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MINIMISING RISK PROBABILITY FOR VESSELS TRAFFIC CONTROL

Steps that are being taken to improve safety of navigation are mainly based on separation schemes. The schemes along with Vessel Traffic Services improved existing standards. Its role seems passive and it is assumed that it will be beneficial in terms of collision or accident risk reduction once active measures are introduced. The concept raises wide variety of problems that are to be discussed, defined and solved.

ZMNIEJSZANIE RYZYKA W PRZYPADKU STEROWANIA RUCHEM STATKÓW

Kroki, jakie obecnie podejmuje się w celu poprawy bezpieczeństwa nawigacji, oparte są na systemach rozgraniczenia ruchu statków. Systemy te wraz ze służbami ruchu znacznie udoskonaliły istniejące standardy. Rola ich wydaje się być bierna i zakłada się, że będą one przynosiły korzyści w kategoriach obniżenia ryzyka kolizji lub wypadków po wprowadzeniu środków aktywnych. Koncepcja podejmuje szeroką i różnorodną problematykę, która powinna być przedmiotem dyskusji, definicji i rozwiązania.

1. INTRODUCTION

Studies discussed in many papers, for example [14], report very high human involvement in all marine accidents. One of the reports said that human error was the main cause of 90% of all collisions. Obviously each collision poses serious threat to the environment. Closer look at the nature of error indicates information processing along with high situational stress as accounting for 84% of accidents. Wider use of computers and computer networks should reduce data processing faults. Automatic control should decrease level of stress. These ideas are to be implemented within Vessels Traffic Systems, which role is a basic one in improving safety standards.

Operation area of sea going vessels can be divided into three major parts: port, restricted area and open sea. It appears that collisions and groundings create biggest problem for the environment. Record of well-known and gloomy accidents with huge tankers involved proves the statement referring to restricted waters. Restricted area with heavy traffic is of special care

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for everyone involved in safe navigation. The case is worth exploring, for this reason it also gained main focus in the report.

Traffic separation schemes along with Vessel Traffic Services (VTS) are those, which improved existing safety standards within restricted areas. The VTS is any service designed to improve safety and efficiency of traffic and the protection of the environment. It may range from the provision of simple information messages to extensive management of traffic within a port or waterways [4]. Since the aim is clear one can put a question of possible development. It seems that proposed reference model [8] for such system may contribute to easy interconnection at least in terms of data flow. The General Management and Traffic Planning layer of such model was focused in a few papers delivered by the author [5][7][8]. Its role seems underestimated and it is assumed that it will be crucial in terms of collision or accident risk reduction wherever implemented.

Anderson and Lin [1] developed collision risk model; the survey was done for three dimensions air traffic. Dropping vertical co-ordinate the formula that reflects the probability of collision at intersection area says that the probability of collision depends on crossing area topology as well as on an encounter rate. Encounter mean situation of penetrating domain area of any ship by another vessel. Any way of distributing the traffic that result in avoidance of local cumulating of ships should be considered vital for restricted areas since it leads to decreased number of encounters. The paper deals with the problem aiming at reduction of the overall encounter number for each vessel while passing restricted area.

The concept is based on zones of a special care. Such zones or sectors are those areas where it is considered necessary to maintain congestion free. The amount of traffic within a sector, at any time, should not exceed a predefined capacity value. Passing particular route by the specific vessel will be associated with so call cost value. The higher the cost the less recommended is the passage. The basic control problem is to not exceed allowed capacities of sectors and maintain the overall cost low.

2. BASIC CONCEPT

The fundamental concept is based on zones of a special care, first proposed by Goodwin [9]. The concept was preliminary exploited by the author in [6]. Such zones, called sectors, are those limited areas where it is considered necessary to control the movement of ships. Amount of traffic within a sector should be kept below predefined level referred as capacity. Every ship coming within the area has a safety factor number assigned to it. The factor will vary on an integer scale such that the higher the number the more disastrous the consequences of an accident. Arbitrary assigned safety factors are shown at table 1. The sum of the safety factor numbers is called load of the sector. The sector's load, at any time, should not exceed its capacity. The assumption introduces constraint to the discussed problem.

Timetable of passage, for all vessels, and for given sector is a vector of so-called slots, which are pairs of values. First value is arrival time at the sector and the second reflects departure time from the sector of the particular vessel. Both values are rather fuzzy then deterministic. Due to variation of speed and unforeseen deviation from the prescribed track arrival as well as departure times changes around an estimated value.

Table 1

Arbitrary assigned set of the safety factors

Sort of craft	Safety Factor
Large and loaded tanker	10
Medium and loaded tanker	8
Small and loaded tanker	6
Large bulk carrier as well as medium general cargo vessel with dangerous cargo	5
Medium bulk carrier as well as small general cargo vessel with dangerous cargo	4
Ships without dangerous cargo	3
Others	1

While given ship with prescribed safety factor passing the sector its load is calculated as maximum of safety factors sum of all ships being inside or entering the area within considered slot. Introducing the concept of sectors system of routes in the area can be treated as a network with the restrictions on the flow. The idea requires the traffic to be reduced to the defined level. The sectors and buffers divide the area so that it can be treated as network for which a wide variety of problems can be formulated.

The presented concept creates opportunity to adopt some of published solutions devoted to stochastic networks. The Stochastic Multiobjective Shortest Path algorithm developed in [13][15] is a good candidate for alternative routes environment where best passage conditions for particular vessel are sought. There is also good chance to generalize approach and to consider vessels traffic control. The problems will be presented as single and multiobjective one.

The final aim of implementation of the scheme is to take over the ship after entering the controlled area. It is assumed that there is traffic separation within the area. The separation is to embrace elements such as sectors and possibly alternative routes. An example of restricted area with traffic separation is shown at figure 1. There are two main directions of flow with alternative routes for south-northbound vessels. The routes are labeled with *T1, T2, T3* and so on. Crossing and junctions of routes are treated as zones of special care or sectors.

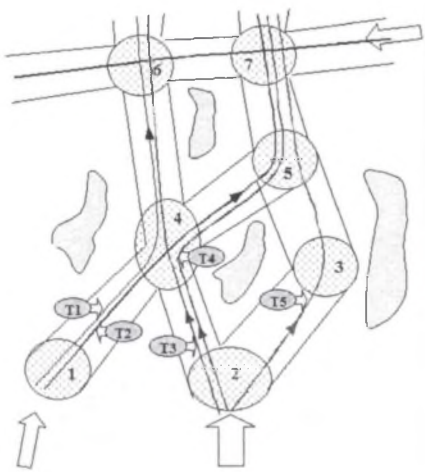

Fig.1. Example of restricted area with traffic separation and safety zones

The moment when one will be able to put special plug into the socket on the bridge and then watch what is going on seems remote. Many difficulties including standardization, legal as well as human factors are to be overcome.

3. CONTROL PROBLEM

Passing particular route by the specific vessel can be associated with cost value. The higher the cost the less recommended is the passage. As an example fully loaded tanker steaming through narrow channel although possible will be considered "costly". Higher cost value will be also assigned to a vessel that for any reason remains longer in the area then necessary. Steaming along shorter route is preferred over the longer one. Cost function is related to the passage of given ship with prescribed safety factor along particular route. It reflects local preferences and is considered to depend on type, length and cargo of the vessel as well as depth and breadth of the channels.

3.1 ASSUMPTIONS

Given are: structure of a system, set of vessels with a safety factor numbers assigned, allowed load (capacity) of sectors and a timetable of passage for each vessel. To adjust the load one can delay entering the sector by one or more vessels if needed. This can be achieved by slowing down at the adjacent buffer zone. Although possible such measure is doomed to give rise to wide variety of complaints. The proposed approach is to adjust load through proper selection of routes to be passed while maintaining speed unchanged. To fulfil that additional, following assumptions are made:

- Route is treated as a sequence of adjacent nodes (sectors) is characterized by maximum value of load of its nodes,
- To decrease a load of the given sector some vessels must be redirected to a different route. Two or more can be treated as the same from a given node point of view. In node 4 at figure 1 at least two routes have the same predecessor – node 2.

One seek an answer for the question: Is there such assignment of routes to each of the vessels for which capacity of sectors are not violated at any moment and the cost function is equal to a given value? It was proved that such problem belong to the NP-complete class of the generalized allocation problems (GAP). Since this problem will be referenced quite often in the report let us have closer look at its definition.

3.2 PLA METHODS

Metaheuristcs or extended heuristics are of growing popularity nowadays. These algorithms require powerful computers to obtain solution close to an optimal value within reasonable time. At the other hand are able to produce satisfactory outcome run on available PCs. Population Learning Algorithms (PLA for short) are those emerging extended heuristics that bring a new approach towards computational technique. PLA reflect idea that lies behind social education systems. They are based on evolution of population of individuals. The computation scheme enables combining different optimization techniques. Like in normal education system PLA start with basic level training applied to randomly selected individuals. Promoted are those which pass necessary tests and satisfy promotion criteria. Subsequent stages of education involve more sophisticated methods of education as well as more difficult criteria of selection. The number of educated individuals can vary from stage to stage. Contrary to their natural counterpart this number can increase. The best from the final stage population is a solution. Mentioned above are called scenarios of education or solving a problem. Scenarios play important role in PLA computations. Carefully selected and implemented can bring expected result within reasonable time. Case of choosing "first to fit" scenario can result in unacceptable outcome. In this respect scenarios are to be treated as problem oriented.

PLA work with individuals very much like other genetic algorithms [2]. An individual for the presented problem is a vector of integer numbers. An appropriate representation of an individual is important and it should be liable to crossover, mutation and other problem specific operators. In the vector representation the integer numbers identify the ships as assigned to routes.

The individual should be easily generated, mutated and crossed over in pairs [12]. Selected computational results were presented in the author's paper [8]. The results were good enough even for very demanding tasks.

4. MULTIOBJECTIVE APPROACH

Above mentioned is approach to solve route allocation problem using population learning evolutionary algorithm. It was also shown that Lagrangian relaxation might be successfully adopted [7][11] for this task. The approach is single objective, the goal is to minimize overall cost function. Such objective applied to a network of limited capacity sectors enables distribution of the traffic within the area.

Most real problems are multiobjective ones, which have many criteria. To satisfy each of them at the same time is usually simply impossible since they are conflicting quite often. In the discussed problem besides minimizing overall cost function decision maker can be interested in situation within particular area or in a passage of particular vessel. Objective should additionally penalize encounters of crafts with high safety factors. Extra penalty might be applied if too many vessels are gathered at area of special concern, which is not a single sector. In other words each allocation of routes is a subject to variety of assessments. Mentioned are criteria, which are to be minimized for the sake of solving the presented, multiobjective problem. The ships' routing analysis can be based on the following criteria:

- minimizing overall cost function,
- reducing number of encounter regarding particular vessel,
- reducing number of ships present in area of special concern (particular set of sectors and surrounding waters) from local authority point of view,
- minimizing maximal load of sector,
- minimizing chaos in the adjacent area.

Evolutionary algorithms are particularly suitable to solve multiobjective problems [3]. Since they deal with individuals within population. This allows to verify each of them regarding wide scope of criteria. The last remark plus very good quality of obtained results justify chosen way of solution.

Individuals that improve any of the goal functions compose so called Pareto optimal or non-dominated set of solutions. One allocation dominates another if it is better for one criterion and not worse for any other [15]. Contrary to a single criteria approach the set contains more then one vector of decision variables. Such set contains allocations, which represent available tradeoffs. As an example consider three allocations with parameters presented in table 2.

Table 2

Comparison of routes allocations

Allocation	**Overall cost**	**Encounters with SF>4 involved**	**Encounters within area X with SF>4 involved**	**Max. load**	**Outside crossings**	**Dominance**
1	350	5	3	80%	4	dominated by 3
2	330	6	3	79%	3	non-dominated (neither by 1 nor by 3)
3	325	5	2	80%	3	dominates 1 but does not dominate 2

In the example solution number 3 dominates allocation number 1 since it has overall cost lower and is not worse regarding any other criteria. While generating Pareto optimal set solution 1 is to be neglected. Allocation 2 is dominated neither by 1 nor by 3.

4.1 DECISION MAKING

Multiobjective approach usually involves at least two stages: search for non-dominated vectors and decision-making. The stages are usually considered separately. At the final step decision maker has to select one of the alternatives, presumably the best, present in the Pareto optimal set. There are quite many methods available that can be readily used. The simplest way of approach, see [3], is to combine objectives into a single function. Usually each objective receives its weight and the function is a polynomial, which minimal (maximal) value is sought. Multiple attribute utility theory is the basic one that enables creating function to order actions from best to worst. The method can be adopted everywhere comparable criteria are taken into account. Incomparability eliminates usage of the method. One cannot compare total cost function (in units of time) with the load of sector (relative measure given as a consumed percentage of total capacity). Incomparability made the author to direct toward other approaches. One can quite often find criteria, which are incomparable. Outranking methods have been developed to cope with such cases.

An outranking binary relation defined for two arguments (actions) stipulates as follows: "Given what is known about the decision maker's preferences and given the quality of the valuations of the actions and the nature of the problem, there are enough arguments to decide that first is at least as good as the second, while there is no essential reason to refute that statement" [16]

There are series of ELECTRE methods, which were upgraded for multicriteria selection. The aim of these methods is to create a subset (as small as possible) of actions, which elements outrank at least one action being outside this subset. Fundamental for the methods are concordance and discordance matrices. For each pair of actions there is assigned concordance index. The index can be understood as a measure of correctness of the statement "first is better then second" or "x outranks y". Since there are criteria, which are doubtful from possibility of comparison point of view, for this reason discordance index was introduced. This also enables proper approach towards extremes. The discordance index increase if preference of one action becomes very large over the second one for at least one criterion from among comparable ones. Discordance indexes might eventually be substituted by discordance sets in case of incomparability. A set contains pairs of extreme values for which preferences are refused regardless to results of another comparison.

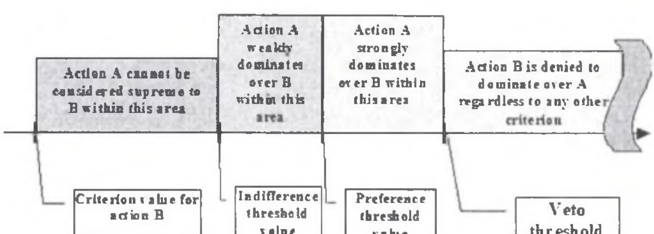

Fig.2. There are three threshold values defined in ELECTRE III method

The first two ELECTRE methods deal with true criteria. In ELECTRE II strong and weak relations are introduced based on selected threshold values. In ELECTRE III indifference, preference and veto thresholds appear (see figure 2) these shifts the approach towards pseudo-criteria and outranking credibility. The idea contributes to a flexibility of approach. The veto value, if exceeded, enables denying preference regardless to any other relations.

Let us consider routes allocation set as shown in table 3. There are five weighted criteria with coefficients presented in the title row of the table along with abbreviated criterion name. Indifference, preference and veto thresholds are also specified for each criterion. The highest concern (ratio 0.35) is attributed to encounters of vessels with larger safety factors within particular area called X. The set of Pareto optimal solution embraces five numbered records named from A0001 to A0005. There are decision maker preferences specified for each criterion. For of encounters of ships with safety factor greater then 4 involved (ESF4) values of weight, indifference, preference and veto thresholds are 0.3/2/4/7. None of the assignment can be considered supreme to another if its ESF4 factor is greater for more than 7 (see veto point at figure 2).

Table 3

Example of routes allocations set

Al	**OC /0.25/10/20/-**	**ESF4 /0.3/2/4/7**	**ESFX /0.35/1/2/-**	**ML /0.1/5/20/-**	**OCS /0.1/1/3/-**
A0001	310	19	7	75%	3
A0002	295	21	6	88%	2
A0003	325	15	9	80%	3
A0004	350	13	10	82%	4
A0005	370	15	9	70%	3

Result in shape of hierarchy graph generated by software implementing principles of ELECTRE III method is shown at figure 3.

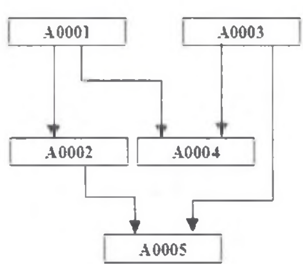

Fig.3. Graph of solution generated by the available software using ELECTRE III method

Presented ranking shows allocations A0001 along with A0003 at the same highest level. One cannot tell the preference of each other, nor can treat them as indifferent. Nodes at the same level are of the equal rank. Allocations A0001 and A0003 should be treated as the best ones. Second level consists of equal with respect to the considered set of comparisons allocations A0002 and A0004, both are dominated by A0001 and A0003. The worst placed at the lowest level is allocation A0005, nevertheless relation between A0004 and A0005 is not clear.

5. CONCLUSIONS

Vessels traffic control is to be considered as a set of multicriteria problems. The way of solution consists of two stages. At the first one a set of non-dominated or Pareto optimal solutions are generated. Multiple attribute utility theory that enables to order the set elements from best to worst could be adopted in case of comparable criteria. Incomparability eliminates usage of the method. One cannot compare total cost function (in units of time) with the load of sector (relative measure given as a consumed percentage of total capacity). Incomparability made the author to look for outranking methods. They have been developed to cope with incomparability therefore are considered suitable for the discussed problems. The ELECTRE methods appear to produce readily interpreted output even for robust multicriteria sets of Pareto optimal solutions.

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