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Rationalization of servicing reefer containers in sea port area with taking into account risk influence

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ABSTRACT

This paper is aimed at presentation of a set of methods for rationalization of servicing containerized refrigerated cargoes in sea ports. During servicing reefer containers in port container terminals, take place various combinations of risk factors which can lead to loss of quality merits of cargoes contained in them. In the paper the risk factors capable of influencing quality of cargoes during their servicing in sea port, are identified, and the elaborated model for assessing risk level with the use of assumptions of fuzzy logic theory, is presented. Also, a simulation of servicing reefer containers in port, was performed. Moreover a prototype of an expert system which makes it possible to take correct decisions on servicing reefer containers in sea port, depending on impact level of risk factors, was proposed.

Keywords: sea port; reefer container; refrigerated cargo; risk factors

INTRODUCTION

Servicing reefer containers in sea port area belongs to a group of logistic tasks. Apart from loading, storing and intra-port transporting, in servicing cargoes of the kind such operations as: switching-on the container to an electricity source, veterinary and custom inspection, monitoring climatic conditions inside the reefer container during its stay in port etc, occur [5, 10, 11]. Specificity of fast spoiling cargoes forces to use another approach to servicing reefer containers in port than that for conventional containers. Refrigerated cargo is susceptible to change in climatic conditions during storing and transporting, hence it requires special care [3, 9, 13]. Extraordinary situations occurring in port area may lead to loss of quality merits (QM) of cargo, which in consequence may negatively influence repute of the port [4, 6, 10, 11]. Such problems take place in different ports worldwide, including the Baltic and Black Sea ports, where a degree of automation of loading operations is rather not very high: unattended container handling vehicles are not there in use, lack of a system for continuous remote monitoring operation parameters of reefer containers, etc. In order to prevent situations of the kind and take, in proper time, a correct decision against possible loss of quality of containerized reefer cargo (CRC), possible occurrence and effects of different combinations of risk factors should be carefully analysed. This paper is aimed at presenting a proposal of a method for rationalization of servicing reefer containers in sea port. Its scientific aspect is elaboration a model for assessment of risk level of loss of CRC quality merits, by using fuzzy logic theory.

LINKS OF CHAIN OF SERVICING CONTAINERIZED REFRIGERATED CARGOES IN SEA PORT AREA

To elaborate possible combinations of chains of servicing containerized refrigerated cargoes in sea port, should be collected in advance necessary data dealing with, a. o., a system of container servicing in port and elaborated a series of data bases to which the following belong:

- Characteristics of fast spoiling cargoes.
- Characteristics of reefer containers.
- Characteristics of reefer - container - carrying ships.
- Characteristics of infra- and supra- structure of sea ports.
- Particular links of chains of servicing containers in port area.
- Legal acts on transport and storage of food cargoes.
- Regulations and customs binding in ports etc.

In Tab. 1. an example of elements of the data base on "Particular links of chains of servicing containers in port area", is presented. The links were completed on the basis of the data dealing with Polish and Ukrainian sea ports.

Main and auxiliary links of chains of servicing the containers in ports can be distinguished. The main links can be met almost in every port which renders services dealing with the servicing of containers. The auxiliary links (marked "*" in Tab.1) may not appear in CRC servicing chains in certain ports. The links serve for performing additional operations associated with servicing the container on request of a forwarder or needs of the port. In this paper have been analyzed the main links of container servicing chains, which play crucial role in their functioning.

Tab. 1. Particular links of chains of servicing containers in port area

No.	Link	Illustration	Goal
A Prz B	Unloading the container at ship side		- Relocation of the container from the ship on to quay or a land transport facility (unloading). - Relocation of the container from quay or a land transport facility on to ship (loading).
B Skł N	Temporary location of the container on to quay		- Short-time storing the container on quay at ship side, aimed at waiting for further relocation.

C
Prz P
	Reloading the container over the port area		- Relocation of the container in the relations of:
			  - Store place - car.
			  - Store place - lorry (or in opposite relations) etc.

D Pw P	Intra-port transport of the container		- Relocation of the container between port store places or dedicated port areas, by means of port tractor.
E Prz-Pw	Relocation of the container over a store place area [1)] (reloading/ transport)		- Relocation of the container over a store place area to make it possible to reload containers placed in lower tiers. - Relocation of the container over a terminal area by means of port vehicles.
F Skł Pl	Storing/keeping the container on a store place		- Location of the container on to a store place and connecting it to a power source. - Control of external state of the container and recording CRC storage parameters.
G* Skł TP	Storing/keeping the container on a temporary store place		- Temporary relocation of the container in order to perform different control operations or wait for further servicing.

H
KW
	Veterinary control of CRC		- Inspection of content of the container by a veterinary doctor. It comprises:
			  - Opening the container door
			  - Taking cargo samples.
			  - Closing the container and sealing it with lead.
			  - Issuing a quality certificate for CRC.

I
KCiG
	Custom inspection and frontier control of CRC		- Examination of container content by custom and frontier service:
			  - Opening the container doors.
			  - Examination of container content.
			  - Closing the container and sealing it with lead.
			  - Issuing documents.

No.	Link	Illustration	Goal
J Pw O	Transport of the container by car of receiver/provider		- Relocation of the container over port area by using ship owner's transport means in the relation of carry-in/carry - out (export/import).
K* Skan	Ray control of the container		- Scanning the container to check state of its content.
L* Weigh	Weighing the container		- Determination of total mass of the container and its cargo.
M* Compl	Completing/decompleting of the container		- Loading the refrigerated cargo into the container - Unloading the refrigerated cargo out of the container and its dislocation to a car, lorry or port cold store.
N* Pw chł	Dislocating the refrigerated cargo inside a refrigerated truck		- Dislocation of the cargo inside a refrigerated truck to unload it from or load into the container.

[1)] the link covers both the reloading and transport of the container and is performed by using straddle and head carriers,
* auxiliary links of container servicing process

Source: the author's original elaboration

RISK WHICH CAN OCCUR DURING SERVICING REEFER CONTAINERS

During designing transport systems of any kind is performed an analysis of development of every situation in which the system in question can be used, including extraordinary ones. Any hazard is very tightly connected with the notion of risk which is usually defined as the product of occurrence frequency (or probability) of a given hazardous event within certain time interval and consequences associated with the event [1, 12, 14]. The risk of loss of CRC quality merits can be calculated by using the formula (1).

$$P(V) \cdot K(V) = R \le R_{akc} \qquad (1)$$

where:
P (V) – probability of loss of QM of CRC [0 ÷ 1],
K (V) – amount of loss in the case of loss of QM of CRC (it depends on a kind of containerized cargo) [zł] (Polish currency),
V – conditions of realization of CRC servicing,
R – calculated risk [zł],
R_{akc} – acceptable risk [zł].

Number of combinations of risk factors which result in extraordinary situations in port area is very large [4, 6, 7, 8], therefore all the risk factors are proposed to be reduced to the groups presented in Tab. 2.

As results from Tab. 2, the human factors constitute a group of factors most often appearing in port area. Analyzing the methods for assessing risk level one can state that human behaviour is hard to be assessed by using traditional methods (e.g. probability theory) as man thinks in a fuzzy way. Hence in this paper the assumptions of fuzzy logic theory were selected for assessing all the factors contributing in loss of QM of CRC in port area. The theory makes it possible to assess objects and processes in which input data are not precisely determined. Because in the case of loss of CRC quality merits the amount of losses K(V) (i.e. the cost of servicing a given CRC) is known and determined, in this paper the risk assessment (PR) was mainly based on estimation of certainty level of losing CRC quality merits, calculated with the use of the fuzzy measure of possibility Poss (V) [0 ÷ 1].

Tab. 2. General classification of risk factors

Group of factors	Risk factors	Frequency of occurrence [%]*)
Human factors (subjective)	- Individual psychological and physiological factors (e.g. state of illness or tire etc)	60 - 70
	- Individual professional factors (e.g. insufficient qualifications etc)	
	- Factors of inproper organization of servicing CRC (e.g. lack of instruction for servicing given cargoes, insufficient number of employees etc	
	- **Collective factors resulting from multi-nationality and lack of knowledge of communication language (e.g. inproper information exchange, unprecisely attributed tasks etc)**	
	- Social factors: strikes, epidemies, thefts, terrorism etc.	
Technical and technological factors (objective-subjective)	- Unsatisfactory state of port infrastructure (e.g. inproper state of intra-port roads, store places etc)	25 - 35
	- Unsatisfactory state of port supra-structure (e.g., unreliability of cargo handling facilities, intra- port transport means etc)	
	- **Unsatisfactory state of reefer container (e.g. failures of elements of refrigerating units and defects of reefer container box etc)**	
	- Inproper technique of servicing the container (e.g. lack of an appropriate number of supra-structure facilities)	
Natural climatic factors (objective)	- Unfavourable climatic and aerologic conditions (e.g. strong winds, snowfall, rains, hurricanes, tornados etc)	5 - 15
	- **Unfavourable hydrological conditions (e.g. tsunami, waving, flooding etc)**	
	- Unfavourable seismic conditions (e.g. earthquakes etc)	
*) expert assessment, the data are different for each of the ports		

Source: the author's original elaboration based on an inquiry action conducted among experts.

MODEL OF RISK LEVEL ASSESSMENT

For elaboration of the model of risk level assessment the following assumptions and limitations were taken:

A) Assumptions:

1. The risk factors defined and split into three groups, characterize real conditions of servicing containers in sea ports and impact CRCs independently.
2. Occurrence of a combination of different risk factors is possible.
3. Risk factors have linear dynamics of impact on to CRCs.

B) Limitations:

1. Duration time of servicing CRC in port area does not exceed expiry time of the CRC.
2. For analysing a separate link it is assumed that risk factor duration time does not exceed duration time of the link in question.

To perform a quantitative assessment of risk level of CRC QM loss a calculation model was elaborated. The model is aimed at the assessing of risk level both during performing particular links of container servicing chains and performing the whole chains. Fig. 1 shows the model's structure.

In Fig. 2 is presented the author's conceptual model which covers data mutual relations used for assessing risk level of CRC QM loss. It was elaborated on the basis of the data acquired from sea ports and saved in data bases.

The conceptual model's structure consists of the peaks and directed connections between them, which define a set

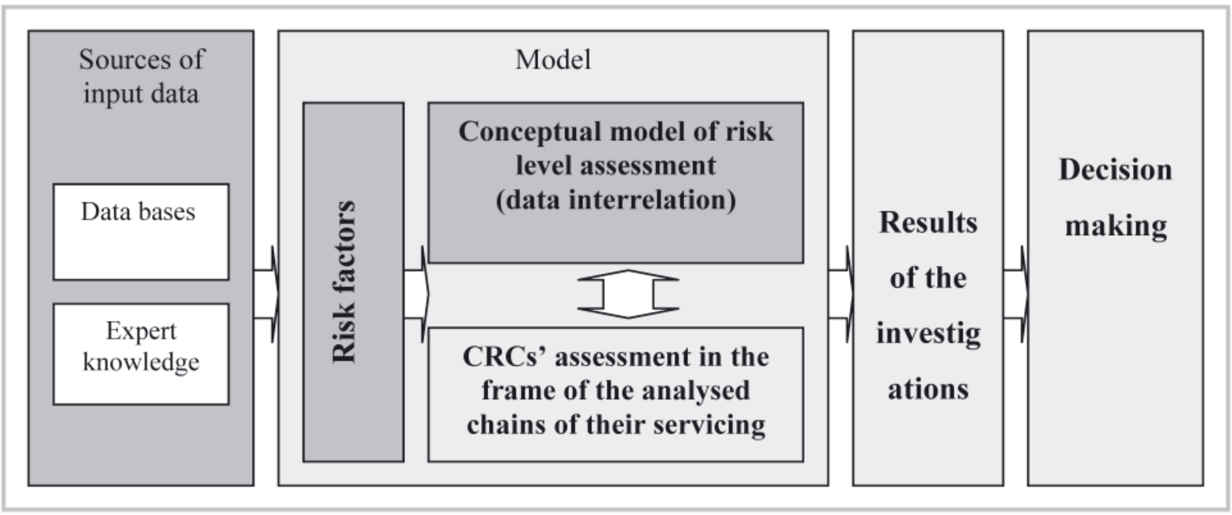


Fig. 1. Structure of the calculation model of risk level assessment of CRC QM loss during designing rational chains of cargo servicing in sea ports.
***Source**: the author's original elaboration*

Tab. 3. Gradations of particular characteristics of the conceptual model

Characteristics of the conceptual model	Particular gradations
State of refrigerating unit	Technical state of: - temperature sensors; - automation and electronic systems; - compressor; - condenser's fan (-s); - evaporator's fans; - valves, including thermostatic expansion valve; - refrigerating agent cycle (leakage or blockage of agent circulation).
State of reefer container box	Technical state of: - container casing; - electric equipment (cable and plug); - container door; - container insulation.
Dynamics of reefer container servicing	- Changes in position and spatial orientation without damage of container casing (due to acceleration, capsizing etc); - Dynamics of electric supply of container refrigerating unit; - Container servicing duration time; - Dynamics of temperature state of container casing; - Degree of.container door opening
Initial state of cargo	- State of cargo inside the container; - State of packaging of cargo inside the container; - Way of arrangement of cargo inside the container; - Presence of conflicting cargoes inside the container (e.g.apples of different kinds or different ripe levels).

Source: the author's original elaboration

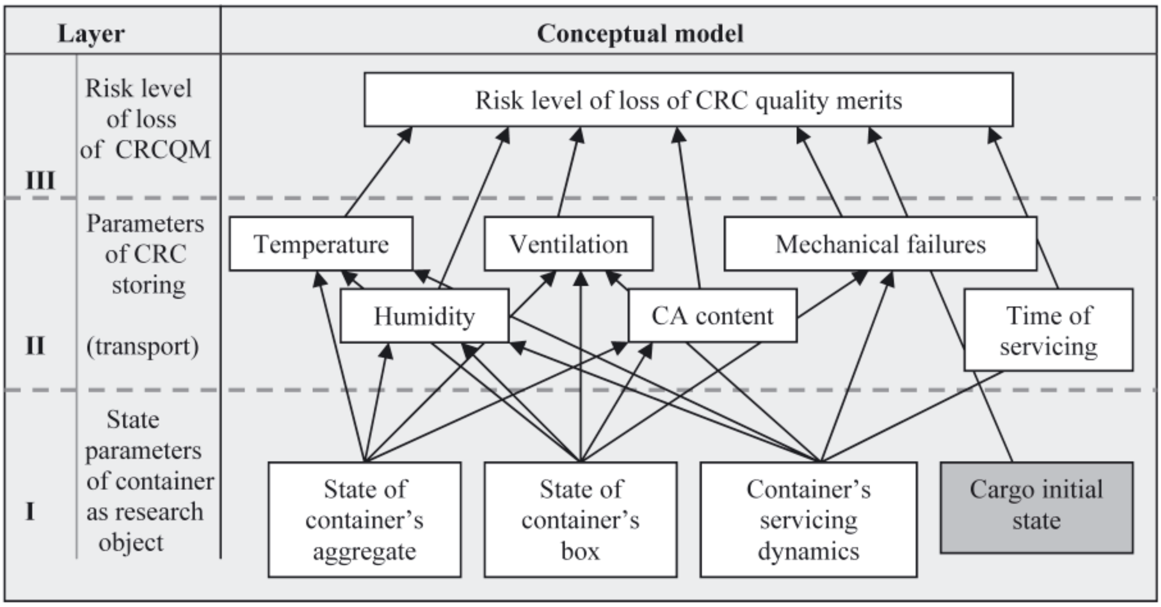


Fig. 2. Information data interrelations in the conceptual model, source: the author's original elaboration

of rules for transition of input data to calculation results. The connections are considered to be relations which describe influence of one category of data on other ones.

The peaks of the 1st layer of the analysed model are called the model's characteristics. They describe state parameters of reefer container serviced in port area. The characteristics are determined by sets of gradations (Tab.3), which form sets of input data and are formalized by scales of possible changes of their particular values.

As known from CRC servicing pactice, impact of risk factors onto the cargoes is time-varying. The fact has been taken into account in the proposed model. In the model, risk factors change values of characteristics of research objects, that consequently has influence on change of integral values in particular layers of the model. By accounting for the influence a dynamics which reveals functioning the CRC servicing chains, is formed.

In order to obtain the correct functioning of the calculation model, consecutive data bases have been elaborated to be used to:

- assigning values (fuzzy measures) in particular peaks of the conceptual model,

- determining values for gradation of characteristics of research objects,

- determining intensity and duration time of impact of risk factors etc.

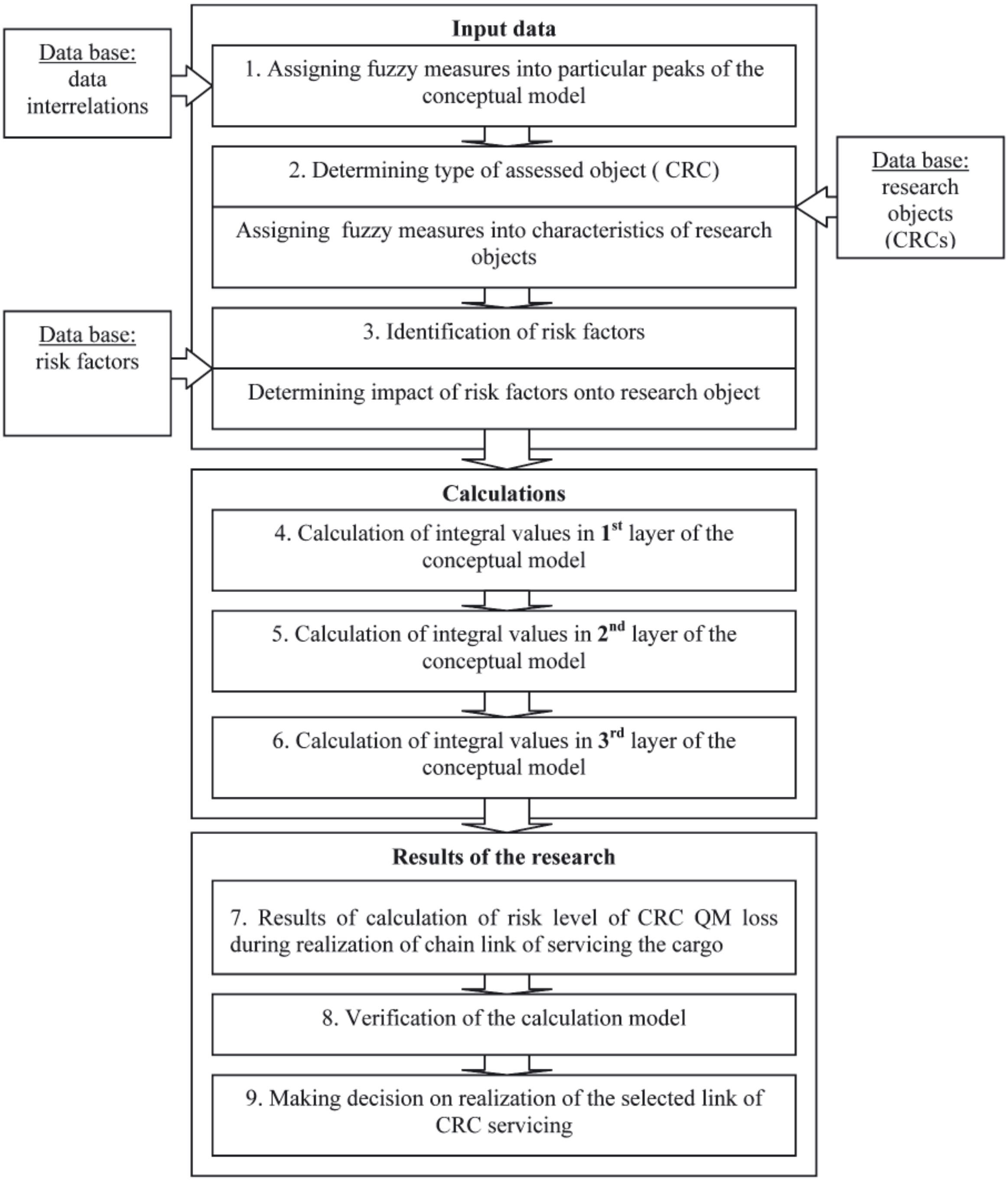


Fig. 3. *Algorithm of calculation of risk level during realization of a single chain link of container servicing in port area, source: the author's original elaboration*

To build the data bases was used information achieved from expert inquiries, rules, standards and legal regulations as well as that gained by this author during her training periods spent in sea ports of Poland and Ukraine.

The calculation algorithm of risk level during realization of a single chain link of container servicing is presented in Fig. 3. In the model, to perform calculations, the assumptions of fuzzy logic theory were used [2, 8]. The calculations were carried out by using an adjusted software based on the complex ExproMaster 6.0, whose results delivered risk levels of loss of CRC quality merits (Fig. 4).

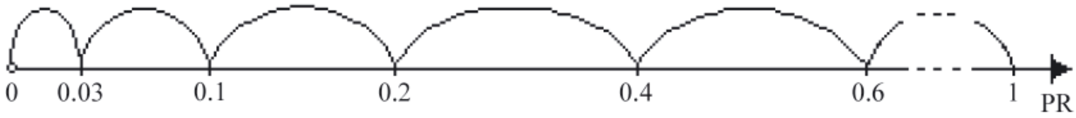
In the process of the model verification a satisfactory convergence of statistical data with those obtained from the calculations, was reached.

MAKING DECISIONS DURING DESIGNING THE CHAINS OF SERVICING THE CONTAINERIZED REFRIGERATING CARGOES IN COMPLIANCE WITH THE RISK LEVEL MINIMIZING CRITERION

After performing the assessment of risk level of CRC QM loss in particular links and during realization the whole servicing chain, decision dealing with final form of the servicing chain of such cargoes in port area, should be made. Example ranges which classify risk levels of CRC QM loss, are presented in Tab. 4.

If the risk level of QM loss of a serviced refrigerated cargo is contained in the acceptable range (PR $\leq$ 0.2), decision-making person is able to accept servicing the cargo in accordance with decisions taken during preliminary design process of a given

__Tab. 4.__ Example ranges which classify risk levels of CRC QM loss, based on the experts' inquiry action



Example range of risk level	Risk level of CRC QM loss	Acceptable risk level of CRC QM loss	State of refrigerated cargo
$0 < PR_{akc} \leq 0.03$	minute	ideal	- cargo maintains its initial merits and can be sold
$0.03 < PR_{akc} \leq 0.1$	insignificant	acceptable	- cargo maintains its initial merits. but insignificant changes of its transport conditions occur
$0.1 < PR_{akc} \leq 0.2$	low	acceptable	- cargo maintains its initial merits but is transported in inproper conditions
$0.2 < PR_{akc} \leq 0.4$	limiting	acceptable provided the decision-making person takes resposibility for it	- short-lasting changes in recommended cargo storing conditions occur
$0.4 < PR \leq 0.6$	critical	conditionally acceptable	- cargo is exposed to loss of its quality
$0.6 < PR \leq 1.0$	disastrous	inacceptable	- cargo is especially exposed to loss of its quality or spoiling
PR – risk level of CRC QM loss; PR_{akc} – acceptable risk level of CRC QM loss			

Source: the author's original elaboration

__Fig. 4.__ Dialogue windows showing particular calculation phases: __a)__ dialogue window for inserting fuzzy measures into gradations of characteristics of examined objects; __b)__ dialogue window for inserting power of impact of risk factor onto object of examination; __c)__ dialogue window showing temporary results of calculations in peaks of 2nd layer of the conceptual model; __d)__ dialogue window showing results of calculation of integral risk level of loss of refrigerated cargo quality merits. __Source__: the author's original elaboration

Tab. 5. Results of assessment of risk level during realization of particular links and the whole servicing chain of a selected CRC, acc. the moderate scenario

No.	Risk level during realization of particular servicing link of a selected CRC	Risk level during realization of the chain
1	0.22, 0.11, 0.20, 0.19, 0.10	0.22 (Limiting)
2	0.19, 0.10, 0.12, 0.15, 0.17, 0.11, 0.19 … … 0.18, 0.10	0.19 (Low)
3	0.15, 0.08, 0.16, 0.10, 0.21, 0.14, 0.24 … … 0.12, 0.12, 0.19, 0.17, 0.10	0.24 (Limiting)
4	0.15, 0.08, 0.16, 0.13, 0.12, 0.10, 0.19 … … 0.11, 0.12, 0.15, 0.12, 0.10, 0.18, 0.11 … … 0.12, 0.20, 0.16 … 0.16, 0.22, 0.17, 0.12	0.22 (Limiting)

Source: the author's original elaboration

chain of CRC servicing, and not to take any action connected with its rationalization. If the PR is located in the range of the limiting risk level (0.2 < PR ≤ 0.4), decision-making person may undertake realization of a given link of CRC servicing chain on his personal responsibility.

If the aforementioned risk level is located in the conditionally acceptable range (0.4 < PR ≤ 0.6), decision-making person may accept CRC servicing in accordance with the prior taken decisions (i.e. on his personal responsibility) or introduce changes into the servicing process of the cargo in question.

If decision – making person chooses the direction of introducing changes into chain of CRC servicing then it will be possible to introduce them into:

- structure of to-be-used elements of infra- and supra-structure of a port,
- structure of organization system of port servicing,
- structure of cargo servicing technology (changes in number and sequence of links put in the CRC servicing chain).

If the risk level during servicing the CRC exceeds the conditionally acceptable level (PR > 0,6), decision-making person should resign himself to service a given cargo in a sea port or undertake definite actions to lower the risk level or - by means of negotiations - to change initial assumptions as to servicing the container in sea port. Decisions made at a given risk level should be aided by additional resources (infrastructural, financial etc).

RESULTS OF SIMULATION INVESTIGATIONS

On the basis of the presented calculation algorithm (Fig. 3) were performed calculations of risk levels of loss of CRC QM during realization of servicing chains of a given CRC in given conditions in a selected port „X". The calculations were carried out for three scenarios of impact of risk factors (optimistic, moderate and pesimistic one). Tab. 5 shows results of the calculations for each of four selected representative servicing

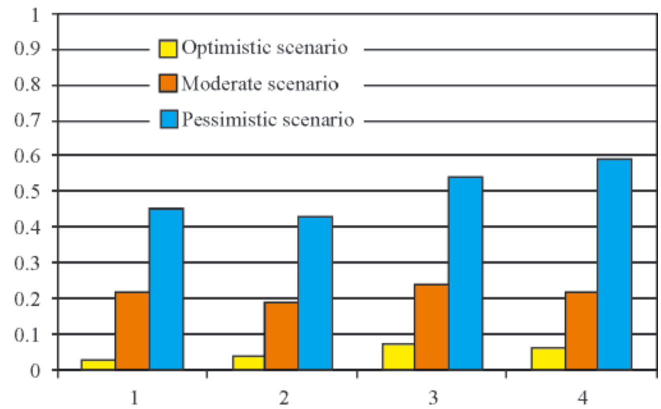


Fig. 5. Results of assessment of risk levels during realization of the investigated chains of CRC servicing in a port „X", acc. three scenarios of impact of risk factors. Source: the author's original elaboration

chains of a given CRC [10, 11] in compliance with the moderate scenario. In the table colours of the links correspond to colours and names of the links in Tab. 1. Combination of the obtained results of risk level calculations for the three scenarios, is given in Fig. 5.

On the basis of the obtained data it is possible to determine variants of change of risk level of CRC QM loss depending on intensity and duration time of impact of risk factors.

In Fig. 6 is presented the dependence of risk level on duration time of realization of the link „Storing the container on store place" for five variants of container servicing.

As results from the diagrams in Fig. 6, risk level of CRC QM loss changes in the range of 5 ÷40 %, depending on a way of realization of CRC servicing link.

With the use of the elaborated model was determined a.o. the dependence of risk level of CRC QM loss on reefer container's age of operation (Fig. 7).

As a result of calculations was also obtained dynamics of change in risk level of CRC QM loss, resulting from the selected groups of risk factors (Fig. 8).

As results from Fig. 8, in the case of realization of the chain "1" (Tab. 5) for the moderate scenario, impact of human factors on risk level exceeds impacts of the remaining groups of risk factors by 10÷15 %. This demonstrates that behaviour of human being and its errors greatly contribute to possible occurrence of extraordinary situations. The decisions made for CRC servicing should hence take into account the intensity and duration time of impact of subjective factors on realization of both particular links and the whole cargo servicing chain in port.

On the basis of the performed analyses of the above mentioned cargo servicing chains the following conclusions can be offered:

1. Change of sequence of realization of links of CRC servicing chains can lead to a change of their weakest links, i.e. occurrence of the highest risk level in another link.
2. There are two ways of lowering the risk level of CRC QM loss: - to introduce changes in realization of the weakest link (-s) of CRC servicing chain or - to choose another chain of servicing the cargo. In the first case the risk level may be lowered by 10÷18 %, in the other - by 8÷21 %. As

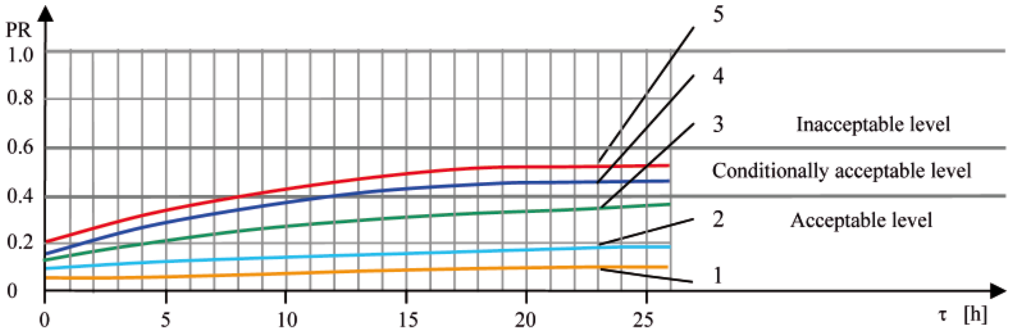


Fig. 6. *Dependence of risk level on duration time of realization of the link „Storing the container in store place". **PR** – risk level of CRC QM loss, **τ** - duration time of realization of the link „Storing the container in store place", **1** – the container was stored in store place in 1st tier, **2** – the container was stored in store place in 2nd tier during hot weather, **3** – the container was relocated several times over store place, **4** – custom control was performed in store place (the container's door was opened), **5** – the container was left for a long time without electric supply in store place. **Source**: the author's original elaboration*

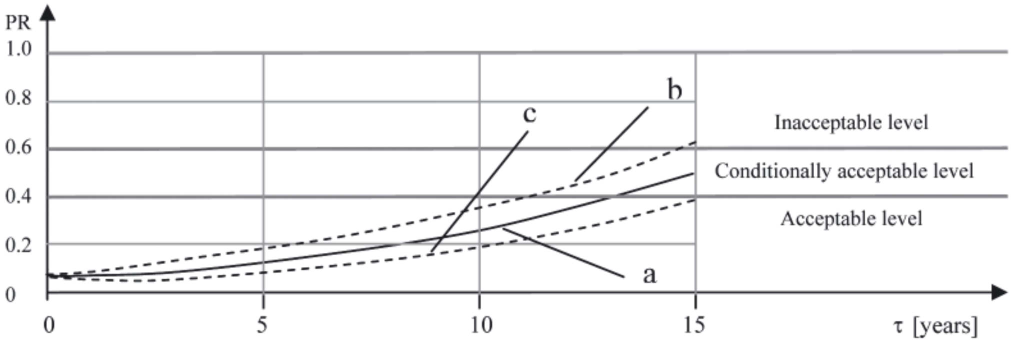


Fig. 7. *Dependence of risk level of CRC QM loss on reefer container's age of operation. **PR** – risk level of CRC QM loss, τ - reefer container's age, **a** – function of risk level versus reefer container's age, **b** and **c** – upper and lower variation interval of uncertainty of the function a, respectively. **Source**: the author's original elaboration*

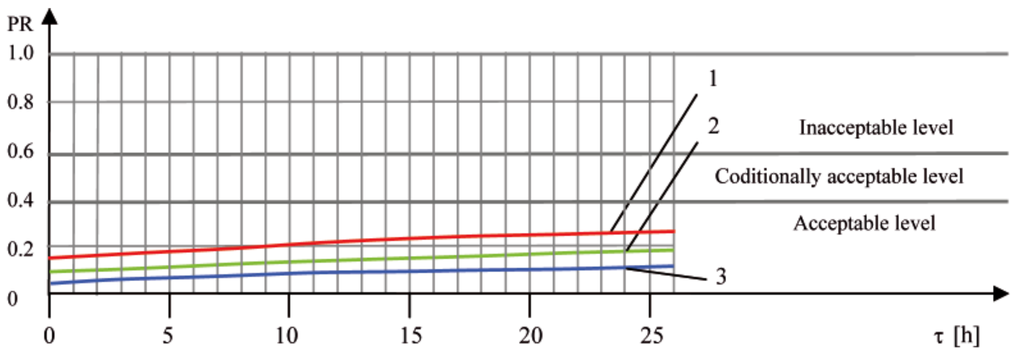


Fig. 8. *Dynamics of change in risk level of CRC QM loss for different groups of risk factors during realization of the chain „1" acc. the moderate scenario. **PR** – risk level of CRC QM loss, τ - duration time of realization of the link „Storing the container in store place", **1** – impact of human factors, **2** – impact of technical and technological factors, **3** – impact of natural climatic factors. **Source**: the author's original elaboration*

results from this, it is important to introduce changes both into realization of the weakest link and sequence of links of the CRC servicing chain. Change in sequence of realization of links results as a rule in a lower financial expenditure.
3. Because values of the calculated risk levels during realization of particular links of the analysed chains are rather close to each other, it is not always possible to identify the weakest link on realization conditions of which the integral risk level of the whole chain depends. Therefore it can be stated that in majority of cases decisive impact on integral risk level of servicing chain is associated with number and sequence of its realization links.
4. As a result of the performed investigations it can be stated that, disregarding situations connected with accidents and damages of reefer containers, the fact of disconnection of the container from electric supply is of the greatest detrimental effect on CRC QM loss [6], regardless of kind of risk factors causing a given situation. As number and duration time of the disconnection events depend on number of links of CRC servicing chain, sequence of their realization as well as port infra- and supra- structure angaged in it, cause-effect relation between the CRC QM loss and sequence and way of carrying out operation of servicing the cargo in port area, is this way revealed.
5. Simultaneous realization of certain operations, e.g. custom and veterinary control, decreases duration time of realization of link (-s), that consequently results in lowering the risk level. It seems that the problem of coordination of operations of all the services taking part in CRC servicing in the organizational, technical and technological aspects is presently more and more widely observed as an active dialogue between scientists, port personnel, administration officials and cargo owners has been initiated [5].

SUMMARY

The presented set of methods constitutes a prototype of an expert system aimed at generating alternative variants of servicing reefer containers in sea port area, and making their subsequent comparisons.

Tendency of sea ports towards rationalization of cargo servicing in their areas is associated not only with improvement of their infra- and supra- structure but also creation of suitable conditions for rational decision-making by entitled persons. Activity of ports should be directed towards elaboration and implementation of the systems for rational decision - making during forming CRC servicing chains in port area. Investing into the systems (a.o. expert systems) for aiding decisions to be taken should make it possible to improve quality of CRC servicing as well as reduce risk of CRC's QM loss in port area.

The set of methods for rationalization of CRC servicing in sea ports, proposed by this author, makes it possible to form different CRC servicing chains and compare them with taking into account risk factors affecting quality merits of the cargoes. As results from the performed analysis, safety of refrigerated cargo during its servicing in sea port area depends both on a state of reefer container reliability and quality of its servicing by port personnel. Impact of human factors characterised by their variety and high frequency of occurrence, on quality of cargo during its servicing in port area, considerably exceeds impact of other risk factors.The application of fuzzy logic to analysing risk level of loss of quality merits of refrigerated cargoes is justified and makes it possible to assess impact of subjective factors onto CRC servicing.

The elaborated set of methods for rationalization of CRC servicing, based on computer software, makes it possible to improve operational effectiveness of sea port functioning in contemporary market conditions.

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