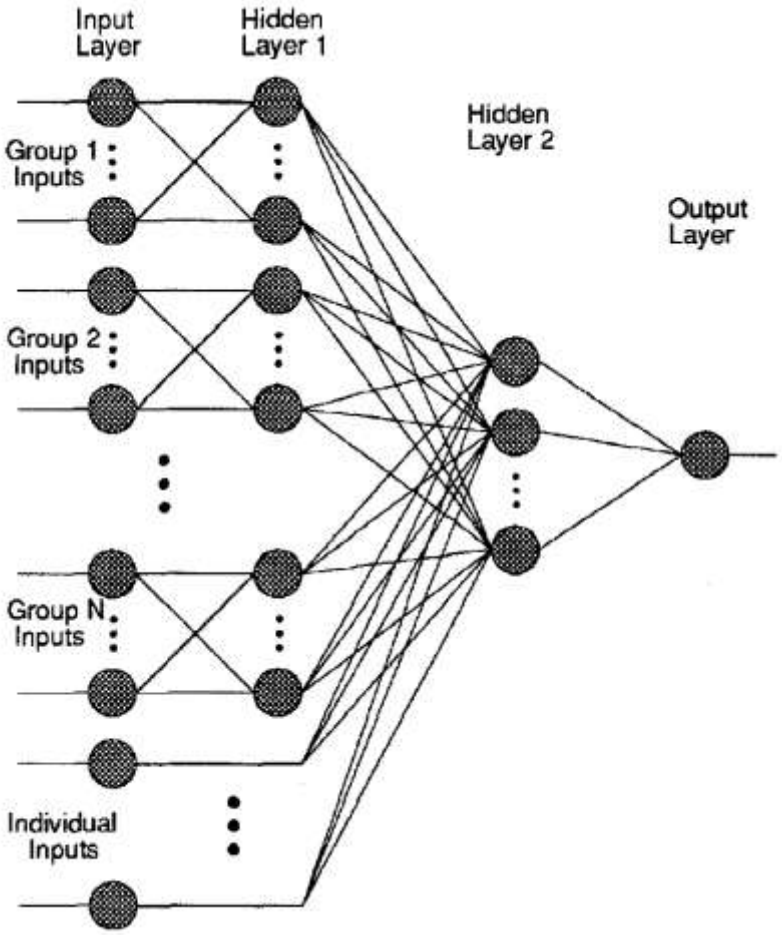



**Fig. 10.3 ANN topology used in** [27]

Data preprocessing was the first step of analysis. A reduction of sensors' number

allowed to simplify the system and had a positive impact on computational time. Large number of data dropouts did not allow to treat this set as a time-series, so these data was considered as discrete samples. Quality records containing information about defects were also included in the data collection. Statistical analyses like spectral density estimation allowed to recognize the number of periodicities in the data. Because neural networks will firstly attempt to match the strongest feature in the data, a low-pass filter was applied in order to minimize that effect.

Network topology was designed to represent the production process. Fig. 9.3 presents the developed neural network scheme with two hidden layers. Selected inputs ware grouped into subnets base on real functional or spatial relations. Dedicated inputs reflect human factors such as shift and quality control personnel. Prepared data were divided into two groups, one for network training and the other for testing. Besides testing the defect prediction, the ANN weights were analyzed to establish most powerful factors related to an out-of-control situation. This allowed to determine the human factor as crucial for the product quality.

The results obtained in [27] showed that DM techniques may be useful as an enhancement of traditional SPC, especially in the situation when nonlinearity occurs within the data and many factors have to be considered.

The above presented examples confirm that application of computational intelligence methods in the control and fault diagnosis of production processes may positively affect both the quality of product and economic potential of a company through reduction of the defect ratio.

## 10.3 RELATIVE SIGNIFICANCE ANALYSIS OF PROCESS PARAMETERS

As indicated in Section 2, significances of process parameters play an important role in control and fault diagnosis of manufacturing processes. However, introducing available CI-based and statistical tools in industry is often difficult due to the lack of a deep insight into the characteristics of particular methods and algorithms. Comparative analyses of different methods made from the point of view of their performance in carrying out specific tasks are therefore very important. Those aimed at assessment of tools suitable for determination of relative significances of the process variables are relatively rare. Hence, the selection of appropriate methodology is often casual.

The significance of an input variable can be understood in different ways. One is based on the sensitivity analysis, which returns changes of the output variable due to small variations of the input variable, calculated at particular levels of the input. However, in the opinion of the authors, the practitioners in industry would be rather interested in finding potentially greatest overall effect of a process variable on the process results or equipment behavior.

For the significance analysis, a suitable input output model, based on the observations (past production data), should be built. Dependent on the output, different types of the models are suitable. For predicting the process outputs of numerical type, such as the fraction of off-spec products or their physical characteristics, the regression models are appropriate whereas for the fault diagnosis the classification models seem to be more useful as the outputs are often in the categorical form, e.g. ‘faulty’ or ‘acceptable’ for the product quality.

In the previous works [17, 18] extensive studies on the methodologies of determination of process input variables have been presented. Below some most important issues in this field will be discussed.

For the regression-type process outputs, an original procedure of determination of the input variables relative significances has been developed and evaluated in [17]. It is based on the so called "pedagogical" approach, i.e. uses a specially designed interrogation procedure to obtain the desired information. The significance factor for an input is defined as the maximum difference of the output, which can be obtained by changing the value of the analyzed input. The two extremes of the output are found by a gradient method, with the starting points found by a specially developed procedure, permitting to avoid local minima in most cases. These differences are calculated repeatedly a number of times for the other variables set at random levels. The final values of significance or interaction factors are calculated as the arithmetic averages of the differences. It is worth noticing, that the magnitude of the resulting scatter of the significance factor of a given input can be also a measure of the possible interactions with the other input variables.

For the classification tasks the other approaches are suitable and have been utilized in [18]. The first one is called 'decompositional' and is based on the analysis of the values of the model's parameters. The second approach, dedicated especially for determination of the overall significances of input variables, is based on the reduction of the prediction accuracy obtained from a model with reduced number of inputs, compared to the model built for all input variables.

It should be noticed, that some non-parametrical statistical methods such as ANOVA for and contingency tables, seem to be relative simple and natural methods for detection and measurement of the dependencies between variables represented by data sets, without necessity of making assumptions about forms of those dependencies. These tools are suggested by some commercial statistical packages for preliminary assessment of variables' significances and are also included in the presented works. All the significances are normalized by dividing them by the value obtained for the most significant variable.

For the assessments of the methodologies used for the significance analysis, two types of data sets were used: simulated (synthetic) data, with assumed hidden dependencies between inputs and output, as well as the real industrial data. The synthetic data were obtained by assuming analytical formulas of the type Y = f(X1, X2, …), from which, for random values of continuous-type input variables X1, X2, …, the continuous-type dependent variable Y was calculated. A Gaussian-type noise was then imposed on the input variables, with maximum deviation ±20%; that value was found to be characteristic of many real manufacturing processes. For the classification tasks all continuous values in most cases were converted to categorical ones, assuming the equal intervals method. The analytical formulas were assumed in the forms which correspond to the situations often observed in practice. The industrial data sets were essentially related to metal casting processes. Further details can be found in [17, 18].

The main findings related to the regression-type tasks are as follows. The proposed definitions of significance, based on specially designed interrogation procedures of CI regression models of processes, have proved to be valid and accurate for ANNs and Support

Vector Machines (SVMs), for all simulated data sets, i.e. with pre-defined hidden relationships. The non-parametric statistical method based on analysis of variance (ANOVA), sometimes used for initial analysis of the data, predict relative significances of single variables which reflect general tendencies but they remarkably underestimate the actual values. The observed tendency of the ANOVA-based significance analysis can therefore lead to unjustified elimination of a variable from a predictive-type model. Exemplary results are presented in fig. 10.4.

The developed methodology of finding the significances of process parameters appeared to be also promising for an industrial case. In fig. 10.5 some results obtained for ductile cast iron melting process are presented, where the input variables are the contents of chemical elements and the output was its tensile strength.

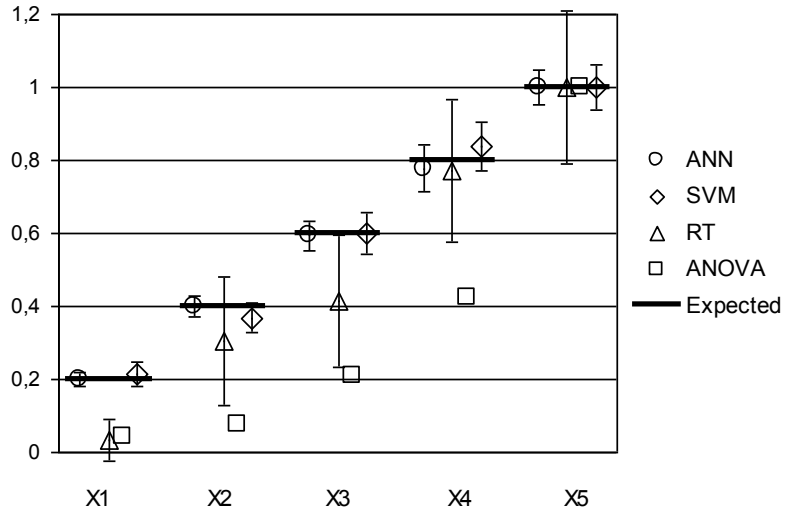



**Fig. 10.4 Comparison of relative significance factors obtained from regression models using various learning systems and ANOVA for the simulated data set generated from the basic formula Y=X1+2·X2+3·X3+4·X4+5·X5;**
**the scatter bars are calculated as average deviations resulting from randomly set values of the other variables** [17]

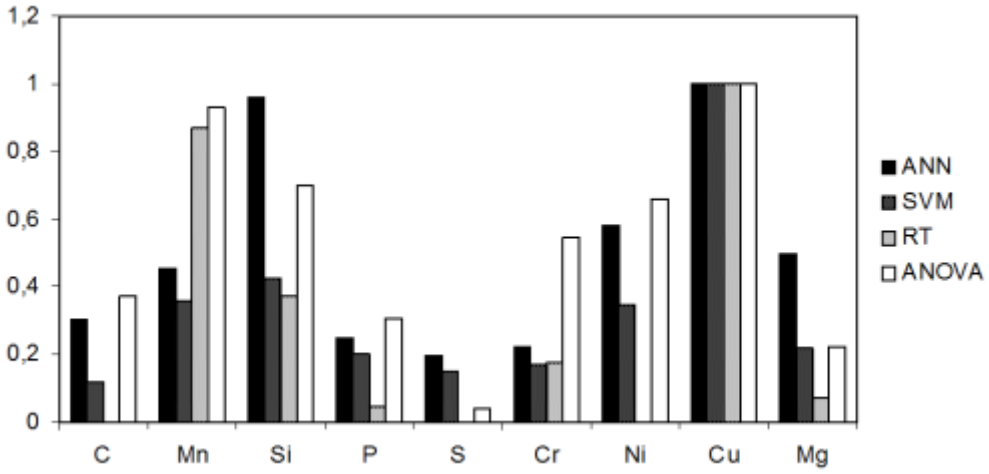



**Fig. 10.5 Relative significance factors for the industrial data set (tensile strength of ductile cast iron vs its chemical composition defined by 9 elements) obtained from regression models using various learning systems and ANOVA** [18]

For the classification-type tasks the results appeared to be substantially different [18]. The overall best performance in determination of relative significances of input variables revealed a simple statistical method, namely that based on contingency tables. For the simulated data, the performances of the advanced CI models, such as ANNs and SVMs as well as in several cases DTs, appeared to be worse for the simulated data sets. The generally accepted view, that any problem that can be solved with traditional modeling or statistical methods can most likely be solved more effectively with a neural network [13], is probably based on the neural models behavior in different situations from that appearing in the present study or for another expectations of their performance.

The performance of Naïve Bayes Classifier (NBC) and the classification models based on the Rough Sets Theory (RST) could be evaluated as acceptable. A summary of the classification errors is presented in fig. 10.6.

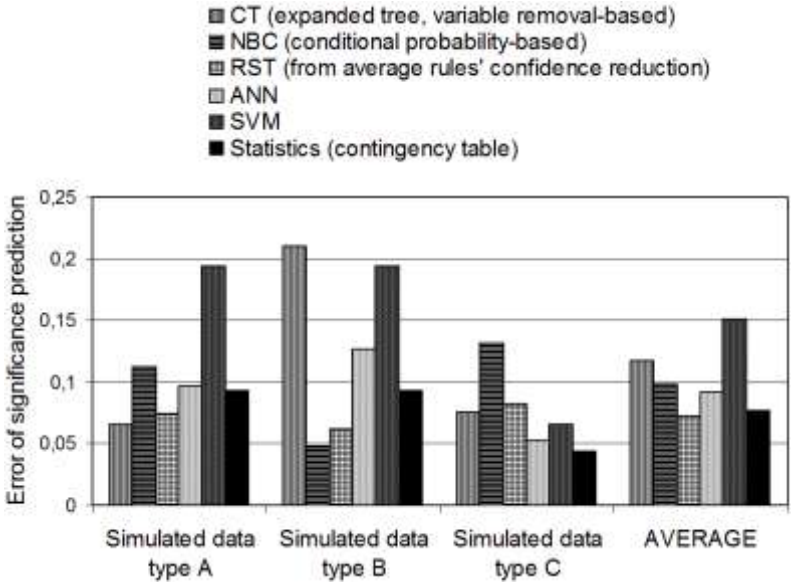



**Fig. 10.6 Absolute errors of calculated significances of input variables obtained from various models for various simulated data sets containing 1000 records; simulated data of types A, B and C were generated from three basic formulas, described in** [18]

For several industrial data sets, related to the melting process of ductile cast iron and feeding of grey cast iron castings, practically all the models appeared to be satisfactory and the statistical ones were also among the best ones.

## 10.4 PREDICTIVE CAPABILITIES OF THE TIME-SERIES ANALYSIS APPLIED FOR A FOUNDRY PROCESS

As indicated in Section 2, time-series analysis can be a useful tool in the feedback control of manufacturing processes. Time-series analysis is one of the DM methods, which deals with series of data recorded in a chronological order, usually in regular time intervals or in another sequences. There are two main purposes of that kind of analysis: the discovery of the nature of the given process or phenomenon and prediction of future values. Time-series prediction can be considered as a particular case of the regression task, where the input and

output variables are the same quantity but measured at different time moments.

The analysis and prediction of time-series can be done by many different methods. Time-series models have three classical types: Auto Regressive (AR), Integrated (I) and with Moving Average (MA). The compositions of those three classes make the popular autoregressive with moving average models (ARMA) as well the autoregressive integrated with moving average (ARIMA).

An alternative is application for a time-series a generalized regression model, described in detail in [13]. The idea is to utilize a multivariate regression model (in the present work it was a linear regression) in which the input variables are values of the given quantity recorded in several consecutive moments, and the output variable is its next value (i.e. shifted by one measurement from the last input point). The regression model is built for the residual data, i.e. obtained by subtraction form the original data the following components: the means's trend, the variability amplitude trend and the periodical component. The idea of this methodology is to use a regression model for modeling finer changes than those which can be easily described by trends and periodicity.

In this section some most important findings concerning applications of the time-series analysis in predicting future values of melting process parameters are presented, based on the previous works of the current authors [19, 20].

The production data were collected in one of Polish foundries. The quality of the alloy was controlled by its chemical composition in about 0.5 hour time intervals. The general approach is based on the residual data regression modeling, described above. The computations were made using the authors' own software having a wide range of capabilities, including detection of important periodicity in data as well as linear regression modeling of the residual data.

It can be expected, that the results of modeling of the residual data should be valuable if the information content in that data is significant. The software used in the computations provides that kind of information in a verbal form, based on results of two statistical tests: the runs test (also called Wald-Wolfowitz test) and the Durbin-Watson test, both described in [19] and the literature cited there. These messages were converted to a numerical score scale ranging between 1 (residual data are only a noise) and 5 (residual data contain a significant information).

The predictions presented below concern the manganese content in a grey cast iron. Wednesdays in the period of 3 months were chosen as the working days with the largest numbers of measurements. The values recorded before 12 am were used as training data, in which the 5 consecutive measurements were inputs and the 6th one was an output in the linear regression models implemented in the software. The predictions for Mn contents were made for the first measurements after 12 am.

In fig. 10.7 the relative prediction errors are shown. The relative errors do not exceed 40% and their average value is less then 20%. For the industrial melting process it means that, with a great confidence, the operators would be able to predict weather the next value of a given chemical element content will be 'high', 'medium' or 'low'. This would enable them to adjust the current amounts of the additives with a greater accuracy than if they rely only on the current results of chemical analysis.

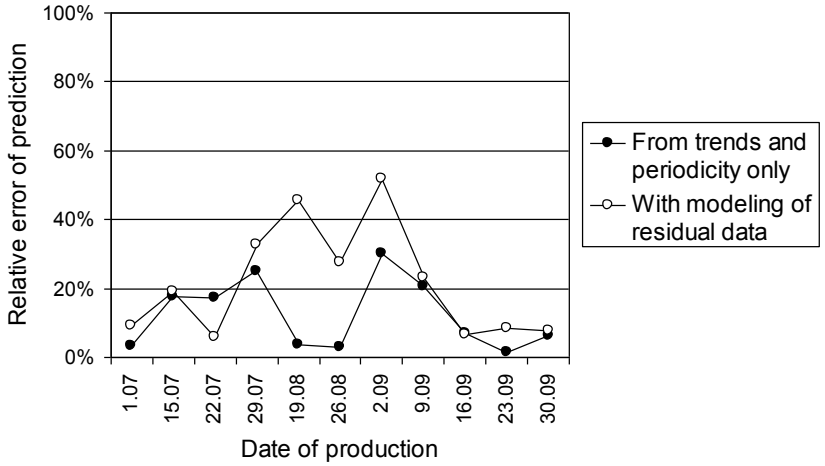



**Fig. 10.7 Comparison of prediction errors for Mn contents in gray cast iron, for the first measurements recorded after 12 am, on Wednesdays, during three months**

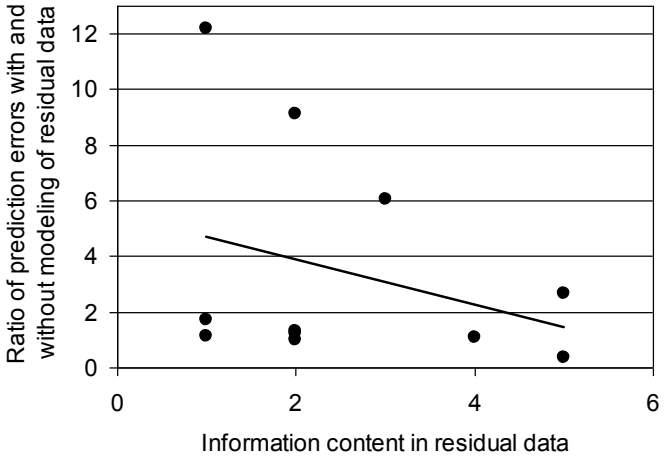



**Fig. 10.8 Influence of the information contents in residual data on the effectiveness of regression modeling, data as in fig 10.7**

In fig. 10.8 the ratios of the prediction errors obtained with modeling residual data to those obtained only from the both types of trends and periodicity, are presented as a function of the information contents in the residual data.

These results indicate that the linear regression modeling of the residual data may not necessary improve the prediction accuracy. For the Mn content predictions, the residual data modeling increased the prediction errors in most of the cases, compared to those based only on the both types of trends and periodicity. This can be possibly attributed to the low information contents in the residual data; the increase of the information content apparently reduces this negative effect.

Although the prediction accuracy appeared to satisfactory for the control of the considered process, a future research would be desirable in order to analyze the behavior of the regression models for residual data, including more advanced, non linear ones, e.g. artificial neural networks or regression trees.

## 10.5 ASSESSMENT OF CI MODELS CAPABILITIES TO IDENTIFY PROCESS DISTURBANCES ON SPC CHARTS

Application of CI models to detection and identification of the sequences of points on SPC charts, being signals of an occurrence of process disturbances, was a subject of several works. Most of them utilize ANNs to detect the process mean gradual shifts of various slopes (e.g. [2, 22, 33]) and only few of them consider different patterns of points. In an in-depth study [6] various patterns are analyzed, such as upward trend, downward trend, cyclic, decreased variation around the centerline, systematic up and down and sudden shift. In [7] the standard patterns of the points sequences are considered but the numerical results have not been reported.

In the present work a comparative study of utilization of learning systems for detection and classification of the standard patterns of points on SPC charts was made. The purpose of the numerical tests was to evaluate the capabilities of ANNs and DTs to identify patterns of points, different from the random variations. These tests should be considered as preliminary ones, leading to the application of CI models in situations different from typical ones, e.g. combined disturbances, more subtle disturbances, process-specific disturbances (when the patterns of points are not predefined but obtained from the production experience) and when the results in a stable process are not distributed normally around the actual mean.

### 10.5.1 Methodology

The sequences of points used in the present study included the 7 standard patterns. Some of them are defined using the notion of three zones above and below the chart centerline, typically denoted as: Zone A – the area between $2\sigma$ and $3\sigma$ above and below the center line; Zone B – the area between $\sigma$ and $2\sigma$, and Zone C – the area between the center line and $\sigma$, where $\sigma$ is the standard deviation of the points from the centerline in a stable process. These patterns are defined as follows [26]:

Pattern 1: 9 points in Zone C or beyond (on one side of central line).
Pattern 2: 6 points in a row steadily increasing or decreasing.
Pattern 3: 14 points in a row alternating up and down.
Pattern 4: 2 out of 3 points in a row in Zone A or beyond.
Pattern 5: 4 out of 5 points in a row in Zone B or beyond.
Pattern 6: 15 points in a row in Zone C (above and below the center line).
Pattern 7: 8 points in a row in Zone B, A, or beyond, on either side of the center line.

The testing data were generated in the form of records including 20 points. The sequences of points, meeting one of the above requirements, where generated randomly and were placed at the end of the records. The remaining (preceding) points, were also generated randomly, according to a normal distribution. In Fig. 10.9 the examples of records are shown. For each out-of-control pattern, as well as for the stable process, the points from five records, selected by chance, are plotted. The black arrows point at the beginning of the out-of-control sequences. For comparison, the five examples of records for stable processes, denoted as Pattern 0, are also presented.

Two types of data sets were used in testing. First, the 7 sets, corresponding to the above 7 patterns, were generated, each including 500 records: 250 records of the stable process plus

250 records containing one of the out-of-control patterns.

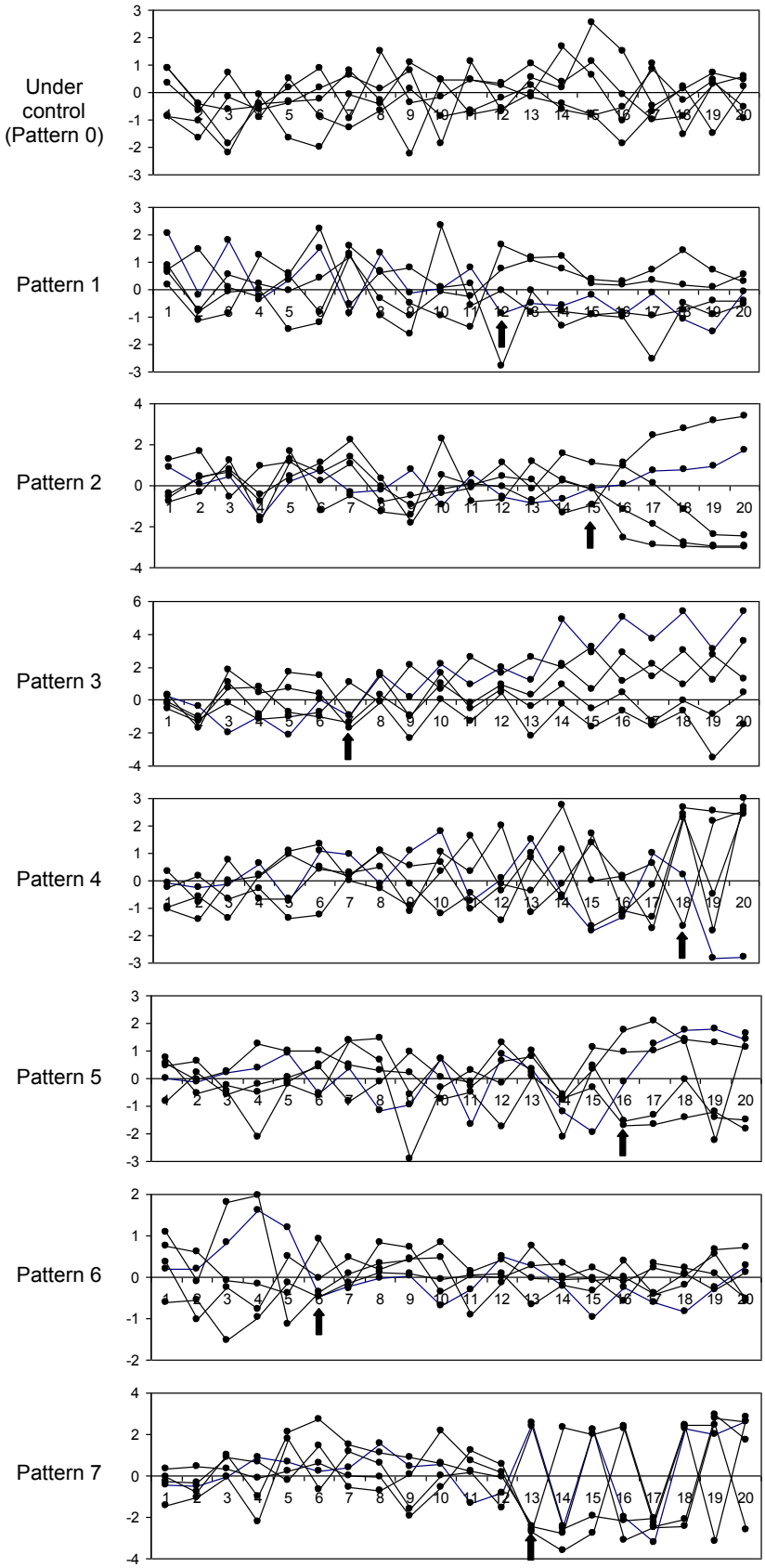



**Fig. 10.9 Examples of the records used for testing the ANNs and DTs abilities to identify the out-of-control patterns**

The second type of data was in the form of one 2000-records set, including about 87% of records containing all 7 out-of-control patterns and about 13% of the stable process records. The MLP classification-type ANNs were built, using Statistica v8 software, with a random choice of the number of hidden neurons (in one hidden layer) and the logistic transfer function. 10% of records were distinguished as the test subsets used for checking the stopping criterion (increase of the prediction error for these subsets). The best of 100 networks was selected in each case, basing on the lowest prediction errors obtained for the test subsets.

The classification-type DTs were built using the C&RT algorithm and Statistica v8 software. The optimum tree was obtained by application of the 10-fold cross-validation procedure, without setting the minimum number of records in nodes.

In all cases, 10% of records were not involved in the training process and were treated as new data, used for the evaluation of the classification capabilities of the models.

### 10.5.2 Results presentation and discussion

In fig. 10.10 the misclassification errors are shown for the training data and in fig. 10.11 for the new data. The values shown in the charts show all types of misclassifications, covering the three possible cases: (1) a stable process recognized as an out-of-control process, (2) an out-of-control process recognized as a stable process and (3) a false type of the out-of-control pattern.

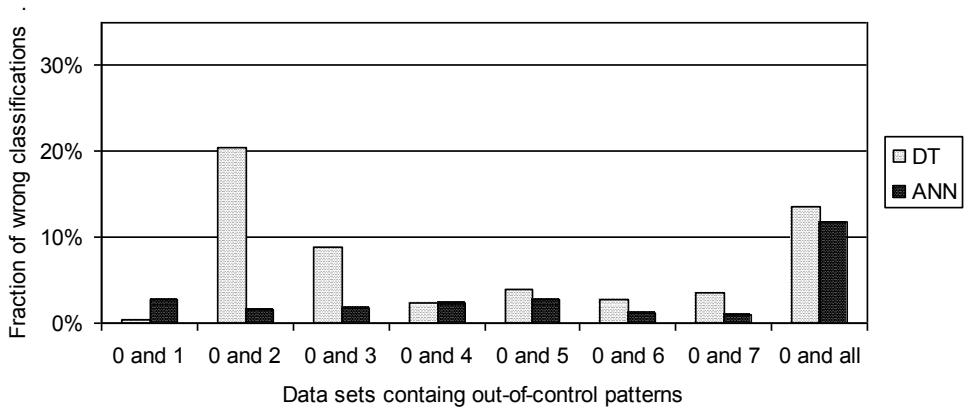



**Fig. 10.10 Fractions of misclassified cases for training data**

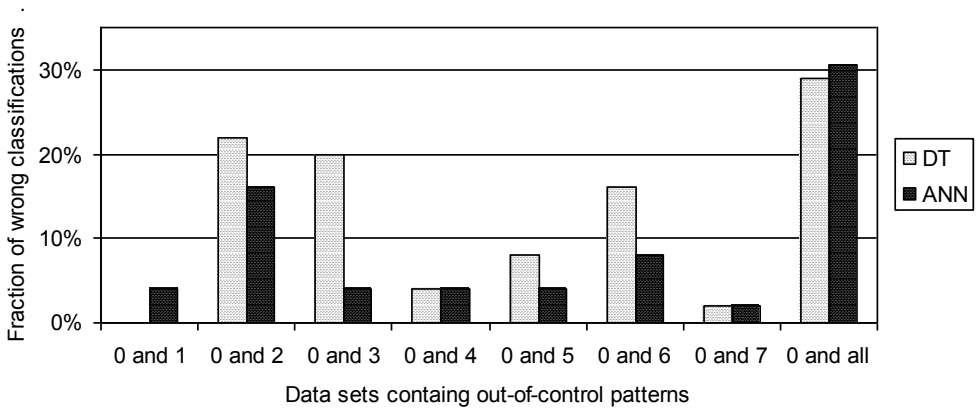



**Fig. 10.11 Fractions of misclassified cases for new data**

Based on the charts presented in fig. 10.10 and 10.11, the following observations can be made. In all cases the magnitude of the misclassification errors for the new data is obviously larger than those obtained for the training data. The general level of the errors obtained from DTs is comparable with those obtained from ANNs. However, in the majority of cases the misclassification fractions obtained from DTs are larger, which can be interpreted as a result of the lower flexibility or accuracy of this type models, compared to ANNs.

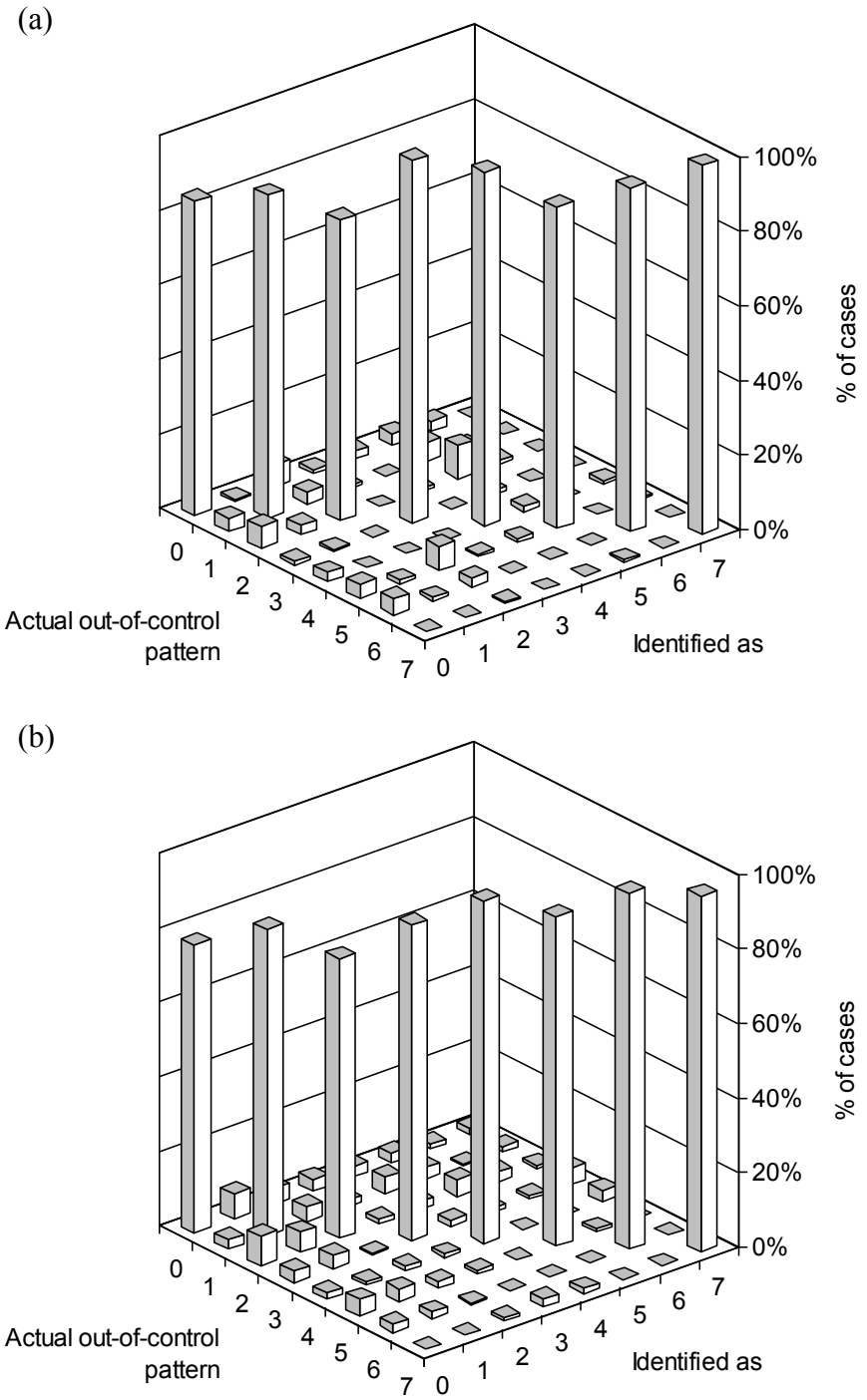



**Fig. 10.12 Distribution of correct and incorrect classification fractions obtained for the training data set including all out-of-control patterns: (a) from DTs, (b) from ANNs**

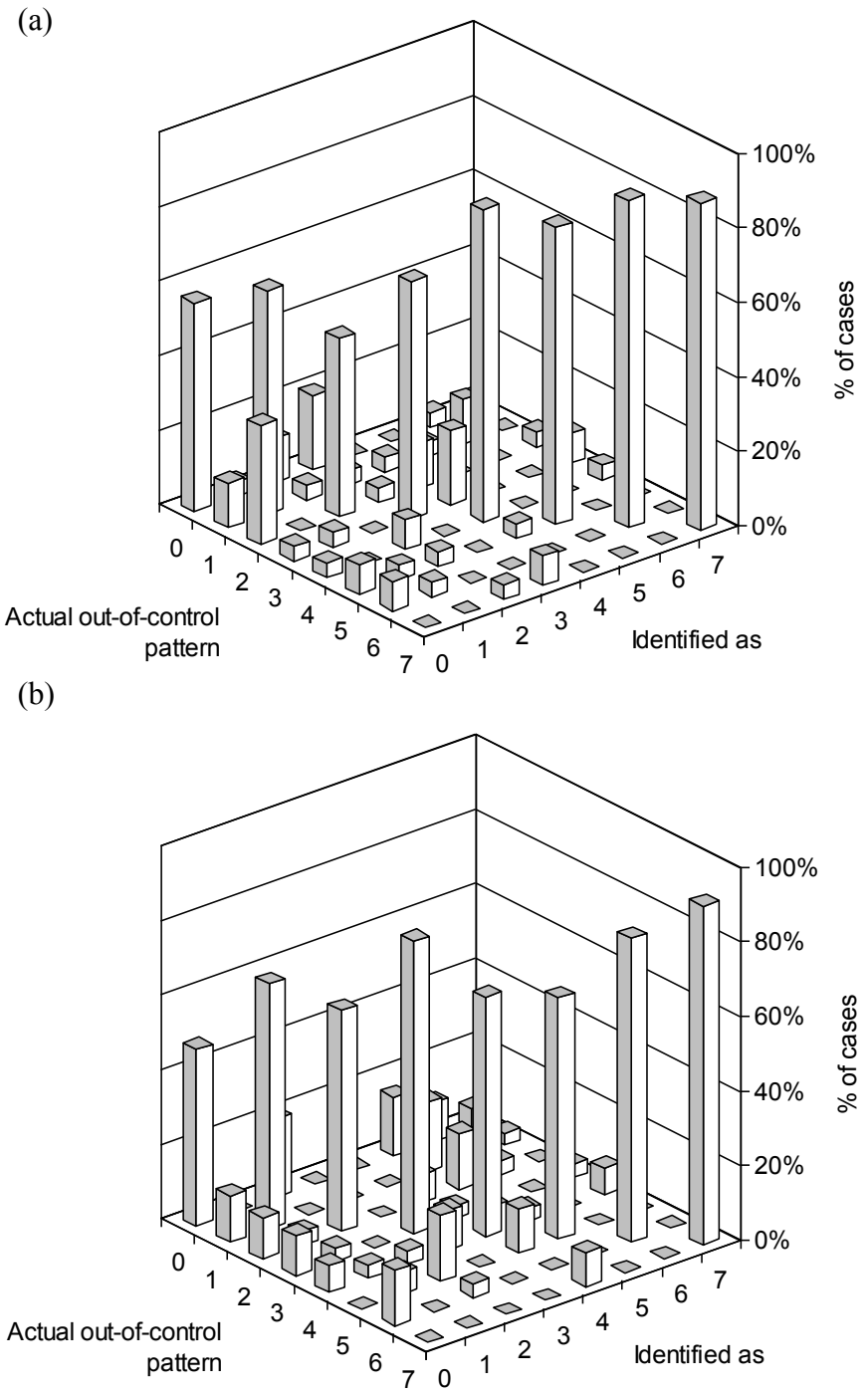



**Fig. 10.13 Distribution of correct and incorrect classification fractions obtained for the new data set including all out-of-control patterns: (a) from DTs, (b) from ANNs**

In particular, for the new data including single out-of-control patterns number 3, 5 and 6, the classification capability of DTs turned out to be much lower. This does not apply to the most complex data set, i.e. including all out-of-control patterns, where the misclassification fractions for both models are very similar.

In fig. 10.12 and 10.13 the misclassifications types are presented for the data set including all out-of-control patterns.

The distribution of the misclassification types is different for the both models. For example, the largest misclassification fraction for the new data was obtained from DTs in the case where the out-of-control process of the Pattern 2 was recognized as a stable process. For the ANNs, Pattern 5 turned out to be the most difficult and was often classified as Pattern 1 or Pattern 2, or recognized as a stable process.

The general evaluation of the magnitude of misclassification errors should take into account the fact that the classification task was extremely difficult. Referring to the exemplary data shown in fig. 9.9 it should be noticed that, in most cases, points having very different values have to be identified as belonging to this same class. Also, because the out-of-control patterns were of various lengths, some of the points (numbered between 7 and 18) play different roles as the input variables. Another difficulty results from the methodology assumed for the data generation. In the sequences of randomly obtained points for the stable process, some out-of-control patterns could occur accidentally. Similarly, in the records generated for obtaining an assumed pattern, some other patterns could also appear. However, the probability of these undesired instances is rather low and it should not be very significant for the results.

## CONCLUSION AND FUTURE WORK

The control and fault diagnosis of manufacturing processes, both discrete and continuous, can be considerably supported by application of advanced, data-driven models, particularly obtained from learning systems and other tools making up the data mining technology. They can be successfully applied both in the Statistical Process Control and Engineering Process Control, in a form of various prediction and identification tasks.

It is a real need to present these possibilities to manufacturing industry and to develop the company-oriented systems. Since selection of the appropriate methodology is often casual, the research aimed at comparative assessments of different types of tools is also desirable.

## REFERENCES

1. Chen W. H., Tseng S. S., Hsiao K. R., Liu C. C., A data mining project for solving low-yield situations of semiconductor manufacturing, Proc. IEEE International Symposium on Semiconductor Manufacturing Conference, Boston, MA, USA, May 4-6, 2004, 129-134.
2. Chiu C. C, Shao Y. E., Lee T. S., Lee K. M., Identification of process disturbance using SPC/EPC and neural networks, Journal of Intelligent Manufacturing, 14 (2003), 379-388.
3. Harding J. A., Shahbaz M., Srinivas M., Kusiak A., Data mining in manufacturing: a review, Trans. ASME, J Mfg Sci Engng 128(2006) 969-976.
4. Huang C. H. and Lin Y. N., Decision rule of assignable causes removal under an SPC-EPC integration system, International Journal of Systems Science, 33 (2002) 855-867.
5. Huang H., Wu D., Product quality improvement analysis using data mining: A case study in ultra-precision manufacturing industry, Lect Notes Comput Sci 3614LNAI (2006) 577-580.
6. Hwarng, H. B. and Hubele, N. F., Back-propagation Pattern Recognizers for X Control Charts: Methodology and Performance, Computers and Industrial Engineering, 24 (1993) 219-235.

7. Jacobs D. A., Luke S. R., Training Artificial Neural Networks For Statistical Process Control, Proceedings of the Tenth Biennial University/Government/Industry Microelectronics Symposium, Research Triangle Park, NC, USA, May 18-19, 1993, 235-239.
8. Jiang W. and Farr J. V., Integrating SPC and EPC Methods for Quality Improvement, Quality Technology & Quantitative Management, 4 (2007) 345-363.
9. Kamal A. M. M., A data mining approach for improving manufacturing processes quality control, Proc. 2nd Intern. Conf. on Next Generation Information Technology, ICNIT 2011, Hong Kong, China, 2011, p 207-212.
10. Koonce D., Fang C. H., Tsai S. C., Data mining tool for learning from manufacturing systems, Comput Ind Eng 33 (1997) 27-30.
11. Kusiak A., Data mining: manufacturing and service applications, Int. J. Prod. Res. 44 (2006) 4175-4191.
12. Lewicki P., Hill T., Multivariate Quality Control, Quality Magazine, 2007, April, 38-45. Available from: www.qualitymag-digital.com/qualitymag/200704/.
13. Masters T., Practical neural network recipes in C++, Academic Press, San Diego, 1993, 248-249.
14. Montgomery D. C., Keats J. B., Runger G. C. and Messina W. S., Integrating statistical process control and engineering process control, Journal of Quality Technology; 26 (1994) 79-87.
15. Ozturk A., Kajaligil S., Ozdemirel N. E., Manufacturing lead time estimation using data mining, European Journal of Operational Research 173 (2006) 683-700.
16. Perzyk M., Data mining in foundry production, in Research in Polish metallurgy at the beginning of XXI century, Committee of Metallurgy of the Polish Academy of Sciences, Cracow, Poland, 2006, 255-275.
17. Perzyk M., Biernacki R., Kozlowski J., Data mining in manufacturing: significance analysis of process parameters, J Eng Manuf, Proc Inst Mech Eng Part B, 222 (2008) 1503-1516.
18. Perzyk M., Kochanski A., Kozlowski J., Soroczynski A. and Biernacki R., Applications of data mining to diagnosis and control of manufacturing processes in "Knowledge – Oriented Applications in Data Mining", Kimito Funatsu (editor), ISBN 978-95-307-154-1, Publ. InTech (2011), 147-166.
19. Perzyk M., Krawiec K., Kozłowski J., Application of time-series analysis in foundry production, Archives of Foundry Engineering, 9 (2009), 109-114.
20. Perzyk M., Rodziewicz A., Application of Time-series Analysis in Control of Chemical Composition of Grey Cast Iron, Archives of Foundry Engineering, 12 (2012), 171-175.
21. Shahbaz M., Srinivas M., Harding J. A., Turner M., Product design and manufacturing process improvement using association rules, Proc. IMechE Part B: J. Engineering Manufacture, 220 (2006) 243-254.
22. Shao Y. E., Wu C. H., Ho B. Y., Liu J. F., Identifying the Change Point of a Process with the Integration of SPC Charts and Neural Networks, Proc. Second International Conference on Innovative Computing, Information and Control, 2007. ICICIC '07, Kumamoto, Japan, 400-403.

23. Shen L., Tay F. E. H., Qu L., Shen Y., Fault diagnosis using Rough Sets Theory, Computers in Industry 43 (2000) 61-72.
24. Shu-guang H. E., Li L. I., Er-shi Q. I., Study on the Continuous Quality Improvement Systems of LED Packaging based on Data Mining, Proc. International Conference on Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007, Shanghai, China, 5625-5628.
25. Stanley G. M., Guide to Fault Detection and Diagnosis, White Paper available from: http://gregstanleyandassociates.com/whitepapers/FaultDiagnosis/faultdiagnosis.htm, 2013.
26. StatSoft, Inc. (2012). Electronic Statistics Textbook. Tulsa, OK: StatSoft. WEB: http://www.statsoft.com/textbook/.
27. Stites R., Ward B. Walters R., Defect Prediction With Neural Networks, Proceedings of the Conference on Analysis of Neural Network Applications ANNA ’91, May 29-31, 1991, Fairfax, VA, USA, 199-206.
28. Tsang K. F., Lau H. C. W., Kwok S. K., Development of a data mining system for continual process quality improvement, Proc Inst Mech Eng Part B: J Eng Manuf 221 (2007) 179-193.
29. Tseng T. L., Jothishankar M. C., Wu T., Xing G., Jiang F., Applying data mining approaches for defect diagnosis in manufacturing industry, IIE Annual Conference and Exhibition, Institute of Industrial Engineers, Houston, 2004, 1441-1447.
30. Vazan P., Tanuska P., Kebisek M., Moravcik O., Data Mining Model Building as a Support for Decision Making in Production Management, Advances in Computer Science, Engineering & Applications, Proc. Second International Conference on Computer Science, Engineering and Applications (ICCSEA 2012), New Delhi, India, Vol. 1, May 25-27, 2012, 695-701.
31. Wang K., Applying data mining to manufacturing: the nature and implications, J Intell Manuf, 18 (2007) 487-495.
32. Wardell, D. G., Moskowitz, H. and Plante, R. D., Control charts in the presence of data correlation. Management Science, 38 (1992), 1084-1105.
33. Zobel C. W., Cook D. F., Nottingham Q. J., An augmented neural network classification approach to detecting mean shifts in correlated manufacturing process parameters, International Journal of Production Research, 42 (2004) 741-758.

# APPLICATION OF COMPUTATIONAL INTELLIGENCE METHODS IN CONTROL AND DIAGNOSIS OF PRODUCTION PROCESSES

**Abstract:** *This chapter presents actual and potential applications of advanced data-driven models in control and fault diagnosis of manufacturing processes. Types of process control are discussed and the role of the computational intelligence as well as other data mining methods in them is shown. The main findings of the present authors, based on results of the previous works, are presented. They include the methodologies of determination of relative significances of process parameters and evaluation of prediction capabilities of time-series modeling. Results of a new research, aimed at assessment of capabilities of learning systems to detect out-of-control patterns of points observed in SPC charts, are presented.*

**Key words:** *manufacturing, process control, fault diagnosis, data mining, computational intelligence*

# ZASTOSOWANIE METOD INTELIGENCJI OBLICZENIOWEJ DO STEROWANIA I DIAGNOSTYKI PROCESÓW PRODUKCYJNYCH

**Streszczenie:** *Niniejsze opracowanie przedstawia rzeczywiste i potencjalne zastosowania zaawansowanych modeli opartych na danych w sterowaniu i diagnostyce usterek procesów wytwarzania. Omówiono rodzaje sterowania procesem oraz pokazano rolę, jaką pełnią w nich metody inteligencji obliczeniowej i inne metody eksploracji danych. Zaprezentowano główne stwierdzenia, do jakich doszli autorzy na podstawie wyników wcześniejszych badań. Obejmują one metody określania istotności względnych parametrów procesu oraz ocenę zdolności predykcyjnych modelowania szeregów czasowych. Przedstawiono także wyniki nowych badań, mających na celu ocenę zdolności systemów uczących się do wykrywania układów punktów na kartach kontrolnych SSP, świadczących o rozregulowaniu procesu*.

**Słowa kluczowe:** *wytwarzanie, sterowanie procesem, diagnostyka usterek, eksploracja danych, inteligencja obliczeniowa*

prof. dr hab. inż. Marcin PERZYK, dr inż. Jacek KOZŁOWSKI
Warsaw University of Technology
Faculty of Production Engineering
Institute of Manufacturing Processes
ul. Narbutta 85, 02-524 Warszawa
tel. +4822 8499797, +48 509 093 935, e-mail: M.Perzyk@wip.pw.edu.pl,
tel. +48 512 081 953, e-mail: kozlows76@gmail.com
mgr inż. Krzysztof ZARZYCKI
Reckitt Benckiser Production (Poland) Sp. z o.o.
ul. Okunin 1, 05-100 Nowy Dwór Mazowiecki
tel. +48 663 334 552, e-mail: k.zar@wp.pl

# 11

# NOISE EMISSIONS TEST FROM THE COMMUNICATION ROUTE – A CASE STUDY

## 11.1 INTRODUCTION

In large cities, the quality of existence residents is dependent on many factors including the quality of the environment. One of the factors affecting the quality of life of the acoustic emission generated and emitted from the passageways. However, more can be said about noise occurring because the value of the issue often exceeds acceptable level of nuisance noise. Noise from traffic routes is generated by car engines that produce low-frequency sounds, and is a result of the effect of turning the wheels of vehicles on the road surface and in this case the noise is a high frequency sound [6]. However, in practice the level of road noise is a function of many variables. These include, among others: the type, quality and condition of the road surface, number of lanes and their distance from residential development, the number of vehicles passing per unit of time, the structure of daily traffic volume, type of vehicle and its condition, traffic variability forced by his specific organization, the number of intersections regulated by traffic lights, the duration of one cycle traffic light changes or the right of its synchronization by creating a so-called. "Green wave" [9]. The undeniable fact is that the number of moving the high-traffic urban vehicles such as cars and trucks, is constantly increasing, as a result there is an increase in noise level.

Against this unfavorable environmental influences on recent changes existence man came to European Union legislation. Adopted in 2002 by the EU Directive, which sets out the approach to the assessment and management of environmental noise in order to protect public health. He treats it as noise pollution, to which you should take the same general principles, responsibilities and forms as for the other pollutants and related environmental fields. Entered on January 23, 2008, the amended Environmental Protection Act (consolidated text. Laws of 2008 No. 25, item. 150) is also the result of alignment with EU standards. Currently applicable legal act regulating the levels of noise is the Minister of Environment of 14 June 2007 (Journal of Laws No. 120, item 2007. 826) together with the amendment of 2012.

One of the factors of the environment, on which the alleged nuisance is often especially in big cities, of course, noise. This subjective sound level as a nuisance is determined by each person individually. This is due, of course, the individual characteristics of man and his acceptability threshold sound level for proper the functioning and existence. Classification of the noise produced by the National Institute of Hygiene in Warsaw on the basis of the respondents, which is related to the value of an equivalent level $L_{Aeq}$:

– small nuisance $L_{Aeq} < 52$ dB,

- average nuisance 52 dB < $L_{Aeq}$ < 62 dB,
- big nuisance 63 dB < $L_{Aeq}$ < 70 dB,
- a very big nuisance 70 dB < $L_{Aeq}$ [6].

Well-being of residents of large cities often depends on the ambient sound from of climate life. In order to improve the acoustic climate has already made a number of steps relating to, inter alia, the implementation of noise barriers or other technical means, but also the mapping of acoustic and acoustic monitoring. Nevertheless, in this area there is still much to accomplish and it is on many levels.

Like many Polish cities, Zabrze also facing the problem of excessive noise, and residents often raise the problem of noise nuisance, among others. in the communication al. W. Korfantego where is a high traffic area, a study conducted in 2011 [4] showed a negative acoustic climate in the region.

## 11.2 OBJECT OF RESEARCH [4]

Object of traffic noise emission test covers part of the avenue W. Korfantego in Zabrze, where the research was conducted in six measuring points, plus the points of reference. Avenue is a road connecting the district center of Zabrze Mikulczyce of the two-lane asphalt pavement (roadways separated by a green belt) with three lanes in each direction.

This thoroughfare are moving several thousand vehicles per day. Moving vehicles are not only cars, but also provide a large number of lorries and buses. Along the avenue are located ten-apartment buildings with a height of about 30 meters. These buildings are not protected acoustically according to [5], and the inhabitants raise the problem of excessive noise.

According to the Minister of Environment of 14 June 2007 (Journal of Laws of 2007 No. 120, item. 826) [7], the area in which the measurements are classified as multi-family residential areas and living collections. Under that regulation, revised in 2012 for the analyzed area limits are as follows:

- 65 dB $L_{Aeq\ D}$ (equivalent sound level for the time of day, understood as the period of time from 6 hours to 22 hours),
- 56 dB $L_{Aeq\ N}$ (equivalent noise level for night time, understood as the time interval from 22 hours to 6 hours 6).

In order to determine whether these values are standardized satisfied, measurements were performed at six points. Measuring point first and sixth to end points on the test section of the road. Measuring points, second and third were chosen to measure the noise running on the roadway, and the fourth measurement point on the area included in the next row in the space between the buildings of the first row. Fifth measurement point was located close to the road in such a way as to measure the noise, which runs on Albert's house, located on this street (background measurements were carried out in the additional points for buildings – fig. 11.1).

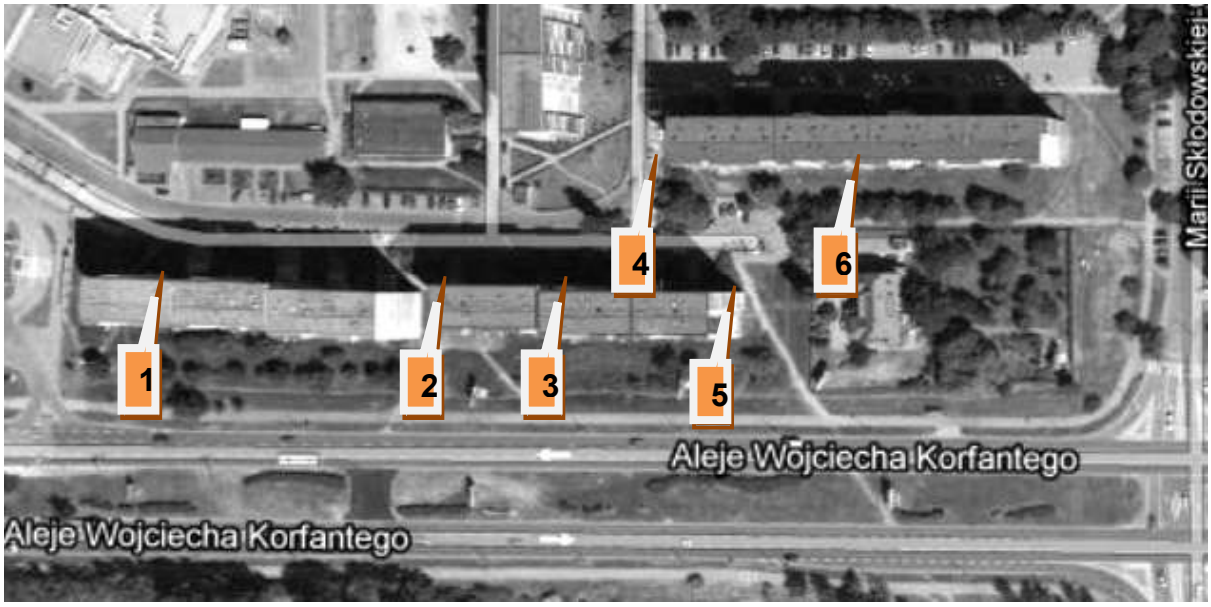



**Fig. 11.1 Satellite view from Google Maps Avenue W. Korfantego with marked test points**

## 11.3 DESCRIPTION OF THE MEASURING APPARATUS AND TEST METHOD

Acoustic measurements were made using a measuring kit comprising:

- sound level meter and vibration produced by SVAN a 948 with a serial number 12631 having a calibration certificate No. 1483.1-M34-4180-411 issued by the PGUM,
- SV22 measurement microphone type of BSWA Tech/SVANTEK with a serial number 4012856 having a calibration certificate No. 1483.1-M34-4180-411 issued by the PGUM,
- a microphone preamplifier SV 12L with a serial number 17301 having no 1483.1-M34-4180-411/08 calibration certificate issued by PGUM,
- Draft shield and measuring stand.

Before and after measurements of a 948 SVAN analyzer with measurement microphone type SV22 company BSWA Tech/SVANTEK marked with acoustic calibrator type SV30 No. 14155 SVANTEK production, having a calibration certificate No. 1483.2-M34-4180-411 issued by the PGUM.

The measurements previously established punks used the direct method of measuring noise measurements. Performed equivalent sound level measurements were recorded at a distance of 1.5 m from the facade of buildings, at the height of 4 m, as in the year 2011. The measurements were carried out in July 2012, in the three days of the week. Weather conditions during the measurements were as follows: temperature ranging from 15°C to 25°C, relative humidity of 67% – 69%, the atmospheric pressure in the range 1044 hPa – 1069 hPa, no precipitation occurred. In order to minimize the effect of wind on the results of the microphone mounted on the windscreen. At each time point measurements were performed at five-hour intervals and the measurements of the background [8].

## 11.4 RESULTS OF MEASUREMENT

The results of measurements of the individual points are shown in table 11.1 and 11.2.

**Table 11.1 Results of the measurement of the noise emission from test points from 1-3**

| Interval | Measurement point 1 | | | Measurement point 2 | | | Measurement point 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ |
| **06:00 – 07:00** | 58.9 | 57.9 | 58.9 | 54.1 | 552 | 55.0 | 53.9 | 56.3 | 56.5 |
| **07:00 – 08:00** | 62.1 | 63.1 | 61.9 | 58.9 | 56.8 | 56.3 | 59.2 | 57.5 | 58.1 |
| **08:00 – 09:00** | 61.9 | 62.8 | 61.3 | 55.8 | 56.7 | 56.4 | 56.8 | 58.5 | 58.3 |
| **09:00 – 10:00** | 61.5 | 61.2 | 62.3 | 57.5 | 55.9 | 56.7 | 57.7 | 58.4 | 57.8 |
| **10:00 – 11:00** | 63.2 | 63.4 | 67.4 | 55.9 | 57.1 | 56.4 | 59.1 | 57.6 | 57.9 |
| **11:00 – 12:00** | 64.3 | 63.2 | 62.4 | 61.3 | 57.2 | 57.6 | 58.5 | 57.4 | 59.4 |
| **12:00 – 13:00** | 63.4 | 64.1 | 65.2 | 56.4 | 57.8 | 58.2 | 56.7 | 57.3 | 57.3 |
| **13:00 – 14:00** | 64.4 | 62.5 | 63.2 | 55.8 | 58.2 | 57.1 | 56.8 | 57.6 | 58.4 |
| **14:00 – 15:00** | 65.4 | 66.0 | 67.9 | 65.7 | 64.8 | 67.2 | 59.7 | 61.2 | 63.4 |
| **15:00 – 16:00** | 68.9 | 69.2 | 69.4 | 65.6 | 63.1 | 67.8 | 59.8 | 59.0 | 58.4 |
| **16:00 – 17:00** | 74.8 | 75.5 | 74.5 | 73.5 | 72.3 | 71.6 | 64.9 | 65.6 | 63.2 |
| **17:00 – 18:00** | 74.3 | 73.1 | 74.2 | 61.8 | 60.1 | 58.9 | 61.2 | 62.7 | 59.3 |
| **18:00 – 19:00** | 72.1 | 73.2 | 72.3 | 59.9 | 59.6 | 58.3 | 59.2 | 59.4 | 58.5 |
| **19:00 – 20:00** | 68.1 | 69.2 | 68.7 | 57.9 | 57.5 | 58.1 | 59.2 | 58.7 | 58.2 |
| **20:00 – 21:00** | 61.1 | 63.2 | 61.1 | 58.9 | 56.4 | 57.8 | 58.7 | 59.2 | 57.5 |
| **21:00 – 22:00** | 59.3 | 58.1 | 58.9 | 57.8 | 56.7 | 56.3 | 56.1 | 58.3 | 55.4 |
| **22:00 – 23:00** | 57.3 | 58.5 | 57.8 | 56.9 | 54.9 | 56.1 | 54.9 | 54.3 | 54.6 |
| **23:00 – 00:00** | 55.3 | 53.2 | 52.1 | 52.1 | 51.9 | 52.7 | 52.7 | 53.9 | 53.9 |
| **00:00 – 01:00** | 47.8 | 46.7 | 46.9 | 47.2 | 48.0 | 47.9 | 48.1 | 48.4 | 48.3 |
| **01:00 – 02:00** | 46.2 | 47.5 | 47.8 | 46.2 | 45.1 | 44.9 | 45.6 | 46.2 | 46.9 |
| **02:00 – 03:00** | 46.6 | 48.3 | 47.9 | 48.2 | 47.6 | 47.7 | 47.6 | 46.4 | 46.8 |
| **03:00 – 04:00** | 47.4 | 47.8 | 48.2 | 49.7 | 48.9 | 48.2 | 48.6 | 47.4 | 50.2 |
| **04:00 – 05:00** | 47.9 | 47.4 | 48.1 | 51.2 | 52.7 | 51.8 | 49.9 | 51.2 | 51.7 |
| **05:00 – 06:00** | 52.1 | 51.3 | 52.3 | 55.7 | 56.2 | 56.7 | 55.2 | 57.6 | 58.1 |

**Table 11.2 Results of the measurement of the noise emission from test points from 4 to 6**

| Interval | Measurement point 4 | | | Measurement point 5 | | | Measurement point 6 | | |
|---|---|---|---|---|---|---|---|---|---|
| | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ | $L_{Aeq}$ |
| **06:00 – 07:00** | 51.7 | 53.9 | 52.8 | 59.7 | 60.1 | 61.3 | 52.3 | 52.5 | 52.7 |
| **07:00 – 08:00** | 58.0 | 56.3 | 54.1 | 59.9 | 62.3 | 60.3 | 54.7 | 54.8 | 54.1 |
| **08:00 – 09:00** | 53.8 | 55.8 | 51.1 | 56.8 | 60.3 | 62.1 | 55.8 | 55.2 | 55.6 |
| **09:00 – 10:00** | 56.7 | 53.3 | 52.1 | 57.7 | 62.3 | 63.4 | 55.7 | 54.5 | 55.2 |
| **10:00 – 11:00** | 55.4 | 53.4 | 53.1 | 63.4 | 62.9 | 63.0 | 54.8 | 54.6 | 55.2 |
| **11:00 – 12:00** | 60.3 | 51.2 | 51.3 | 62.3 | 62.2 | 63.2 | 55.4 | 55.3 | 55.3 |
| **12:00 – 13:00** | 56.6 | 57.4 | 55.2 | 63.2 | 62.9 | 62.7 | 55.6 | 53.3 | 54.3 |
| **13:00 – 14:00** | 65.8 | 62.4 | 64.2 | 64.7 | 63.3 | 64.0 | 54.8 | 54.5 | 55.2 |
| **14:00 – 15:00** | 67.7 | 65.4 | 65.1 | 63.7 | 62.3 | 63.3 | 55.6 | 54.9 | 54.1 |
| **15:00 – 16:00** | 60.9 | 60.9 | 61.5 | 64.5 | 67.1 | 68.9 | 57.3 | 56.7 | 56.8 |
| **16:00 – 17:00** | 69.5 | 69.2 | 62.2 | 72.3 | 71.2 | 69.9 | 57.1 | 57.2 | 57.9 |
| **17:00 – 18:00** | 662 | 61.4 | 64.0 | 72.3 | 72.9 | 71.3 | 57.6 | 57.5 | 57.3 |
| **18:00 – 19:00** | 59.4 | 58.8 | 60.1 | 69.7 | 67.4 | 68.6 | 57.4 | 55.9 | 55.2 |
| **19:00 – 20:00** | 59.0 | 58.4 | 57.3 | 65.2 | 66.1 | 67.4 | 54.8 | 53.9 | 54.2 |
| **20:00 – 21:00** | 58.7 | 58.8 | 59.8 | 60.3 | 62.2 | 62.1 | 53.7 | 53.9 | 53.2 |
| **21:00 – 22:00** | 54.1 | 55.1 | 53.2 | 61.1 | 60.2 | 61.3 | 50.5 | 51.7 | 51.2 |
| **22:00 – 23:00** | 52.5 | 50.7 | 49.9 | 60.7 | 60.3 | 61.1 | 49.1 | 48.2 | 49.0 |
| **23:00 – 00:00** | 45.2 | 44.6 | 46.9 | 59.4 | 59.8 | 57.9 | 48.5 | 46.9 | 47.5 |
| **00:00 – 01:00** | 44.9 | 44.6 | 45.0 | 57.9 | 58.3 | 58.0 | 45.2 | 45.5 | 44.9 |
| **01:00 – 02:00** | 45.2 | 44.5 | 45.4 | 55.8 | 53.7 | 52.3 | 45.2 | 44.2 | 45.7 |
| **02:00 – 03:00** | 44.5 | 44.2 | 43.1 | 52.8 | 51.4 | 52.8 | 45.6 | 44.3 | 43.4 |
| **03:00 – 04:00** | 45.1 | 44.3 | 44.2 | 48.9 | 49.8 | 48.3 | 48.4 | 46.9 | 47.5 |
| **04:00 – 05:00** | 44.7 | 44.6 | 45.5 | 48.9 | 49.3 | 49.5 | 44.7 | 45.3 | 46.1 |
| **05:00 – 06:00** | 47.6 | 46.9 | 46.5 | 59.9 | 59.4 | 59.1 | 50.0 | 51.3 | 51.4 |

## 11.5 DETERMINATION OF UNCERTAINTY IN MEASUREMENT AND ANALYSIS OF RESULTS

In a further stage, calculated in accordance with (11.1) [8] has a level equivalent to the sum of listening situations for each of the division of the measuring point on the time of day and night for the test results obtained in tables 10.1 and 10.2:

$$L_{Aeq} = 10 \cdot \log\left(\sum_{k=1}^{m} \frac{t_k}{T} \cdot 10^{0,1 \cdot L_{Aeq}}\right) \tag{11.1}$$

where:
$L_{Aeq}$ – equivalent sound level in dB acoustic situations,
$L_{em\,k}$ – equivalent sound level for a given situation in dB,
$t_k$ – follow-up included in the normative time s,
$T$ – normative observation time in s,
$M$ – volume listening situations.

The results obtained from the calculation of a level equivalent to the sum of $L_{Aeq}$ listening situations for each of the point of taking into account the time of day and night are summarized in table 11.3.

**Table 11.3 Equivalent level of sound of the sum of acoustic situations for test points in the period of the day and the night**

| Measurment points | **2011r.** [4] | | **2012r.** | |
|---|---|---|---|---|
| | **Day time $L_{Aeq\,D}$ [dB]** | **For night time $L_{Aeq\,N}$ [dB]** | **Day time $L_{Aeq\,D}$ [dB]** | **For night time $L_{Aeq\,N}$ [dB]** |
| 1 | 64,2 | 49.3 | **65.3** | **50.1** |
| 2 | 59.5 | 50.2 | **59.9** | **50.7** |
| 3 | 58.6 | 50.5 | **59.1** | **50.7** |
| 4 | 53.2 | 45.5 | **53.8** | **45.8** |
| 5 | 63.1 | 55.8 | **64.0** | **55.2** |
| 6 | 53.8 | 46.3 | **54.8** | **46.8** |
| Nor. value | 60 [dB] | 50 [dB] | **65 [dB]** | **56 [dB]** |

Then an analysis of the expanded uncertainty of measurements: where calculated uncertainty of type A and type B uncertainty for every situation at a confidence level of 95% [3]. The expanded uncertainty (11.2) determined for a confidence level of 95% is due to the noise test scattering measurements considered together with the background noise and the acoustic background noise and uncertainty associated with the measurement hardware used and applied measurement procedure.

$$U_{R,95} = \sqrt{U_{A,95}^2 + U_{B,95}^2} \tag{11.2}$$

gdzie:
$U_{R,95}$ – expanded uncertainty,
$U_{A,95}$ – Type A uncertainty associated with the projection of the measurement results,
$U_{B,95}$ – Type B uncertainty associated with the equipment and procedure of measurement.

The values of equivalent sound level for the sum of acoustic situations with values of expanded uncertainty at the 95% confidence level ($U_{R,95}$) of the upper and lower deviation are shown in table 11.4.

**Table 11.4 Equivalent value of the level of sound of the sum of acoustic situations along with the uncertainty widened ($+U_{R,95}$, $-U_{R,95}$) for test points in the period of the day and the night**

| Measurment points | 2011r. [4] | | 2012r. | |
|---|---|---|---|---|
| | Day time $L_{Aeq\,D}$ [dB] | For night time $L_{Aeq\,N}$ [dB] | Day time $L_{Aeq\,D}$ [dB] | For night time $L_{Aeq\,N}$ [dB] |
| 1 | **64.2 (1.0;1.0)** | **49.3 (0.9;1.0)** | **65.3 (0.9;0.9)** | **50.1 (0.9;0.9)** |
| 2 | **59.0 (0.7;0.8)** | **50.2 (1.0;1.1)** | **59.9 (0.8;0.7)** | **50.7 (0.8;0.8)** |
| 3 | **58.0 (0.7;0.7)** | **50.5 (0.9;1.1)** | **59.1 (0.8;0.8)** | **50.7 (0.7;0.8)** |
| 4 | **53.2 (0.7;0.7)** | **45.5 (0.9;1.0)** | **53.8 (0.7;0.8)** | **45.8 (0.9;0.9)** |
| 5 | **63.1 (0.6;0.7)** | **55.8 (1.0;1.2)** | **64.0 (0.7;0.7)** | **52.3 (0.7;0.8)** |
| 6 | **53.8 (0.7;0.7)** | **46.3 (1.0;1.2)** | **54.8 (0.7;0.7)** | **46.8 (0.7;0.8)** |
| Nor. value | **60 [dB]** | **50 [dB]** | **65 [dB]** | **56 [dB]** |

As a result of the preliminary analysis of the obtained measurement results (table 11.1 and 11.2) may be noted that in the fifth step of the gauge closest roadway, measurements of the value of the $L_{Aeq}$ exceeded the limit values (night crossing did not occur). This has happened in every era of measurement and is therefore equivalent values for day, night, and total $L_{Aeq\,D}$ acoustic situations were not exceeded in accordance with the amendment in 2012 of the Minister of Environment of 14 June 2007 on the levels of environmental noise increasing the traffic noise levels allowed from 5 to 10 dB (in 2011 these values were exceeded 4.2 dB $L_{Aeq\,D}$ – table 11.3).

In the fourth and sixth point (table 11.2), which were furthest from the road, recorded the lowest value of the noise level. During the day there were no crossing over the well standardized in 2011 as there were no such levels.

The first measurement point (table 11.1) in each age exceeded the limit value applicable to the $L_{Aeq\,D}$ by up to 9.8 dB (4.2 dB maximum in 2011). In the event of the night crossing occurred in the hours between 22:00 and 23:00, by up to 2.5 dB (0.4 dB maximum in 2011). The equivalent sound level of total listening situations for the night was 50.1 dB, but with the upper deviation ratio of 0.9 dB value does not exceed the limit value (table 11.4).

The second measurement point (table 11.1) limit value for daytime $L_{Aeq}$ were exceeded in parts $L_{Aeq}$ measurements in each age measured in the range between 11:00 and 18:00, and an equivalent level for the sum of acoustic situations $L_{Aeq\,D}$ was 59.9 dB. Given the uncertainty of measurement of sound intensity value at this point is not exceeded (table 11.4). The night-time limits are exceeded between the hours of 22:00 and 23:00, 5:00 and 6:00, but that did not result in a situation that for the sum of acoustic $L_{Aeq\,N}$ exceedance of code (table 11.4). In 2011, the value of $L_{Aeq\,D}$ was 59.0 dB and the $L_{Aeq\,N}$ 50.2 dB).

The third measurement point (table 11.1) for daytime $L_{Aeq\,D}$ in each of the nights of measurement recorded single crossing during the day, but at night time exceeded absent. Given the uncertainty of measurement (table 11.4) the situation for the time of day or night does not change (in the year 2011 the value of $L_{Aeq\,D}$ was 58 dB and the $L_{Aeq\,N}$ 50.5 dB).

## 11.6 CALCULATIONS OF THE ACOUSTIC SCREEN [4]

The primary objective is to provide an acoustic screen acoustic shadow, the area of which does not reach the source direct acoustic waves. Acoustic shielding can be achieved not only by setting the flat screens, but also other obstacles [1, 2]. Often the passageways where

values are exceeded noise emission standard applied acoustic screens. Their effectiveness varies, for example, shows the effectiveness of screening is currently the most common method Maekawy [2].

Typical baffle, which is being built by Polish passageways, the vertical screen height of 5 meters. According to the permissible sound level at al. W. Korfantego to 65 dB for the interval from 6 to 22 and 56 dB from 22 to 6 hours The largest deviation from the norm is 0.3 dB, which occurred in the first measuring point, the effectiveness of screening must reach, including the expanded measurement uncertainty, at least 1 dB.

To check the efficiency of acoustic and acoustic shadow range were calculated using a screen Maekawy vertical height of 5 meters. Dimensions constants that occur in the source system – screen – observer (fig. 11.2) are: H = 5 [m], the height of the screen, and h1 = 1 [m], since roughly the amount emitted is the noise of the vehicles. The distance from the noise source observer is based on the map 30 meters (max. DF) and the acoustic screen 8 feet. The height of the observer will be increased by 1 meter, in the range of from 4 to 10 meters and the other dimensions are calculated in accordance with the method Maekawy.

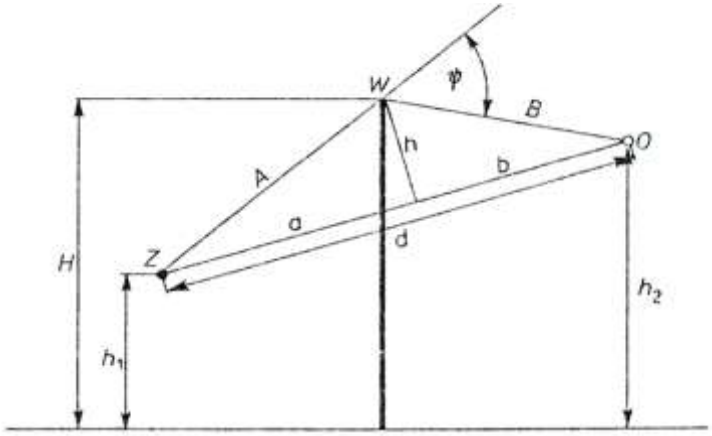



**Fig. 11.2 Source system baffle – the observer** [1]

The calculation results are shown in table 11.5.

**Table 11.5 Dimensions of the agreement source – screen – observer depending of $h_2$ parameter**

| Lp. | Fixed dimensions | | | | Par. | Calculated dimensions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***H*** | ***h₁*** | ***odl. ZO*** | ***odl. od ekr.*** | ***h₂*** | ***A*** | ***B*** | ***d*** | ***h*** | ***a*** | ***b*** |
| 1 | 5 | 1 | 30 | 8 | 4 | 8.9 | 22.0 | 30.1 | 3.2 | 8.4 | 21.8 |
| 2 | 5 | 1 | 30 | 8 | 5 | 8.9 | 22.0 | 30.3 | 2.9 | 8.5 | 21.8 |
| 3 | 5 | 1 | 30 | 8 | 6 | 8.9 | 22.0 | 30.4 | 2.6 | 8.5 | 21.9 |
| 4 | 5 | 1 | 30 | 8 | 7 | 8.9 | 22.1 | 30.6 | 2.4 | 8.6 | 22.0 |
| 5 | 5 | 1 | 30 | 8 | 8 | 8.9 | 22.2 | 30.8 | 2.1 | 8.7 | 22.1 |
| 6 | 5 | 1 | 30 | 8 | 9 | 8.9 | 22.4 | 31.0 | 1.8 | 8.8 | 22.3 |
| 7 | 5 | 1 | 30 | 8 | 10 | 8.9 | 22.6 | 31.3 | 1.5 | 8.8 | 22.5 |

Based on the calculated size in table 11.5 shielding effectiveness is calculated according to the method Maekawy [2], assuming the wavelength λ = 0.5 m, the results are shown in table 11.6.

**Table 11.6 Effectiveness of the shielding of the acoustic screen calculated Meakawy method**

| Lp. | Parametr | Values calculated | | |
|---|---|---|---|---|
| | $h_2$ | δ | N | $\Delta L_e$ [dB] |
| 1 | 4 | 0.8 | 3.3 | 18.2 |
| 2 | 5 | 0.7 | 2.7 | 17.3 |
| 3 | 6 | 0.6 | 2.2 | 16.5 |
| 4 | 7 | 0.4 | 1.8 | 15.5 |
| 5 | 8 | 0.3 | 1.4 | 14.4 |
| 6 | 9 | 0.3 | 1.0 | 13.1 |
| 7 | 10 | 0.2 | 0.7 | 11.9 |

The presented results of calculations effectiveness of typical acoustic screen which dominates the Polish passageways that shadow area in this case is sufficient to cover the protection of all blocks of flats 10-storey closest to the road, in the light of the revised in 2012, the Minister of the Environment of June 14, 2007 on the permissible noise levels in an environment of increasing the road traffic noise levels allowed from 5 to 10 dB.

## SUMMARY AND CONCLUSIONS

As a result of research and analysis of road noise with the calculation of the expanded measurement uncertainty specified place, where it was exceeded VALUE ONLY normalization and acoustic nuisance at the same time set the site, which is at the level of medium and large in line with the guidelines of the National Institute of Hygiene in Warsaw. You may also find that the obtained results exceed a maximum value of 0.3 dB $L_{Aeq\ D}$ standardized values. Striking is the fact that the value exceeded the standard in 2011 to this point was 4.2 dB, this value even in 2012 increased by another 0.9 dB, in the light of the amendments made in 2012 of the Minister of Environment of 14 June 2007 the permissible noise levels in the environment normalized value was exceeded only by 0.3 dB.

Analyzing the values of equivalent sound level can be clearly stated that the acceptable level $L_{Aeq\ D}$ was exceeded in the first measurement point. The values of equivalent sound level for daytime within the normal range in the other measuring points for the day-time and all measuring points for the night. In 2011, the standardized values were exceeded in the first and fifth measuring point for the season genie and the second, third and fifth for the night. Considering the case of transgression occurring in the first measuring point can be stated that action should be taken to minimize this risk.

The calculation of the effectiveness of a typical acoustic screen that shadow area in this case is sufficient for all floors of apartment blocks located close to the road at al. W. Korfantego. For the analyzed case, it meets the requirements of security to protect the residents of multi-storey buildings against noise from traffic, but you should also consider other means of financial support to minimize noise, even changing the windows to the sound.

According to the amendment in 2012 of the Minister of Environment of 14 June 2007 on the levels of environmental noise for Increasing traffic noise levels allowed from 5 to 10 dB in a formal solution to the issue of noise, inter alia, for this case but also Whether the terms of its impact on the lives and health of people or comforts existence ?

**REFERENCES**

1. Engel Z.: *Ochrona środowiska przed drganiami i hałasem*, Wydawnictwo Naukowe PWN, Warszawa 1993.
2. Engel Z., Sadowski J., Stawicka-Wałkowska M., Zaremba S.: *Ekrany akustyczne*, Wydawnictwo Akademii Górniczo-Hutniczej w Krakowie, Kraków, 1990.
3. Kirpluk M.: *Metodyka szacowania niepewności rozszerzonej, Księga Jakości Laboratorium NTL – M. Kirpluk, 2009*
4. Profaska M., Korban Z., Krnert R.: *Przykładowe badania uciążliwości emisji hałasu z ciągu komunikacyjnego,* Rocznik Ochrony Środowiska 2012, t.14, str. 800-813.
5. Sadowski J.: *Akustyka w architekturze, budownictwie i urbanistyce*, Arkady, Warszawa 1971.
6. Wyrwas P., Szyguła A.: *Ekrany akustyczne – zasady projektowania i kryteria doboru*, IV Ogólnopolska Konferencja Mostowców – Konstrukcja i Wyposażenie Mostów, Wisła 2005, str. 271-280.
7. Rozporządzenie Ministra Środowiska z dnia 14 czerwca 2007 r. w sprawie dopuszczalnych poziomów hałasu w środowisku wraz z nowelizacją z roku 2012.
8. Rozporządzenie Ministra Środowiska z dnia 16 czerwca 2011 r. w sprawie wymagań w zakresie prowadzenia pomiarów poziomów substancji lub energii w środowisku przez zarządzającego drogą, linią kolejową, linią tramwajową, lotniskiem lub portem.
9. Czaja P.: *Ekrany akustyczne, a hałas komunikacyjny*, http://techbud.com.pl.

## NOISE EMISSIONS TEST FROM THE COMMUNICATION ROUTE – A CASE STUDY

**Abstract:** *The publication presents a study on the issue of noise from the communication route al. W. Korfantego in Zabrze in 2012 in aspect of noise nuisance. The results were related to measurements made in 2011, in the context of the amendment of the Minister of Environment of 14 June 2007 on the levels of environmental noise. It also presents the method of calculating noise barriers by Maekawy*.

**Key words:** *traffic noise, noise studies, noise nuisance*

## BADANIA EMISJI HAŁASU Z CIĄGU KOMUNIKACYJNEGO – STUDIUM PRZYPADKU

**Streszczenie:** *W publikacji przedstawiono badania emisji hałasu z ciągu komunikacyjnego al. W. Korfantego w Zabrzu w roku 2012 w aspekcie uciążliwości akustycznej. Wyniki badań odniesiono do pomiarów wykonanych w 2011 roku w aspekcie nowelizacji Rozporządzenie Ministra Środowiska z dnia 14 czerwca 2007 r. w sprawie dopuszczalnych poziomów hałasu w środowisku. Przedstawiono również obliczenia ekranów akustycznych metodą Maekawy*.

**Słowa kluczowe:** *hałas, badania hałasu, uciążliwości hałasu*

dr inż. Marek PROFASKA
Silesian University of Technology, Faculty of Mining and Geology
Institute of Mining Mechanisation
ul. Akademicka 2A, 44-100 Gliwice
tel.: +4832 237 2317, +48609 130 910; e-mail: marek.profaska@polsl.pl

# 12

# THE EFFECT OF HIGH SOLIDS CONCENTRATION ON THE RHEOLOGY OF LIMESTONE SLURRY

## 12.1 INTRODUCTION

Rheology is a science of deformation and flow of materials. The constitutive relations between shear stress and shear rate, and dependence of shear rate on viscosity are the base to solve the engineering problems. In many industry sectors used raw materials, semi-finished and finished products show non-Newtonian fluids characteristics. Number of non-Newtonian fluids that occur in a technological complex processes is growing very fast. This creates serious problems in processing and prompting fluids conducted with processes. It is particularly important to determine the rheological properties in the production process such as plastics, pharmacy, as well as in the environmental engineering and mining processes. Properties of non-Newtonian fluids may be completely determined by various types of rheometers [7].

Rheometric measurements of liquids demonstrate viscous and elastic features. Characteristics of the viscous properties refer to determination of flow curve, which is dependent on shear stress and shear rate.

In slurry composed of solid particles in a carrier liquid, the combination of the size and quantity of particles with the type of the transporting liquid determines the characteristics and flow properties of the hydro-mixture. Those factors can have a significant impact on performance and costs. Non-settling mixtures contain very fine particles that can form stable homogeneous system which require very careful consideration when selecting the correct pump. It is important that such slurries often do not behave in the manner of a pure liquid. When mixture has sufficient quantity of fine solids particles, it causes non-Newtonian behavior. Settling mixtures have a tendency to form an unstable system [3]. It is worth to mention that viscous properties are difficult to measure in an unstable system of settling particles [5].

One of the most important factors in slurry is a solids concentration which is often a variable value in manufacturing process. At limestone factory, where the slurry is a transported over long distances, it is important to determine the rheological properties of transported solid-liquid mixture. Different flow conditions and frictional losses require knowing properties due to choosing the right pump capacity used in hydrotransport. Moreover, particles in a carried liquid have a natural tendency for degradation and to settle when slurry is transported through a pipe. It is important to determine terminate velocity, which determines slurry velocity in a pipe, as slurry velocity supposes to be higher comparing

to terminate velocity. If slurry velocity is below terminate velocity particles start forming a bed on the bottom of the pipe. This is undesired process because it can cause a pipe plugging. Remove of the blockage, even at a simple pipe system, is a very expensive incident, which could result a downtime in the production.

Considering the fact that the slurry can have different composition, there is a limited knowledge on concerning the limestone slurry rheological properties, especially when yield stress appears. Slurries with higher yield stresses require a higher initial input energy before the fluid starts to flow. Experience shows that rheological parameters should be measured for different mining because slurry components are always different.

It is observed that even small increments of the solids concentration bring the increase of the viscosity [9]. At high solids concentrations the particle-particle interactions increases, which cause a significant impact on the viscous properties [2]. Mostly in fine particle suspensions interparticles attraction could promote the formation of flocs. Hydrodynamic interactions give rise to viscous dissipation in the liquid [4], however, in some cases opposite result like turbulence damping could appears [1].

The main objective of the paper is to determine the flow curves for high solids concentration of slurry at limestone factory and to fit the proper rheological model.

## 12.2 EXPERIMENTS

### 12.2.1 Raw material

The raw material was obtained from "ZPW Trzuskawica" mine in Poland at the final stage of production, where the fine particles are carried by the water. At the mine the slurry is treated as a waste and finally deposited on the landfill.

Table 12.1 shows the chemical analysis of the limestone. The size distribution of the particles was measured using Sympatec Helos BR and the weighted-average particle diameter of the sample was determined to be 7.6 μm, [10].

**Table 12.1 Chemical analysis of composition of the limestone slurry**

| Main chemical composition | Percent (%) |
|---|---|
| CaO | 73.64 |
| $SiO_2$ | 13 |
| $Al_2O_3$ | 1.11 |
| MgO | 0.61 |
| $Fe_2O_3$ | 0.319 |
| $SO_3$ | 0.28 |

### 12.2.2 Experimental procedure

Procured raw material from manufacturing process has a low solid concentration. In order to obtain higher solids concentration, pure water was manually pulled above the sediment. Solids concentration ($C_m$) was calculated as a ratio of mass of solid particles ($m_s$) to total mass of slurry, which is sum of solid particles ($m_s$) and liquid phase ($m_l$). The solids concentration is described by equation (12.1). Evaporating of water from the slurry allowed us to determine the mass of solids while mass of liquid was determined by subtraction of mass of solids from the total mass of slurry (solids and liquid). Solids concentration varied from

$C_m$ = 20% to $C_m$ = 35% and was arbitrary chosen for the measurements. Such values of chosen solids concentration frequently exist in industry application.

$$C_m = \frac{m_s}{m_s + m_l} \cdot 100\% \quad (12.1)$$

Determination of the shear stress and viscosity was performed using the Anton Paar rheometer (model MCR 302). To provide accurate results it was important to choose a proper measuring system. We have decided that CC27 measuring system is appropriate for such slurry. It uses concentric cylinder geometry with stationary outer cylinder and rotating inner cylinder with a gap equal 1.1 mm. This measuring system requires about 18 ml of a sample. Experiments were performed at temperature of 20°C with accuracy of ± 0.01°C.

We observed phase separation in the experiments above the critical shear rate. Similar results were obtained in silica sand based suspensions [8]. Schramm noticed that the inertia forces push the solid particles in the direction of the outer cylinder [11]. Besides, in the cylinder-cylinder measuring system above the critical shear rate value the turbulent flow appears and that phenomenon interfere with the measurement results. Above critical shear rate value shear stress start to grow significantly. For the $C_m$ = 20% this phenomena was observed around the 385-390$s^{-1}$ shear rate. If $C_m$ increases the critical shear rate increases too, which fig. 12.1 demonstrates. Therefore, considering the nature of the slurry, our measurements were analyzed at the shear rates from 0.001$s^{-1}$ to 380$s^{-1}$.

To avoid sedimentation process, which naturally exists in such a type of slurry, each slurry sample was pre-sheared for 1 minute at the 1000$s^{-1}$ shear rate prior to the measurements. Afterwards, measurements started from the higher shear rate value (380$s^{-1}$) and stepped down linearly one by one until the shear rate reaches the minimum setpoint value (0.001$s^{-1}$). The results of measured shear stress (τ) and viscosity (η) were recorded at each share rate (□) and analyzed afterwards.

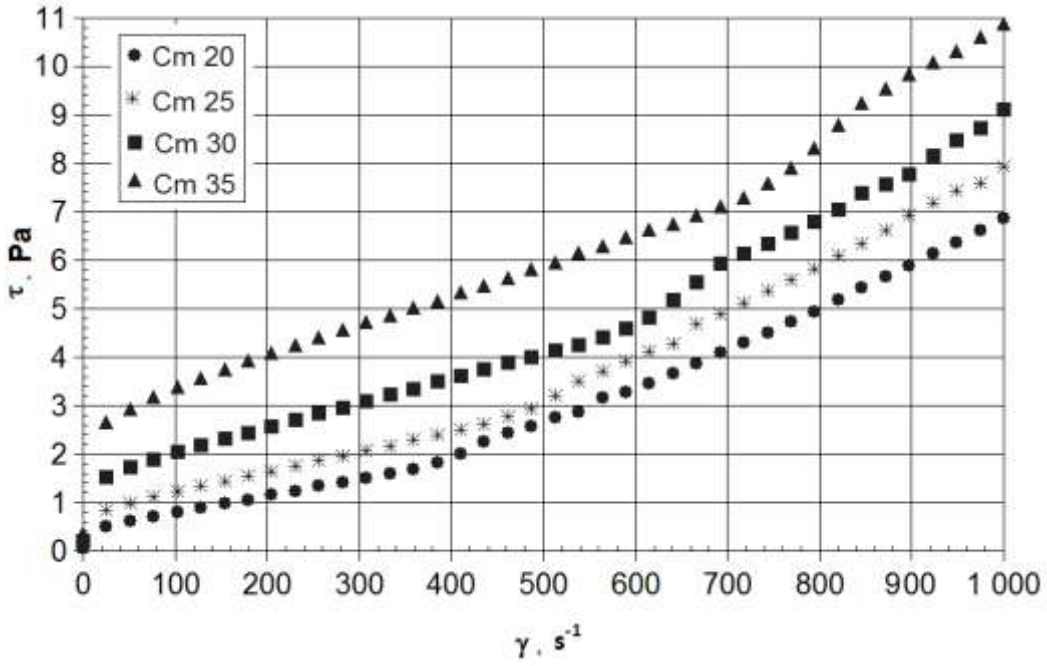



**Fig. 12.1 Occurrence of the phase separation at different solids concentration**

### 12.2.3 Experimental results and discussion

For each solid concentration the variation of the shear stress with the shear rate was recorded. Fig. 12.2 shows flow curves for the $C_m$ = (20-35)%. For all solids concentrations flow curves are non-Newtonian. It is worth mentioning that for higher shear rate values flow curves looks like Newtonian, but non-Newtonian behavior was visible in the range of (0-20) $s^{-1}$ shear rate. There was a considerable fall in shear stress in that range.

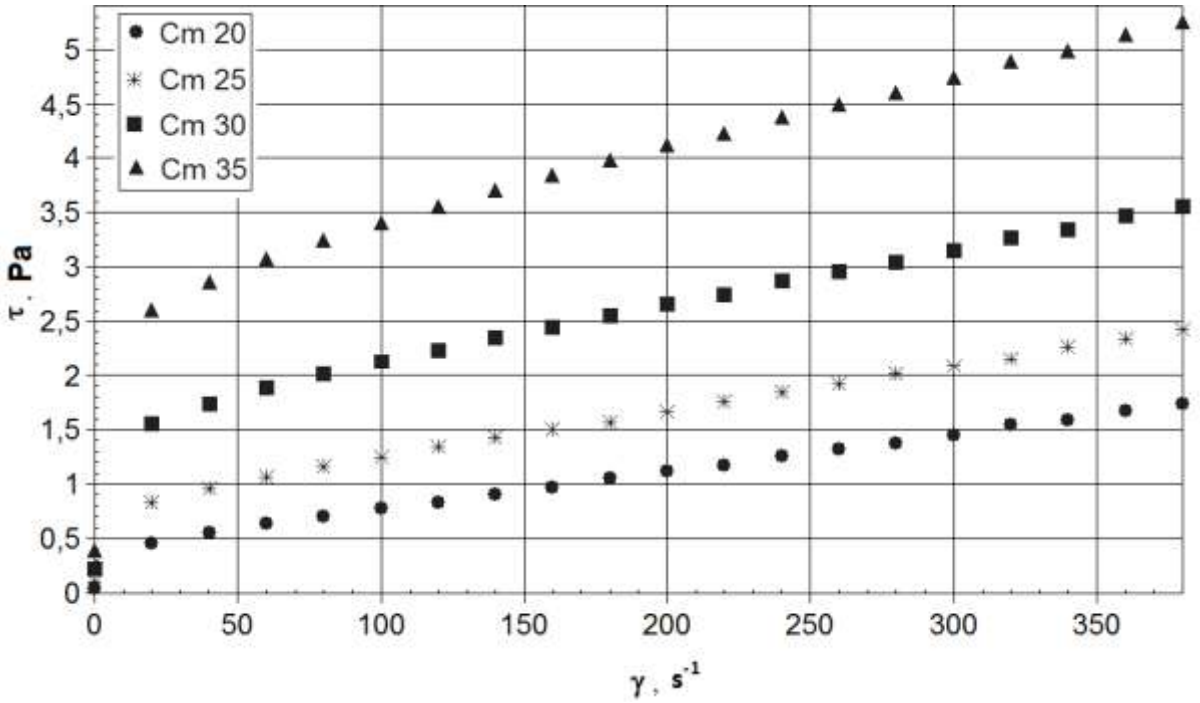



**Fig. 12.2 Dependence of the shear rate on shear stress at different solids concentration**

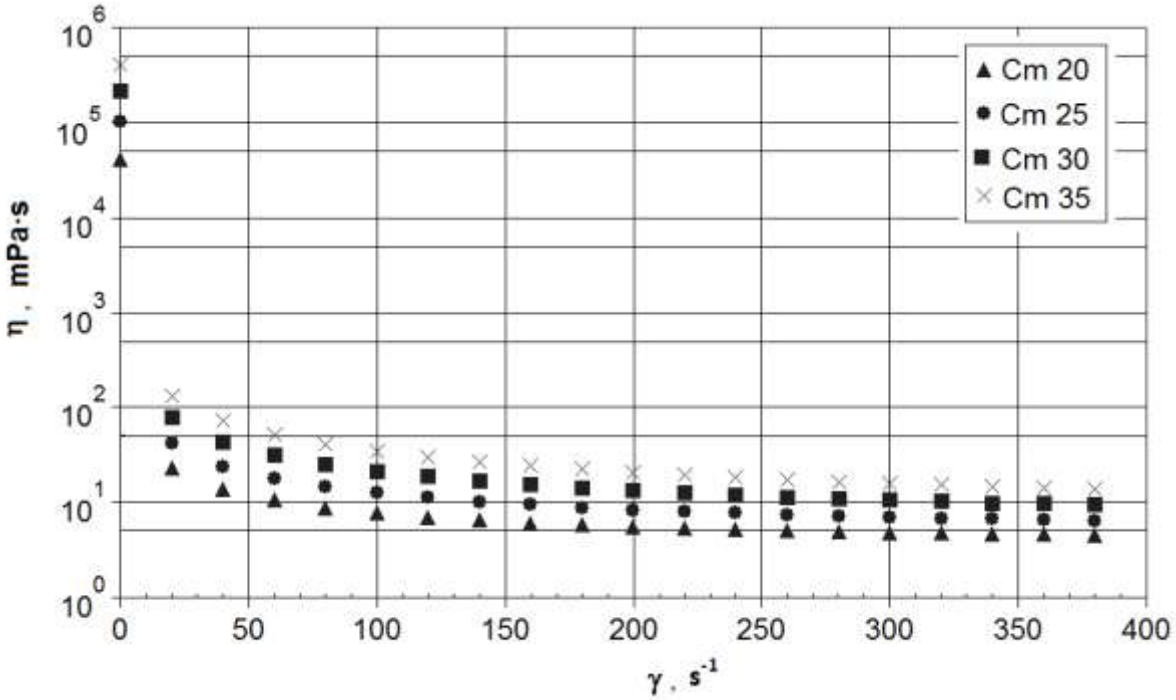



**Fig. 12.3 Dependence of the shear rate on viscosity at different solids concentration**

It was observed that the shear stress increased with increase of shear rate for all cases. The results indicate a pseudoplastic behavior of limestone slurry. It can be also seen that the shear stress and yield stress increased with the increase of solids concentration.

The variation of viscosity with shear rate at different solids concentration is shown on fig. 12.3. The curves indicating the viscosity are non-Newtonian. Viscosity is decreasing with increase of shear rate for all solids concentrations (shear thinning) and there is a considerable fall between $0.001s^{-1}$ and $20s^{-1}$ shear rates in all cases. For a very low shear rate values of viscosity are extremely high. Slurry behavior is similar to a solid body. This is a result of the particle-particle contact that brings the interactions at high solids concentrations [4]. It can be also seen that the viscosity increases with increase of solids concentration.

Comparing the results to low and medium solids concentration in the limestone slurry, the results are unequivocal [10]. Shear stress values at low and medium concentration are considerably lower and have tendency to follow Newtonian liquids. Moreover, the shear stress value for $C_m$ = 5% at $160s^{-1}$ shear rate is more than ten times smaller in comparison to results for $C_m$ = 35%.

**Table 12.2 Herschel-Bulkley parameters for test performed at $C_m$=20-35%**

| $C_m$ | 20% | 25% | 30% | 35% |
|---|---|---|---|---|
| $\tau_0$ (Pa) | 0.039154 | 0.095635 | 0.1738 | 0.24704 |
| $\eta_{pl}$ (Pa·s) | 0.074889 | 0.17534 | 0.45777 | 0.94343 |
| n | 0.50961 | 0.42102 | 0.32512 | 0.27091 |

Viscosity values at high solids concentration in the limestone slurry are also higher comparing to low and medium solids concentration.

Various rheological models were analyzed in an attempt to find the model that best fit the experimental data of the shear stress. On the base of analyzes the Herschel-Bulkley model achieved the best fitting ($R^2$ = 0.97). Parameters of the Herschel-Bulkley rheological model for performed experiments at different solids concentration are listed in table 12.2, fig. 12.4 and fig. 12.5 show a comparison of the Herschel-Bulkley fit for $C_m$ = (20-35)%.

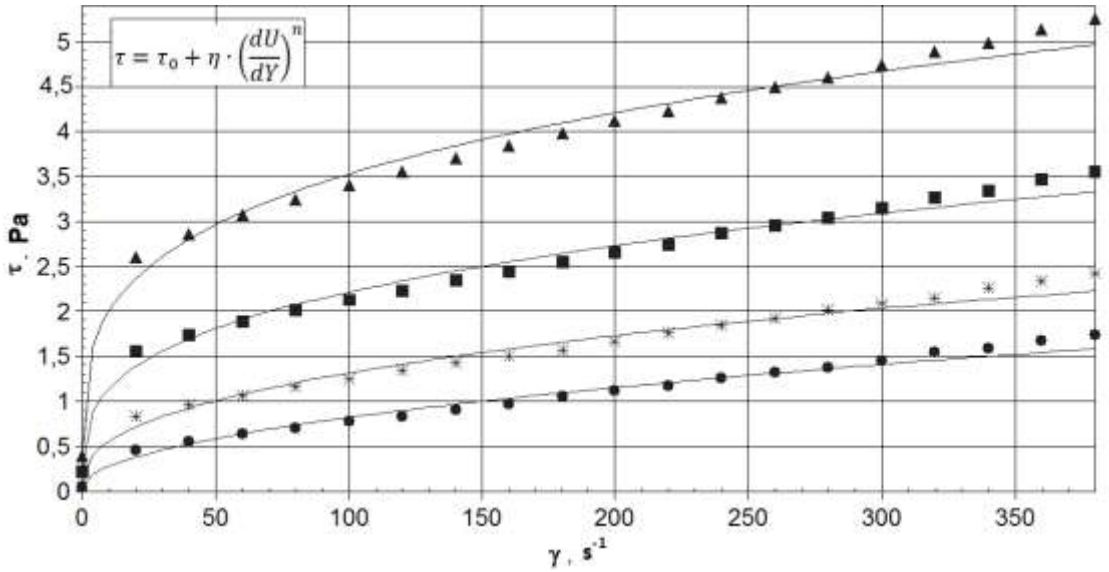



**Fig. 12.4 The Herschel-Bulkley model fit to shear stress for different solids concentration**

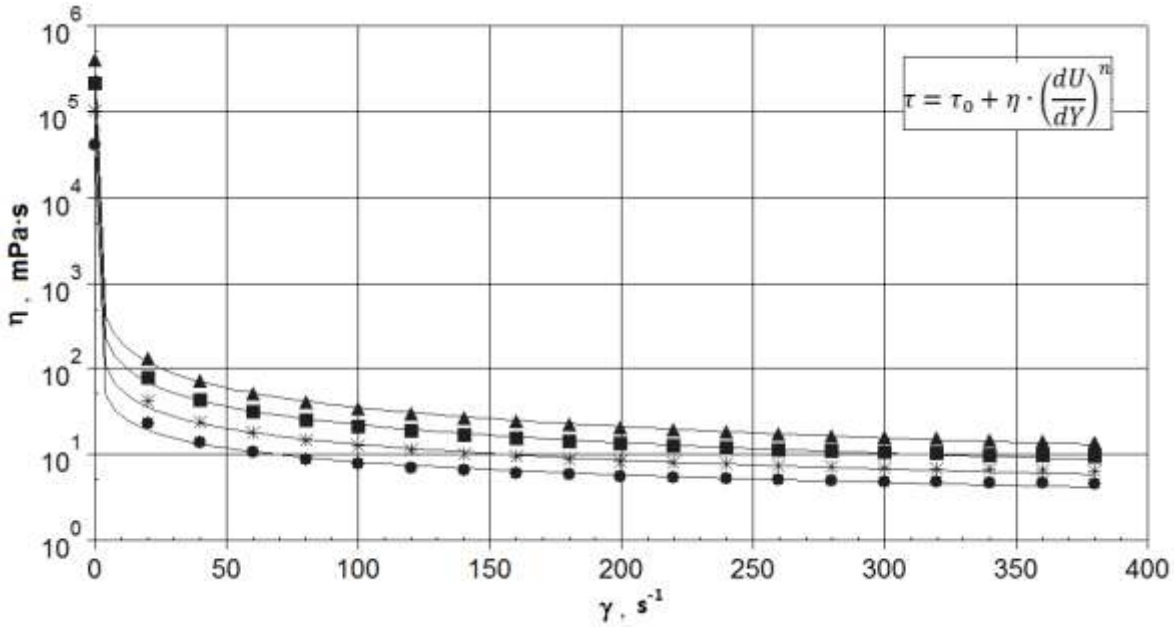



**Fig. 12.5 The Herschel-Bulkley model fit to viscosity for different solids concentration**

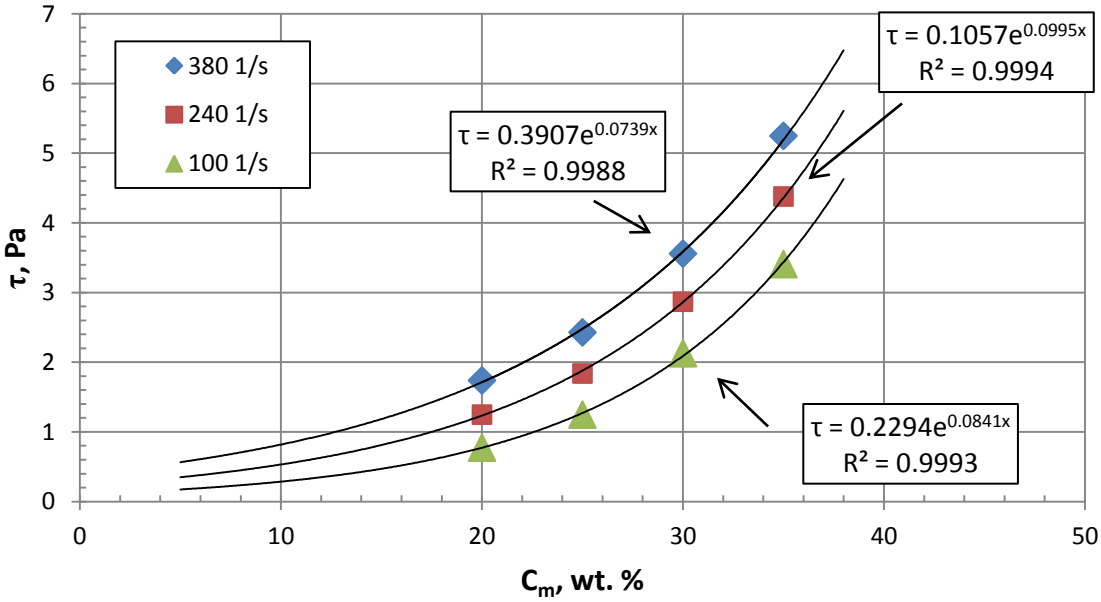



**Fig. 12.6 Dependence of solids concentration on the shear stress for a given shear rate**

The shear stress of the limestone slurry increases exponentially with increasing the solids concentration. Fig. 12.6 shows dependence of solids concentration on the shear stress at $100s^{-1}$, $240s^{-1}$, $380s^{-1}$ shear rate values.

The viscosity of the limestone slurry also increases exponentially with increasing the solids concentration which is shown in fig. 12.7.

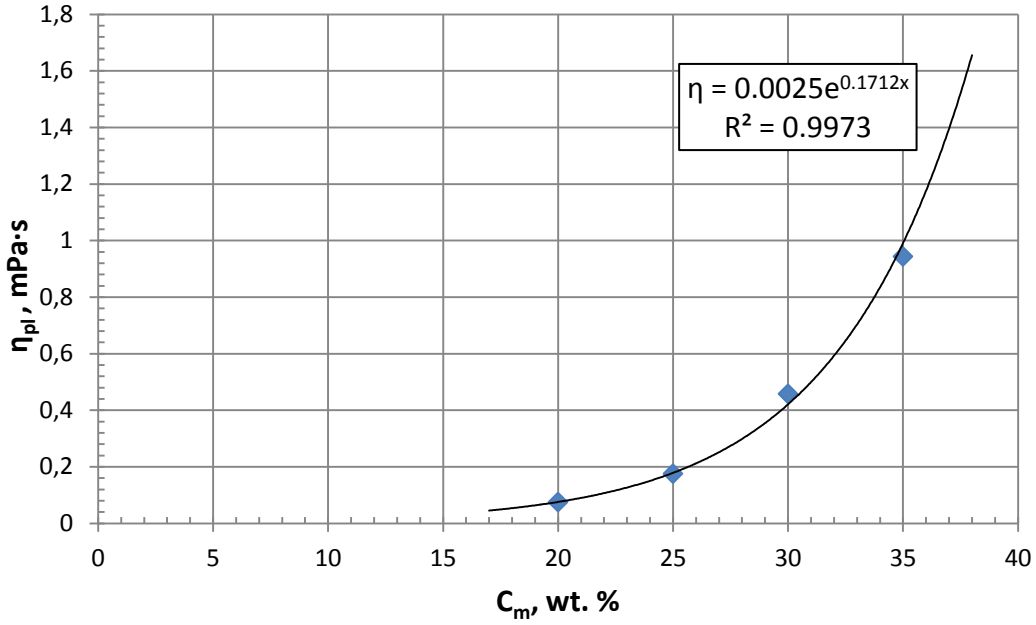



**Fig. 12.7 Dependence of solids concentration on plastic viscosity**

## CONCLUSION

The effects of high solids concentration on the rheological behavior of limestone slurries have been examined. It was noticed during experiments that turbulent flow and phase separation appeared for $C_m$ = 20% above 380$s^{-1}$ shear rate and its tendency was the same with increase of solids concentration. Therefore, measurements were performed at the shear rates from 0.001$s^{-1}$ to 380$s^{-1}$.

The flow curves are non-Newtonian in chosen range of solids concentration, (20-35)%. A shear thinning behavior was observed at all solids concentrations. It was also observed that the shear stress increased exponentially with increase of solids concentration in all cases. For the slurry from ZPW Trzuskawica mine the Herschel-Bulkley rheological model achieved best fitting and well described flow curves and viscosity. The viscosity increased exponentially with increase of solids concentration due to the frictional interactions per unit volume. The yield stress also increased with solids concentration.

High solids concentration gives considerably higher values of shear stress and viscosity than low and medium solids concentration at the same shear rate.

## REFERENCES

1. Bartosik, A.: Laminarisation effect in fine-dispersive slurry flow. Archives of Thermodynamics. vol. 29. No.3, 2008, pp. 69-82.
2. Bartosik A.: Simulation and Experiments of Axially-Symmetrical Flow of Fine- and Coarse-Dispersive Slurry in Delivery Pipes. Monograph M-11. Kielce University of Technology 2009.
3. Benretem A.: Benidir M., Chaib R.: Factors Influencing Slurry Rheology. World Pumps, July 2010, p. 30-32.
4. Cheng.: Viscosity-Concentration Equations and Flow Curves for Suspensions. Chemistry and Industry. vol. 17, 1980, pp. 403-406.

5. Clarke B.: Rheology of Coarse Settling Suspensions. Trans. Inst. Chem. Engrs. vol. 45, 1967, pp. 251-256.
6. Ferguson J., Kembłowski Z.: Reologia stosowana płynów. DWN. Lódź 1995.
7. Kiljański T., Dziubiński M., Sęk J., Antosik K.: Wykorzystanie pomiarów właściwości reologicznych płynów w praktyce inżynierskiej. EKMA. Warszawa 2009.
8. Mangesana N., Chikuku R.S., Mainza A.N., Govender I., Westhuizen A.P., Narashima M.: The Effect of Particle Sizes and Solids Concentration on the Rheology of Silica Sand Based Suspensions. The Journal of The Southern African Institute of Mining and Metalurgy. vol. 108, 2008, pp. 237-243.
9. Rutgers R.: Relative Viscosity and Concentration. Rheologica Acta, vol. 2, 1962, pp. 305-348.
10. Sarnecki K., Bartosik A.: The Effect of Low and Medium Solids Concentration on the Rheology of Limestone Slurry, (in printing).
11. Schramm G.: Reologia. Podstawy i zastosowanie. OWN. Poznań 1998.
12. Shi F.: Slurry rheology and its effects on grinding. PhD Thesis. Julius Kruttschnitt Mineral Research Centre. University of Queensland 1994.

# THE EFFECT OF HIGH SOLIDS CONCENTRATION ON THE RHEOLOGY OF LIMESTONE SLURRY

**Abstract.** *The paper deals with solid-liquid limestone slurry with a high solids concentration, which appears widely in a mining and civil engineering industries. Experiments performed in the paper deal with influence of solids concentration on the shear stress. Solids concentration various from 20% wt. to 35% wt. which is most suitable to industry. The main objective of the paper is to determine the flow curves for high solids concentration of slurry at limestone factory and to fit the proper rheological model. The paper proves that most suitable model which fits measured dependence of shear rate on the shear stress is the Herschel-Bulkley rheological model. The exponential increase of shear stress and plastic viscosity with increasing the solids concentration is demonstrated for high solids concentration of limestone slurry.*

**Key words:** *limestone slurry, non-Newtonian slurry, shear stress in slurry, experiments in rheology*

# WPŁYW WYSOKIEJ KONCENTRACJI FAZY STAŁEJ NA WŁASNOŚCI REOLOGICZNE HYDROMIESZANINY

**Streszczenie**: *W artykule przedstawiono wyniki badań dla wysokiej koncentracji fazy stałej hydromieszaniny wapiennej, która szeroko występuje w przemyśle wydobywczym i budowlanym. Przedstawiono badania wpływu koncentracji fazy stałej na naprężenie styczne. Masowa koncentracja fazy stałej zmienia się od 20% do 35%, co odpowiada warunkom przemysłowym. Celem artykułu jest wyznaczenie krzywych płynięcia dla wysokiej koncentracji fazy stałej w hydromieszaninie oraz dopasowanie właściwego modelu reologicznego. W pracy udowodniono, że najlepsze dopasowanie do mierzonych zależności naprężenia stycznego od szybkości ścinania daje model reologiczny Herschela-Bulkleya. Ukazano również, że dla wysokich koncentracji fazy stałej w hydromieszaninie wraz ze wzrostem koncentracji fazy stałej lepkość i naprężenie styczne rośną wykładniczo.*

**Słowa kluczowe:** *hydromieszanina wapienna, hydromieszanina nienewtonowska, naprężenie ścinające w hydromieszaninie, badania reologiczne*.

mgr inż. Konrad SARNECKI
Kielce University of Technology
Faculty of Mechatronics and Machine Design
dr hab. inż. Artur BARTOSIK, prof. PŚk.
Faculty of Management and Computer Modeling
Al. Tysiąclecia P.P. 7, 25-314 Kielce
e-mail: ksarnecki@tu.kielce.pl; artur.bartosik@tu.kielce.pl

# 13

# MEASUREMENT SYSTEM ANALYSIS OF ATTRIBUTE OR CONTINUOUS DATA, AS A ONE OF THE FIRST STEPS IN LEAN SIX SIGMA PROJECTS

## 13.1 INTRODUCTION

Lean management as well as Six Sigma, have become one of the main improvement trends of production in factories specializing not only in the automotive market, but covering all sectors of industry. Lean and Six Sigma methodology are no longer separated, because combining them, gives a very measurable and significant impact for projects. The success of each project is derived strictly from the structured DMAIC path, whose letters are the steps: Define, Measure, Analyze, Improve and Control. In this work has been presented one of the Measure phase step, which includes an measurement system analysis and the common errors, as well as explanation how important and significant it may be to check that system before attempting to improve of our manufacturing process. The importance of this analysis is significant because it often can finish or change Lean Six Sigma projects in the early phase of the project. All data and examples come from an extrusion process, and an inspection (length control) area. Extrusion is the first step of preparation in compression molding production – raw material (rubber strips or sheets) is milled and extruded on screw or ram extruder. Extruded blanks (with required shape and cross section) have very big impact on molding process and finished product – therefore controlling of their main parameters is a significant step in production. Whenever gasket is molded and post-cured – length has to be check. Not in all cases are required sophisticated measurements equipment or methods – very often we can use simple Go/No-go gauge to assess required level of information, which in this case is overall gasket length (fit check). If gasket would be to long there is a high risk that it will not fit to the plate heat exchanger unit – which can seriously affect on production timing.

## 13.2 DATA TYPES

The data we collect during the manufacturing process can be divided into two types [3, 4, 5]:

1. attribute data,
2. continuous data.

Attribute date – the terms applied to „Categorical" data where are distinct boundaries between adjoining values.

Continuous data – the terms applied to „Measurement" data where there are no barriers between adjoining values.
Attribute data can be divided further into:

- Defectives data (the unit is good or bad (defective)) – those data uses Binominal Distribution;
- Defects data – the unit contains x number of defects – those data uses Poisson Distribution.

When we measure continuous characteristics such as length, weight, thickness, etc., there are two metrics to describe the sample:

- Position – usually describe by the mean;
- Spread – usually describe by the standard deviation.

## 13.3 COMPONENTS OF MEASUREMENT ERROR

Each component of measurement error can contribute to variation, causing wrong decisions to be made. The error components can be divided into six types [3, 4, 5]:

**13.3.1 Resolution** – the capability to detect the smallest acceptable change – increments in the measurement system should be one-tenth the product specification or process variation,
Resolution is a simplest measurement system problem, where the impact is often recognized but not addressed. It is easily detected and no special studies/"known standards" are necessary.

As an actions for poor resolution we can:

- Use a device that can measure to a greater resolution,
- Move to a sample and record an average,
- Live with it, but understand the repercussions – which may be:
  - Cannot tell one component from another,
  - Cannot tell where component lies within upper and lower specification limits,
  - Cannot accurately Centre Process,
  - Cannot Improve the Process

**13.3.2 Accuracy/Bias** – difference between observed average value of measurement and the master value.
As an actions for poor Accuracy we have to:

- Calibrate regularly,
- Use operations instructions,
- Review specifications to check for '10 bucket' rule,
- Validate Data Systems input accuracy,
- Create Operational Definitions.

**13.3.3 Linearity** – measurement is not "true" and/or consistent across the range of the "gauge".
If a linearity problem appears we have to:

- Rebuild/Replace Gauge,
- Use only in restricted range,

- Use with correction factor/table/curve.

**13.3.4 Stability** – measurements remain constant and predictable over time.
When stability problem occurred:
- Ensure equipment is properly,
- cleaned and maintained,
- Use control charts,
- Use/update current SOP,
- Ensure adequate training,
- Regular audit.

**13.3.5 Repeatability** – variation that occurs when repeated measurements are made of the same item under absolutely identical conditions.
Main actions to improve problems with repeatability:
- Repair, replace, adjust equipment,
- SOP.

**13.3.6 Reproducibility** – the variation that results when different conditions are used to make the measurements.
Main actions to improve problems with reproducibility:
- Training,
- SOP.

## 13.4 MSA – MEASUREMENT SYSTEM ANALYSIS

At the beginning of measurement system analysis, we have to answer the question, of with which type of data we are going to work – attribute or continuous [2, 3, 4, 5]. The results for the attribute are described by acceptance criteria or lack of them, e.g. Pass, Fail, OK., NOK, etc. Results for continuous data, measure value of the sample and can be given, for example, in grams, millimeters, etc.

For measurement system analysis, will be used Minitab software, which includes a set of tools to carry out a comprehensive statistical analysis. If we consider the analysis of the measurement system for attribute data – use Attribute Agreement Analysis (fig. 13.1), if however, we are dealing with continuous data – we use Gage R&R Study (Crossed) (fig. 13.5) – for non-destructive testing, and Gage R & R Study (Nested) – for destructive testing.

Before starting of MSA, we also have to be sure that the data collected will reflect our actual production process, but also to the process of collection will not take too much time. For an appropriate analysis, it is good to choose three operators and the products that we will examine in relation to the standard. The minimum recommended number of samples (attribute agreement analysis) is 10 – the number of repeats – 3, the last measurement in random order.

### 13.4.1 Attribute acceptability indicators and Kappa interpretation

- Acceptability Between Appraisers:
  - > 80% – needs improvements,

  - 80%-95% – probably adequate,
  - 95% > – good for most purposes,
  - Approaching 100% may be necessary where there is a risk to safety or of litigation,
- Acceptability All Appraisers Vs Standard:
  - > 80% – needs improvements,
  - 80%-90% – probably adequate,
  - 90% > – good for most purposes,
  - Approaching 100% may be necessary where there is a risk to safety or of litigation,
- Kappa statistics – kappa measure the level of agreement among multiple appraisers when evaluating the same samples:
  - If kappa = 1, then perfect agreement exist,
  - If kappa = 0, then agreement is the same, as would be expected by chance,
  - Negative values occur when appraisers are consistently working against the standard,
  - Kappa less than 0.7 indicates that the measurement system is inadequate,
  - Kappa above 0.9 is to be preferred but required level depends very much on the nature and purpose of the attribute assessment,

### 13.4.2 Continuous acceptability indicators

- % Contribution – which is measurement system variation (R&R) as a percentage of total observed variation and includes both repeatability and reproducibility,
  - > 9% – needs improvements,
  - 1%-9% – marginal but acceptable,
  - < 1% – good for most purposes,
- % Tolerance – which is measurement error as a percent of tolerance, includes both repeatability and reproducibility, can use 5.15 sigma's to represent 99% of variation,
  - > 30% – needs improvements,
  - 10%-30% – marginal but acceptable,
  - < 10% – good for most purposes,
- Distinct Categories – it is number of divisions that the measurement system can accurately measure across the process variation and it can show how well a measurement process can detect process output variation – process shifts and improvements
  - < 5 – needs improvements or indicates Attribute conditions,
  - 5-10 – marginal but acceptable,
  - > 10 – good for most purposes.

## 13.5 METHODOLOGY AND RESULTS

For both type of data attribute and continuous we used MiniTab statistical software – which contain number of useful statistical tools. Data has been collected from two different steps of rubber gaskets production. Attribute analysis is based on Go/No-go length check for plate heat exchanger gaskets; continuous analysis was prepared in extrusion area, where blanks thickness has to be control to avoid an excessive material usage and potential molding problems in the next process step [5].

## 13.6 MSA – ATTRIBUTE DATA

The main steps (fig. 13.1) for this analysis ware [1, 4, 5]:

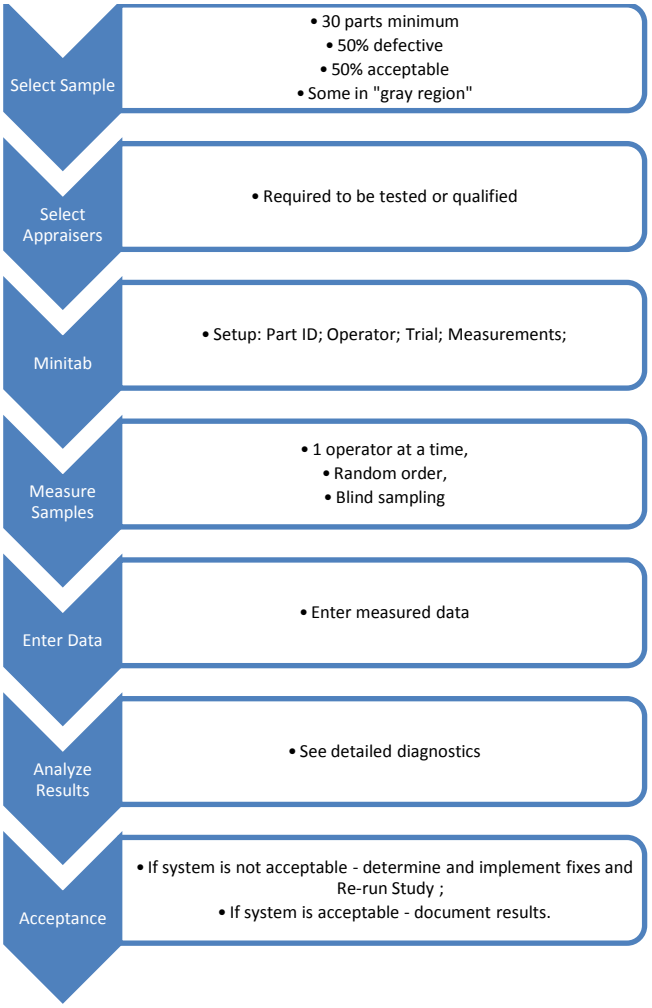



**Fig. 13.1 Roadmap to Attribute Assessment Analysis**

Source: TSS Black Belt training materials

- Sample selection – 30 pcs minimum; 50% good; 50% bad – some of them can be in "gray region" – difficult to assess whether they are OK or NOK.
- Appraisers selection – required to be tested or qualified,
- Preparation for measurements – parts have to be marked – it is not visible for appraisal,
- Measurements – 1 operator at a time; first measurement from sample number 1 up to 30, second measurement in random order – sampling is blind for appraisers;
- Analysis;
- Assessing that measurement system is acceptable or not; if not we have to determine and implement fixes and re-run the study. If yes we can document data and plan the next control.

In order to perform measurement system analysis for attribute data, we have to chose in "Stat" menu: "Attribute Agreement Analysis" (fig. 13.2),

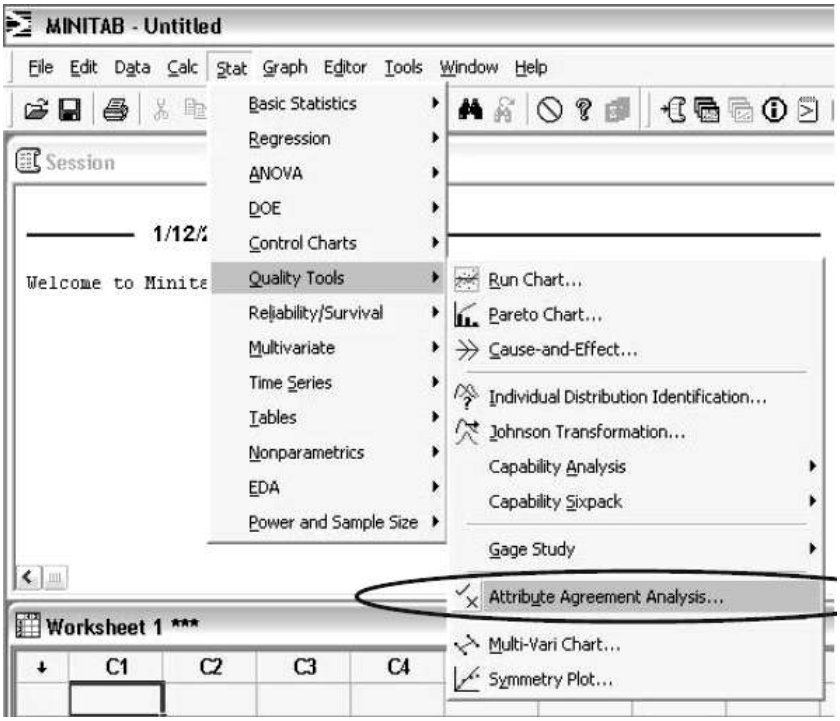



**Fig. 13.2 Attribute Assessment Analysis path in Minitab menu**

Source: Minitab print screen

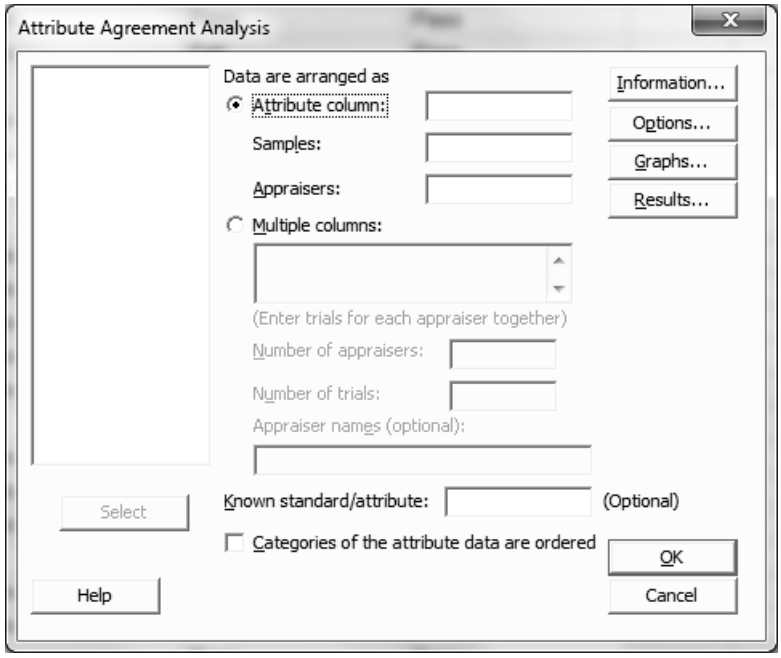



**Fig. 13.3 Attribute Assessment Analysis session window**

Source: Minitab print screen

In attribute agreement window we have two options for data which are stack and unstuck (fig. 13.3). For stack type of data, we have to use: Attribute column; Samples and Appraisers cells. For unstuck data we have to use Multiple columns; Number of appraisers and Number of trials cells. As an option we can add appraisers names and known standard.

As a result we will receive graph (fig. 13.4) and session window with data analysis.

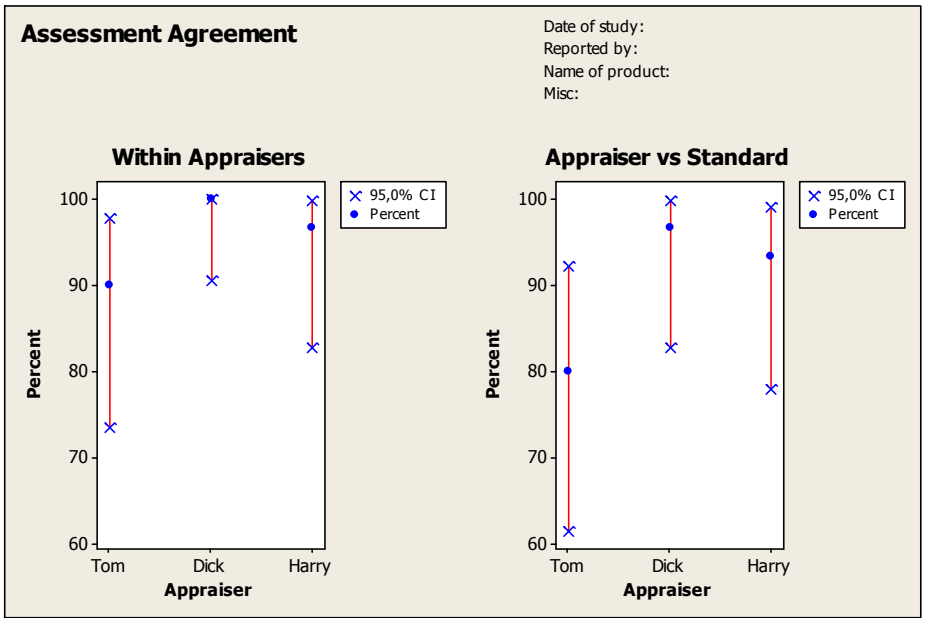



**Fig. 13.4 Attribute Assessment Agreement**

Source: Minitab print screen

### 13.6.1 Graphical analysis

"Within Appraisers" – Repeatability: Appraiser's ability to agree with himself; data show that operator Tom has the biggest problem to agree with himself.
"Appraiser vs. Standard" – Appraiser's ability to agree with himself and the standard, data show that Tom and Harry have problems to agree with standard.

### 13.6.2 Data analysis

## Within Appraisers

**Assessment agreement within appraisers show, how Appraiser agrees with him/herself across trials.**

| Appraiser | # Inspected | # Matched | Percent | 95 % CI |
|---|---|---|---|---|
| Tom | 30 | 27 | 90,00 | (73,47; 97,89) |
| Dick | 30 | 30 | 100,00 | (90,50; 100,00) |
| Harry | 30 | 29 | 96,67 | (82,78; 99,92) |

**Kappa statistics - measure the level of agreement among multiple appraisers when evaluating the same samples.**

| Appraiser | Response | Kappa | SE Kappa | Z | P(vs > 0) |
|---|---|---|---|---|---|
| Tom | Accept | 0,86560 | 0,105409 | 8,21185 | 0,0000 |
| | Reject | 0,86560 | 0,105409 | 8,21185 | 0,0000 |
| Dick | Accept | 1,00000 | 0,105409 | 9,48683 | 0,0000 |
| | Reject | 1,00000 | 0,105409 | 9,48683 | 0,0000 |
| Harry | Accept | 0,95151 | 0,105409 | 9,02680 | 0,0000 |
| | Reject | 0,95151 | 0,105409 | 9,02680 | 0,0000 |

## Each Appraiser vs Standard

**Assessment agreement for each appraisers vs. standard, show how Appraiser's agrees with the known standard. Dick agreed with known standard 29 times out of 30.**

| Appraiser | # Inspected | # Matched | Percent | 95 % CI |
|---|---|---|---|---|
| Tom | 30 | 24 | 80,00 | (61,43; 92,29) |

```
Dick                30         29    96,67  (82,78; 99,92)
Harry               30         28    93,33  (77,93; 99,18)
```

**Assessment Disagreement**

**Reject / Accept: Assessments across trials = Reject / standard = Accept.**
**Accept / Reject: Assessments across trials = Accept / standard = Reject.**
**Mixed: Assessments across trials are not identical.**

| Appraiser | # Reject / Accept | Percent | # Accept / Reject | Percent | # Mixed | Percent |
|---|---|---|---|---|---|---|
| Tom | 3 | 14,29 | 0 | 0,00 | 3 | 10,00 |
| Dick | 1 | 4,76 | 0 | 0,00 | 0 | 0,00 |
| Harry | 1 | 4,76 | 0 | 0,00 | 1 | 3,33 |

**Kappa statistics - measure the level of agreement among multiple appraisers when evaluating the same samples and considering acceptance and rejection.**

| Appraiser | Response | Kappa | SE Kappa | Z | P(vs > 0) |
|---|---|---|---|---|---|
| Tom | Accept | 0,669289 | 0,105409 | 6,34943 | 0,0000 |
| | Reject | 0,669289 | 0,105409 | 6,34943 | 0,0000 |
| Dick | Accept | 0,922978 | 0,105409 | 8,75614 | 0,0000 |
| | Reject | 0,922978 | 0,105409 | 8,75614 | 0,0000 |
| Harry | Accept | 0,874326 | 0,105409 | 8,29459 | 0,0000 |
| | Reject | 0,874326 | 0,105409 | 8,29459 | 0,0000 |

## Between Appraisers

**Assessment agreement between appraisers show, how Appraiser agrees with him/herself across trials. Data below show 83,33% of agreement, which means that is probably adequate.**

| # Inspected | # Matched | Percent | 95 % CI |
|---|---|---|---|
| 30 | 25 | **83,33** | (65,28; 94,36) |

**Kappa statistics - measure the level of agreement among multiple appraisers when evaluating the same samples and considering acceptance and rejection.**

| Response | Kappa | SE Kappa | Z | P(vs > 0) |
|---|---|---|---|---|
| Accept | 0,854805 | 0,0304290 | 28,0918 | 0,0000 |
| Reject | 0,854805 | 0,0304290 | 28,0918 | 0,0000 |

## All Appraisers vs Standard

**Assessment agreement for each appraisers vs. standard, show how all Appraiser's agrees with the known standard. Data below show 80%, which means that it is border values, but system is probably adequate.**

| # Inspected | # Matched | Percent | 95 % CI |
|---|---|---|---|
| 30 | 24 | **80,00** | (61,43; 92,29) |

# Matched: All appraisers' assessments agree with the known standard.

**Kappa statistics - measure the level of agreement among multiple appraisers when evaluating the same samples and considering acceptance and rejection. Data below show level 0,82 for both acceptance and rejection, which means that based on acceptance criteria that system is probably adequate.**

| Response | Kappa | SE Kappa | Z | P(vs > 0) |
|---|---|---|---|---|
| Accept | **0,822198** | 0,0608581 | 13,5101 | 0,0000 |
| Reject | **0,822198** | 0,0608581 | 13,5101 | 0,0000 |

## 13.7 MSA – CONTINOUS DATA

Below is presented MSA from extrusion line, which prepare rubber blanks for compression molding production. It was part of the black belt project, so there are two steps, which shows measurement process before and after improvements [1, 2, 3, 4, 5].

Discrepancies in measurement system can be indication for the project in itself, and we cannot to ignore it, because further analysis very often is built on our measurements. Before we start analysis, it is required wider understanding of repeatability and reproducibility for measurement system.

Repeatability – variation that occurs when repeated measurements are made of the same item under absolutely identical conditions:

Same:

- Gauge,
- Operator,
- Set-up,
- Units,
- Environmental conditions.

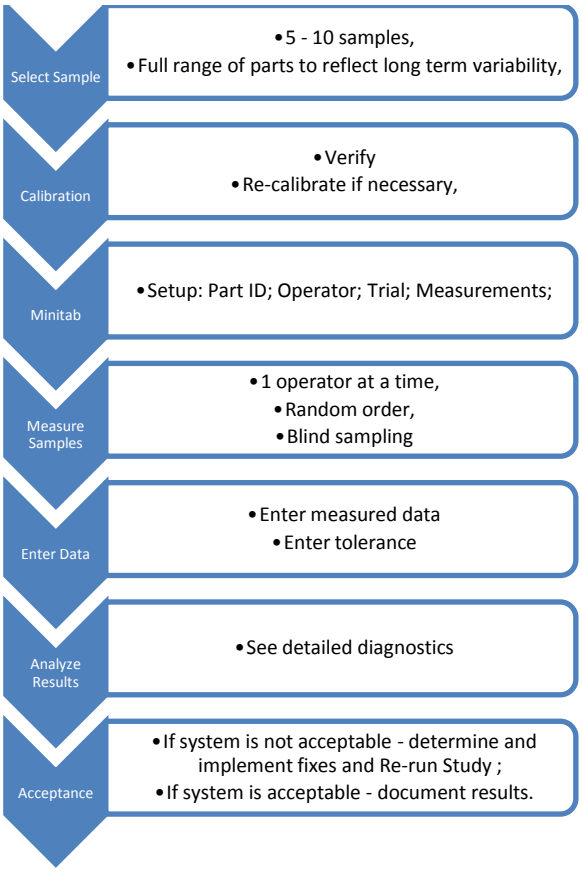



**Fig. 13.5 Roadmap to Gage R&R Study**

Source: TSS Black Belt training materials

Reproducibility – variation that results when different conditions are used to make the measurements.

Different:

- Operators,
- Set-ups,
- Test units,

- Environmental conditions,
- Locations,
- Companies.

First analysis of measurement system, shown bigger problem with reproducibility. After small adjustments – training for extruder operator and when measurement equipment has been changed/upgraded – we can observe positive results in all measurements.

In order to perform measurement system analysis for continuous data (fig. 13.5), we have to chose in "Stat" menu: "Quality Tools\Gage Study\Gage R&R Study (Crossed)" (fig. 13.6). For not destructive test we have to use Gage R&R Study (Crossed); for destructive test we have to use Gage R&R Study (Nested).

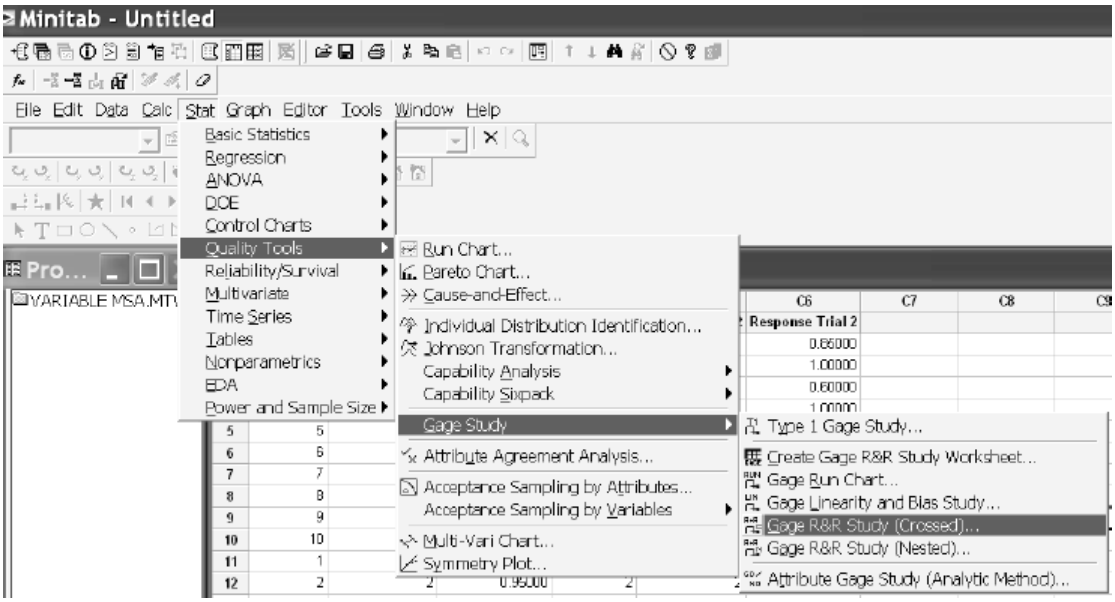



**Fig. 13.6 Roadmap to Gage R&R Study**

Source: Minitab print screen

In Crossed – Gage R&R Study window we have two options for data analysis: Anova and Xbar (fig. 13.7). For purpose of this analysis we choose Anova one.

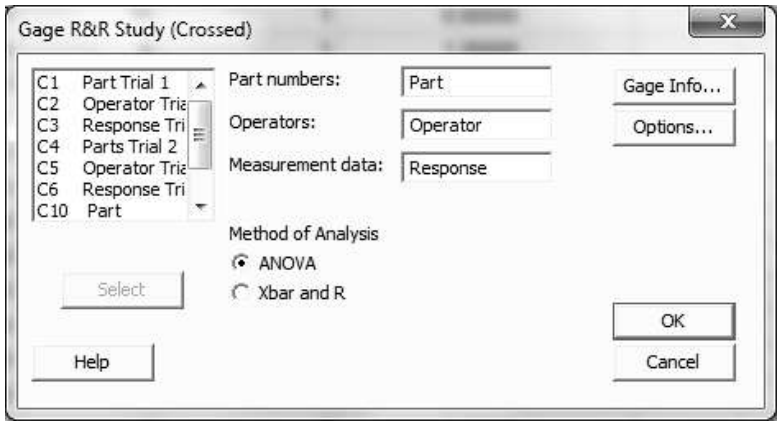



**Fig. 13.7 Gage R&R Study session window**

Source: Minitab print screen

After clicking an option (fig. 13.8) we can choose study variation level (number of standard deviation), specification limits, and historical standard deviation. In most cases we will Check the "Do not display percent study variation" unless analysis specifically required such option. Percent study variation' is similar to 'Percent contribution' but is less statistically sound & adds little to the study.

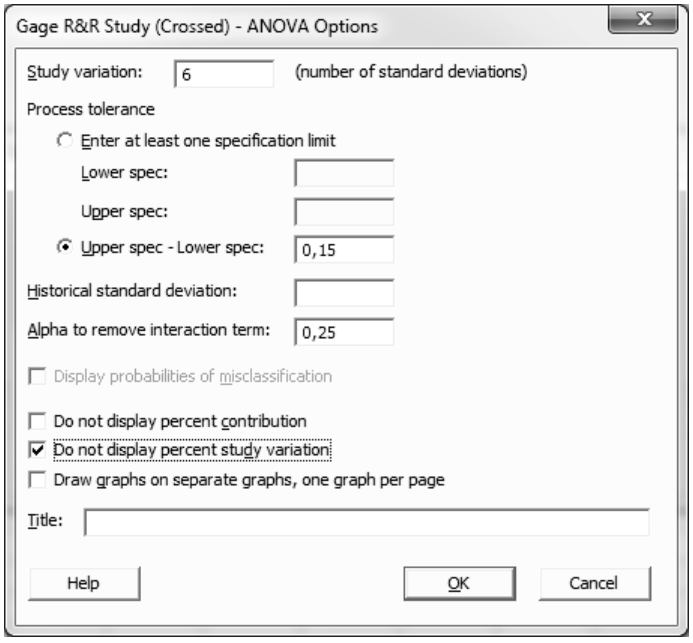



**Fig. 13.8 Options in Gage R&R Study session window**

Source: Minitab print screen

As a result we will receive graphical (fig. 13.9) and session window with data analysis.

***Measurement system before improvements***

### 13.7.1 Graphical analysis:

Going down from the left top diagram

1. Components of variation – show two or three different components of variation:
   - % of Contribution – Measurement System Variation (R&R) as a percentage of Total Observed Process Variation – in this case variation come not only from the part, but also from measurement process,
   - % of Study Variation (total variation),
   - % of Tolerance – measurement error as a percent of tolerance, includes both repeatability and reproducibility,
2. R chart by operator – Difference between 1st and 2nd measurement for each Operator – Exposes gauge repeatability & resolution issues – In Control Required. Each point is the range of the measurements for a part. In this study, 4.2% of the points are above the upper control limit, indicating parts were measured inconsistently. In such case, we have to try to understand why the measurements are inconsistent and determine whether there were any data entry errors.

3. Xbar chart by operator – Average Measurement for each part – Exposes discrimination issues – Out of Control Required. The control limits are based on Repeatability. Ideally, the variation from repeated measurements is much less than the variation between parts. Guidelines suggest that approximately 50% or more should fall outside the limits. – In this study, 66.7% are outside,
4. Dot plot of all Measurements (Diameter) by part – all results for each part in order, to see if particular part ware difficult to measure – in this case parts 4, 6, 7 and 8 have very variable results
5. Dot plot of all Measurements (Diameter) by operator – chart helps to show reproducibility by showing all the results by appraiser. In this study, one operator measures parts consistently higher or lower than other operators, which might be worth investigating,
6. Interaction plot (Operator * Part interaction) – results for each part in order, but splitted by appraiser – Operator 1 in many cases, measured differently in comparison to the rest of operators.

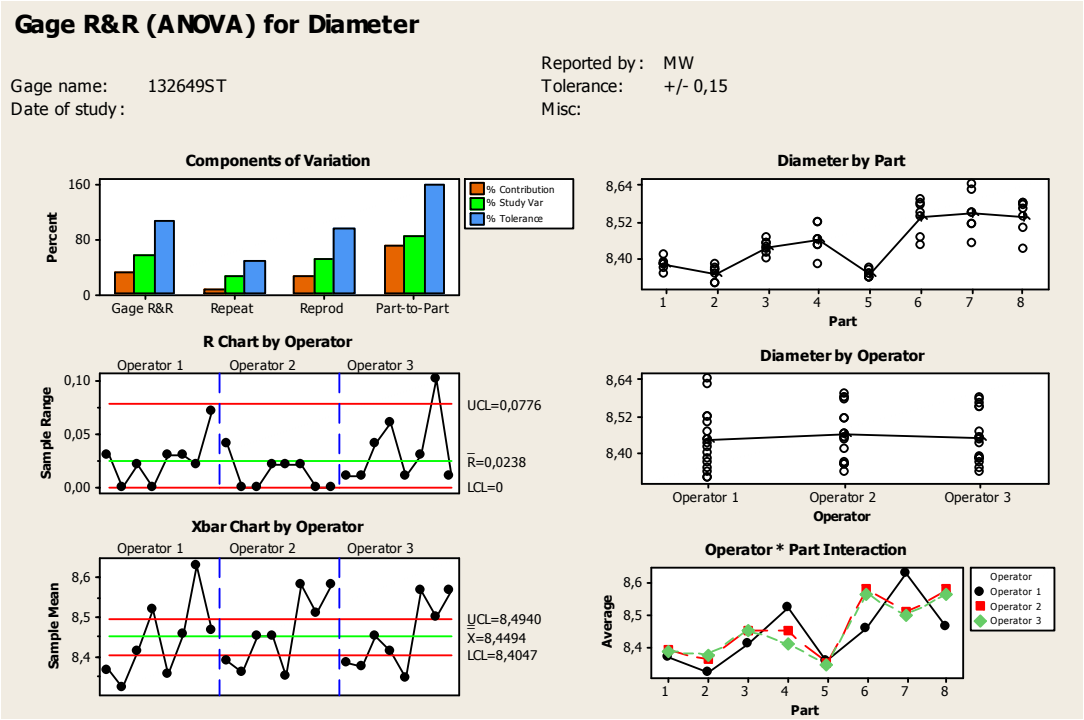



**Fig. 13.9 Graphical analysis – Gauge R&R before improvements**

Source: Minitab print screen

### 13.7.2 Data analysis

Minitab uses the analysis of variance (ANOVA) procedure to calculate variance components, and then uses those components to estimate the percent variation due to the measuring system. The percent variation appears in the gage R&R table. The two-way ANOVA table includes terms for the part, operator, and operator-by-part interaction. If the p-value for the operator-by-part interaction is $\geq 0.25$, Minitab generates a second ANOVA table that omits the interaction term from the model.

## Gage R&R Study – ANOVA Method

```
Gage R&R for Diameter
Gage name:       132649ST
Date of study:
Reported by:     MW
Tolerance:       +/- 0,15
Misc:
```

## Two-Way ANOVA Table With Interaction

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Part | 7 | 0,291865 | 0,0416949 | 8,22685 | 0,000 |
| Operator | 2 | 0,002813 | 0,0014063 | 0,27747 | 0,762 |
| Part * Operator | 14 | 0,070954 | 0,0050682 | 8,78236 | 0,000 |
| Repeatability | 24 | 0,013850 | 0,0005771 | | |
| Total | 47 | 0,379481 | | | |

The ANOVA table show that P value for part is 0.000, indicating that there is a difference between parts. P value for operator is 0.762, indicating that operators haven't significant difference in their mean measurements of the same part.
Minitab calculates a column of variance components (VarComp) and uses the values to calculate % Gage R&R with the ANOVA method. The gage R&R table breaks down the sources of total variability:

- Total Gage R&R consists of:
  - Repeatability – the variability from repeated measurements by the same operator,
  - Reproducibility – the variability when the same part is measured by different operators. (This can be further divided into operator and operator-by-part components.).
- Part-to-Part-the variability in measurements across different parts.

Variance components are used to assess the amount of variation that each source of measurement error and the part-to-part differences contribute to the total variation. Ideally, differences between parts should account for most of the variability; variability from repeatability and reproducibility should be very small.

Percent of contribution is based on the estimates of the variance components. Each value in VarComp is divided by the Total Variation, and then multiplied by 100. Therefore, 68.38% of the total variation in the measurements is due to the differences between parts. This rather low % Contribution is considered bad. When % Contribution for Part-to-Part is high, the system can distinguish between parts.

Because % Contribution is based on the total variance, the column of values adds up to 100%. Minitab also displays columns with percentages based on the standard deviation (or square root of variance) of each term. These columns, labeled %StudyVar and %Tolerance, typically do not add up to 100%. Because the standard deviation uses the same units as the part measurements and the tolerance, it allows for meaningful comparisons.

Contribution indicate 6.46% for repeatability which is marginal value, 25.15% for reproducibility which is bigger than 9% and is not acceptable.

## Gage R&R

| Source | VarComp | %Contribution (of VarComp) |
|---|---|---|
| Total Gage R&R | 0,0028226 | 31,62 |
| Repeatability | 0,0005771 | 6,46 |
| Reproducibility | 0,0022455 | 25,15 |
| Operator | 0,0000000 | 0,00 |
| Operator*Part | 0,0022455 | 25,15 |
| Part-To-Part | 0,0061045 | 68,38 |
| Total Variation | 0,0089271 | 100,00 |

Process tolerance = 0.3

We can also use percent of study variation % StudyVar to compare the measurement system variation to the total variation. Minitab calculates % StudyVar by dividing each value in StudyVar by Total Variation and then multiplying by 100. % StudyVar for gage R&R is (0.318770/0.566899) 100 ≈ 56.23% – we can't adequately assess process performance because it is more than 30% we can clearly state that system is unacceptable. Minitab calculates StudyVar as 6 times the standard deviation for each source. 6s process variation Typically, process variation is defined as 6s, where s is the standard deviation, as an estimate of σ. When data are normally distributed, approximately 99.73% of the data fall within 6 standard deviations (± 3 standard deviations from the mean), and approximately 99% of the data fall within 5.15 standard deviations (± 2.575 standard deviations from the mean).

Comparing the measurement system variation with the tolerance is often informative. If we enter the tolerance, Minitab calculates % Tolerance, which compares measurement system variation to specifications. % Tolerance is the percentage of the tolerance taken up by the measurement system variability. Minitab divides the measurement system variation (6·SD for Total Gage R&R) by the tolerance. Minitab multiplies the resulting proportion by 100 and reports it as % Tolerance. % Tolerance for gage R&R is ≈ 106.26%.

We can use % Tolerance or % StudyVar to evaluate the measuring system, depending on the measuring system:

- If the measurement system is used for process improvement (reducing part-to-part variation), % StudyVar is a better estimate of measurement precision,
- If the measurement system evaluates parts relative to specifications, % Tolerance is a more appropriate metric.

Because measurement system variation equals 106.26% of the tolerance, so also more than 30%, which means that system is not satisfactory for any of application.

As a major point, where we should put more attention is reproducibility – Operator and Operator by Part components: The variation that occurs when different people measure the same item. This equals 89.2% of the measurement variation and is 50.2% of the total variation in the process.

Number of distinct categories value estimates how many separate groups of parts the system can distinguish. Minitab calculates the number of distinct categories that can be reliably observed by:

$$\frac{S_{part}}{S_{measuring_{system}}} \cdot \sqrt{2}$$

Minitab truncates this value to the integer except when the value calculated is less than 1. In that case, Minitab sets the number of distinct categories equal to 1. Here, the number of distinct categories is 2, so it is less than 5 which mean that measurement process cannot detect process output variation, process shifts and improvements.

## Gage R&R

| Source | VarComp | %Contribution (of VarComp) |
|---|---|---|
| Total Gage R&R | 0,0028226 | 31,62 |
| Repeatability | 0,0005771 | 6,46 |
| Reproducibility | 0,0022455 | 25,15 |
| Operator | 0,0000000 | 0,00 |
| Operator*Part | 0,0022455 | 25,15 |
| Part-To-Part | 0,0061045 | 68,38 |
| Total Variation | 0,0089271 | 100,00 |

Process tolerance = 0,3

| Source | StdDev (SD) | Study Var (6 * SD) | %Study Var (%SV) | %Tolerance (SV/Toler) |
|---|---|---|---|---|
| Total Gage R&R | 0,0531283 | 0,318770 | 56,23 | 106,26 |
| Repeatability | 0,0240226 | 0,144135 | 25,43 | 48,05 |
| Reproducibility | 0,0473871 | 0,284323 | 50,15 | 94,77 |
| Operator | 0,0000000 | 0,000000 | 0,00 | 0,00 |
| Operator*Part | 0,0473871 | 0,284323 | 50,15 | 94,77 |
| Part-To-Part | 0,0781311 | 0,468786 | 82,69 | 156,26 |
| Total Variation | 0,0944832 | 0,566899 | 100,00 | 188,97 |

Number of Distinct Categories = 2

### *Measurement system after improvements*

Going down from the left top diagram (fig. 13.10).

### 13.7.3 Graphical analysis:

1. Components of variation – after system improvements the biggest part of variation come from the measured parts. Total gage R&R variation has been decreased, problem with repeatability and reproducibility significantly reduced.
2. R chart by operator – Each point is the range of the measurements for a part. In this study, 10.0% of the points are above the upper control limit, indicating parts were measured inconsistently. Number of points on the same line can suggest perfect repeatability or poor resolution – in that case good repeatability.
3. Xbar chart by operator – The control limits are based on Repeatability. Ideally, the variation from repeated measurements is much less than the variation between parts. Guidelines suggest that approximately 50% or more should fall outside the limits. In this study, 96.7% are outside.
4. Dot plot of all Measurements (Diameter) by part – all results for each part in order, to see if particular part ware difficult to measure – in this case part 7 have some variability during measurements,
5. Dot plot of all Measurements (Diameter) by operator – after measurement system adjustments it has been observed improvement in measurements,

6. Interaction plot (Operator Part interaction) – results for each part in order, but splitted by appraiser – Operators measure parts on similar level.

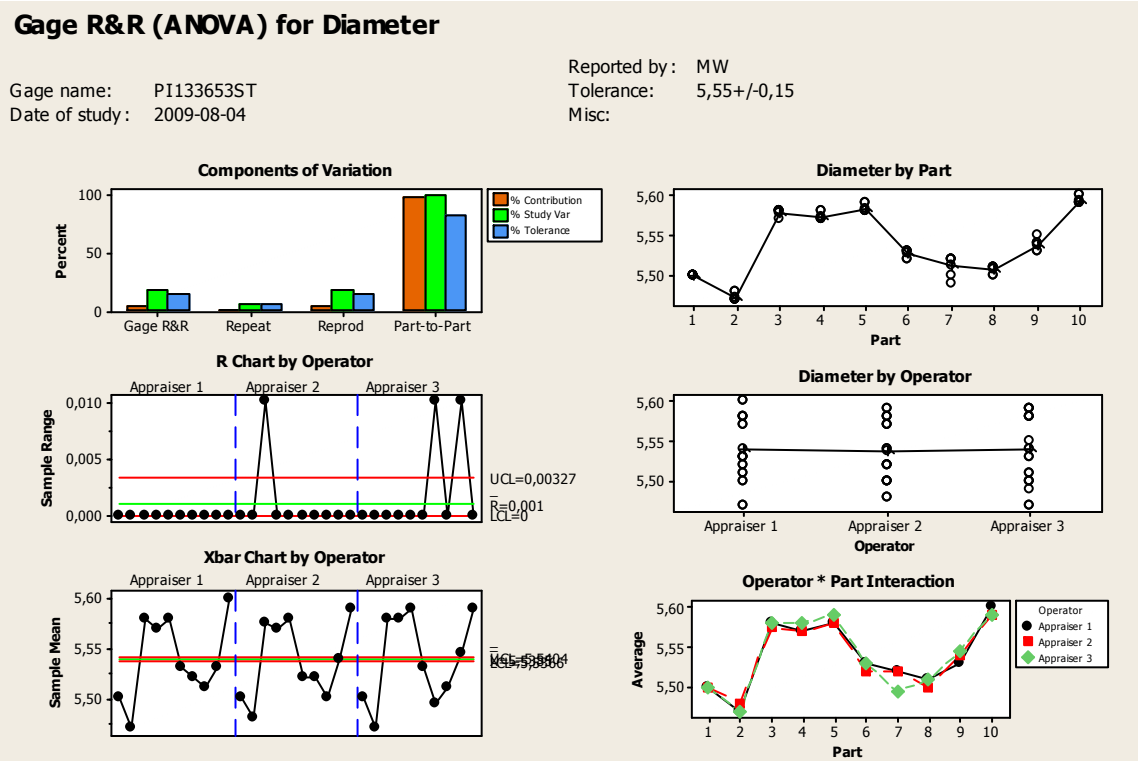



**Fig. 13.10 Graphical analysis – Gauge R&R after improvements**

Source: Minitab print screen

### 13.7.4 Data analysis

The ANOVA table show that P value for part is 0.000, indicating that there is a difference between parts. P value for operator is 0.857, indicating that operators haven't significant difference in their mean measurements of the same part.

## Gage R&R Study - ANOVA Method

```
Gage R&R for Diameter

Gage name:        PI133653ST
Date of study:    2009-08-04
Reported by:      MW
Tolerance:        5,55+/-0,15
Misc:
```

## Two-Way ANOVA Table With Interaction

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Part | 9 | 0,092515 | 0,0102794 | 98,9465 | 0,000 |
| Operator | 2 | 0,000030 | 0,0000150 | 0,1444 | 0,867 |
| Part * Operator | 18 | 0,001870 | 0,0001039 | 20,7778 | 0,000 |
| Repeatability | 30 | 0,000150 | 0,0000050 | | |
| Total | 59 | 0,094565 | | | |

Alpha to remove interaction term = 0,25

Contribution indicate 0.29% for repeatability which is acceptable value, 2.82% for reproducibility which is also acceptable.

The measurement system variation equals 17.64%, (we can marginally assess process performance) because it is less than 30% we can clearly state that system is marginally acceptable. The measurement system variation equals 14.76% of the tolerance, so also less than 30%, which means that system is marginally satisfactory for application. Reproducibility has been improved, but there is steel room to make an improvements – Operator and Operator by Part components: The variation that occurs when different people measure the same item. This equals 95.3% of the measurement variation and is 16.8% of the total variation in the process.

Distinct categories is 7, so it is marginal and mean that measurement process can detect process output variation, process shifts and improvements.

## Gage R&R

| Source | VarComp | %Contribution (of VarComp) |
|---|---|---|
| Total Gage R&R | 0,0000544 | 3,11 |
| Repeatability | 0,0000050 | 0,29 |
| Reproducibility | 0,0000494 | 2,82 |
| Operator | 0,0000000 | 0,00 |
| Operator*Part | 0,0000494 | 2,82 |
| Part-To-Part | 0,0016959 | 96,89 |
| Total Variation | 0,0017504 | 100,00 |

Process tolerance = 0,3

| Source | StdDev (SD) | Study Var (6 * SD) | %Study Var (%SV) | %Tolerance (SV/Toler) |
|---|---|---|---|---|
| Total Gage R&R | 0,0073786 | 0,044272 | 17,64 | 14,76 |
| Repeatability | 0,0022361 | 0,013416 | 5,34 | 4,47 |
| Reproducibility | 0,0070317 | 0,042190 | 16,81 | 14,06 |
| Operator | 0,0000000 | 0,000000 | 0,00 | 0,00 |
| Operator*Part | 0,0070317 | 0,042190 | 16,81 | 14,06 |
| Part-To-Part | 0,0411816 | 0,247090 | 98,43 | 82,36 |
| Total Variation | 0,0418374 | 0,251025 | 100,00 | 83,67 |

Number of Distinct Categories = 7

## SUMMARY

The measurement system analysis is a very important part of Lean Six Sigma Projects. As an important point of Measure phase, makes it easy to understand the potential problems that may significantly affect all measurements. Measurements process cannot be treated as a baseline without this analysis – because only with "true" data we are able to provide that we fully understand the problem. To carry out the measurement system analysis, we can use simple spreadsheet, but the preparation of the data and calculations are time-consuming. Currently on the market there are available number of computer aided engineering statistical software – the most popular is Minitab. This software, when is used skillfully, provides full range analysis of the measurement system, however, does not in itself change the approach to measurements and standards that have been previously introduced. This is the only tool that will show us how our system is good and where we need to improve, and this is particularly important when there is a fluctuation of employees. In many of Green or Black Belt projects,

which has been not completed successfully, we can say that one of the common reasons that, is the lack of a clear understanding of the measurement system analysis and ignore it as a potential source of variation. However at the root cause of these problems is, a way of Lean Six Sigma project management and/or lack of support from top management in the organization. Proper Green or Black Belt training has to be relevant and meaningful to provide knowledge of the methodology, but also a structured project management. To lead projects, top management cannot afford to ignore the facts alleged by the DMAIC methodology, as well as the need to generate time for Green/Black Belts, and the project team. Each Green/Black Belt is a person having a set of tools that properly used, fully ensure that the project/issue is fully resolved. If Green/Black Belt, does not receive this support – a set of these tools becomes completely useless. As a Black Belt, later Master Black Belt responsible of leading the projects, the implementation of Lean Six Sigma ideology in the manufacturing plant, as well as training, I encountered the problem of a proper understanding of the basic tools – MSA Capability, SPC, DOE – therefore developed a training program to ensure that these tools will be expertly and properly used. Starting from the analysis of the measurement system, the training program covers all methods of its implementation, the errors that can occur during the analysis, the problems that result from lack of proper understanding of the problem and from the same analysis as well as a detailed explanation of the use of computer-aided engineering statistical software. All presented examples were part of the Lean Six Sigma projects that have been positively completed and brought to the company's high annual profits – problems has been solved implemented solutions are monitored till now. In all these examples, the analysis revealed a significant measurement system process noise that has been removed, before the next step of the project.

## REFERENCES

1. Minitab 15 – software documentation, Rel.15, State College Pennsylvania 2007.
2. Gage Studies for Continuous Data, Rel.16 Ver. 1.0, Minitab Inc. 2010.
3. QSB Consulting: Six Sigma and Minitab – A Complete Toolbox Guide for all Six Sigma Practitioners, 2nd Edition, 2006-2009.
4. Michael L. George, David Rowlands, Mark Price, John Maxey: Lean Six Sigma pocket Tool book, 2005.
5. Training materials – TSS Black Belt Training Program – 2009.

# MEASUREMENT SYSTEM ANALYSIS OF ATTRIBUTE OR CONTINUOUS DATA, AS A ONE OF THE FIRST STEPS IN LEAN SIX SIGMA PROJECTS

**Abstract:** *Measurement System Analysis is a part of "Measure" phase, which is a structured project management approach. This approach consist of the following steps: Define, Measure, Analyze, Improve, Control – "DMAIC" and is a path to resolve production problems based on Lean Six Sigma methodology. This method has been presented by using of computer aided statistical software – Minitab – which is a most common statistical software, used by Green or Black Belts. As a Master Black Belt I faced to the problem of lack an appropriate explanation of using it by the Belts – which contributed by implementation of a proper training program. Measurement system analysis in this program, is divided by Attribute Agreement Analysis, which is analysis of attribute data, and Gage R&R – analysis for continuous data. Therefore it is very important to understand differences between attribute and continuous date and their main metrics. Understanding data types, allowed to explain components of measurement errors. This base knowledge is a foundation of measurement system analysis and going further – base knowledge of each Green or Black Belt.*

**Key words:** *Measurement system analysis, Lean Management, Six Sigma, Gage R&R, measurement error*

# ANALIZA SYSTEMU POMIAROWEGO DANYCH ATRYBUTOWYCH I CIĄGŁYCH, JAKO JEDEN Z PIERWSZYCH KROKÓW PROJEKTÓW LEAN SIX SIGMA

**Streszczenie:** *Analiza systemu pomiarowego jest częścią fasy "Pomiar", która jest ustrukturyzowanym podejściem do zarządzania projektami. To podejście składa się z następujących kroków: definiowanie, pomiar, analizowanie, poprawa, kontrola/sterowanie – "DMAIC" i jest drogą do rozwiązania problemów produkcyjnych opartych na metodologii Lean Six Sigma. Metoda ta została przedstawiona za pomocą komputerowego wspomagania statystycznych prac inżynierskich – Minitab – jest najczęściej spotykanym oprogramowanie statystyczne, wykorzystane przez Green lub Black Beltów. Jako Master Black Belt zetknąłem sie z problemem braku odpowiedniego wyjaśnienia/zrozumienia I jego wykorzystania przez Beltów – co przyczyniło by wdrożenia odpowiedniego programu szkoleniowego. Analiza systemu pomiarowego w tym programie, jest podzielona na analizę systemu pomiarowego dla danych atrybutowych, oraz Gage R&R – analiza systemu pomiarowego dla danych ciągłych. W związku z tym bardzo ważne jest, aby zrozumieć różnice pomiędzy danymi atrybutowymi, a ciągłymi oraz ich główne współczynniki/metryki. Zrozumienie typu danych pozwoli na wyjaśnienie składników błędów pomiarowych. Ta podstawowa wiedza jest fundamentem analizy systemu pomiarowego, a idąc dalej – podstawową wiedzą każdego Green lub Black Belta*.

**Słowa kluczowe:** *Analiza systemu pomiarowego, zarządzanie szczupłe, Six Sigma, pomiar powtarzalności i odtwarzalności, błąd pomiarowy*

mgr inż. Maciej WOJTASZAK
Trelleborg Sealing Solutions
ul. Legionów 255, 43-502 Czechowice-Dziedzice
tel. 602 491 946; e-mail: maciej.wojtaszak@trelleborg.com
dr hab. inż. Witold BIAŁY, prof. Pol. Śl.
Silesian University of Technology, Department of Organization and Management
Institute of Production Engineering
ul. Roosevelta 26, 41-800 Zabrze
e-mail: wbialy@polsl.pl

# 14

# MOTYVATION AND CONTROL IN TECHNICAL SYSTEMS

## 14.1 INTRODUCTION

In the control theory, motivations of human actions, has big meaning. Even in ancient times, it was noted that as a result of an appropriate incentives provided to the public, increases its control ability. These developments are particularly evident in states of increased social activity which is most often the result of threats. How to explain differently a situation where better armed and more numerous forces defeated by less large opponent. The impact on society through of one form of media may enhance his activity, on another hand, with help of the second – can act destructively on society. In psyche of human the driving force of actions are motivations. Psychology, probably, as the first area of science, examined the motoric factors that determine the human activity. Understanding the phenomena that affect the psyche and next on the mental and physical condition was necessary to bring aid to people in a state of depression, or for which the requirements were placed far above average. The study of psychology certainly were used and developed in sociology dealing with the processes and rules of social coexistence. It is well known term "psychology of the crowd", which means a human collective reactions when exposed to external stimuli. Encouraging social or professional activity has always played a big role in the organization of social life, in the functioning of technical systems. Mechanisms affecting the human psyche and thus causing a change in his activity are still the subject of much research in the science of organization and management. It is not just about influencing the growth of labor productivity. It is important to ensure the safety, healthy living and human development. Control issues in technical systems are dealing by cybernetics. It explores the parallels between the principles of operation of living organisms, social layouts (systems) and engineering (machines). The key to effective control is to know the motivation of human action and skillful managing them.

## 14.2 MOTIVATION IN CLASSICAL TERMS

By a classic statement on meaning of motivation, will be understood definitions made on the basis of the wording of psychology, sociology and management science.

All what a man makes has a reason, a reason that is not always fully realized. Then, reasons of proceeding are motives. Below is listed breakdown of motives in psychology:

– biological (e.g. hunger),

– social (e.g. altruism – behavior involving action for the benefit of others),

– intermediate between biological and social (e.g., operating under the influence of anger, jealousy, for ideological reasons).

To understand the behavior of people it has to be understood rules of their motivations. Motivation can be defined as a goal, intent, intention, goal oriented, need, lack, urge (inclination, impulse), and desire.

Psychologists use the term urge, when the source of motivation has biological nature. Terms: motive, need they use when it comes to social or psychological motivation [1].

By Reykowski [2] motivation is the process of psychological adjustment, thanks to it, aspirations are formulated, by which should *be understood, the tendencies to takes action, oriented on a specific purpose. The task of aspirations is to steer efforts of human activities that have led them to a specific, consistent with the intention, effect.

Next, Reykowski argued that the change of motivation pursuing the same activity can alter efficiency.

In general, the motivation should be understood here, as a process that produces, directs and sustains certain behaviors of people, from other alternative forms of behavior, in order to achieve certain goals. This process occurs when two conditions are met:

1) the goal achievement must be seen by the man as useful.
2) Probability of achieving the goal by the man must be greater than zero.

In order to establish motive, the process control of activities, must be produce the belief that a certain action will lead to a result which is useful for the man (individual) [2]. Such a conviction may be based on experience or the intellectual analysis of the situation.

In order to launch the motivation, an entity must assume that even has a chance to achieve a result. When in his opinion, the chances are zero, the motive is not actuated. A state which at that time appears can be described as a request of unsatisfied desire, etc. Also, opportunities equal one does not inspire motivation, because they correspond to the situation where the result has been achieved. So that the motivation could rise, the probability of the outcome must be greater than zero and less than one. Increase of the probability may increase motivation, but with a very high degree of certainty the motivation can be reduced. With the increase in the probability of success, decreases the probability of failure. If the probability of failure increases, it may increase the level of motivation. Since the each components of the emotional process is under-go changes both under the influence of what is going on in the man (e.g. fluctuations associated with the activities of the internal organs, mental activity) and as well as under the influence of what is happening in the external environment (the inflow of new information), it changes adequately strength of motivational processes, and by this their mutual relationship. As a result, in human behavior are manifested a various motives, but the resulting behavior is determined by the strongest motives that often achieve control over the operation of the man. The motive, which took control over the behavior, affects both the direction of the taking actions as well as their course [2].

The goals pursued by people can be of two types:

1) material (e.g. salary),
2) assets (e.g., satisfaction).

The purpose of the employee can be getting a reward or pay increase. Goals and expectations of employees are a function of their personal characteristics, their skills and

value systems. Age, sex, level and type of education, experience, professional staff position occupied in the workplace, in force the cultural patterns, define their aspirations. The basic model of the motivation can be represented by the diagram in fig. 14. 1.

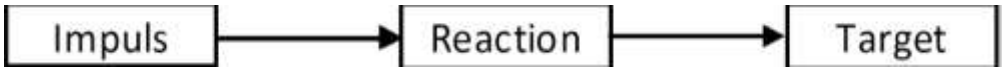



**Fig. 14. 1 Model of motivation** [2]

The essence of motivation is in the human response to sustained stimulus (mean of motivation). If the stimulus will have sufficient ability to influence, then the reaction will be action to achieve a particular goal. Otherwise, the stimulus will be ignored.

The concept of motivation can be also seen at a different angle. According to Maslow [3, 4], motivation of people action depends on the needs which govern them. We can distinguish five groups of basic needs:

1) Physiological needs (thirst, hunger, meal).
2) The needs of security.
3) Social needs (belonging and love).
4) The needs of respect and appreciation.
5) Self-actualization needs.

In a five hierarchy of needs, a man meets them in a certain order – starting with the core and ends on the needs of higher order [5]. Maslow's model diagram is shown in fig. 14.2.

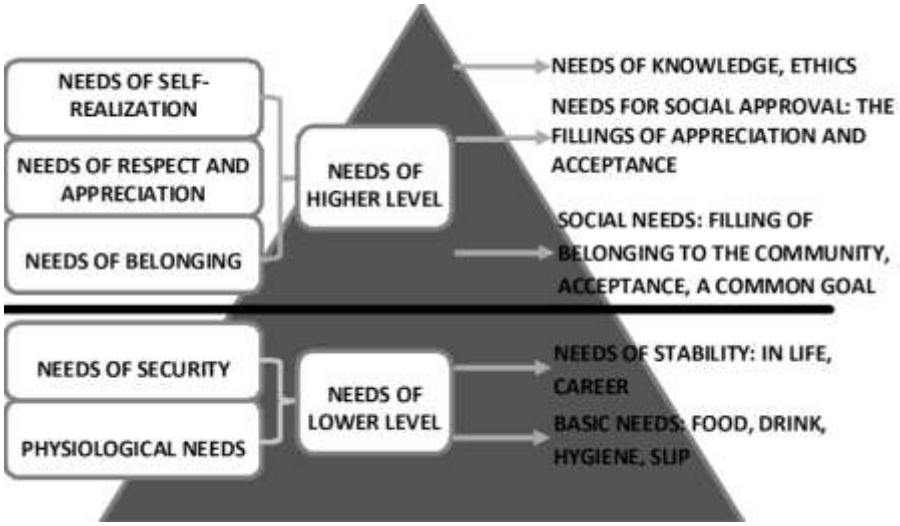



**Fig. 14.2 Pyramid of needs by Maslow** [5]

In order to be able to meet the needs of a higher order, first of all must be satisfied needs of lower level. In the case when the need of lower level has been met, than automatically it stops be a source of motivation.

In addition to these five needs mention above, Maslow distinguished also co-called additional needs that may manifest it only in some people. These include the needs of knowledge and aesthetics needs. [6] In addition, Maslow says that motivation is constant, never disappearing, subject to volatile and complex, and it is almost a universal feature, practically for every state of the organism [7].

In Herzberg's two-factor theory of motivation factors motivating people to act are divided into two groups: external (so-called hygiene factors or dissatisfaction) and internal (co-called motivators or factors of satisfaction). Interpretation of Herzberg model is shown in fig. 14.3.

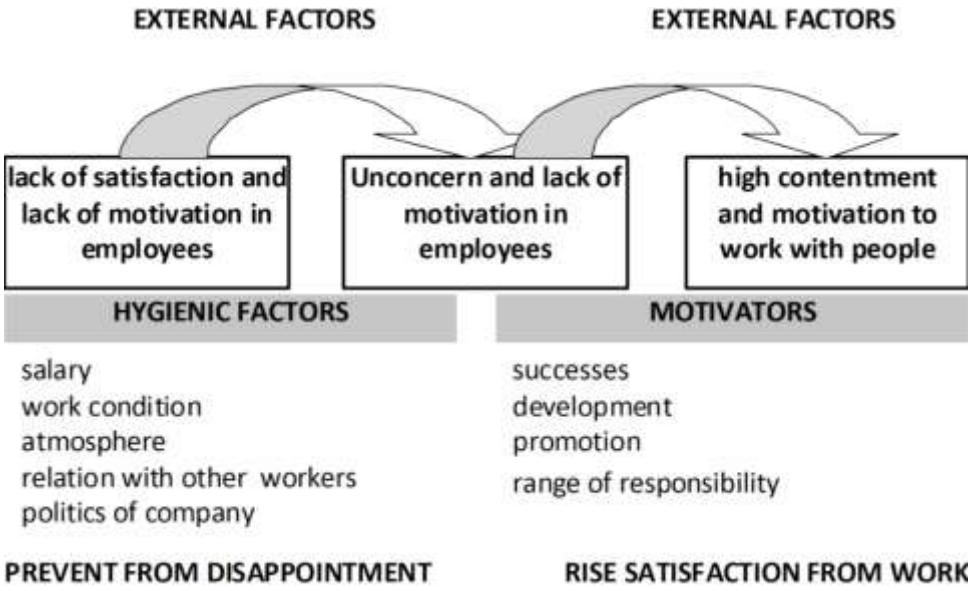



**Fig. 14.3 Diagram of the two-factor theory of motivation according to Herzberg** [5]

Motivators relate to the content of performed work. They refer, among others, to: recognition, promotion, interest in work, responsibility, achievement, growth opportunities. These factors contribute in increasing satisfaction of performing work, which in turn leads to higher employee productivity. Hygiene factors do not lead directly to job satisfaction, however, they affect the level of dissatisfaction with it. Hygiene factors include: company policy, supervision, interpersonal relations, salary, working conditions, health and safety conditions, etc.

Herzberg concluded [5] that for the proper functioning of the motivators, it is necessary first of all, to secure health factors for workers. However, focusing solely on health factors not guarantee to reach the desired level of motivation by employees, these factors are perceived by subordinates as natural conditions of work.

Therefore, the provision of health factors at the appropriate level leads only to reduce employee dissatisfaction and is a kind of starting point for the use of motivators that are authoritative source of job satisfaction.

Herzberg's opponents acknowledged that his approach to the issue of motivation somewhat simplifies reality. Some of the factors – such as wage, many people include it into the motivators, especially when it is high [6].

It seems that thanks to Herzberg, was to highlight the often reproduced stereotypes, according to which, factors as for e.g.; company policy and working conditions, had effectively motivate people to work.

This brief sketch of the concept of motivation, of course, does not exhaust the discussed topics. Characteristically is, that in the sciences associated to psychology and sociology, particularly important issues is raised, related to the internal nature of a human, with its

sensitivity to: stimuli, the method of experiences and even brain functioning and decision-making systems.

Mainly the research is focused on the mechanisms of human reaction (and even generalizing – alive organisms) as a result of the impact of the environment on him. Not at the same time are creating ways of impact, but only are examined correlations between phenomena or events specific for the given environment to the examined subject.

In the sociological sciences, especially in the management sciences, motivation issue is of particular importance, because it determines the social and professional activities in the workplace. The studies are based mainly on trial and error method. This method involves methodical repetition of different treatments unless they prove to be effective until the expected result. Often are used scientific surveys.

In the management sciences, there are a very large number of different types of studies and the results of examinations. In general, they refer to a narrow field of business (economical sector) or social or even raise issues unique to a particular company. This multitude various of results imply discussions, which will lead surely to some generalizations. A broader research study related to the essence of motivation and the mechanisms of its creation can be found in work [6, 8].

## 14.3 MOTIVATION IN TERMS OF CYBERNETICS

Cybernetics is the science of control. It began to deal with the problems of decision-making, resulting in increased demand for professional advisors, the committee of experts, and even for the institutions involved in the improvement of organization and management. Therefore, cybernetics is the science of control, and thus of any intentional act inclusive deciding. One of the basic concepts of cybernetics is a system; it is defined as a set of elements and relations existing between them. Because of the large role it plays in the concept of cybernetics, cybernetics could be defined as the study of the behavior of the systems [9].

Mazur [9, 10] treats man as an autonomous system. On the basis of analysis of the autonomous control system can be inferred about the properties of human control, or the reasons (motives) of human behavior.

An autonomous system is a system capable of long duration as possible in an environment, which means that it must have:

1) the ability to control,
2) the ability to prevent the loss of capacity control.

In order to meet these requirements, an autonomous system must include the relevant authorities (subsystem), namely:

– effectors (the organs for impact on the environment),
– receptors (the organs to collect information from the environment),
– a correlator (the organ to process and store information),
– alimentators (the organs to collect energy from the environment),
– a accumulator (the organ to process and store energy),
– a homeostat (the organ to prevent flows of information and energy, which reduce the possibility of system to impact on the environment).

Into the effectors, should flow information determining, which of the possible impacts

on the environment are to take place. It should also flow into them, the energy allowing performance of necessary work in the actions on the environment. The border between the autonomous system and its environment is marked by broken lines. The autonomous system diagram is shown in fig. 14.4.

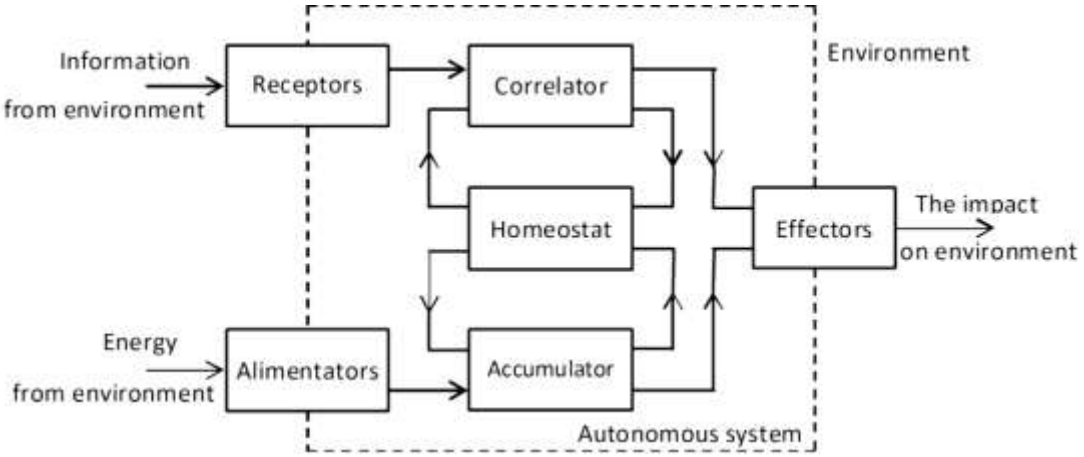



**Fig. 14.4 An autonomous system** [10]

The receptors, the effectors and the alimentators are the organs providing communication of autonomous system with the environment, where the receptors and the alimentators are inputs of the system, and the effectors are the outputs of the system. The correlator, the accumulator and the homeostat are internal organs of the autonomous system. Gathering information in the correlator and gathering energy in the accumulator allow using them independently from the time of collection.

The homeostat task is to maintain an autonomous system in stage of the functional balance. A lot of emphasis on the subject-matters of functional balance is included in the work [11], where is discussed the interplay of competing technical systems.

Functional imbalances are caused by changes which happen in the environment. The greater change occurs in the environment, the greater will be the impact on the system. Through mediation of receptors and alimentators it will be provided greater impact on the input of the accumulator and the correlator and on their outputs, so also on the input of homeostat. Therefore, disturbance of functional balance is the impact of the correlator and battery on homeostat. Homeostat, the internal body system, does not have contact with the environment, that why distortion for him is, what is happening in the correlator and acumulator. That why, he can remove disturbance only by impact on the correlator and the battery. If the impact of the correlator and the acumulator on homeostat increases, then the impact of homeostat on the correlator and the acumulator will decrease (and vice versa). Consequently, the impact of the correlator and the acumulator on homeostat also decreases, and thus the functional equilibrium (balance) is restored.

Example of homeostat functioning with regard to the human body is preventing overheating of the body due to strong solar radiation. Then, there is the phenomenon, homeostasis the body's self-regulation in order to maintain the basic biological parameters. As a result of thermal changes caused by strong sunlight will occur the following phenomena: the increased activity of the sweat glands (evaporation of water helps to remove heat from the

body), the appearance of pigment in the skin (tan hinders the penetration of solar radiation), thirst (drinking habits compensates the loss of water in the body and allow to keep sweating), lack of appetite (preventing intake of high-calorie). In the information processes, it appears interaction such decisions, such as: to hide in the shadows; to be in a ventilated area or cool off with a swim.

Treatment of man as an autonomous system is fully justified, because for a man, it is fulfilled every definitions of the autonomous system [10]:

1) the man has the ability to control itself and capacity to counter the loss of ability to control;
2) the man is able to maintain the functional balance despite changes in the environment;
3) the man is seeking to maintain its existence;
4) the man works in its own interest.

In the autonomous system, exist two symmetrical areas of interaction:

1) the area of information, including the information path: receptors – correlator – effectors and feedback from homeostat and correlator (upper part of fig. 14.4).
2) the area of energy, including energy path: alimentators – acumulator – effectors and feedback from acumulator and homeostat (lower part of fig. 14.4).

Information area of autonomous system is shown in fig. 14.5. Total of processes in the information is called the psyche of an autonomous system. The correlator has two inputs and two outputs (or more precisely – the two types of inputs and outputs). It functions as a transmitter of interactions (it is analogous to the human brain), which means that the processes are taking place in it.

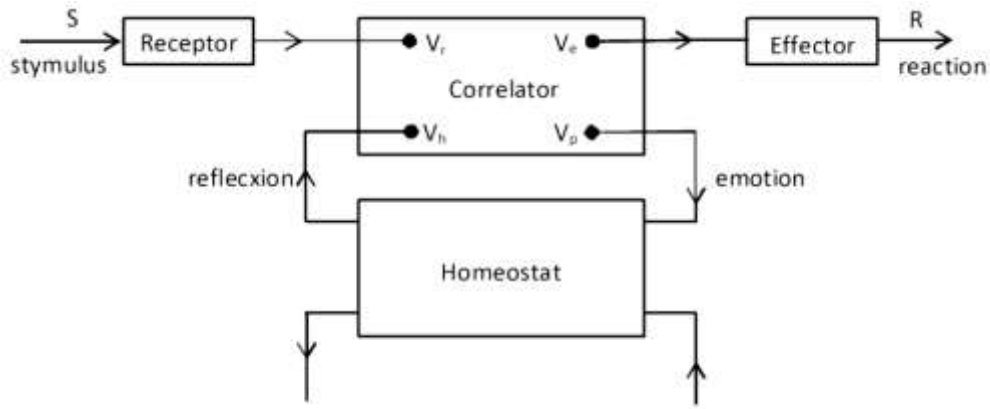



**Fig. 14.5 Information area of autonomous system** [10]

As a result of these processes the inputs potentials causes a flow of energy, resulting in the formation of the outputs potentials. In the correlator are four potentials:

– receptor potential ($V_r$), introduced by the receptor to the correlator,
– effector potential ($V_e$), introduced by the correlator to the effector,
– perturbation potential ($V_p$), introduced by the correlator to the homeostat,
– homeostatic potential ($V_h$), introduced by the homeostat to the correlator.

Emotion is the impact on homeostat by correlator (fig. 14.5). In particular, it may be:

– aversion (aversion feeling), the emotion involving growth of the perturbation potential;
– attraction (feeling attractive), the emotion that reduces the perturbation potential.

Reflection is the impact of the homeostat on the correlator (fig. 14.5).
It can be:
– disapproval (disapproval reflection), a reflection of which is to reduce the homeostatic potential;
– approval (approval reflection), which is a reflection consists in the growth of the homeostatic potential.

Here's an example to illustrate the use of these terms in connection with the operation of homeostat. Everyone has their own sense of the normal course of social events. It can has also typical Smith, who participated in a social conversation, he treat it as a normal course. Let now the following situations to occur.
First situation.

The social conversation joys a few new people very talkative. For Smith this is a deviation from the normal state. Excess heard words make in him growth of the perturbation potential $V_p$ (aversion), for that his homeostat reacts by reduction of homeostatic potential $V_h$ (disapproval), power correlation decreases, reducing Smith's reaction. As a result, Smith has taken a silent position. In this way, he improved his status in the balance, but also the state of social conversation in which an excess of words fell by his silent.
Second case.
Talkative people moved away, resulting decrease in a perturbation potential $V_p$ of Smith (attraction) but for the homeostatic potential $V_h$ (approval) increase, Correlation power will also increase adding to his reactions. As a result, he becomes chattier. In this way, he improved his status in the balance. Also was restored equilibrium in the environment, as insufficiency of words was offset by increased talkative of Kowalski.

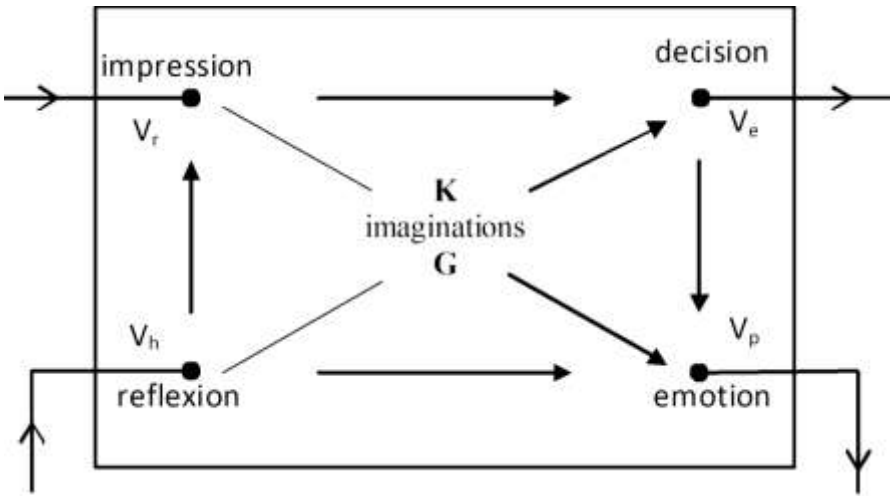



**Fig. 14.6 It is a general scheme of correlation occurring in the correlator** [10]

Among the four potentials occurring in the correlator, there is a number of possible associations on which will depend on the behavior of the autonomous system. A detailed analysis of all the associations presented in work [10]. Mileage correlation between these potentials is such that the inputs of the correlator ($V_r$ and $V_h$) flows the correlation power K (fig. 14.6) to the correlator outputs, in which it causes appearance of the effector potential $V_e$ and the perturbation potential $V_p$. In other words, impressions and reflections produce ideas

which in turn produce decisions and emotions.
Size by correlation K depends on the conductivity correlation G and the input potential

$$K = (V_r + V_h) \cdot G \tag{14.1}$$

If we express the energy potentials as $V_r$ and $V_h$ in joules, and the power in watts K, then the correlation conductivity G is essentially speed of operating correlator (1/s).

According to Mazur [10], the motivation is the dependence of the effector potential from homeostat action, that is, from emotion and reflection. In other words, it is the dependence of the decision from emotion and reflection. There are two extreme types of motivation:
– offensive motivation (approval of impressions and approval of decisions);
– defensive motivation (aversion of feeling and aversion of decision).

Motivation of offensive is motivation in which, action of homeostat supports the decision. The motivation of this, even if the power correlation, flowing through the Vr to Ve due to the appearance of a stimulus S, is not sufficient to cause the reaction R, however, this reaction may be due to flow of the correlation power on the way from $V_h$ to $V_r$ and on the way from $V_e$ to $V_h$. In other words, even a poor impression, but reinforced by perceptions caused by reflections in the form of approval of impressions and decisions, may result in the decision and reaction.

Defensive motivation is a motivation, in which the homeostat action blocks decision. Even if the correlation power which flows on the way from $V_r$ to $V_e$ due to the appearance of the stimulus S, was sufficient to cause the reaction of R, however, this reaction can be prevented by the correlation power drains on the way from the $V_p$ to $V_r$ and on the way from $V_e$ to $V_p$. In other words, even a strong impression, but weakened by perceptions caused by emotion in the form of aversion (disapproval, dislike) of impressions and decisions, cannot make a decision and response of system.

Energy area (fig. 14.7) of the autonomous System includes getting power from the accumulator in cooperation of homeostat and distribution energy to the environment through effectors. With the accumulation of energy in the accumulator, input power and power spent not have to be equal. The larger the capacity of the battery is, the greater the ability of the autonomous system to control itself in the environment, the longer the system can issue energy without simultaneous downloading it from the environment.

Part of the energy drawn from the physiological environment by an autonomous system, is consumed to perform so-called idle work, while the remaining portion is utilized to operate dispositional work. Idle work is the work which has to be done so that the system could exist at all. This work can be compared to the fixed costs of the company, while the company's costs directly associated with the production is dispositional energy of the system.

In fact, we are dealing with streams of energy flowing and flowing out of the system. That is why, we operate with the term power, so the physiological power P, the idle power $P_o$ and the dispositional power $P_d$ (fig. 14.7), wherein

$$P = P_0 + P_d . \tag{14.2}$$

Absorbing physiological power P from the environment is related to the specifically performing work for what must be used a part of the dispositional power, defined as working (operating) power $P_r$. What was left of the dispositional power $P_d$, after covering operating

power is called the free power $P_s$ that can be consumed freely (optionally). Thus,

$$P = P_0 + (P_r + P_s) \tag{14.3}$$

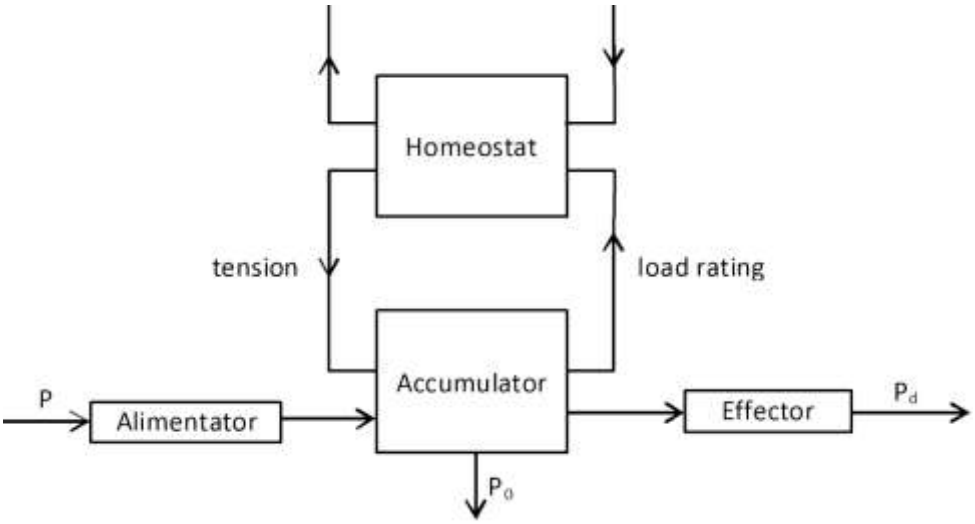



**Fig. 14.7 Energetic area of autonomous system** [10]

For example, a person living on their own work must be obtained in the diet not only energy to cover the basic metabolism (idle power), but also performed their job (working power). Similarly, the industry must have at least as large production, that given income from it could enable to cover overhead cost and the cost of the production.

Thus, the existence condition of an autonomous system is that the physiological power is at least, equal to the sum of the idle and operating power.

The idle power $P_o$ is dependent on condition of the autonomic system and operating (working) power $P_r$ depends of the situation in the environment. The free power $P_s$ can be used to change the situation in the environment for the better, so that to provide the same idle power $P_o$ will suffice less operating power $P_r$. Then, from the dispositional power Pd will remain free power $P_s$ and will enable further improvement of situation. Thus, the free power enables gain so-called sociological power, which used leads to a reduction of working power and, consequently, increase the free power.

The homeostat is an organ common to both areas – information and energy, it indicates that via it the information processes have an impact on energy processes, and energy processes have an impact on information processes. This means that:

– reflection is dependent not only on emotions but also on the accumulator load,

– tension (potential entered to the accumulator by homeostat – fig. 14.7) depends not only on the load of the accumulator but also on emotions (fig. 14.5),

– emotion affects not only reflection, but also tension,

– load of the accumulator affects not only the tension but also the reflection.

Since the correlation power (collerator load) depends on the information effects of environment (ambient) and of the homeostat action; and the physiological power P depends on the energetial effects of ambient and of homeostat action, wherein the homeostat action depends on both the correlation power K and of the physiological power P, so as in a result

the correlation power depends on the interaction of the information and the environment. Similarly, the physiological power depends on the information interactions and energy interactions of the environment.

The analogical situation is with the motivation of action of autonomous system – due to the information impact and energetic impact of the environment on the correlation power, the motivations of the system action have both informative and energetic character.

It follows that, for the proper functioning of the autonomic system, it should have ability of:

1) the collection of information,
2) the issue of information,
3) the intake of energy,
4) the issue of energy.

Information processes and energy processes are closely related. Any deficiencies in one or another impair a person.

According Kossecki [12] human society consists in the exchange of energy (including matter) and information. As a result of the coexistence, it takes place socialization in society, in other words they adapted to the requirements of social life. The process of adapting people to the needs of human social life is to produce the relevant rules of behavior. These rules are called social norms.

Social norms depend on the history of the system – that is, both on the personal stories of people that determines their personal experience, as well as on the history of the whole society. In terms of cybernetics social norms are considered as the relationship between stimuli acting on members of the public and relevant, caused by them behavior (reactions).

Stimuli that affecting the society become the direct cause of social activities broadly divided into:

– stimuli of informational character,
– stimuli of energetical character.

The most important stimuli types of informative character are messages which contain specific ethical commands, not backed up by any threat of reprisals or payment, ideological propaganda convincing the rightness of a given case, the messages containing information on the ambient conditions, satisfying the desire to know the reality, and the payment for which people acquire good information - for example, cultural, cognitive, etc.

The most important stimuli types of energetical character are the repression and the payment for which people acquire various goods necessary for the energetical functioning of their body – food, clothing, fuel, housing, etc.

If stimuli that cause social activities are informative, then we deal with the motivation of information. Conversely, if the social actions are caused by the stimuli with the nature of energy, then we deal with the energetical motivation.

Societies that operate under the influence of motivation of information, they are more energy efficient than the public acting under the influence of power motivation – that calling certain actions require less energy (these populations are therefore less loss of energy). This is because the people who work under the influence of ethical motives, ideological or driven by selfless desire to know the truth does not need to be coerced, controlled or highly paid as

people working under the influence of power motivation. It should be remembered that the public in order to be able to take any action must always have provided the energy necessary to perform these actions.

Cybernetics treats social norms as the relationship between the stimuli acting on members of the public and relevant, caused by them reactions (action).

Kossecki [12] defines five specific norms which affect the motivation of human action:

1) *Cognitive norms*. They define what in a given society is considered to be the truth, what are the criteria of truth, also what should be the method of reaching it. The desire to know the truth (hunger for information) becomes the motive of people action. These standards are the result of learning by man about the human surrounding world and himself. Next, these norms have the same effect on this process. There are categories of institutions that produce cognition norms. These are: scientific institutions, administrative institutions, institutions of mass media information.

2) *Constitutive norms*. Define the structure of society and its reactions to the environment. This means that they define the relationships between the various organs of the society as an organized system and the reactions of the public in relation to the external environment, from the point of view of society business as an independent system. The most important types of constitutive norms include: ideological norms, ethical norms, legal norms.

3) *Aesthetic norms.* They have a close relationship with the whole culture of the society; include arts and aesthetics generally understood. Art on the one hand reflects the mentality of the society, on the other hand is shaping it. Norms and aesthetic stimuli can negatively or positively impact on all other types of social norms, they can serve a variety of functions in the life of Individuals and society, and the therefore the related motivations with them are mixed. Aesthetic norms also always played a certain role not only in the cognitive area or in the ideologically ethical, but also in the field of biological and economic live (development) of society. Art-related Institutions can operate spontaneously, but can also exist in an organized manner, and even undergo far-reaching formalization.

4) *Economic norms*, estimate, what is beneficiary for the society, and what is not beneficiary regarding economics, also identify methods for achieving the economic benefits. These norms are developed by the aspirations of the people to ensure for themselves and other members of the society, energetical recourses of living. That is why, among the motivations related to economic norms, motivations about an energetical nature dominate.

5) *Vital norms* determine what is healthy for people and what is unhealthy for them, from the point of view of the physiological functioning of the body and determine how to maintain human health in appropriate condition. For that they are often called health norms. Specific importance here has the adequate legislation, for the public health issues, and the level of ethics, especially medical ethics. The development of vital norms has a significant impact on all areas of society and, therefore, on all kinds of social norms.

Between different groups of social norms there is a strong correlation, stimuli associated with one group of norms can result social activities within the range of another group norms. For example, under the influence of ideological precepts, people can take action of a scientific, economic, health or the arts nature.

Systems of social norms should be so shaped and so harmonize with each other to

assure to provide to the society ability to keep functional balance and the development of its own structure under certain external and internal condition and the possibility of achieving the desired objectives. So, if the conditions are changing in which society operates, must also change the adequate social norms.

Change of ones social norms leads usually as a rule to the need of change also other norms. For example, changing the state of our knowledge of reality often involves not only a change of cognitive norms, but also the economic and health norms, which in turn could lead to a change of legal norms. Understanding the new laws of physics can become a basis for the invention of new tools for work, and this in turn may result in a change of economic norms, which sooner or later will also have impact on the changes other social norms, especially legal norms.

Presented above breakdown of social norms is very useful for the study of control processes in society. It turns out that in the case of social activities related to the norms cognitive and constitutive norms (ideological, ethical and legal, if they are based on the conviction of its rightness, and not just on the threat of repression) there is a predominance of informative motivation; in case of social activities related to economical and vital norms we have the advantage of an energetistic motivation (repression, payment); while the aesthetic norms occupy an intermediate position

In the cognitive norms participation of informative motivation is the biggest, while in the vital norms the biggest is participation of the energetistic motivation.

The fig. 14.8 shows the share of motivation of information I and energetical motivation E in the respective types of social norms.

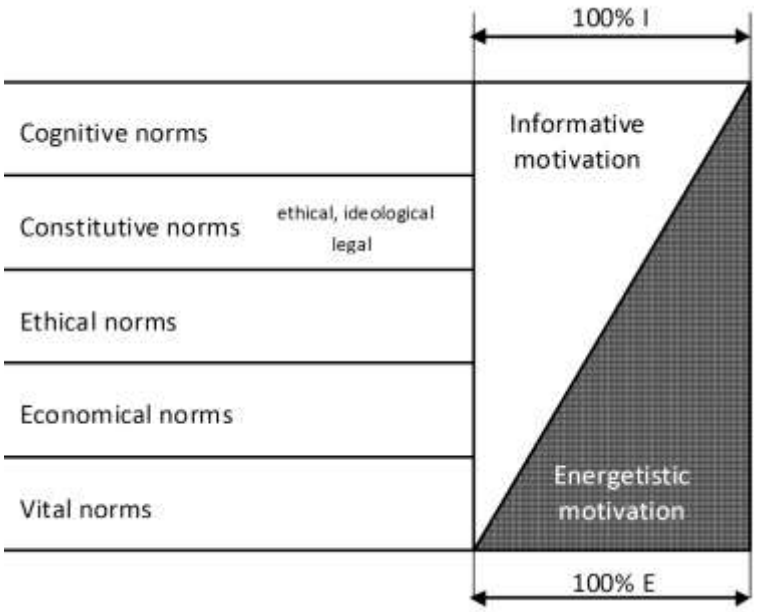



**Fig. 14.8 Share of informative motivation I and energetistic motivation E in the particular types of social norms** [12]

The role of informative and energetistic motivation very clearly is seen when observing the work of people in different areas of social life. Real scientists are working on issues of interest to them regardless of the payment and whatever other personal benefits. One example

can be here Albert Einstein, who developed his theory of relativity at a time when he was not a professional researcher and could not aspect any material benefits of these materials. Similarly, the idealists who worked under ideological or ethical influence, they can gain a great deal of effort and dedication, not only do not waiting for the payment, or any other material benefits, but even in spite of different energetistics stimulus, by the means of which, the opponents often try to get them appropriate action to be discontinued [12].
On another hand, in the economic activities it is difficult to imagine, for example, the workers working for a long time without proper payment, or officials in the company worked with no hope of advancement and related to it material benefits. Similarly, in the case of measures aimed at improving health. It is hard to imagine, that people for a long time took up in the social scale, various activities (e.g., environmental protection) for which they do not have any grounds to expect that actually, it improves their health.

## 14.4 MOTIVATION IN TERMS OF THE COMPARATIVE STUDY OF CIVILIZATIONS

A single set of social norms covering the entire social life is called civilization [13, 14]. These norms govern the principles (rules) relationships that taking place between people in society. Social relations are associated with the proceedings, human action in his environment. The reasons for such actions, these are motivations. Because the rules for the organization of collective life in every civilization are diversed, so too are diversed motives of actions.

Koneczny [15] has provided tools to identify the individual civilizations with. Identification is possible by analyzing the characteristics of civilization compared to the category of social existence, they are:
1) Good (ethics, law and ideology guiding the social life).
2) True (its widely understood system of education and information).
3) Beauty (fine art and aesthetics).
4) Health (social norms laying down the rules of hygiene, medicine and therapeutics).
5) Welfare (economic activities, institutions, economic systems, and all the factors that ensure the material being).
A more detailed description of the categories of social existence can be found in [13, 14, 15].
In a comparative study of civilizations health and welfare are called material categories, as it is related to meeting the physical and material needs of man.
The good and the truth is called spiritual categories spiritual as it is related to the life and work of human, and meet the needs of a higher order.
Beauty occupies an intermediate position, belonging partly to the spiritual and partly to material categories.

On the basis of the category of social existence can therefore be characterized the various types of human or in other words - people with certain preferences (motives) of activities. These are people with informative and energetistic motivations.

People with informational motives perceive the social existence in terms of good and truth; they are taking the cognitive actions, contributing to the increase in the progress of science, technology and art.

People on the motivation of energy, perceive social existence in terms of public health

and welfare. In the simplest terms is this consumer's type.

The present division recognizes opposite types of people to clearly show the differences in the motivation of action. Often, however, we are dealing with the intermediate's types, which in terms of motivation are very diverse.

## 14.5 THE EFFECTIVENESS OF INFORMATION

In the control (driven) theory motivations of human actions are essential. By information's impact on society can be shaped norm-types of social behaviors and then can be effectively controlled in order to achieve the desired functional balance.

Information transmitted by the technical system to the environment, in order to achieve a favorable balance of functional, should fulfill the following functions: integrative, cognitive-methodical and selective [11, 12].

The integrative function is to develop homogeneous norms of social behavior. The methodological-cognitive function is to inform about the progress in the given field and to indicate the direction of change. The selective function is reduced to the impact of information on a particular social group.

The implementation of these functions makes it easier to obtain a part of society that will identify them-self with the system forcing changes. Implementation by the information specified functions is a necessary but not sufficient condition in order to guarantee the effectiveness of the information.

The effectiveness of the control information will depend on whether it will be done according to certain rules. Rules of transmitting information are used to provide information to the planned impact on the psyche of people with an informative stimulus to induce appropriate action or shape appropriate social norms [12].

The principles for submitting information are [11, 12]:

1) The principle of truth – it means harmony of the derived information derived with the information in the appropriate collection of originals, especially the experience of society.
2) The principle of mass and long duration of action – as true are accepted these information which come from different sources or are transmitted over a long period of time.
3) The principle of desired information – accepted as true are these information which correspond to the most people, and whose realization would like to see.
4) The principle of emotional stimulation – refers to feelings and usually has an advantage over the information only operates on a rational argument.
5) The principle of rationality – the informations must be understandable or raise specific associations.
6) The principle of specialization – adjusting information to the level and terms of different environments, on which information want to impact.
7) The principle of not putting dot on "i" – means that the information should not always indicate a course of action but to stimulate motivation associated with cognitive norms.
8) The principle of the alleged (pretended) obviousness – is proving the thesis other than the one you actually want to promote.
9) The principle of gradation – occurs when the changes that a technical system wants to call in the environment are so deep, that the sudden attempt to carry them out could meet with

harsh resistance from the environment.

As mentioned above, the transmission of information is planned impact on the psyche by a stimulus of informative character. This does not mean that by the informative impact may be treated only people with informative motivations. Model of autonomous system clearly shows that the correlation strength depends on the impact of information and energy of the environment. Similarly, it happens with the physiological strength. This means that regardless of the motives of human action (autonomous system), you can affect him by the incentives (stimulus) both information and energy.

The efficiency of information on the environment will depend on the degree of use the above principles. Remember to correct, according to the rules, the preparation and content of the communication process and about to whom the information is intended (addressed). Also remember about the recipient's motivations if they are of the type of information or energy, because on the motivation depends not only the receipt of information but also the way of respond to the information.

Table 14.1 shows the effectiveness of the various rules contained in communications of information in regard to the people with the informative and energetistic motivations. (+) Sign means the effective information interaction, and the sign (—) means no effective interaction.

**Table 14.1 The effectiveness of the procedures for submitting information in relation to people with informative and energetistic motivations, (+ - effective interaction, — - ineffective interaction)**

| S.n. | Principle of submitting information | People with information motives | People with energy motives |
|---|---|---|---|
| 1 | The principle of truth | + | + |
| 2 | The principle of mass and long duration of action | — | + |
| 3 | The principle of desired information | — | + |
| 4 | The principle of emotional stimulation | — | + |
| 5 | The principle of understandability | + | + |
| 6 | The principle of specialization | + | + |
| 7 | The principle of not putting dots on „i" | + | + |
| 8 | The principle of alleged obviousness | — | + |
| 9 | The principle of gradation | + | + |

From Table 14.1 we can see that the effectiveness of impact assessments of information is much higher for people with the energy motivations. No doubt this is due to the fact that the recipient of information motivations are able to read the actual content of the message, understand the intention of the emitter. Recipients of the motivations of power, either in the struggle for existence, or in order to achieve immediate benefits do not read the intentions of the emitter information but yielded to them frequently uncritically. If there is manifested desire to verify the information transfer, it is usually done through trial and error.

To get more familiar with the data contained in Table 14.1, we may use the following example of the information impact.

**Example**

The TVP I, the morning news (February 2000), among others, issued the following statement: "In France, drivers' strike demanding higher wages for a shorter work week." This

short text on strike was accompanied by a commentary about the social burden of strikes and material losses generated by the strikes.

From the content of the strike can be concluded that French drivers not only did not want to work, but more than that they want to compel the authorities to higher salaries. In this transmission strike is unjustified and, in addition, of course, to burdensome for the public.
Here are the facts of the events of that period. For the automotive's strikers, of haulage sector (France) administratively reduced the work week from six to five days. Reduction in earnings resulted from a short-time working. On the other hand, shorter working hours caused a decline in the competitiveness of the French transport companies in Europe (in the rest of the European Union the working week for track's workers was six days). The strikers have used roadblocks and have demanded the restoration of the six-week of work or compensation for losses (e.g. in the form of subsidies), as a result of the administrative decision.

The principle of the true here is fulfilled both for people with informative's motivations and energy information. People with informative's motivations will take this messages as at least incomplete, and therefore requiring review, as a result, they will know the real course of events. People with the energy motivations energy can take this information as a real one. Information about the strike in the rich Western Europe can be received by people in Central and Eastern Europe as an attempt to further improve the strikers' existence in the country already, with high standard of living.

If the information is broadcast at least for the duration of the strike, then for people with the energy motivations sustainability principle is fulfilled and the multitude of operation rule is also fulfilled. People with the information's motivation are immune to this rule, as the quality of information does not depend on its exposure to time.

The transmitted information can inspire or at least justify the claim of an energetic group of workers with the lowest standard of living. It performs the required information for people with the energy motivation. It is different for people with information's motivations for which information is desired that one which is due to their profession or interests. This does not mean that people with these motivations cannot carry out protest actions. Indeed yes, - for example, protests against the war, but the supplied information must be characterized by high integrity and complete, honest (reliability).

For people with energy motivations is met principle of emotional stimulation. This applies to those people who claim they stand out and prepare employee strikes and those who believe that because of strikes affecting them, they experience too great annoyance in everyday life – for example, because of roadblocks. For people with informative motivation principle of emotional stimulation does not apply, because their behavior is based on rational thinking. Indeed, the emotions they might take place – for example, protests against human rights, commitment to life-saving action, humanitarian actions, etc.

The principle of comprehendness (rationality principle) is satisfied for both the people with informative motivations and with energy motivations. People with motivations of information, based on the information given in the example, may investigate the actual intentions of the emitter. For people with energy motivations in the countries of Central and Eastern Europe, the information can be seen as the next step claims of workers' organizations in Western Europe, against employers.

Similarly as before, the specialization rule here is met. The information message is well correlated with the level of concepts from both communities with informative motivations and energy motivations. For those communities such topic as strike is well known because of the many strikes in the modern world.

The principle of not putting dots on "i" should promote the motivations associated with the cognitive norms. It refers not only to the people with informative motivations but also with energy motivations. According to this principle, the information should be presented to the recipient himself so he could draw the conclusions. Then he will identify himself with the final thesis being sure that it is the result of his independent thinking. For people with the informative motivation final conclusion can be complete knowledge and understanding of the events related to the strike of French transport workers. In the case where people are with energy motivations, may arise two communities with opposing views. One, they considered that the strikes are a source of instability and deterioration in strikers standard of living, while the second – will be seen in strikes an opportunity to improve the conditions of strikers existence.

In principle of the alleged obviousness fact, actually promoted the idea is given as a fact, but the thesis being proven are of minor importance. In the given example, the fact of certainty is the totally unfounded led strike (demand higher wages for less work), and the thesis being proven are hardship and economic losses caused by the strike.

But keep in mind that the essence of the strike is just causing a nuisance in all available forms. The strike is the energy impact of protesting people in the situation, when the information impact was not effective (for various reasons).

From these few comments is obvious that the principle of the alleged obviousness is effective only for people with energy motives.

The principle of gradation is used when the target state which is to take place in the system or the environment is far from the status quo. This principle is effective impact of information works for both for people with energy motivation and people with energy information. It is used for e.g. in science, medicine, sports and the economy. It plays an important role in the struggle between competing technical information systems [11].

It is difficult to assign the principal of gradation to the information in describe above example. It should have some information issued in a certain period of time, consider taking the correlation between them and if any occur – implicate thesis on the real purpose of the information's influence. Despite these obvious disadvantages, taking into account the contents of this form of communication can be risk a string of probable impacts of successive information: to deter strike, ignoring the strikers, repression of strikers.

The effectiveness of information thus depends on the intentions of the emitter and the nature of the motivation of people to whom the information is addressed. The example shows that the issue of information by the technical system can cause different effects of control in an environment of informative motivation and energy motivation. Moreover, the same information can divide the environment with energy motivations into two antagonistic groups. In the shown example they are the proponents and opponents of strikes.

## DISCUSSION AND CONCLUSIONS

Motivations of activities play an important role in human life. They have influenced the course of his education, career and personal life. What's more, motivations are constantly under shaping, they are a result of psychological adjustment. This means that it can be influence on the motivations, human motivations can be controlled. Developing the motivations actually, this is control of human activities in order to achieve the desired effect.

Determinants of human motivations are well recognized as a result of psychological and sociological research. It systematized them into two main groups. First one of an energy character contains factors: such as wages, the need for social and cultural life and the wider consumption, safety in terms of health and existential. Second one informative refers to the spiritual (internal) of man and contains min. factors such as the need to possess the knowledge, ethics, recognition at work and possible activities for the public (e.g. charities). Depending on which factors are preferable for the division of people's motivations respectively with energy, and the motivations for such information. The same result occurs on the basis of cybernetics, and comparative study of civilizations.

Control of human beings to change the motivation in the performance of the same action can alter the efficiency of the system. Of course, such a change may be beneficial to the system (increased productivity, better quality of production), or fatal in consequences (loss of productivity and quality, staff turnover). Confirmation of the positive impact of changes in motivation to score production will let the following example [16].

In the 70s of the last century were carried out in Poland sociological research, which aimed to study the influence of awareness on the quality of the worker's work he does. It was promoted the view that the employee does not need to know what for serves element on which he is working on. Just will be enough that he will do it according to the technical documentation. The economic stimulus will be the factor that will ensure a high quality of work, understood as minimizing the defects. It was done by letting two different factories, the departments machining, to perform the same elements. The staff of the first department did not know which these elements are used for. They should perform it according to the technical documentation and the economic pressure – the more products with defects, the lower the discretionary premium.

To the employees of the second division, was exactly explained that they produce machine parts to the modern combine with specification what kind of function these parts will perform in this machine. Of course, in the second department uses the same technical documentation and for deficiencies was applied the same economic pressures.

Evaluation of the work of each department was the amount of defects created in the production process. It turned out that more defects noted in the first department. Therefore, greater effectiveness was characterized work done by second department. This example shows that the informational motivations of workers have a very positive impact on the functioning of the technical system.

Control processes of human beings take place in the area of the system, as well as, focused on the environment, where there are also other technical systems.

As part of the given technical system, the task is to control the phenomenon of homeostasis, so that will maintain the desired internal state of functional balance, which

comes down to for e.g.: high productivity, continuous improvement of the offered products, a high level of education whether to continuously and effectively reduce the cost of living of the population. The guarantor of effective homeostasis is to prefer stimuli of informative character.

The impact of the technical system on the environment is control processes, which purpose is to produce a functional balance between the system and the environment. The interaction can take various forms depending on the purpose, which was selected by the system. Because people with the energy motivation are more susceptible to control, so purpose of the initial (pilot project) impact on the environment is to develop in it energetistic motivation. This process can be lengthy and not always (for various reasons) succeeds. For striking example of actions aimed at changing people's behavior motivation are the times of occupation or annexation (conquests). Towards enslaved population informational constraints are much more severe than energy. Aboriginal population was mainly needed to perform physical labor, so it had to provide the necessary force (labor power). Delivered to them knowledge was only related to work and it ensured the maintenance of obedience.

Although such drastic methods it is difficult today to experience, it must be remembered that in a highly competitive environment need to continually reduce the cost of production. The main component of these costs is salary (wages). Therefore, efforts to acquire, so called cheaper labor force, it will focus on shaping energy motivation societies. On the other hand, the comprehensive development of society requires shaping the attitudes of an informative nature.

So it comes to a situation that seemingly has no satisfactory solution. But the experience of the societies of the past periods shows that the key to solving is to develop in them appropriate attitudes, motivating effective human action, even in very difficult socio-economic circumstances.

## REFERENCES

1. PG Zimbardo P.G., Ruch F.L., Psychology and Life, Scientific Publisher PWN, Warsaw, 1996, s. 312.
2. Reykowski J., Emotional processes, motivation, personality, General Psychology, edited by Tadeusz Tomaszewski, Scientific Publisher PWN, Warsaw, 1992, p. 113.
3. Maslow A., Toward a psychology of being. Publishing House "Rebis", Poznan, 2004.
4. Maslow A., Motivation and personality. Scientific Publisher PWN, Warsaw, 2006.
5. Theories of motivation in remuneration systems, http://hrwpraktyce.blogspot.com/2012/07/teorie-motywacji-w-systemach.html, 2012.
6. Pavlovska B., Theories of motivation, The Institute of Sociology at the University of Lodz, Lodz, 2005, p. 3.
7. Cofer Ch. N., Appley M.H., Motivation: Theory and research, PWN, Warsaw, 1972, p.14
8. The mechanisms of formation of motivation, http://www.nauki-spoleczne.info/mechanizmy-tworzenia-sie-motywacji, 2008.
9. Mazur M., Social significance of cybernetics, New Road, No. 5, 1980, pp. 152-163.
10. Mazur M., Cybernetics and character, PIW, Warsaw 1976.

11. Wojcik J., Information management for technical systems, The Polish Association for Knowledge Management, Studies and Research, No. 40, Bydgoszcz 2011, s. 344-355.
12. Kossecki J., Cybernetics culture, PIW, Warsaw, 1974.
13. Kossecki J., Fundamentals of comparative study of civilizations, Pedagogical University in Kielce, Kielce 1996.
14. Wojcik J., Civilizations and production methods, SSPE, Monographs, Gliwice 2012, s. 250-266.
15. Koneczny F., The multiplicity of civilizations, Publisher Antiquity, Warsaw, 2002.
16. Goćkowski J., Lectures on social engineering, Technical University of Wroclaw, Wroclaw 1979.

## MOTYVATION AND CONTROL IN TECHNICAL SYSTEMS

**Abstract:** *The study presents issues related to the motivation of human action and its shaping. The issues are presented from the point of view of psychology, sociology, management science and cybernetics. It was found that in the application of appropriate stimuli may affect motivation to change and consequently the change in quality of performance. The common denominator of these areas of study is the conclusion that the motivation may be the result of the conditions of information or energy. Maslow, human motivations, addicted from needs. He introduced the so-called pyramid of needs, from which it follows that the greatest impact of human motivations are the needs of an energetistic nature. But the Herzberg in his two-factor theory of motivation found that motivations are the result of exposure to man, so-call motivators such as stimuli (incentives) of the informative nature. At the same time he provided the conditions which made the effectiveness of these motivators. Mazur introduced the man as an autonomous system and describe the processes that determine the motivation of action. He said that the man, as the system must be able both to retrieve from environment as well to place on in to the environment, the information and energy. This means that the motives of human actions can have only informative and energetistic character, what largely corresponds with the results of sociological research. Kossecki linked motivations of human activities with distinctive social norms and depends of the human norm type, he found that motivations can be informative, energetistic, or mixed. To similar conclusions is reaching when it is depending the type of motivation of man's relation to the basic categories of social existence, given by Koneczny. Using the principles of transmission of information it has been shown that the efficiency of the control depends on the motivation. People with the energetistic motivation are more likely susceptible to control. In the discussion are presented examples of control in technical systems, typical for the problems presented in the work.*

**Key words:** *motivation, control, technical systems, the impact of information*

## MOTYWACJE I STEROWANIE W SYSTEMACH TECHNICZNYCH

**Streszczenie:** *W pracy przedstawiono zagadnienia związane z motywacją działań człowieka i jej kształtowaniem. Problematykę przedstawiono z punktu widzenia psychologii, socjologii, nauk o zarządzaniu oraz cybernetyki. Wspólnym mianownikiem wymienionych dziedzin nauki jest wnioskowanie, że motywacja może wynikać z przesłanek informacyjnych lub energetycznych. Masłow motywacje ludzkie uzależnił od potrzeb. Przedstawił tzw. piramidę potrzeb, z której wynika, że na motywacje człowieka największy wpływ mają potrzeby o charakterze energetycznym. Z kolei Herzberg w swojej dwuczynnikowej teorii motywacji stwierdził, że motywacje są wynikiem oddziaływania na człowieka tzw. motywatorów, tj. bodźców o charakterze informacyjnym. Jednocześnie przedstawił warunki, od których uzależnił skuteczność tych motywatorów. Mazur przedstawił człowieka jako system autonomiczny oraz opisał procesy determinujące motywacje działań. Stwierdził, że człowiek jako system musi mieć możliwość zarówno pobierania z otoczenia jak i wprowadzania do niego informacji oraz energii. Oznacza to, że motywacje działań człowieka mogą mieć tylko charakter informacyjno-energetyczny, co w dużym stopniu koresponduje z wynikami badań socjologicznych. Kossecki powiązał motywacje działań człowieka z charakterystycznymi normami społecznymi i w zależności od normotypu człowieka stwierdził, że motywacje mogą mieć charakter informacyjny, energetyczny lub mieszany. Do podobnych wniosków dochodzi się uzależniając typ motywacji od stosunku człowieka do podstawowych kategorii bytu społecznego, podanych przez Konecznego. Posługując się zasadami przekazywania informacji pokazano, że skuteczność sterowania zależy od rodzaju motywacji.*

**Słowa kluczowe:** *motywacje, sterowanie, systemy techniczne, oddziaływanie informacyjne*

dr inż. Juliusz WÓJCIK
Silesian University of Technology, Faculty of Organisation and Management
Institute of Production Engineering
Roosevelta 26 Str., 41-800 Zabrze, Poland
tel.: +4832 277 73 72
e-mail: juliusz.stanislaw.wojcik@polsl.pl

# 15

# EMISSION INVENTORY FOR LIGNITE BASED PUBLIC POWER AND ENERGY SECTOR – MERGING INFORMATION FROM VARIOUS SOURCES

## 15.1 INTRODUCTION

Compilation of the national emission inventory always is connected with possibilities of committing mistakes, misuse or misunderstanding the data. According to Frey's approach [1, 2], there are rarely known real values of estimated uncertainties, however his identification of main sources of uncertainties is still of the moment. Understanding of the sources of uncertainties and possibility of misusing the data is strictly connected with compilation of emission inventory accordingly to "best practices", described as IPCC guidelines (GHGs) [3, 4] or guidebook (air pollutants) [5] and should guarantee proper quality assurance and quality control (QA and QC) of used data.

The result of emission inventory, considered as a single value describing annual emission of particular compound to atmosphere is always charged with various uncertainties. Emission inventory for significant sources, like public power and energy sector merge pieces of information from: statistical surveys (Polish Main Statistical Office and EUROSTAT), data from NED, specific data on GHGs emission from EU–ETS[1], national emission factors and fuel characteristics. A large number of analysis is still based on expert knowledge. Strictly statistical calculations are used in the first step – for obtaining input data, or as final tool for quantitative assessment of uncertainties.

Polish emission inventory reports, elaborated at the National Centre for Emission Management (NCEM) (the part of Institute of Environmental Protection – National Research Institute) for the purposes of international conventions, EU directives or as another obligations, are the final link in the chain of compilation of emission inventories.

The article shows, how works merging the pieces of various (scientific and technical) data in the context of compiling of carbon dioxide emission inventory for public power and energy sector based on lignite.

## 15.2 HOW DOES IT WORK

In practice, the national GHGs inventory is compiled similarly to many other elaborations where merging of information from various sources is required, also with using the specific guidelines providing the proper level of QA and QC [6]. However that guidelines

1 European Union – Emission Trading Scheme

are not straightforwardly connected with experimental procedures or measurements and they are rather second step of QA and QC in the context of supplying proper result of the inventory, considered as emission of particular compound to air. Apart from meticulously following the guidelines, there is still some space for including *ad hoc* results of scientific surveys, measurements, sectoral analysis national forecasts or simulations.

The good example of that kind of data management is estimation of carbon dioxide emission from combusted lignite in public power and energy sector.

The emission of $CO_2$ from combusted lignite is estimated by the following formula:

$$E_{CO2,\ lignite} = A_{lignite} \times EF_{CO2,\ lignite} \tag{15.1}$$

where:

$E_{CO2,\ lignite}$, emission of $CO_2$ from combusted lignite,

$A_{lignite}$, mass of combusted lignite,

$EF_{CO2,\ lignite}$, named the emission factor, represents the mass of $CO_2$ created from mass of combusted lignite.

The value of emission factor comes directly from carbon content in lignite. Emission of carbon dioxide from combusted lignite comes directly from carbon content in lignite. There is assumed that total carbon content in lignite is converted to $CO_2$ during combustion process.

Currently published results of the scientific elaborations show using observed correlation between carbon content and net calorific value for lignite for obtaining domestic emission factor from combusted fuel [7, 8, 9]. The generated formula is linear in both approaches: by Fott [7], based on data from Czech coal and lignite and by Stefanović et al. [8, 9], based on Serbian lignite from Kolubara basin. The main difference between following approaches concerns Kolubara lignite, where the combustible part of coal (represented by 100 reduced by sum of ash and water content, all values expressed in percents) is also taken into consideration.

Polish data on lignite held by NCEM was also analyzed for obtaining emission factors from carbon and lignite. Current state of analysis, including separate formulas for hard coal and lignite is included in national emission inventory report [10]. Formulas currently used for compilation of the Polish emission inventory are a result of investigation of the linear correlation between obtained measurement data on carbon content and net calorific value for lignite.

Accordingly to Frey's elaborations [1, 2] that kind of analysis might be problematic in the context of his classification of various uncertainties. Apart from statistical uncertainties, enumerated by Frey and earlier investigation done by Jagóra and Szwed-Lorenz [11], there are also identified problems with geospatial matters on obtaining average values of the qualitative parameters of lignite [12, 13, 14, 15, 16]. Apart from problems mentioned above, there are still problems with new opencast mines in Poland till 2040 [17] and new possibly available data on qualitative parameters of lignite.

Problems listed above and also other various discrepancies might make the current analysis [10] quickly outdated.

## 15.3 METHODOLOGY AND ANALYSIS

Part of previously analyzed dataset [10], held by NCEM, concerning data on measured

carbon content and net calorific value of lignite combusted by Pątnów power plant.
The following analysis presents the characteristics of the held sample (further named: "Pątnów" sample, where Ctr is carbon content in lignite, expressed in % and Qir is net calorific value in lignite).

### *Summary statistics*

Following table presents summary statistics for Ctr and Qir of "Pątnów" sample (table 15.1):

**Table 15.1 Summary statistics of the Pątnów sample**

| Parameter | Ctr [%] | Qir [MJ/kg] |
|---|---|---|
| Minimum | 23.40 | 8.005 |
| 1st Quartile | 25.28 | 8.967 |
| Median | 25.90 | 9.136 |
| Mean (average value) | 25.92 | 9.127 |
| 3rd Quartile | 26.57 | 9.295 |
| Maximum | 30.07 | 9.961 |
| Shapiro – Wilk normality test result ($\alpha = 0.05$) | + (p-value: 0.0661) | - (p-value: 0.0052) |

### *Further analysis*

Following the analysis, conducted by Fott [7] also partly analysis by Stefanović et al. [8, 9], there are scatter-plot presenting dependency between Ctr and Qir in "Pątnów" sample. The look of plot shows that is highly probable that combusted lignite from "Pątnów" sample came from 2 independent sources and it is not possible to describe the Ctr (Qir) dependency in simple way, with using only one linear formula (fig. 15.1):

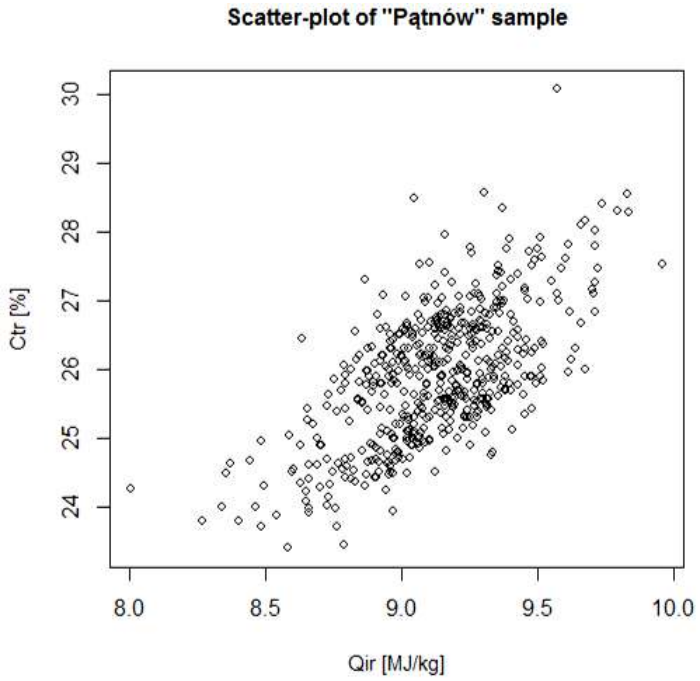



**Fig. 15.1 Scatter-plot. Dependency between Ctr and Qir in "Pątnów" sample**

For more detailed analysis there is presented, histogram of auxiliary factor *a*, (table 15.2), expressed in: % × kg × $(MJ)^{-1}$, derived by following formula:

$$a = Ctr \times (Qir)^{-1} \quad (15.2)$$

**Table 15.2 Summary statistics of the factor *a***

| **Parameter** | ***a* [% × kg × $(MJ)^{-1}$]** |
|---|---|
| Minimum | 2.654 |
| 1st Quartile | 2.774 |
| Median | 2.835 |
| Mean (average value) | 2.840 |
| 3rd Quartile | 2.906 |
| Maximum | 3.148 |
| Shapiro – Wilk normality test result ($\alpha = 0.05$) | - (p-value: $2.607 \times 10^{-7}$) |

Histogram of factor *a* is made for 100 breaks within the interval, between minimum and maximum of *a*.

Shape of histogram of the *a* factor (fig. 15.2), confirms probability of mixing 2 independent sub-samples within "Pątnów" sample. The split point of "Pątnów" sample was identified by using "stem and leaf" (fig. 15.3), plot of factor *a*.

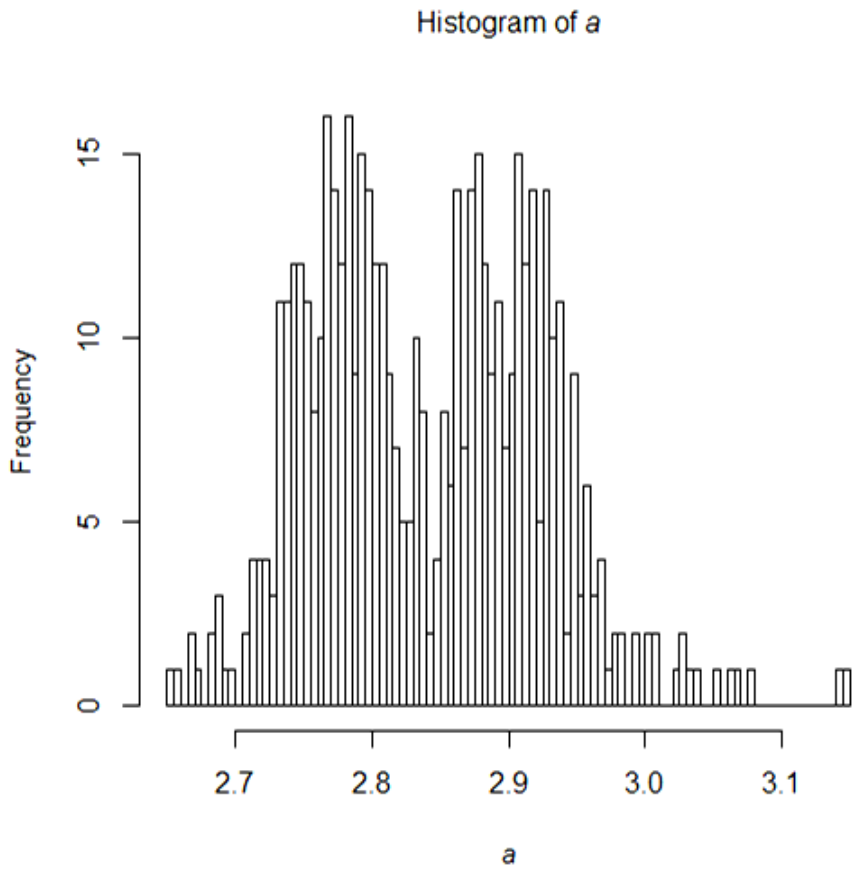



**Fig. 15.2 Histogram of factor a**

264 | 46
266 | 891
268 | 0266049
270 | 7803456679
272 | 345567801222334444677788999
274 | 000112222344456667788999000111233334477999999
276 | 0001122244555566666888899990111123334444555677889999
278 | 000001112233344556667888880011111222233555666667888899 9
280 | 00122223444555667778889911233344567899 99
282 | 11235556900112333555566677 79
284 | 23668000112444666667
286 | 00111222233444557889001122223334455556666778899
288 | 000011233344455589999999011113334445788899
290 | 011334445566666677788899000111122233566667888999 9
292 | 00123355666666777788911111223456666677889
294 | 013666677890445577889
296 | 1245888177
298 | 2422
300 | 1167
302 | 36026
304 | 2
306 | 208
308 |
310 |
312 |
314 | *28*

**Fig. 15.3 Stem and leaf plot of factor *a***
**(The assumed split point is bolded, the probable outlier values is marked *italic*)**

### *Analysis of sub-samples*

Splitting "Pątnów" sample to 2 independent sub-samples created possibility of create 2 independent linear formulas describing dependency between carbon content and net calorific value in lignite. Following table 15.3 presents basic statistics for split "Pątnów" sample:

**Table 15.3 Summary statistics of the "Pątnów" sample and derived sub-samples**

| Parameter | Pątnów sample | | 1st sub-sample | | 2nd sub-sample | |
|---|---|---|---|---|---|---|
| | Ctr [%] | Qir [MJ/kg] | Ctr [%] | Qir [MJ/kg] | Ctr [%] | Qir [MJ/kg] |
| Minimum | 23.40 | 8.005 | 23.40 | 8.401 | 23.80 | 8.005 |
| 1st Quartile | 25.28 | 8.967 | 24.89 | 8.993 | 26.05 | 8.942 |
| Median | 25.90 | 9.136 | 25.43 | 9.170 | 26.51 | 9.105 |
| Mean (average value) | 25.92 | 9.127 | 25.39 | 9.157 | 26.49 | 9.095 |
| 3rd Quartile | 26.57 | 9.295 | 25.86 | 9.325 | 26.91 | 9.262 |
| Maximum | 30.07 | 9.961 | 27.53 | 9.961 | 30.07 | 9.836 |
| Shapiro – Wilk normality test result ($\alpha = 0.05$) | + (p-value: 0.0661) | - (p-value: 0.0052) | + (p-value: 0.6162) | + (p-value: 0.6913) | - (p-value: 0.0003) | - (p-value: 0.0027) |

Similar technique was used for analysis of 2nd sub-sample. Results are presented below.

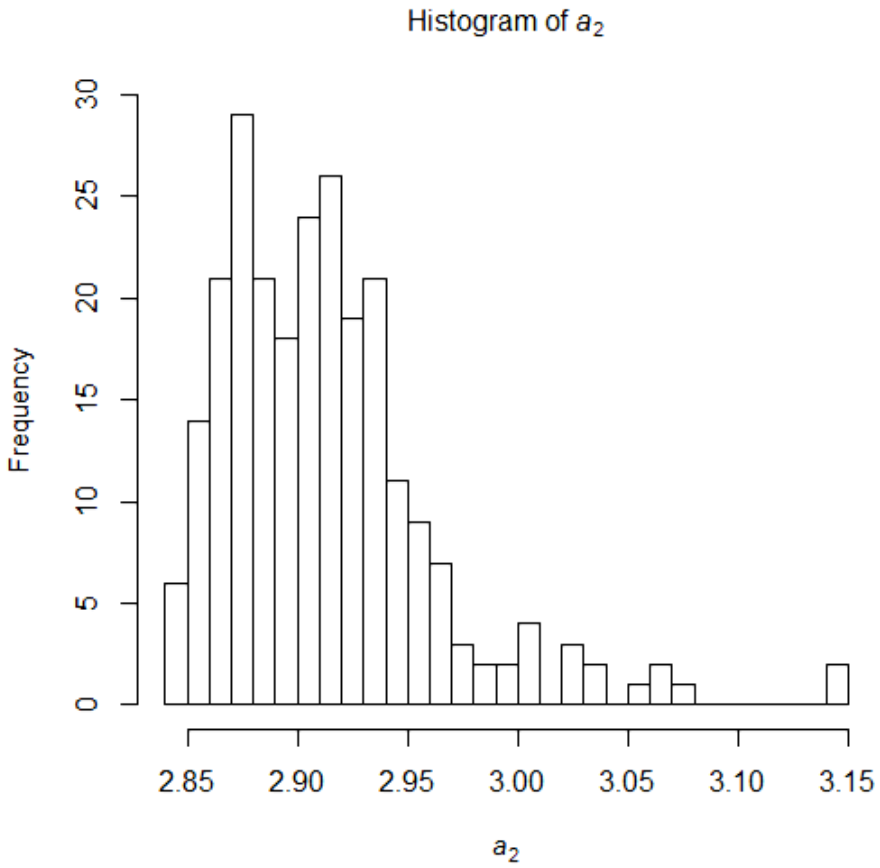



**Fig. 15.4 Histogram of factor $a_2$**

**Table 15.4 Summary statistics for fator $a_2$, derived by using formula** (13.2)

| **Parameter** | **$a_2$ [% × kg × (MJ)$^{-1}$]** |
|---|---|
| Minimum | 2.842 |
| 1st Quartile | 2.877 |
| Median | 2.906 |
| Mean (average value) | 2.913 |
| 3rd Quartile | 2.933 |
| Maximum | 3.148 |
| Shapiro – Wilk normality test result (α = 0.05) | - (p-value: $1.107 \times 10^{-12}$) |

Presented histogram (built for 25 classes) and parameters in table below suggest that combusted lignite ("Pątnów" sample) came from more than 2 independent sources. Also the shape of histogram on the figure 15.4 suggests existence of 2 independent samples or bimodal distribution of sample. Independent source of coal could be separate mining plant in the neighborhood of power plant or separate bed in the same mine.

Further analysis and splitting of sample is rejected due to constantly decreasing number of elements in sample and possibility of committing significant mistakes.

### *Dependency between carbon content and net calorific value*

The empirical formulas of dependency were built for "Pątnów" sample and 1st sub-sample, using investigation of Pearson's correlation coefficient (cor) and least square method (for fitting linear function of regression). Below there are presented results of analysis and little comparison between applying approaches of: Fott [7], Stefanović et al. [8, 9] and currently used in Poland [10].

**Table 15.5 Results of analysis – empirical formulas describing investigated dependency**

| Sample | cor (Ctr, Qir) | Formula |
|---|---|---|
| Pątnów sample | 0.6448 | Ctr = 2.339 × Qir + 4.546 |
| 1st sub-sample | 0.8835 | Ctr = 2.547 × Qir + 2.064 |

For comparison between formulas there are assumed combustion of 10.000 tons of lignite with net calorific value 8 MJ/kg and amount of carbon dioxide produced during combustion. There is also assumed that all amount of carbon in lignite is converted to $CO_2$ during combustion.

**Table 15.6 Comparison between various approaches (by literature)**

| Formula by: | Formula | Calculated Ctr [%] | Amount of $CO_2$ [t] |
|---|---|---|---|
| Fott [7] (wet coal and lignite) | Ctr = 2.400 × Qir + 4.1232 | 23.32 | 8551.84 |
| Fott [7] (dry and ash-removed coal and lignite) | Ctr = 2.333 × Qir + 5.511 | 24.18 | 8864.17 |
| Fott [7] (selected country specific values) | Ctr = 2.334 × Qir + 5.5786 | 24.25 | 8891.89 |
| Fott [7] (set A+B) | Ctr = 2.344 × Qir + 5.056 | 23.81 | 8729.70 |
| Stefanović et al. [8] (Slovenia, "Šoštanj" power plant) | Ctr = 2.2477 × Qir + 5.8216 | 23.80 | 8727.84 |
| Stefanović et al. [8] (Velenje) | Ctr = 2.3878 × Qir + 4.6548 | 23.76 | 8710.97 |
| Stefanović et al. [8] (Kolubara) | Ctr = 2.3718 × Qir + 4.2637 | 23.24 | 8520.64 |
| Poland [10] (current analysis) | Ctr = 1.9272 × Qir + 9.3856 | 24.80 | 9094.51 |
| Pątnów sample (own analysis) | Ctr = 2.339 × Qir + 4.546 | 23.26 | 8527.93 |
| 1st sub-sample (own analysis) | Ctr = 2.547 × Qir + 2.064 | 22.44 | 8228.00 |

## CONCLUSIONS

Presented results, taking into consideration number of investigated linear dependencies between carbon content and net calorific values, referred to different countries, coal reservoirs, mining fields, power plants (in the context of combustion of lignite) or lignite state could be significant in compilation of emission inventory.

Because of large diversification of qualitative parameters as: carbon content, net calorific value, ash and water content, also other, summary analysis on the level of separate country seems to be quite difficult. As a result, estimated emission of carbon dioxide from

lignite-based public power and energy sector [7, 8, 9, 10, 11] might be charged with significant uncertainties. Additionally, taking into consideration geospatial variability of parameters of lignite (various resources, beds and other) [12, 13, 14, 15, 16], there is created the possibility that linear dependency between carbon content and net calorific value is not enough for effective compilation of emission inventory.

In the context of intensive development of brown coal industry in Poland [17] is worth to estimate "stepping" (year by year) formula of dependency between carbon content and net calorific value also make the national emission inventory data more reliable.

Observed facts confirm assumptions [7, 8, 9, 10] concerning existence of dependency between carbon content in lignite and net calorific value. This dependency could be observable as a linear function.

## REFERENCES


1. Frey H. Ch., 2007a, Quantification of Uncertainty in Air Pollutant Emission Inventories, Emission Inventory Conference, Raleigh NC.
2. Frey H. Ch., 2007b, Quantification of Uncertainty in Emission Factors and Inventories.
3. Intergovernmental Panel on Climate Change (IPCC), 1995, Greenhouse Gas Inventory Reporting Instructions.
4. IPCC, 2006, Guidelines for National Greenhouse Gas Inventories.
5. EMEP/EEA Air Pollutant Emission Inventory Guidebook, current version available under address: http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009
6. Zawadzki J., 2012, How to merge environmental information using meta-analysis, chapt. 27 in: Biały W., Kaźmierczak J., Systems supporting production engineering, pp. 279-287, ISBN 978-83-62652-34-1.
7. Fott P., 1999, Carbon emission factors of coal and lignite: analysis of Czech coal data and comparison to European values, Environmental Science & Policy (2) pp. 347-354,
8. Stefanović P., Marković Z., Bakić V., Cvetinović D., Spasojević V., Živković N., 2012a, Domestic Lignite Emission Factor Evaluation for Greenhouse Gases Inventory Preparation of Republic of Serbia, http://wbalkict.ipa.ro/wp-content/uploads/2012/06/Domestic-Lignite-Emission-Factor-Evaluation-for-Greenhouse-Gases-Inventory-Preparation-of-Republic-of-Serbia.pdf
9. Stefanović P., Marković Z., Bakić V., Cvetinović D., Spasojević V., Živković N., 2012b, Evaluation of Kolubara Lignite Carbon Emission Characteristics, Thermal Science, Year 2012, Vol.16, No. 3, pp. 805-816.
10. NCEM, 2012, Poland's National Inventory Report 2012. Greenhouse Gas Inventory for 1988-2010. Submission under the UN Framework Convention on Climate Change and its Kyoto Protocol. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php, date of access 8th of April 2013.
11. Jagóra E., Szwed-Lorenz J., 2005, Analysis of variability of main parameters of western part of Szczerców mining field, Prace naukowe Instytutu Górnictwa Politechniki Wrocławskiej, No. 31 [in Polish].

12. Bartuś T., 2007, Contribution to research of the local, horizontal variability the main lignite qualitative parameters in the central part of the Bełchatów lignite deposit. Statistical analysis, Geologia vol. 33, issue 1, pp. 89-107 [in Polish].
13. Bartuś T., Słomka T., 2009, Geostatistical estimation of lignite qualitative parameters using knowledge of local variability on example of Bełchatów area, Gospodarka Surowcami Mineralnymi, vol. 25, issue 2, pp. 5-21 [in Polish].
14. Bartuś T., 2012, Anisotropy of the main lignite parameters variability of Bełchatów area, Gospodarka Surowcami Mineralnymi, vol. 28, issue 2, pp. 5-29, DOI 10.2478/v10269-012-0014-2, [in Polish].
15. Kokesz Z., 2006, Difficulties and limitations in geostatistical modelling of mineral deposits variabilities and resources/reserves estimation by kirging, Gospodarka Surowcami Mineralnymi, vol. 22, issue 3, pp. 5-20 [in Polish].
16. Naworyta W., 2008, Variability analysis of lignite deposit parameters for output quality control, Gospodarka Surowcami Mineralnymi, vol. 24, issue 2, pp. 97-109 [in Polish],
17. Kasztelewicz Z., Kozioł K., 2007, Production possibilities of brown coal industry in Poland after 2025, Polityka Energetyczna, vol. 10, special issue 2, pp. 141-158, PL-ISSN 1429-6675 [in Polish].

# EMISSION INVENTORY FOR LIGNITE BASED PUBLIC POWER AND ENERGY SECTOR – MERGING INFORMATION FROM VARIOUS SOURCES

**Abstract:** *The purpose of this article is presentation of emission inventory as a field, where integration of information from various sources is widely used. One of tasks of emission inventory is combining pieces of information about any significant source of emission of air pollutants or greenhouse gases (GHGs) to estimate value of emission in the most reliable way. Sources of used information are not only environmental studies. They are elaborations from completely various fields as e.g.: mining, metal casting, agricultural sciences or forestry.*
*National emission inventory merge data from: statistical surveys, scientific elaborations, interior and international analysis, National Emission Database (NED) and specific international statistical questionnaires on energy sector. Emission inventory in public power and energy sector is the good example of using data from different sources. There are possibility of encounter data on: combusted fuels (type and amount), composition and calorific value of fuels, average emission factors, parameters of particular systems of air pollution control and many other.*

**Key words:** *data-integration, carbon dioxide, emission inventory, statistics*

# INWENTARYZACJA EMISJI Z WĘGLA BRUNATNEGO PUBLICZNEGO SEKTORA ENERGETYCZNEGO – SCALANIE INFORMACJI Z RÓŻNYCH ŹRÓDEŁ

**Streszczenie:** *Celem artykułu jest prezentacja możliwości zastosowania integracji danych w inwentaryzacji emisji. Jednym z zadań inwentaryzacji emisji jest wykorzystanie informacji charakteryzujących każde istotne źródło emisji (zanieczyszczeń powietrza albo gazów cieplarnianych) tak, aby oszacować wielkość emisji zanieczyszczeń z w/w źródła w sposób jak najbardziej miarodajny. Źródła wykorzystywanych informacji nie dotyczą jedynie nauk o środowisku, ale są opracowaniami dotyczącymi np.: górnictwa, odlewnictwa metali, nauk rolniczych, czy też leśnictwa. Krajowe inwentaryzacje emisji integrują dane z (m.in.): opracowań statystycznych, prac naukowych, analiz krajowych i międzynarodowych, baz danych (o emisjach) oraz międzynarodowych kwestionariuszy statystyki energetycznej.*
*Inwentaryzacja emisji sektora energetyki zawodowej stanowi dobry przykład integracji danych z różnych źródeł: o charakterystyce zużytego paliwa, składzie, wartości opałowej, średnich wskaźnikach emisji, danych o zastosowanych systemach oczyszczania powietrza i wielu innych.*

**Słowa kluczowe***: integracja danych, dwutlenek węgla, inwentaryzacja emisji, statystyka*

dr hab. inż. Jarosław ZAWADZKI, prof. P.W.
Warsaw University of Technology
Faculty of Environmental Engineering
Nowowiejska Str. 20, 00-653Warsaw
e-mail: j.j.zawadzki@gmail.com
mgr inż. Damian ZASINA
Warsaw University of Technology
Institute of Environmental Protection – National Research Institute
National Centre for Emission Management
Chmielna Str. 132/134, 00-805 Warsaw
e-mail: damian.zasina@gmail.com

# 16

# CONCEPT OF A DECISION SUPPORT SYSTEM TO SELACT THE OPITMAL CCT SOLUTION FOR A CHOSEN LOCATION IN SILESIA REGION

## 16.1 INTRODUCTION

The implementation process of Clean Coal Technology (CCT) belongs to complex investment projects. Implementation of innovative technologies in response to the stringent requirements of energy and climate policies should be done in accordance with the principles of sustainable development. This is also as a result of the project scale and the conduction of the investment process. Selection and evaluation of technologies and also the implementation of the project leads to the point of making the right decision.

Human factor plays the main role during the process of decision-making, because of the decision responsibility. In classical terms, the decision process is based on expert opinion and analysis carried out in the form of compiled documentation, containing a number of technical and economic – financial assumptions. On those bases the decision-maker makes a choice between rejecting or accepting the project for implementation or among several presented variants selects the most efficient one, having the best chances to succeed, or taking under consideration other criteria set up by them. The main drawback of this ongoing process is time-consuming and the impact of "human factor" on decision's objectivity. Reviews and ratings of experts are formulated on the basis of their knowledge and experience, are often dependent on decision-makers point of view, guided by the appropriate investment of financial resources at their disposal. This narrows down the field of criteria and freedom of choice [1].

Due to the nature of CCT implementation process, the investment risk is borne not only by the potential investor but also by the local community. It is also an important issue for officials fully responsible for the agreement process and partially for decision-making. A large number of data to be analyzed prior to the investment process makes it difficult to take the right decision without adequate support of computer-based systems. The role of computer support systems were found to be significant in making strategic decisions, the implementation of which involves a long time span and the result is dependent on external factors.

The authors believe that it is necessary to develop a system supporting decision-making in the context of the selection of the most optimal technology of clean coal technologies for a specified and considered location in Silesia region. The expected effects of the decision support system development for the implementation of the CCT will be:

- General availability to data on CCT
- Dissemination of information on CCT,
- Access to data related to geological characteristics of the Upper Silesian Coal Basin (USCB).

## 16.2 DECISION SUPPORT SYSTEM – GENERAL INFORMATION

The research literature has shown that so far there has not been developed a system of implementation of clean coal technologies, which can strongly improve the time-consuming process of implementing innovative technologies, taking into account the location choice and community dialogue as the determinants of the investment process. The use of this tool during the decision-making process allows the sustainable development of USCB by using the available resource base.

The Decision Support System (DSS) it will be an interactive computer system aimed to aid decision makers use data and models to solve unstructured problems. In other words, helps the user in the organization and management of rational decision-making process and contains a representation of knowledge about the decision by means of the analytical model.

DSS has: precision in recreating a wider perception of the world, where solutions suggested by the system may be used without any modification; immunity, although the values used as parameters are only an estimate of the truth; modifiability, allowing you to change the parameters of the models, resulting experience gained during the operation of the system and through the use of communicative support, tailored to different users. The term "user" refers to all users of the system, i.e. decision-maker, expert, system analyst or a group with a common objective [2].

The basic components of the scheme are:

- user interface, i.e. menu with the language allowing to give commands to the system;
- the system knowledge base, i.e. database, spreadsheets, models, graphics;
- processing system of the problem, i.e. inference, database management and analysis of the results.

The general structure of the decision support system is shown in figure 16.1

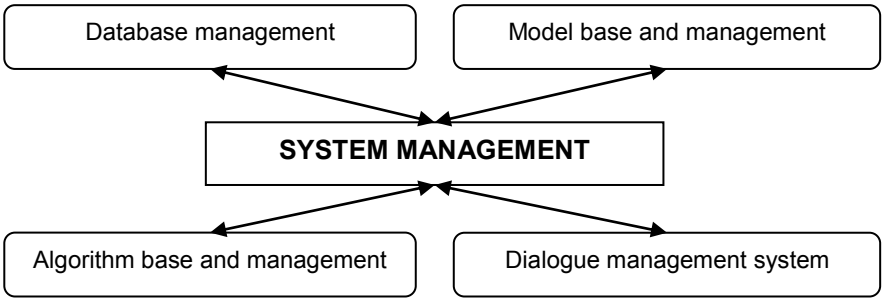



**Fig. 16.1 Main structure of the decision support system**

Source: [3]

The issue of implementation of the CCT in the USCB offers a wide range of criteria that have to be examined in order to accurately and reliably predict the technology which is to be implemented. To this purpose serves the designed system, its task will be the juxtaposition of

the information resulting from the EU and national legal requirements, the characteristics of the region and the resource base, technical parameters of coal technologies and components of sustainable development, i.e. the potential environmental risks, optimization of economic investment and community dialogue.

## 16.3 FUNDAMENTAL COMPONENTS OF DSS CONSTRUCTION

### 16.3.1 Knowledge base

The knowledge base on which is embedded the real information system will enable the processing of the information collected in the parameterized analytical models. In the first building phase of the targeted solution the authors predict the creation of a database that will provide a base of knowledge about the technology, construction of geological - mining of USCB and aspects of sustainable development. This will enable collecting and organizing data in a logical way for data collection system which has been elaborated by the authors of the information system support concept and decision-makers associated with the selection of technological solution for the location.

The base for each construction investment is the location factor, so the authors recognize the location as a criterion for successful implementation process of clean coal technologies in Silesia region. Implementation of the investment process of CCT in Silesia region and the knowledge base of the proposed system is shown in figure 16.2.

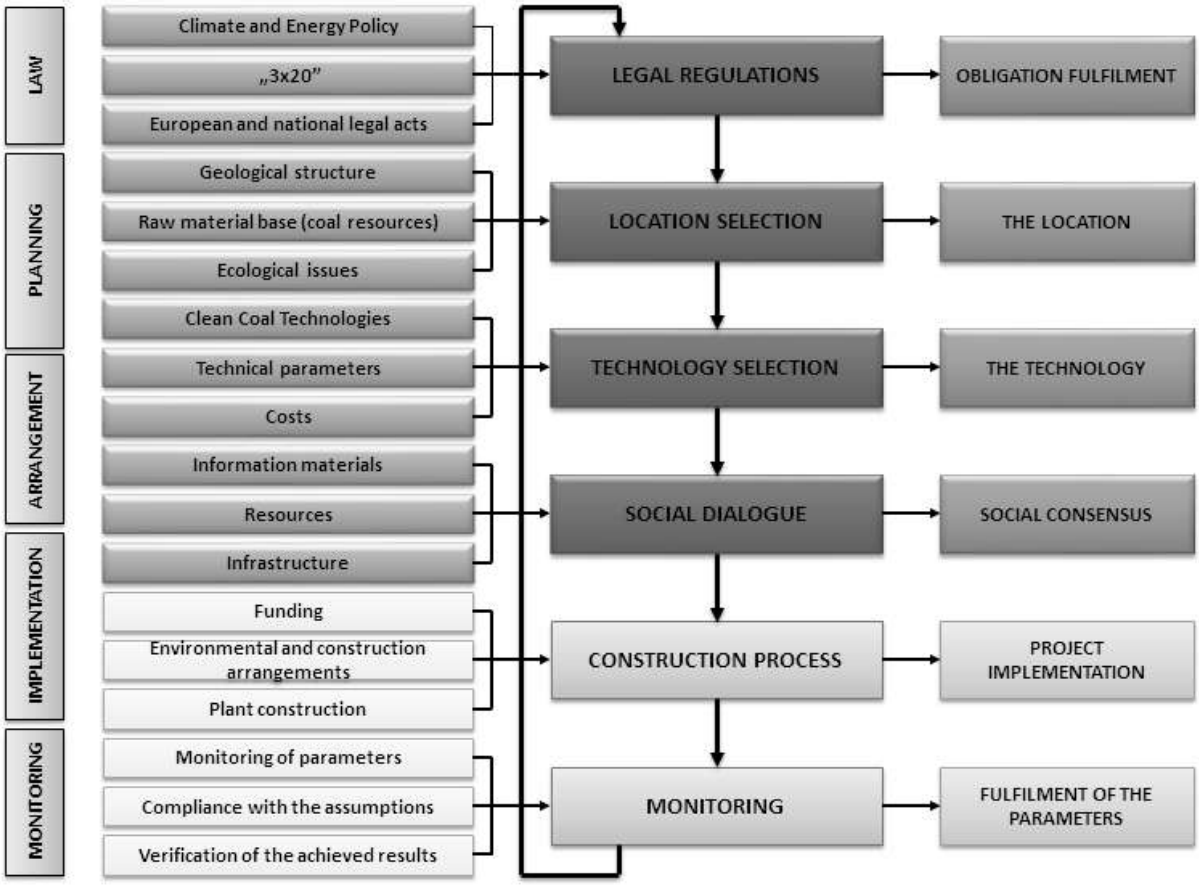



**Fig. 16.2 Implementation process of CCT in the area of USCB**

Source: [4]

### 16.3.2 Database

The database module is an essential part of the decision support system. It allows to collect data that will form the basis of analyzes carried out within the system. The structure of the proposed system will include database related to the location, technology and sustainability aspects.

The conducted survey shows that the eligibility criteria concerning the location such as: ownership structure, type of the premises possession and land legal status clearly determine the qualification of the location for further consideration. Spatial factors such as density or spatial arrangement of buildings play an important role in decision-making, therefore should be assessed as well.

In addition to the formal criteria of the location, the database will contain information about the occurrence of various factors that may influence the selection process technology in place. Please note that USCB is a densely built-up area with developed industrial and communication infrastructure, which may limit the coal exploitation. Regional specification of USCB and existing coal exploitation has led to considerable environmental degradation. Currently, due to the surface and underground mining operations, the threat in the form of a mass movement still remains high. Hence accurate identification, development and inclusion in decision support system of reliable characteristics of land is needed to reduce the occurrence of mining damage like land collapsing and other forms of ground deformation.

Regardless of the database related to the location there is a database of available technologies on the world market such as: mechanical processing of CCT, carbon technologies, ground and underground coal gasification, co-firing of coal and biomass technologies, ground and underground coal liquefaction technologies for the capture and sequestration of $CO^2$. Database is the result of earlier technology analysis designed to meet the CCT determinants of the possibility for their implementation in Silesia region. As in the case of location, the technology database will contain information about clearly categorizing them negatively or positively for implementation. These factors are: efficiency, performance, failure and information which may in varying degrees affect the decision making, such as coal cleaning before the process, saving expenditures in production, saving raw materials or the remainder [3].

CCT is a response to strict requirements of the European Union's climate policy in the context of reducing carbon dioxide emissions into the atmosphere, widely regarded as the cause of global warming. The requirements of the climate - energy, package "3x20" and the relevant provisions of EU and national legislation will be reflected in the proposed system.

Previously was mentioned that the implementation of innovative technologies, which is also the subject of strategic importance for the regional and national development must comply with the sustainable development principles, therefore the implementation and decision making process should include components like ecology, economics and ethics, i.e. social factor.

The decision support system, taking into account the environmental aspect will include the assessment of environmental risks resulting from hazards that may be caused by analyzed technologies. Air pollution, soil, surface water and groundwater contamination also the threat of sludge floods, noise, vibration, and waste generation will be evaluated and included in the

proposed system.

Accurate estimation of the risks associated with the implementation of the technology within the USCB area is necessary to maintain public acceptance of the proposed activity. This is due to both the principles of sustainable development and the process of legal regulations for the investment. Lack of social acceptance for large or innovative projects, such as the implementation of clean coal technologies, may be dictated by the fear of potential threats. It may even prevent their further development in the country. The proposed system takes into account a number of factors related to the expectations and concerns of the local community in relation to a potential investment in their place of residence.

The system also includes the last components of sustainable development - the economic aspect of the investment process. The implementation of clean technologies is a process requiring high costs, which are financed by a number of different financial sources. The proposed system will allow the user to make a preliminary feasibility analysis from the financial side.

### 16.3.4 Model base

The purpose of the model base in the proposed system will allow the user to use the developed models without having to create them. Model base will work with databases, allowing for multiple use of the information in a variety of configurations, which once entered into the system is stored in the database. Knowledge base, in turn, will advise what models can be used, or what data are needed.

The control module is responsible for the co-operation of database with the model and knowledge base.

### 16.3.5 Recommendation reports

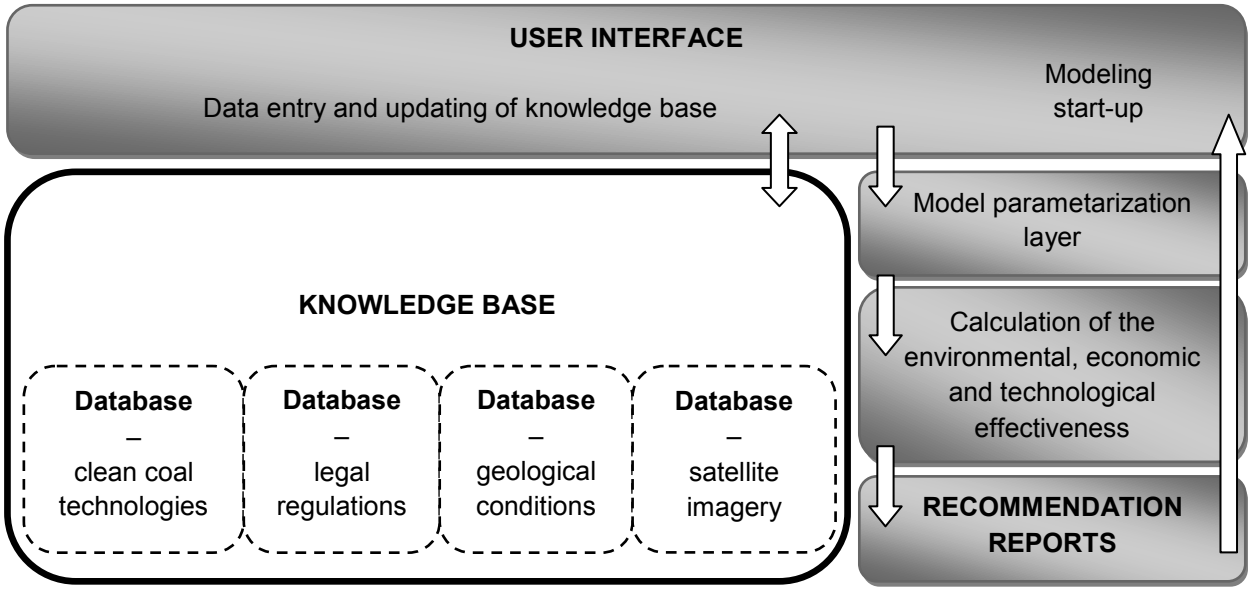



**Fig. 16.3 Design concept of DSS**

Source: own source

The analytical models used in the computer system will allow for the development and

generation of recommendation reports. Possessing the recommendation report the user is capable of making a decision in a conscious way to use or not to use CCT technology selected for analysis.

The concept of the proposed decision support system in the context of the cost-optimal choice, environmentally and socially clean coal technology in the Upper Silesian Coal Basin is shown in figure 16.3.

## 16.4 IDENTIFIED NEEDS OF DSS USERS

The purpose of the system is to assist in decision-making, not substitute the user therefore it is also an important factor in the interaction of the system with the user.

Users of DSS are divided in five groups which have a direct impact on the implementation process of the CCT in the Upper Silesian Coal Basin. These include local governments, investors, academics, representatives of NGOs and the local community [4]. For each of these groups, the designed system will carry out a different function and provide different information. The needs of the system users are summarized in table 16.1.

**Table 16.1 Identified needs of DSS users**

| User of DSS | Identified needs |
|---|---|
| **Local authorities** | - tool to improve the process of issuing administrative decisions and permits,<br>- database about the state of the environment,<br>- tool for providing information on environmental impact assessment |
| **Investors** | - tool for pre-investment feasibility studies,<br>- tool for the presumptive identification of investment risk factors |
| **Representatives of the scientific community** | - tool to identify areas for detailed research,<br>- information base related to CCT<br>- basis for the improvement of DSS or the creation of new decision support tools |
| **NGO's** | - tool for verification of the decisions issued by the administrative bodies<br>- tool to support the conduction of public consultation process |
| **Local communities** | - tool for effectively carrying out public consultation process<br>- information and education platform for the CCT and the impact on the environment |

Source: own source

Additional aspects, convincing for the implementation of a decision support system in order to implement the CCT in Silesia are [5]:

- short-time processing of large amounts of data,
- possibility of carrying out the rapid analyses,
- possibility to combine different techniques of data processing,
- possibility to use intuitive elements,
- access to the information stored in the database,
- possibility to verify the designed system,
- easy to use,
- guarantee of precise and accurate result,
- fast response to the problem posed,
- compatibility with personal computers,
- low equipment requirements.

**SUMMARY**

The decision making process is a complex procedure that includes rationality and intuition, requiring skillful articulation of tasks. The decision precedes information collection, data and preliminary project preparation. The process is an act unfolded in time. Decision support system aids at each these steps.

In case of strategic decision-making for the development of the country which is the selection and implementation of the technology from the CCT group, the decision is influenced by many entities which in their assessments must take into account the multifaceted issues. The problem becomes more complex when taking into the account the fact the local communities expect from decision authorities act based on rational evidence and scientific method but also on activities that are consistent with their expectations.

Through the use of multi-criteria methods, decision support systems, compiling quantitative and qualitative variables, aspects which on one hand seek to maximize the economic efficiency and on the other hand meet social expectations of citizens, allow decision-makers to deliberately and consciously to make a comprehensive analysis of the problem and make a decision from a variety of options, leading to an effective solution [6].

The designed decision support system for the selection of the optimal technology out of CCT group for the selected location is the basis for the creation of a computer application, a tool designed for participants involved in the implementation process of the technology in the Upper Silesian Coal Basin, including local government, investors and the local community as well as representatives of the scientific community and NGOs.

The application not only will help the decision-making process in the context of selecting the technology which will be implemented in the selected location. It will also help to organize the knowledge concerning the availability of clean coal technologies on the market, geological-mining regulations and resource base in Silesia region.

**REFERENCES**

1. Twardowski Z. Stanek S.: „Modelowanie procesów decyzyjnych w strategicznym zarządzaniu organizacją", prace naukowe Akademii Ekonomicznej w Katowicach po konferencji Systemy Wspomagania Organizacji 2005.
2. Kwiatkowska A.: „Systemy wspomagania decyzji. Jak korzystać z wiedzy i informacji w praktyce", Wydawnictwo Naukowe PWN SA, Warszawa, 2007.
3. Hausner J. Białecka B.: „Analiza procesu wdrażania czystych technologii węglowych w Polsce", Prace Naukowe GIG, Górnictwo i Środowisko, Katowice, nr 2/2012.
4. Białecka B., Hausner J.: „Założenia do budowy systemu wspierającego wdrażanie Czystych Technologii Węglowych (CTW)", Monografia pod redakcją: W. Biały, J. Kaźmierczak: „Systemy wspomagania w inżynierii produkcji" Wydawnictwo PKJS, Gliwice 2012.
5. Klonowski Z.: „Systemy informatyczne zarządzania przedsiębiorstwem. Modele rozwoju i właściwości funkcjonalne", Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2004.
6. Książek M.: „Analiza porównawcza wybranych metod wielokryterialnych oceny przedsięwzięć inwestycyjnych", Budownictwo i Inżynieria Środowiska, nr 2/2011.

# CONCEPT OF A DECISION SUPPORT SYSTEM TO SELACT THE OPITMAL CCT SOLUTION FOR A CHOSEN LOCATION IN SILESIA REGION

**Abstract:** *Decision Support Systems (DSS) are computer-based tools which can assist managers of different disciplines, local governments, investors and other stakeholders to simulate, evaluate, and/or optimize management alternatives.*
*This study aims to elaborate and develop a concept design of a DSS and explore the possibilities which it offers in selecting the most optimal Clean Coal Technology for a given location in the Upper Silesian Coal Basin.*
*The implementation of CCT is a very complex process and is characterized by the interaction of many factors such as: economic, environmental, legal and social therefore, as a consequence the decision-making becomes intricate.*
*The study consisted and relied on the draw-up structure, the determination of fundamental components of the DSS and the generation of recommendation reports. Furthermore, the identification of the DSS user's needs was carried out along with the classification of the main groups of users, which have a direct impact on the implementation processes of the CCT in the Upper Silesian Coal Basin.*

**Key words:** *Decision Support Systems, Clean Coal Technologies, decision-making, technology implementation.*

# KONCEPCJA SYSTEMU WSPOMAGANIA DECYZJI WYBORU OPTYMALNEJ TECHNOLOGII CTW DLA WYBRANEJ LOKALIZACJI NA ŚLĄSKU

**Streszczenie:** *System wspomagania decyzji (SWD) jest narzędziem komputerowym, który może pomóc menadżerom z różnych dyscyplin, przedstawicielom środowisk samorządowych i innym zainteresowanym stronom w przeprowadzeniu symulacji, ocenie i/lub optymalizacji procesu zarządzania.*
*Prowadzone badania mają na celu opracowanie i stworzenie projektu SWD, który okaże się pomocny w wyborze optymalnej technologii czystego węgla dla danej lokalizacji w Górnośląskim Zagłębiu Węglowym. Implementacja technologii CTW jest bardzo złożonym procesem i bazuje na interakcji czynników: ekonomicznych, środowiskowych, prawnych i społeczne w związku z tym, w wyniku czego podejmowanie decyzji w tym zakresie staje się skomplikowane.*
*W pracy opisano strukturę systemu, określono podstawowe elementy SWD i uwzględniono generowania raportów rekomendacyjnych. Ponadto zidentyfikowano potencjalne grupy użytkowników SWD, mających bezpośredni wpływ na procesy implementacji WTC w Górnośląskim Zagłębiu Węglowym. Przeprowadzono również identyfikację potrzeb użytkowników systemu.*

**Słowa kluczowe:** *System wspomagania decyzji, czyste technologie węglowe, podejmowanie decyzji, wdrażanie technologii*

prof. dr hab. inż. Barbara BIAŁECKA
Central Mining Institute
Pl. Gwarków 1, 40-166 Katowice
e-mail: b.bialecka@gig.eu
mgr inż. Joanna HAUSNER
Ekobilans Sp. z o.o.
ul. Ligocka 103, 40-568 Katowice

WYDAWNICTWO
P.A.NOVA