SYSTEM RESILIENCE AT AN INTERMODAL TRANSSHIPMENT NODE

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Abstract

Together with the development of new technologies, the interest in intermodal transport has been growing dynamically as one of its main advantages includes transporting goods over long distances. Intermodal transport is defined as transporting an integrated load unit, such as a container, a swap body or a semi-trailer, by more than one means of transport. The point-based infrastructure includes sea ports and inland terminals, which allow trans-shipment or storage. Intermodal transport is a part of a supply chain; therefore, all threats, which may occur, influence the correctness of the entire intermodal transport process. The occurrence of interferences does not influence the vulnerability or resilience of the supply chain. Vulnerability of the supply chain is defined as a function of certain features of the supply chain and losses, which the company will incur as a result of the vulnerability of the supply chain and as a result of the occurrence of interferences in its operation. The operational resilience, on the other hand, is the ability of the supply chain system to reduce the probability of the occurrence of interferences, minimization of these interferences and reducing the time of returning to proper efficiency. The article consists of 3 parts; the first one describes the approaches of various authors to the notion of resilience and vulnerability of a supply chain or a logistic system. The second part characterizes an inland terminal system. The last part contains a description of two most important factors, i.e. redundancy and flexibility. The aim of the article is to present an approach to the issue of system resilience at an intermodal trans-shipment node.

Keywords: Container terminal, vulnerability, resilience, redundancy, flexibility

1. INTRODUCTION

Reliability is defined as a property of the system saying whether a given system fulfils all entrusted functions and activities. It is a very important issue in supply chain analysis, which includes various transport systems. Within the review, the issue of reliability was analysed using the example of various transport systems. The issue of reliability of air transport for the check-in desk and security control was presented in a study by [1,2]. For rail transport, the system operation taking into account reliability was described in a study by [3,4]. The issue of energy consumption as presented in studies by [5,6] can be considered in supply chains. Maintaining resources is an important element of the use of machines and devices [7,8,9] as well as the development of operation models presented by [10,11]. Analysis reliability of real system is shown in papers [12,13] and mathematical method [14,15]. The model inland terminal and different analysis about intermodal transport are shown by [16,17,18].

Together with development of the resilience and reliability science, the notion of vulnerability occurs more and more frequently (system vulnerability to interferences) together with the notion of system resilience. Yossi Sheffi was one of the first authors who defined the notion of resilience, according to whom resilience is a notion borrowed from materials science and it reflects the ability of a material to regain its original shape after deformation. In companies, it measures the ability and rapidity, at which it returns to its normal efficiency (of production, services, deliveries, etc.) after the occurrence of undesirable events [19]. The aim of this article is to characterize resilience as well as to describe main factors, which influence resilience (redundancy and flexibility) to make it possible to correctly design a system at an intermodal trans-shipment node.

A reduction in vulnerability means reduced probability of the occurrence of interferences [19]. It is rarely encountered that events at the level of small effects of interferences should require planning or action.

Interferences combining a high probability and low potential effects of hazards are a part of daily operation at any company. On the other hand, those which are characterized by low probability, but are under a high influence of planning are outside the area of daily activity. Figure 1 presents a map of the vulnerability index. [25].

Fig. 1 Map of the vulnerability index [19]

For a delivery chain, vulnerability can be regarded as a result of natural disasters (drought, flood, windstorm, hurricanes, etc.) or possible economic effects. [20,21] On the other hand, in connection with the susceptibility of the supply chain, negative human actions can also influence the susceptibility, these can be: accidents, wars, terrorist attacks, strikes or acts of sabotage [21,22].

In several studies, a few definitions of susceptibility can be found, for example:

- exposure to severe interferences, [22]
- the propensity of the source of risk and the risk operator to exceed the risk minimization strategy causing undesirable consequences in the supply chain, [23]
- the vulnerability of the supply chain is a function of certain features of the supply chain and losses, which the company will incur as a result of the vulnerability of the supply chain and as a result of the occurrence of interferences in its operation. [24]

In [25], the author explains that the main reason for a growing interest in the management of interferences and their consequences is the awareness of the issues related to resilience and susceptibility of the supply chain promoted by recent research as regards the size of losses (direct and indirect ones) resulting from interferences in the supply chain.

The issue of resilience is related to the vulnerability of the supply chain. A few definitions according to various authors' approaches are presented below:

- the ability to survive, to adapt and an increase in the face of turbulent changes in the complex system of a company, [26,27]
- the ability to maintain, restore and recover operation after the occurrence of interferences, [28]

- the resilience of the supply chain is not only the ability to recover the system after unfortunate accidents, but also to organize and test the possibilities of reconstruction within the delivery chain to handle unexpected events in the future, [29]
- the ability of the supply chain system to reduce the probability of the occurrence of interferences, minimization of these interferences and reducing the time of returning to proper efficiency, [30]
- the ability to respond to negative consequences caused by interferences, which occur at a given time to keep the goals of the supply chain [31].

As results from the description above, the issue of vulnerability and resilience in supply chains or logistic systems is very important. Logistics systems are exposed to interference, i.e. they are vulnerable and the strength, “resilience”, against these threats is resilience, which also allows the system to return to its normal efficiency after the occurrence of undesirable interferences.

2. SYSTEM AT AN INTERMODAL TRANSSHIPMENT NODE

A container terminal is a complex system, in which correctly designed elements will allow its effective operation by operating means of transport, such as the ship, railway or a road truck with semi-trailer. A container terminal should consists of at least three operational areas [32]:

a. an operational area between the wharf wall/railway tracks and the container yard

b. a container yard, where it will be possible to store integrated load units also in stacks,

c. the generally accessible area for all other operations (not only the ones related to trans-shipment), which consists of office buildings, gates, a car park, an area for empty containers to be repaired, etc. [32].

Within research at the container terminal, it was possible to distinguish two subsystems in the operation of a trans-shipment node. The first of these is an information subsystem, in which there is an information flow, while there is also a load flow, which is parallel to the information flow and which is called a mechanical subsystem.

For inland terminals, integrated load units are usually transported from carriages to trucks and delivered to the end client or from a truck to a carriage using trans-shipment facilities. In the subsystem under discussion, an example of trans-shipment from the wagon to a truck is considered. Individual activities can be distinguished in the information subsystem (**Figs. 2, 4**), i.e.:

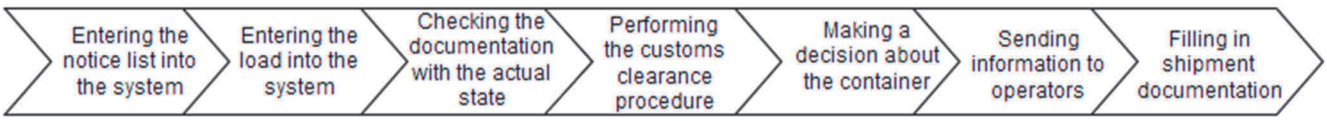


Fig. 2 Flowchart for an information subsystem

Apart from the information system, also a mechanical system can be distinguished (Fig. 3,5), in which a load flow occurs. As in the previous case, a situation is considered, in which a train is accepted at the terminal; devices operating at the terminal are mostly reachstackers. Individual elements were distinguished in this subsystem, i.e.:

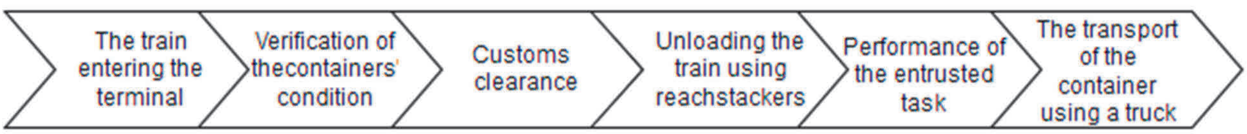
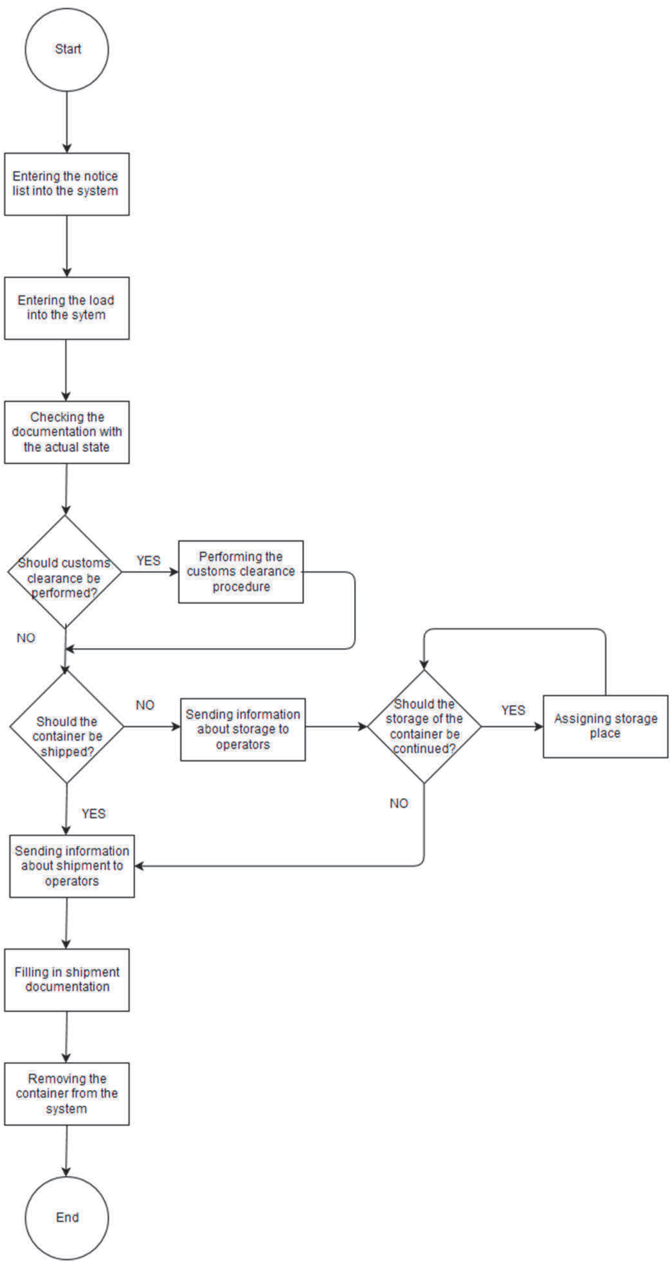


Fig. 3 Flowchart for a mechanical subsystem



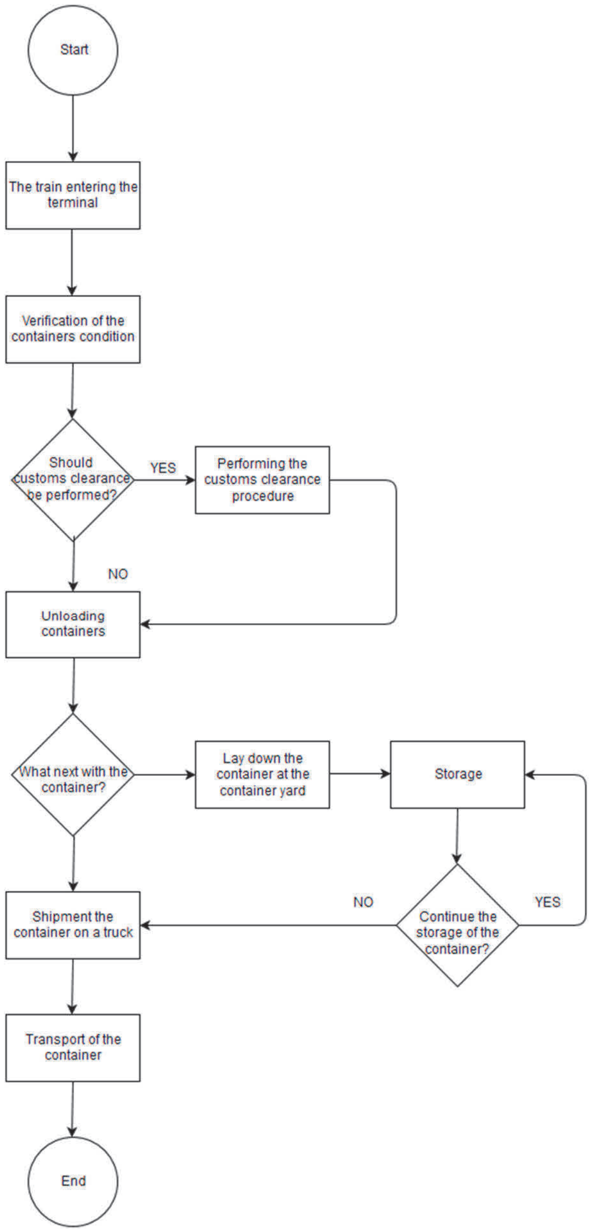


Fig. 4 An information subsystem at an inland terminal **Fig. 5** A mechanical subsystem at an inland terminal

3. SYSTEM AT AN INTERMODAL TRANSSHIPMENT NODE

Within the literature review presented in [33], factors were proposed, which influence the resilience at the inland terminal, which is a part of the logistics system.

Redundancy and flexibility belong to main factors influencing resilience in an intermodal transport system. They will be described in another part of the chapter and also their properties will be characterized. In [2], the author presents the issue of redundancy as an ability to satisfy functional requirements in the case of interference, degradation or loss of functionality.

The author in [32] defines resilience as four related dimensions: technical, organizational, social and economical. The technical dimension refers to physical abilities of systems (including their ingredients, mutual connections and interactions between them as well as the system regarded as a whole), for the operation at an acceptable or allowable level during the occurrence of various interferences. The organizational dimension also applies to the ability of the managerial staff in the area of making difficult decisions as well as in taking actions in response to an interference which has already occurred. This will make it possible to achieve better robustness, redundancy, resourcefulness and will also have a faster rate of restoring the system to the required efficiency. The social dimension of resilience includes measures designed to reduce the degree, to which they were affected because of the hazard. This is similar in the case of the economic dimension. Resilience refers to the ability to reduce direct and indirect economic losses resulting from the interference. Redundancy in this approach belongs to the organizational dimension, for which the managerial staff is responsible. The author proposed the 4 R's method, which applies to robustness, redundancy, resourcefulness, and rapidity [32].

Table 1 Characteristics of factors influencing resilience at an inland terminal [33]

Factor	Definition	Factor	Definition
Redundancy	Maintaining certain reserve resources or means (e.g. trans-shipment facilities)	Flexibility	Flexibility of the system to adapt to changes, e.g. changes in conditions of agreements with clients
Resourcefulness	The ability of the managerial staff to identify and counteract hazards	Recovery	The ability of the system to restore the efficiency level, which occurred between the interferences
Efficiency	Efficiency of the operation of the entire terminal, damage prevention, keeping a high level of readiness	Collaboration	The ability to work effectively with other entities for mutual benefits
Adaptability	The ability of the system to adapt to the conditions at the terminal	Security	Security preventing the occurrence of interferences
Survivability	The ability of the system to survive despite the occurrence of interferences	Robustness	The strength/resilience of the system in the case of interferences

In another study [34], the author describes that resilience can be achieved by redundancy or by building flexibility of the supply chain. A typical use of redundancy includes any ability, which is not fully used (e.g. trans-shipment capacity) or the use of security stocks of materials and finished products. Such a policy can make it possible to return to efficient operation after the occurrence of interferences. An increase in the flexibility of the supply chain may, in turn, help the company not only to withstand interferences, but also to improve its actions in response to the market demand [34].

Apart from this, the author takes into account the cost of redundancy [34]. Redundancy is described as keeping a reserve of some resources which can be used in the event of interferences. The most common form of costs of the security stock with the intentional use of multiple suppliers, even if the costs of secondary suppliers are higher and intentionally low degrees of use of the production capacity. It should be remembered that especially with security stocks, companies must be careful not to err from "just-in-time" to "just-in-case" in their stock management policy. While the latter does not offer redundancy, and together with it, a limited ability to respond immediately, additional stocks may prove harmful to the product quality [34].

On the other hand, in the case of building resilience of the supply chain, the author in [22] analyses the balance between the notion of redundancy and efficiency. Generally, excess production capacity and stock were perceived as "waste" and were undesirable as a result. However, strategic deployment of additional capacity or stocks in relation to potential pinch points can be very advantageous for building resilience of the supply chain. Compromise is inevitably connected with decisions on balancing costs related to keeping to the just-in-case policy as regards the probability and possible consequences of the occurrence of a negative event. However, if the managerial staff is take resilience into account, excess production capacity or stocks can prove to be the lesser evil than stocks which can already be intended for other purposes. Both efficiency and inventory can lead to gaps in the supply chain. The inventory may allow the creation of a decoupling point, at which it can make it possible to manage the uncertainty of the demand more effectively together with additional efficiency (e.g. of transport, production, people). A failure to provide support to restore buffering times at each stage of the supply chain from security stocks or excessive capacity may be the basis for proposing the construction of the resilience of the supply chain by using strategic and selective gaps in the delivery chain.

At the container terminal in the information subsystem, information can be provided in a variety of ways, including oral and written information, e-mails as well as internal communication using special tools of the in-house system. Apart from this, the following elements can be distinguished in this subsystem [22]:

- generating information: it is the moment when an employee prepares a certain piece of information, e.g. an unloading order. In this case, special attention should be paid to making the generated information accurate and understandable for the recipient, which will reduce the probability of committing an error.
- providing information: a process in which the generated information is sent to the recipient. At this stage, the sender should make sure, in particular, that the information reaches the appropriate recipient directly;
- collecting and storing information: it is a stage, at which information is collected and archived, this can be both received and generated information. This stage allows subsequent information processing.
- processing and interpretation of information: the first step involves reading messages by the recipient and next the contents of the message are interpreted;
- use of information: after the stage which involved the interpretation of the message, the next step involves the performance of instructions, which were contained in the information sent. For generated messages (an unloading order), the operator of the container truck takes relevant actions to perform the task.

All of these actions (in the information system at the inland terminal) are performed using various information systems, the Internet, using tools such as the computer or telephone. For redundancy, we do not deal with manufacturing stocks, but with stocks of resources needed to perform tasks if undesirable failures occur.

In the information subsystem, additional resources will include:

- a computer (the cost of purchase + the service of installing the system)
- a telephone (the cost of purchase + the monthly subscription or a card every 12 months)
- backup power (allowing the operation of electric and electronic devices in the event of power cuts, grid failure)
- two-way radio (the cost of purchase)
- people (e.g. an additional operator - the cost of the pay + the cost of the course of operation of the device).

In this case, the issues of redundancy will be related to the issues of the cost of purchasing and maintaining the devices listed above.

In the mechanical subsystem, on the other hand, starting from the beginning of the algorithm, i.e. there is no “substitute” supplier or an additional supplier. If frequent delays occur due to the supplier's fault, the agreement between the parties ceases to be valid only on its expiration date.

At the inland terminal, there are basic and auxiliary trans-shipment facilities as described in a study by [26] reachstackers and gate cranes are usually used at a terminal. For example, the terminal in Gliwice, which belongs to the Cargosped Company has 3 reachstackers, one of which is an additional stacker used in the case of a failure of one of the other stackers. The terminal in Wroclaw, on the hand, also has 3 reachstackers but also 2 gate cranes, 1 of which is an additional crane. The issue of redundancy can be analysed in this way for a mechanical subsystem at an inland terminal.

To build flexibility for resilience, the companies must take into account a lot of aspects while designing a supply chain by [35]:

- developing skills, e.g. by transferring production, replacing worn parts with spare parts and also by introducing various types of training for employees,
- the simultaneous use of various product development processes, their launch and then dealing with the production/distribution,
- designing products, processes as well as other possible actions and decisions in the supply chain with spare time,
- adjustment of ordering strategies to their relations with suppliers [35].

These principles do not only create flexible supply chains which allow for restoring the state before interferences, but will also allow for responding to the demand which changes on a daily basis [35].

In the issue of resilience, flexibility can be regarded as the flexibility of supply and flexibility in order fulfilment. Such an approach is presented by the study [27]. On the one hand, this flexibility of supply is understood as the ability to quickly change the raw material input or the method of collecting the input/raw materials. Such an approach was designated due to various elements (sub-factors) of flexibility, i.e. flexibility of supplies, market flexibility, logistics flexibility, organizational and information flexibility. On the other hand, there is flexibility in order fulfilment, presented as the ability to produce output quickly or to change the method of delivery output. These components include delayed obligations, production, management, inventory, alternative distribution channels and a quick change of the plan of requirements [27].

In the next study [34], the author presents 6 elements of the flexibility of the supply chain distinguished from the flexibility of production, from strategic flexibility and the flexibility of the supply chain, these include [34]:

- Flexibility of the operation system (including production and operation) - the ability to change assets and actions in accordance with changing trends and the client's requirements (the change may apply to a change in the product, its volume, etc.) in each node of the supply chain.
- Market flexibility - the ability to adjust and build good relations with clients, including design and modification of new and existing products.
- Logistics flexibility - the ability to obtain an effective cost and delivery of the product as sources of deliveries and client changes (changes of clients' location, globalization, changing deadlines)
- Flexibility of supply - the ability to reconfigure the supply chain, change the supply of the product in accordance with the client's demand. Flexibility of supply includes freedom in establishing relations with partners. Companies may try to choose short-term offers, to conclude long-term agreements and to establish strategic relations with suppliers creating a joint venture.
- Organizational flexibility - the ability to adapt skills to the needs of the supply chain to become familiar with customer service and to meet the requirements of the demand.
- Flexibility of the information system - the ability of the information systems to adapt to the needs of changes in information together with changing clients' needs [34].

The flexibility of the supply change takes into account two main aspects [34]:

- The flexibility of the process of each supply chain, concerning the number of types of products which can be manufactured at each manufacturing plant (supplier or installer).
- Logistics flexibility connected with various logistics strategies which can be adopted, e.g. releasing the product onto the market or buying components from the supplier.
- There are several dimensions of flexibility, the first two of them belong to the main dimensions [35]:
- Flexibility of the product (flexibility of manufacturing) - the ability to serve difficult atypical orders (e.g. the colour, shape, dimension, etc.) to meet clients' special requirements.
- Flexibility of the volume - the ability to establish close relations between the manufacturer and the supplier, especially in view of the growing demand. Flexibility of the volume has a direct influence on

the efficiency of the supply chain by preventing the situation, in which the demand for sold-out products suddenly increases or preventing high levels of stocks.

- Flexibility of sending (directing / routing) - the ability to produce parts by various machines, flexibility of using materials and flexibility of the transport network. This flexibility reduces the negative impact of environmental uncertainty and unexpected inefficiency in the manufacturing process.
- Flexibility of deliveries - is the company's ability to adapt delivery deadlines to the client's requirements. The “just-in-time” policy is an example of high flexibility (on-time delivery), the supplier provides products to the customer in an appropriate amount, to the appropriate place and just in time.
- Trans-shipment flexibility - is connected with moving the goods (supplies) between the place at the same level to a place, where the physical distance between the location of the demand and the location of the delivery is low.
- Flexibility of extension (postponing) - means the possibility of keeping the product in the generic form as long as possible to introduce the product at subsequent stages on the client's request.
- Flexibility of supplies (sourcing) - is connected with the company's ability to find another supplier for each specific component or another semi-finished product.
- Dimensional flexibility - is used in many branches of the industry, it is a response to the market demand. This flexibility expresses the company's general ability to respond to the needs of its target markets. The responsibility for this flexibility spreads over the entire supply chain; effective actions in this dimension depend on the company's ability to use the possibilities of the supply chain, which may meet or exceed its clients' requirements.
- Flexibility of launching a new product - the ability to quickly launch new products, flexibility is strategically important as it requires integrating a lot of actions of the supply chain.
- Flexibility of access - the ability to ensure a common or intense reach of distribution. This flexibility is possible as a result of close coordination of activities at the lowest level of the supply chain, which are performed inside or outside the company [35].

Considering the issue of flexibility at an inland terminal system, just as in the literature review presented above, it can be analysed on the organizational, technical and economic plane. In the information subsystem, the main emphasis will be placed on the information system, which should correspond to the needs of correct operation of the land terminal. On the organizational plane, it is important that the managerial staff should be flexible in responding to terminal employees' and clients' needs to meet their requirements.

In the mechanical subsystem, operational flexibility and flexibility of deliveries will be the main element. Flexibility can be an index, which provides information about how often the managerial staff adapts its decisions to their clients' needs. For flexibility of deliveries, the terminal should provide for the possibility of a change in the end client's decision and take into account delays in the delivery of the load to the terminal. Further research will make it possible to determine all factors as specified in **Table 1**, thus allowing the determination of resilience for the entire system at the inland terminal.

4. CONCLUSION

Analysis of the issue of vulnerability and resilience in supply chains or logistic systems is very important. Logistics systems are exposed to interference, i.e. they are vulnerable and the strength, “resilience”, against these threats is resilience, which also allows the system to return to its normal efficiency after the occurrence of undesirable interferences. A mechanical subsystem (with a load flow) and an information subsystem (with an information flow) were distinguished at an inland terminal. Both systems are exposed to interference and, as a result, to reduced resilience of the operation of the entire system. Redundancy and flexibility are main factors which influence resilience. For redundancy, it is important to keep some spare resources, while, for flexibility, the managerial staff should pay attention to the possibility of adapting to clients' needs.

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