Taylor & Francis
Taylor & Francis Group

TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2012 Volume 27(1): 40–48
doi:10.3846/16484142.2012.665206

INTEGRATION OF MOBILE CONTROL SYSTEMS INTO INTERMODAL CONTAINER TRANSPORTATION MANAGEMENT

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Submitted 15 October 2010; accepted 19 August 2011

Abstract. Over the last few years, a large number of researches have emerged and approached the use of mobile expert systems and other information management technologies in the area of intermodal container transportation and decision support. However, practitioner literature poorly analyzes the process of monitoring cargo transportation conditions, cargo information security and other important issues. The paper presents an emerging field of intermodal container transportation where the primary objective of the proposed mobile control system is to monitor cargo conditions during transportation in a real time manner and work as a decision support system. Also, the article evaluates potential risks involved in cargo transportation and therefore provides mobile cargo security assurance service. Computational results suggest using an optimum number of RFID and sensor readings to effectively manage the newly proposed elements of operation strategy in a conceptual strategy framework. The overall results indicate that the integration of risk management practice into transportation processes via a mobile control system increases intermodal container transportation mobility, safety and overall effectiveness.

Keywords: intermodal container transportation, mobile control system, elements of operation strategy, RFID readers, sensor technologies.

1. Introduction

Assuring a high level of information and transportation security, improving the efficiency of communication and other transportation operations and upgrading the capability of the general information system by integrating an innovative mobile control system must be the key objectives of managing intermodal container transportation worldwide. In this case, intermodal cargo transportation involves the transportation of cargo in intermodal containers using multiple modes of transportation without any handling of the freight itself when changing modes. The basic idea of a mobile control system is to ensure seamless end-to-end tracking and cargo monitoring. At this point, the evaluation of potential risks involved in cargo transportation and the optimal management of transport resources are given a priority thus providing mobile cargo security assurance services.

While there is much literature about the route optimization of intermodal transport (Macharis *et al.* 2010; Ishfaq, Sox 2010; Macharis, Pekin 2009; Limbourg, Jourquin 2009; Janic 2008; Chang 2008; Sirikijpanichkul *et al.* 2007), logistic chain analysis (Shariat-Mohaymany, Babaei 2010) and intermodal transportation management (Thill, Lim 2010; Kreutzberger 2008; Sirikijpanichkul *et al.* 2007), comparatively little has been written about applying sensors and RFID technologies in intermodal container transportation (Wen 2010; Amador, Emond 2010; Chavali *et al.* 2008), the security of transferring RFID data (Kaya *et al.* 2009) and employing other information technologies (Oztekin *et al.* 2010; Dias *et al.* 2009). The basis for this paper has been provided by Ngai *et al.* (2007), Woo *et al.* (2009) and Ferrer *et al.* (2010).

Since the use of RFID and other information technologies in business applications has been quite recent, we have selected a group of literature examples from the latest researches and enriched them with reports mostly found in practitioner literature. For modelling a mobile control system, the analysis of individual requirements and the main system components becomes important issues (Urbahs *et al.* 2005). Verma and Verter (2010) presented the first attempt at developing an analytical framework for planning rail–truck intermodal transportation of hazardous materials. To plan and manage intermodal shipments, a bi-objective optimization model has been developed and implemented. Wang

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and Tang (2010) provided an optimization model based on chance-constrained programming for transporting containers by sea. It was later translated into an integer programming model to effectively enhance the competitiveness and efficiency of shipping companies. Lee and Chan (2009) proposed a RFID-based reverse logistics framework and introduced the genetic algorithm to optimize the locations of collection points for product returns in order to maximize the coverage of customers, which allowed economically and ecologically reasonable recycling. Hsu *et al.* (2009) explored the custom clearance process of import cargos in international air cargo terminals and constructed a network to analyze cargo, information and human flows. The network of the custom clearance process was reconstructed based on the application of RFID technology and the performance of the proposed system and evaluated in terms of reductions in shippers' inventory cost and operator labour cost.

For the period 1990–2010, the number of TEU containers grew rapidly each year. Thus, it seems to be that along with such fleet increase in the future, any conventional management system of intermodal container transportation will not be capable of dealing with more pressing problems in a timely manner. Therefore, a more complex, agile and secure mobile control system with sensing capabilities is proposed.

2. Proposals for Operational Strategies

Container monitoring is considered a major security issue in many countries where the application of new intermodal container transportation management technologies plays an important role in optimizing performance and reduces the cost and risks of strategies for transportation operations and other services (Fig. 1). Similar systems have already proven their direct value in many fields of scientific research provided in literature review. Thus, at present, the companies worldwide are contemplating using it to benefit their business and overall transportation processes to produce a direct value for their customers while improving operational performance in terms of cost, quality, speed, flexibility and optimal resource management. Based on the framework of the operation strategy proposed by Ferrer *et al.* (2010), an additional strategy element of operations was taken into account to improve the main strategy objectives by optimally utilizing the vast amount of direct and indirect resources that scattered within the transportation chain from the initial cargo to business processes (benefit the company and its customers in terms of transportation quality, reliability, speed of delivery, flexibility and low costs).

The additional benefit of the new element will use the already known limited resources (e.g. time constraints, labour force, etc.) in advance to the mobile control system by initial cargo transportation route planning in a safe manner. Therefore, an additional objective of operation strategy will include the unnecessary management of business processes and deal with uncertainty about the effectiveness of the basic elements of operation strategy and their optimal usage.

Optimum resource management mainly depends on the availability of intermodal containers and ensures that once returned, they are redeployed as quickly as possible and never put to mixed use. This procedure includes a fast turnaround of containers and ensures that those assigned to specific cargos are never put to mixed use. The additional optimum usage of quality elements will minimize risks involved in data transfer within the mobile control system (optimal data cryptography approach). Additionally, active RFID tags include a vari-

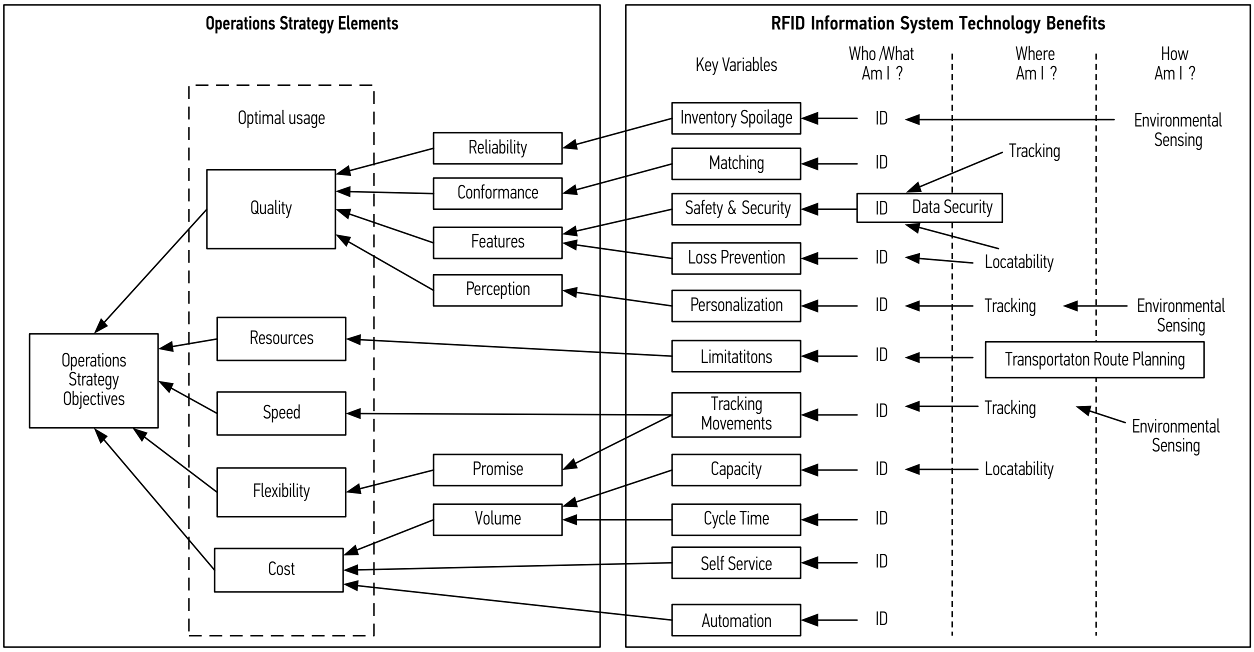


Fig. 1. A strategy framework for intermodal container transportation operations and RFID benefits

ety of environmental monitoring capabilities such as the ability to track ambient temperature and humidity, which enables the tag to act as a mobile sensor to wirelessly collect information about its inner environmental conditions.

3. Description of a Mobile Control System

This section overviews the proposed mobile control system and discusses the main issues of information security.

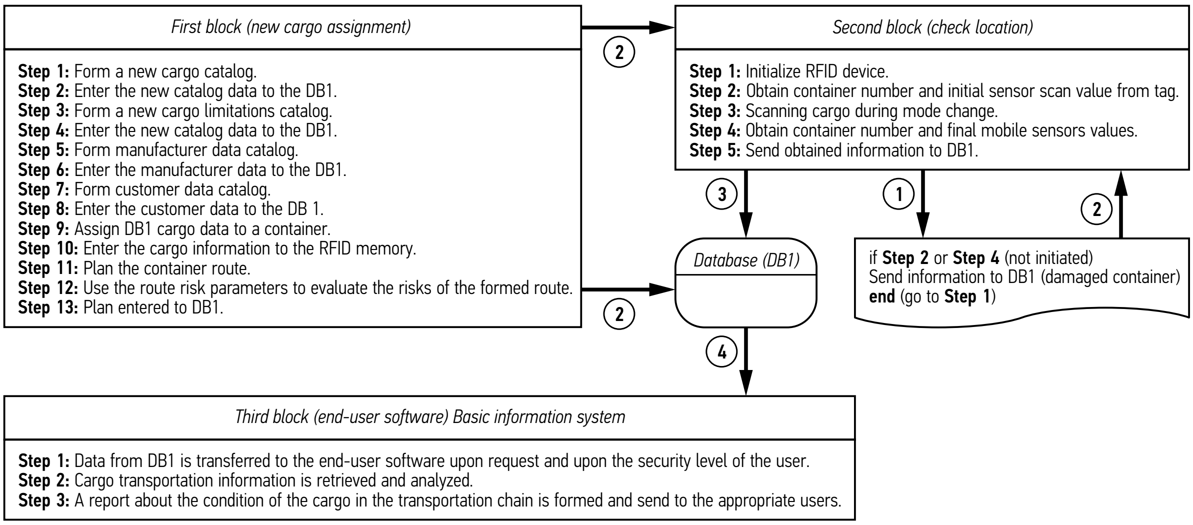
3.1. The Basic Functionality Algorithm of the System

The basic approach is the use of active RFID tags joint with mobile sensors that are attached inside standard intermodal shipping containers (TEU). Mounted sensors can detect if the container has been opened, whereas other sensors inside the container can report on cargo conditions and integrity. It also provides two-way wireless communication within a supply chain network that enables real-time auditing and provides the needed security/safety assurance service. The main objective of the mobile control system is to retrieve all necessary data about cargo conditions during transportation and to analyze it considering managerial decision support. The functionality of the general information system consists of communication between tagged containers and end-user software. Once checking is activated, the transponder (RFID reader) communicates with RFID tags wired to other mobile sensors that measure changes in environmental variables (light, temperature, pressure, etc.), vibration, radioactivity, etc. There is also a possibility of linking RFID tags with GPS technology to furnish shippers and logistics service providers with real-time visibility about the location, status, security and integrity of their cargo. The amount of data to be sent to end-software is defined by the security level of the user.

In that case, the RFID system is the basic component of the proposed mobile control system. It can monitor the needed climate parameters inside the container and report on the conditions and integrity of cargo, thus providing a way to foresee cargo damage before actual damage takes place. Active RFID technology provides a way to automatically collect data on sensors without burdening employees, and therefore no operator intervention is required at that moment. This provides company managers with an up-to-the-minute picture of transportation processes and activities and allows them to respond to developing situations in a timely manner. Active RFID tags are also constantly powered in or out of the range of a reader, and therefore are able to continuously monitor and record the conditions inside the container and control the ability to transmit longer data packets for simplified data retrieval. They can power an internal clock and apply an accurate time/date stamp. The mobile control system is described by 3 step blocks (Fig. 2) where the first block describes information on assignment operation, the second block gives the details of the method for gathering initial data and the third block specifies all later operations concerned with data analysis and decision making.

The detailed data collected from the tags may uncover inefficiencies in the established procedures and among other operation strategy elements that could not be previously identified thus making its transportation processes more agile and safer. This will also improve the overall quality of intermodal container transportation. Technology for automatic information tracking can also be used instead of GPS.

Automatic wireless reading of multiple RFID tags creates an enormous data flow that is very important to the managers, because it can improve the accuracy of delivery promise (the speed of cargo delivery); however, it hardens the part of data analysis in real time. For this reason, as mentioned, the amount of information transferred and data links established at one point in time must be minimal to maximize the performance of the elements of operation strategy. Whereas, in an alert situation, the source of the problem can be defined by some basic predefined rules for a business process: if an object passes into or out of the predefined secure area,



First block (new cargo assignment)

Step 1: Form a new cargo catalog.
Step 2: Enter the new catalog data to the DB1.
Step 3: Form a new cargo limitations catalog.
Step 4: Enter the new catalog data to the DB1.
Step 5: Form manufacturer data catalog.
Step 6: Enter the manufacturer data to the DB1.
Step 7: Form customer data catalog.
Step 8: Enter the customer data to the DB 1.
Step 9: Assign DB1 cargo data to a container.
Step 10: Enter the cargo information to the RFID memory.
Step 11: Plan the container route.
Step 12: Use the route risk parameters to evaluate the risks of the formed route.
Step 13: Plan entered to DB1.

Second block (check location)

Step 1: Initialize RFID device.
Step 2: Obtain container number and initial sensor scan value from tag.
Step 3: Scanning cargo during mode change.
Step 4: Obtain container number and final mobile sensors values.
Step 5: Send obtained information to DB1.

if **Step 2** or **Step 4** (not initiated)
Send information to DB1 (damaged container)
end (go to **Step 1**)

Third block (end-user software) Basic information system

Step 1: Data from DB1 is transferred to the end-user software upon request and upon the security level of the user.
Step 2: Cargo transportation information is retrieved and analyzed.
Step 3: A report about the condition of the cargo in the transportation chain is formed and send to the appropriate users.

Fig. 2. A description of the information system

or if a problem occurs during regular cargo check, then, this action can trigger other events, processes, e-mails or SMS alerts to occur automatically. Such a safe precaution system would minimize managers' response time and would let the system automatically decide when to bother employees.

3.2. The Basic Security Description of the System

Nowadays, the widespread use of modern mobile technologies has introduced a new challenge concerning the security aspect of information transfer between the mobile control system and end-users. At present, designing general information systems to withstand external attacks and internal malfunctions in the system as well as rapid recovering from them have become crucial issues. Chen and Deng (2009) proposed a new authentication and encryption method for ensuring RFID data transfer security between tags and readers. Van Deursen and Radomirović (2009) investigated security claims on the recently proposed RFID authentication protocol, exhibited a flaw unnoticed in RFID protocols and presented the results of authentication, intractability and resynchronization resistance. Kang *et al.* (2008) proposed a secure authentication protocol to avoid providing information to authorized users by applying recognition technology. Wong *et al.* (2006) presented a new lightweight cryptography approach and a simple authentication method based on hash functions for RFID Class 1 passive tags. In this case, each tag carried a particular vendor type of reader's public key and its unique private key. While reading, readers and tags mutually authenticated each other using these embedded keys. Authentication between readers and tags was achieved using a challenge–response technique. The proposed method was determined to be effective and its operation was reliable. Also, in a public key cryptography approach, RFID tags need to have strong computation power in order to do complex and intensive computational tasks (sensor data retrieval and storage). To better understand security issues, determining the most basic communication standards used for RFID data transfer within the mobile control system is required. For that purpose, Knospe and Pohl (2004) specified the basic RFID communication protocols (Table 1) and suggested trends for developing future technology.

Security management is not a single task for constant protection from all external and internal attacks. It also must include such system activities as the management of user permission and improvements in the overall security of the system where:

- user and permission management should include adding and removing users from the system, thus ensuring that appropriate user authentication mechanisms work properly and setting up permissions in the system so that users have access to the resources at the level of their security;
- attack monitoring, detection, recovering and improvement in the overall security should include activities to monitor the system for unauthorized access, detect and put in place strategies for resisting attacks and backup resources for resuming a normal system after attacking; also, it should include continuous improvements on the security protocol.

Overall security management is vitally important for working stability and efficiency. If an attack makes information in the basic information system corrupted or unavailable, it will be impossible to update all data needed to plan the cargo route. For that purpose, specific control mechanisms are needed to ensure that all external and internal attacks are unsuccessful.

4. Limitations on Cargo Transportation

This section provides a brief overview of the external risk factors of the systems. The exception is made to evaluating vibration on the account of necessary additional experemental data due to a lack of research information on mechanical damage to the TEU container during handling, which is mentioned in the section 'Conclusions and Future Work'.

4.1. Transportation Risk Factors

One of the most important things for cargo transportation in intermodal containers is a sufficient knowledge of all major risk factors such as climatic conditions for cargo during intermodal container transportation having a great influence on transportation operations and their main strategies. The conditions include temperature, air exchange rate and humidity and are affected by

Table 1. A summary of RFID standards

Standards	Specifications
ISO 18000	(RFID for item management) defines air interface, collision detection mechanisms and a communication protocol for item tags in different frequency bands
ISO 18000-3 (Part 3-1)	HF systems (13.56 MHz) are compatible with ISO 15693 (but with more flexibility in tag design)
ISO 18000-3 (Part 3-2)	Specifies the RFID system of the next generation in the same frequency band with higher bandwidth (up to 848 Kbit/s) and faster scanning of multiple tags
ISO 18000-4 (Part 4)	Specifies 2.45 GHz systems: in mode 1 – a passive backscatter system and in mode 2 – long range, high-data rates system with active tags
ISO 18000-6 (Part 6)	Defines a passive backscatter system in 900 MHz range band
ISO 18000-7 (Part 7)	Specifies RFID system with active transponders (433 MHz)

Table 2. Basic risk factors during transportation (additional privacy information)

	Main cargo risks during transportation:												
	Temperature	Humidity	Ventilation	Biotic	Activity	Gases	Self-heating/ Spontaneous combustion	Odor	Contamination	Mechanical Influence	Toxicity	Shrinkage/ Shortage/Theft	Insect infestation/ Diseases
Risks considered:	+	+	–	–	–	–	–	–	–	+	–	–	–

external climate conditions, the cargo itself and the type of the used container (Table 2). Most changes in cargo occurring during transport are unwanted and considered damage.

Also, an important point is knowledge of the properties of cargo and its packaging. These properties are based on water content, biotic activity and other cargo climatic requirements. When using the proposed system, it is possible to evaluate the suitability of cargo and to maintain normal transportation conditions. The basic cargo compatibility characteristics must also be taken into account while allocating cargo in a container because the interrelationship between cargos may result in reducing quality and further damage. Any cargo changes during transportation are unwanted and considered as damage. Other cargo properties are described by their characteristic features, specific functions, utility values and quality aspects.

4.2. Impact of External Climatic Conditions on Transportation

External climatic conditions have a strong impact upon sensor measurements and as a result, on the whole process of managing intermodal container transportation. Due to the diversity of cargo risks, it is not straightforward to predict how climate inside the container will change during transportation. Moreover, it is impossible to duplicate data from one transport operation to another for decision support, as transportation conditions each time may vary greatly. However, the awareness of the interaction between these factors is helpful in assessing future risks to cargo transportation and evaluating the planned routes.

First, higher or lower temperatures and humidity levels have to be expected during transportation, thus the first programmed limitations are formed (Fig. 2). Therefore, each cargo specification and packaging is important (Andziulis *et al.* 2010). The best way to increase the security of cargo (to maximize the efficiency of the proposed system) is to match all similar types of cargo in one container. Then, the route is planned with lower cargo risks involved. Hence, it becomes easier not only to maintain good cargo quality during transportation, but also to support decisions reached by managers (make less unnecessary alert situations).

Second, the level of humidity fluctuation is heavily dependent on temperature variations and air flow circulations. Cargo may suffer considerable damage due to their hygroscopicity in standard intermodal containers. Hence, it is essential for cargo to be contained dry when loading.

If any limitation is exceeded, cargo may undergo serious reductions in quality and eventually damage. The assessment of whether risk is worth taking may be carried out. The basic humidity conditions in the intermodal container are primarily determined by internal factors and are largely determined by hygroscopic characteristics and cargo packaging. Seawater or rain may also penetrate damaged containers under extreme weather conditions. Therefore, containers must be examined on a regular basis.

5. Numerical Example

This section proposes a route planning and risk evaluation method based on a case study of analyzing check point risk.

5.1. Expert System Development for Evaluating Cargo Risk Factors

A correct evaluation and forecast of the initial factors in cargo risk is vital for decision support. For that purpose, an expert system (Rao *et al.* 2005) where each new provided risk factor is based on the statistical probability of possible cargo damage has been developed. All input data on the expert system can be split into 4 input parameters:

1) scheduled weather conditions;
2) a model for evaluating each container;
3) a model for the whole infrastructure;
4) additional expert support.

The expert system consists of a base and database for expert knowledge used as input data on the inference engine that consists of a neural network and blocks of statistical data analysis. In this case, the initial factors in cargo risk are introduced as $x', y', z' = \{1:9\}$, $x', y', z' \in Z$, $Z > 0$, the expert evaluation system is described (1) as:

$$\begin{cases} A_1 : 1 < x'_q, y'_q, z'_q \leq 3; \\ A_2 : 3 < x'_q, y'_q, z' \leq 6; \\ A_3 : 6 < x'_q, y'_q, z' \leq 9, \end{cases} \qquad (1)$$

and formulated in the initial expert evaluation matrix (Table 3), where A_1 represents low risk probability, A_2 represents medium risk probability, A_3 represents high

Table 3. The expert evaluations matrix

	E_1	E_2	…	E_q	
x'	A_2	A_3	…	A_1, A_2, A_3	$\overline{x}'$
y'	A_2	A_2	…	A_1, A_2, A_3	$\overline{y}'$
z'	A_3	A_1	…	A_1, A_2, A_3	$\overline{z}'$

risk probability used in the evaluation of the initial factors in cargo risk and E_q represents each new expert in the system, $q \in Z, Z > 0$ (at a later stage - transferred to the knowledge base). Each new expert evaluation must have one factor in cargo risk higher than the rest as to be the main predicted risk. Additional AI (neural network block) adds sufficient advantages by decreasing the use of additional expert support. Additional AI (neural network block) adds sufficient advantages by decreasing the use of additional expert support. This block can update its knowledge base regarding information gained through several sessions of the interaction with the system user and databases as variations in routes are the same each time with the only difference in the forecasted and scheduled weather changes.

Thus, additional expert support is used when specific information is required to perform forecast operations. The basic rule of prediction can be formulated as (2):

$$\text{if } x'_u \in A_1 \text{ and } x'_{u+1} \in A_1 \text{ then } x'_{u+2} \in A_1, \quad u = 1, \ldots, q-2, \; u \in Z. \tag{2}$$

5.2. A Case Study on Evaluating Factors in Route Risk

As mentioned above, RFID readers are the main components of the mobile control system situated in specific locations where the retrieval of sensor data is conducted (e.g. containers, warehouses, etc.). Lets assume that there are 9 locations where RFID readers are installed. In addition, the system is designed to receive sensor information regarding interior temperature (x), humidity (y) and vibration (z) in the container. The location of each RFID reader is described taking into account its unique geographical and other features. Thus, expert evaluations may vary from one RFID reader installation to another (e.g. the first RFID reader is located in a container warehousing facility near the sea cost, so the factor in cargo risk describing humidity is higher than the rest of predictions, see Table 4). Direct dependability betweeen temperature and humidity also has a sufficient impact on expert evaluations. Therefore, additional coefficients $(\delta_x, \delta_y, \delta_z)$, $\delta_{x_\mu} = \sqrt[\beta]{x_\mu}$, $\delta_{y_\mu} = \sqrt[\beta]{y_\mu}$, $\delta_{z_\mu} = \sqrt[\beta]{z_\mu}$, $\mu = 1, \ldots, \beta$ are presented and describe the importance of assigned factors in cargo risk. Here, route risk factor k_e (3) represents the general risk evaluation of the entire route between RFID readers, where β is the number of RFID readers that are currently in use:

$$k_\varepsilon = \frac{\delta_{x_{\varepsilon+1}} x_{\varepsilon+1} + \delta_{y_{\varepsilon+1}} y_{\varepsilon+1} + \delta_{z_{\varepsilon+1}} z_{\varepsilon+1}}{\delta_{x_\varepsilon} x_\varepsilon + \delta_{y_\varepsilon} y_\varepsilon + \delta_{z_\varepsilon} z_\varepsilon}, \quad \varepsilon = 1, \ldots, \beta - 1. \tag{3}$$

The values of the factors in route risk presented in the Table 4 and Fig. 3 indicate the highest possibilities of cargo damage along the whole transportation route.

The simulated route (Fig. 3 and Table 4) has 3 major peaks where the possibility of cargo damage is considered to be the highest. Here, the 7th route has the highest risk (the most noticable deviation) and therefore may indicate the place of actual cargo damage. Therefore, such prediction may be used for supporting managers' decisions. Furthermore, it is important to know the optimum number of RFID readers to be installed and used for each separate cargo with minimum investment in the infrastructure of the system. In our case, the possibility of cargo damage is evaluated taking into account such cargo damage criterias as humidity, temperature, vibration and the age of the container. Additional research analyzed temperature variations in brown and white TEU containers at various locations over the period of 24 hours. The analysis of collected data showed that the distribution of temperature value within the given period of time was closely dependent on Gauss-

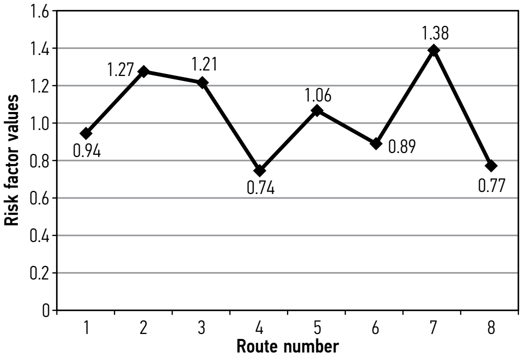


Fig. 3. A comparison of risk factors in the simulated route

Table 4. Simulated factors in cargo risk

RFID readers installations →	1	2	3	4	5	6	7	8	9
Temperature (x)	4	8	8	6	8	8	7	9	8
Humidity (y)	9	4	7	9	5	4	4	5	6
Vibration (z) (Mechanical)	3	3	4	8	4	6	5	8	3
δ_x	1.17	1.26	1.26	1.22	1.26	1.26	1.24	1.28	1.26
δ_y	1.28	1.17	1.24	1.28	1.20	1.17	1.17	1.20	1.22
δ_z	1.13	1.13	1.17	1.26	1.17	1.22	1.20	1.26	1.13

ian (normal) distribution which shows that the effects of solar radiation on containers are not that extreme at an external temperature of 25°C. Air temperature inside the brown-painted container rose to 50 and in the case of the white container, the inside air temperature of 38°C was recorded. In this manner, it should be noticed that temperature and humidity values inside the intermodal container are highly dependent and their overall distribution is considered normal. Accordingly, the main risk probability is formulated as (4):

$$P_{main} = 1-\left(1-K_{\mu} Q_A Q_{AM} Q_T Q_H Q_V\right)^{\mu}. \qquad (4)$$

The age and other parameters of the container are evaluated (5) considering the use of *Panamax* container ship carrying 2200 TEU containers with a total weight of 40000 tons:

$$Q_{AM} = \frac{\sum_{i=1}^{m} \varphi_i \left(\frac{\kappa_i}{\kappa_i + \gamma}\right)}{\sum_{i=1}^{n} \varphi_i}, \qquad (5)$$

where: Q_H – a coefficient defining the probability of cargo within the intermodal container damaged/corrupted with an increase or decrease in humidity; Q_T – a coefficient defining the probability of cargo within the intermodal container damaged/corrupted with an increase or decrease in temperature; Q_V – a coefficient defining the probability of cargo within the intermodal container damaged/corrupted by occurring overtop vibration; Q_{AM} – a coefficient defining the probability of cargo within the intermodal container damaged/corrupted because of the age of the intermodal container; n – the maximum age of the used containers; φ_i is the number of the containers of a specific age; κ_i – the number of the containers of the same age compared to 1000 used general containers; m is the maximum age of all currently exploited containers. The other criteria influencing the probability of the risk event is coefficient K_{μ} (7) introduced to reduce or increase risk probability taking into account the whole planned route and its mean risk value (6):

$$\bar{k} = \frac{\sum_{\varepsilon=1}^{\beta-1} k_{\varepsilon}}{\beta-1}; \qquad (6)$$

$$K_{\mu} = \rho_{\mu}\left(\bar{k} + \frac{\bar{k}}{\beta-1}\right); \qquad (7)$$

$$\rho_{\mu} = \max\left(\delta_x, \delta_y, \delta_z\right). \qquad (8)$$

The final computational results suggest that the probability of cargo damage with an increase in temperature, humidity and vibration levels is almost linear between 20% and 70% when using up to 200 RFID readers (Fig. 4). The effectiveness of the mobile control system starts decreasing at a steady pace when the number of RFID readers is more than 200 (more than 70% of risk possibility). The foremost conclusion indicates that the optimum number of RFID readers needed to efficiently exploit the system is between 40 and 200 on a single transportation route.

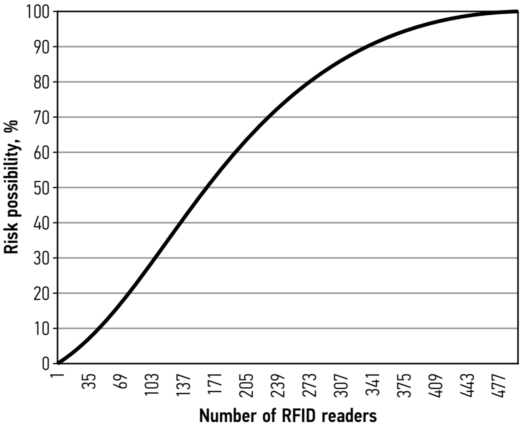


Fig. 4. The dependency of risk possibility on the number of measurements (check points over the whole route)

On the other hand, if used globally, the cost of the overall system (especially RFID readers) is very high (in case there are more than 100 RFID readers). It should be noticed that the system becomes more efficient and cost friendly when using it with more than 35 and less than 200 installed RFID readers (or performed sensor readings). The optimum number of RFID readers or sensor readings must be considered by evaluating the possibility of cargo damage, see Fig. 4 and Table 5.

Table 5. Cargo damage possibilities

	Damage (risk) possibility (%)
1st cargo check	0.17
2nd cargo check	0.35
3rd cargo check	0.53
4th cargo check	0.71
5th cargo check	0.89
6th cargo check	1.08
7th cargo check	1.27
8th cargo check	1.46
9th cargo check	1.66

The actual number of RFID readers and cargo sensor readings must be calculated for each separate case individually (taking into account the transportation route and cargo specifications).

6. Conclusions and Future Work

The integration of RFID and mobile sensor technology in the mobile control system for intermodal container transportation management is a promising innovation and its adoption could significantly improve the performance of operations and other services of any logistics organization of transportation. We have focused on presenting a decision support information system adding new elements to the conceptual strategy framework of intermodal container transportation. Based on appropriate performance objectives, the managers and all other users of the system should be able to identify the main risks involved in cargo transportation and take appropriate actions. Computational results suggest using the optimum number of RFID readers and overall cargo sensor readings for each separate container because of a high price of the system and its management. The computational example demonstrated the key benefits through which RFID and mobile sensor technologies generated an additional value of the selected management area using newly identified key variables.

Finally, as discussed by Ferrer *et al.* (2010), the customization of the proposed mobile control system will only be successful if consumers can trust the new system. The benefits derived from the use of mobile sensors, RFID and other mobile technologies have to outweigh the privacy concessions of the proposed information system.

Our conclusions should further be validated within individual case studies. The quantitative analysis of larger datasets (including containers and cargo vibration experiments) may help with improving the currently proposed mobile control system and further develop the framework of operation strategy. Future work includes the implementation of the proposed information system in the project 'Intelligent Train Control System' carried out by Klaipėda University (Lithuania).

Acknowledgment

This work is supported by project MOBAS *The Development of Information Environment for Mobile and Wireless Services*.

The authors are also grateful for *Anne Marie Kappel*, the Vice President of World Shipping Council, for assistance in writing the manuscript.

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