Operating Determinants of Maintaining the Operational State of Container Terminal Equipment

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Science has developed a number of sophisticated assets maintenance theories and methodologies. However, the example of complex systems, like container terminals, shows that these advanced strategies are not always practically viable. The nature of the transportation industry requires a unique approach, combining two different aspirations – global solutions, on the one hand, and consideration of the individual needs and local circumstances of a terminal on the other. Equipment manufacturers, due to the small batch volume, usually apply nominally traditional maintenance strategies, which, however, elude specific factors that occur locally or only in certain situations. This work aims at drawing readers' attention to this issue, by providing several cases, where the general solutions prove insufficient to local requirements of different nature. It also advocates for the development of customised maintenance strategy for a specific case.

Keywords: container terminal equipment, maintenance strategy, local determinants, customisation.

1. INTRODUCTION

Transportation of goods is one of the pillars of the world economy. It is estimated that approximately ninety percent of the global movement of goods is carried by sea, with more than seventy percent – in the form of cargo container [2]. Despite the recession in 2009, the strong global growth trend can be seen (fig. 1) [19].

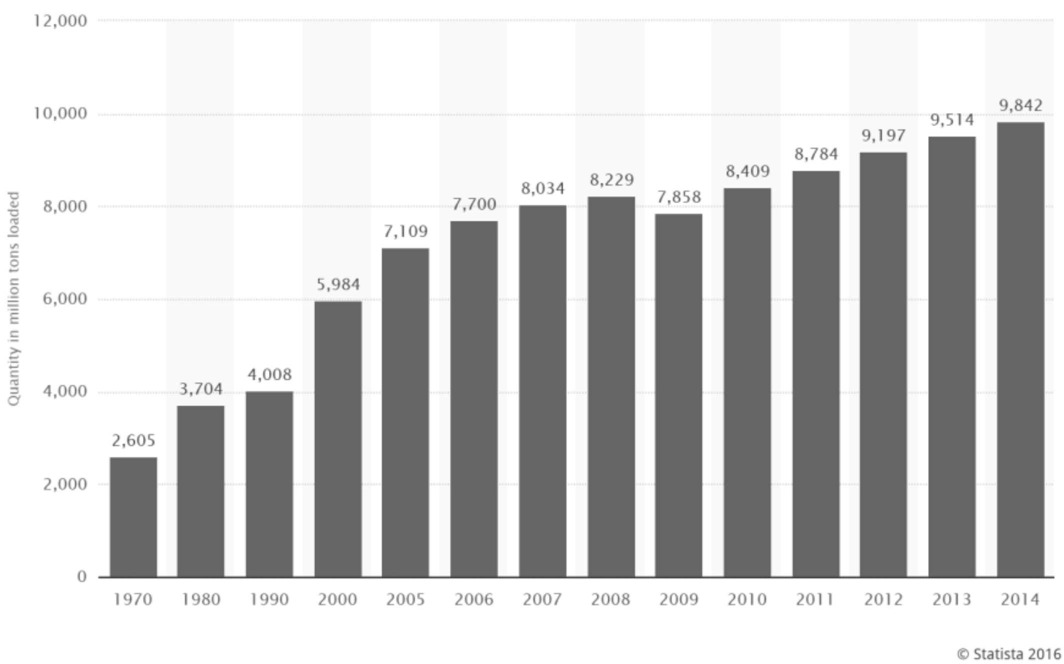

Fig. 1. The amount of cargo transferred by sea in the years 1970-2014, expressed in million tonnes [19].

Container terminals are a key element of the transportation of goods. Their primary function is handling the containers which includes their loading, unloading, horizontal movement, sorting and storage. Figure 2 shows a conceptual diagram of the main areas of the intermodal terminal and the container traffic between them. Containers are delivered by ship to the port where are unloaded and then sorted and stored in stacks in terminal yard. From there, the containers can be routed to another vessel or dispatched by land transportation to the end user At each stage bidirectional movement is possible.

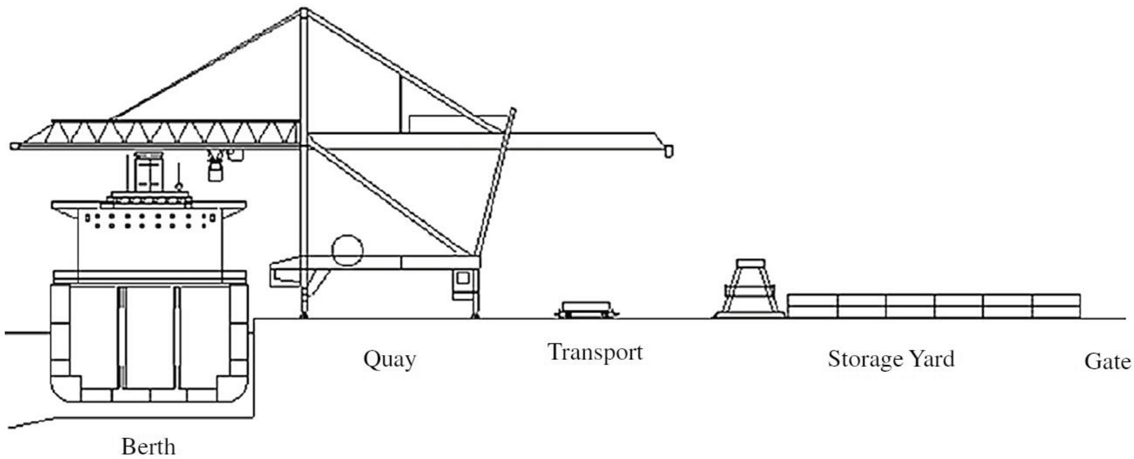

Fig. 2. A conceptual diagram of the containers terminal with its main areas [1].

There are multiple terminal configurations that affect the operations taking place there. In the process of designing the optimal configuration, four main kinds of decision problems originating from the storage yard have been distinguished. The first one considers the yard layout and selection of adequate handling equipment; the second one – takes into account available storage space usage and assignment to containers; the third one – allocation of the most suitable equipment; the fourth one – regards optimisation of stored containers in order to minimise number of idle movements. [1]. In order to perform the terminal designated tasks, they must be backed up with auxiliary operations related to rational, sustainable and efficient asset management, including correct operation and maintenance of technical infrastructure and equipment.

In order to improve the cost effectiveness of terminals, strong emphasis is continuously placed on improving process efficiency and reliability of the technical infrastructure. "*The growing demands on improvements in reliability parameters, increased longevity and availability of the technical systems fuel the growth of the importance of issues related to maintenance*" [15]. The total cost of ownership, beside the initial cost of acquisition, is also affected in later stage by such factors as cost of operating and maintenance. In the economy of the terminal, taken into account are also such issues as loss associated with maintenance downtime, loss related to delays for technical reasons, reputational risk to business partners, etc. In order to properly assess the performance and profitability of technical resources, consideration should be given to time horizon extending beyond the planned duration time of the technical object [16], [20]. Negligence of these tasks can lead to reduced reliability and unplanned downtime, thus consequently, the reduction in the capacity of technical objects and infrastructure to carry out their mission. These task, therefore, affect directly and indirectly the financial condition of the enterprise. For terminal operators it is essential to minimise these extra expenditure and resulting revenue losses.

From maintenance perspective, a container terminal can be seen as a complex system, due to the high level of complexity of the operations taking place and the circular dependencies between them. Effective performance of individual elements – depending on the size of the terminal and implemented logistics system – is closely coordinated with other working machinery [7]. The exploitation, which includes multiple aspects like usage and service, takes place in a wider field and is associated with the flow of materials, energy, information, etc. [15]. Furthermore, each container terminal, by the nature of global transportation, functions in unique surrounding, of its own and often unpatrolled characteristics.

This paper aims at drawing the reader's attention to the question of maintenance strategy with respect to the specific conditions in which container terminals operate. This will be done by analysing typical maintenance strategies in the historical context of transportation system and container terminals, and with consideration of stance of the original equipment manufacturers. By the means of presenting several cases where typical maintenance procedures and policies are affected by local determinants, the emphasis is put to the validity of developing customised maintenance strategy that reflects the specific needs.

2. MAINTENANCE STRATEGIES

Each technical object is subject to degradation caused by the processes of ageing and wear. To counter these processes and keep the system in proper condition for intended work, it is necessary to continuously supply energy from the outside, which are reflected in the tasks of technical systems operation and maintenance. [18] states that "*the primary function of maintenance is to control the condition of facilities. It involves actions to be carried out in order to inspect, repair, replace or modify a component or a group of components of a system*".

Although the problem of maintenance existed for a long time, this concept as a separate issue began to function relatively recently. Over time, approach to this problem has been changing and is now seen as an integral part of the resource management and the way to improve the competitiveness of the company [14]. Maintenance models have evolved with the development of production processes and the economic context. In recent decades many increasingly sophisticated theories and methodologies of maintenance have been developed [21].

Paper [11] describes three periods in the development of the maintenance models. These periods as well as maintenance methods with corresponding costs are shown on figure 3, where Roman numerals designate periods of development, and Arabic numerals - methods of machines operation maintenance. I and 1 is the reactive maintenance, II and 2 – preventative maintenance, III and 3 – predictive (proactive) maintenance (fig.3). Model of reactive machinery and equipment maintenance is characterized by the oldest period, dominant to about the 50s of the previous century. It consisted of responding only in a situation of failure. At that time, when the production was based mainly on the work of people and devices were relatively simple, this method was sufficient. Over time, the production has become more demanding in terms of performance. Also machinery and equipment became more complicated. The increase in requirements resulted in the second period of maintenance - preventive. Machinery and equipment required then scheduled inspections. The most important maintenance tasks were written out in advance. This resulted in the reduction of unplanned downtime. The third period emerged in the mid-70s of the last century and is defined as a period of predictive maintenance. Numerous methods of this period were based on developed diagnostics and the current condition monitoring. Examples of these methods are Total Productive Maintenance (TPM) and Reliability-Centred Maintenance (RCM).

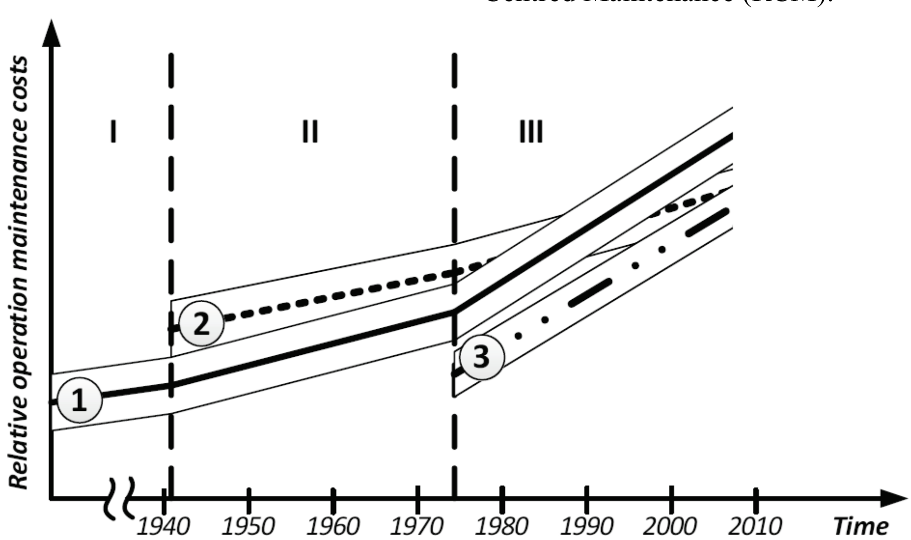

Fig. 3. Three periods of development (I, II, III) and three methods (1, 2, 3) of machines operation maintenance [11].

Many theoretical models of maintenance management from the third period (e.g. so called process oriented models) treat the individual components of the system separately and possibly try to identify and describe the relationships between them [13]. Analysing the literature, one can see the trend of further development of the concept of maintenance towards the holistic view of maintenance activities in conjunction with the management of the organization and seeing the benefits of effective maintenance management. These benefits include [8], [11]:

- creation of a more coherent system for all involved in the activity of the enterprise,
- formulation of the basis for incentives and support the executives,
- high productivity,
- reduction of the overall equipment failure rate,
- performance improvement,
- reduction in the number of accidents,
- verification of the investment profits,
- orientation towards a flexible and multi-skilled organisation development,
- increase of profits and reduction of losses in the business activity.

These strategies, particularly condition based maintenance or the concept of RCM, display their advantages when potential losses are larger than the repair costs. They are rational, because it minimizes the likelihood of failure [15]. For these methods, however, it is crucial to obtain reliable information about the current condition of the device and relation between its elements. Gathering and processing the current state data is a separate issue.

Numerous maintenance models described in the literature have been attempted to organize and structure. Comparison of classification the models due to the varied criteria confirms the complexity of the issues. Figure 4. below summarizes the survey of the maintenance models [15].

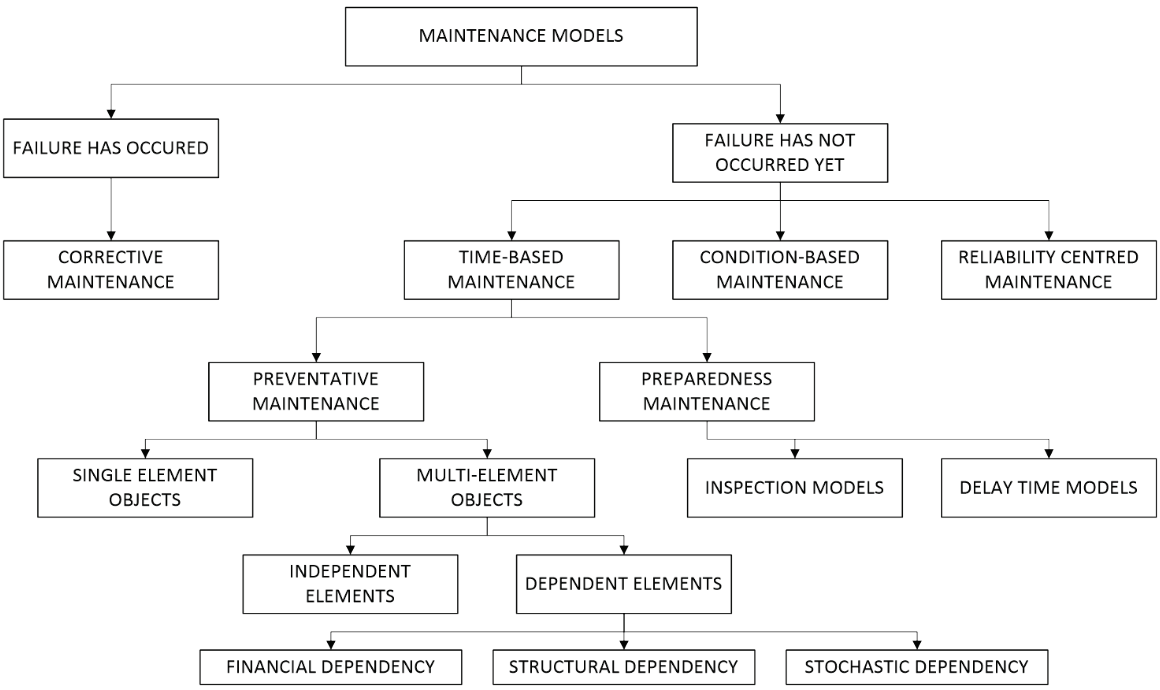

Fig. 4. Classification of principal models of a technical object maintenance, based on [15].

3. TYPICAL MANUFACTURERS' RECOMMENDATION ON EQUIPMENT MAINTENANCE

For clarity, Rubber Tyred Gantry cranes (RTG) will be considered further as a representative of the port equipment (fig. 5). Although a variety possible terminal configurations, RTG can be seen as a typical element of the technical infrastructure of the container terminal, occurring in approximately 2/3 of 114 surveyed terminals [22]. Their primary function (mission) is containers handling on the "landside" of the terminal (RTG are not able to attend ships on the "waterside" of the terminal). Their tasks include: storage containers in the yard, sorting containers on stacks as well as loading and unloading of containers from the trailers (fig. 2.). Stacks of containers are typically organized in blocks, which can be

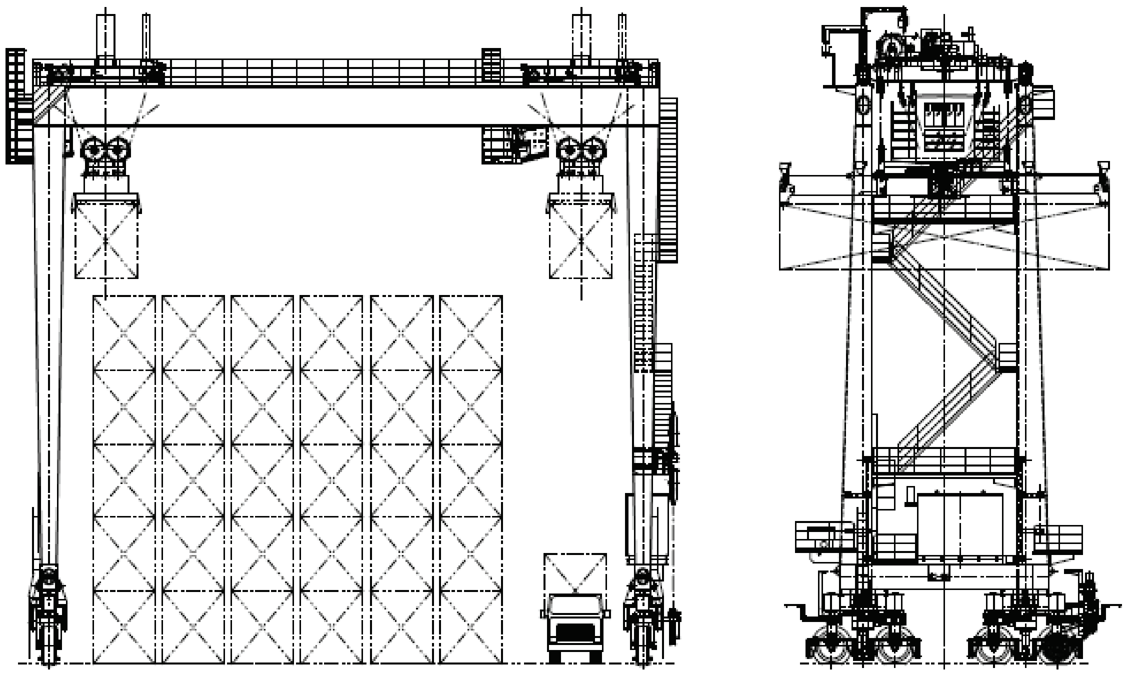

Fig. 5. A typical RTG crane – HDHM reference materials [9].

operated by one to several RTG cranes at the same time [1].

The most important operating parameters of RTG cranes include, among others: lifting capacity, duty classification, operating speeds (gantry travel, trolley travel, lifting / lowering), gantry span and lifting height, efficiency and precision of control (e.g. simultaneous longitudinal, transverse and vertical movement; stability in adverse weather conditions, etc.), efficiency, performance and ease of use, maintainability, high availability and reliability. In turn, the most important components of the RTG cranes for the reason of their mission performance are considered are the following: hoist winch, gantry and trolley travel systems, power supply (e.g. generator sets), electrical installation, PLC control system, safety systems, etc. [3]. In order to make optimum use of the assets, cranes should be reliable and with maximum availability (working 24/7), and their management – including maintenance and service tasks – optimized. There is therefore a need for continuous monitoring of the technical condition and ongoing maintenance of the machines.

The most common causes of unplanned downtime of RTG, which subsequently lead to a reduction of the terminal efficiency are: failures and wear of working elements, accidents and damage, lack of readily available spare parts or awaiting for delivery, not appropriate adaptation to working conditions, inappropriate handling and maintenance, resource management, etc. Respectively, the typical faults occurring in the cranes include [3]: cracked or warped gantry structure – a result of exceeding the permissible stresses, cracks in welds, corroded structure, exceeded tolerances in the crane construction and the components, rolled out or worn rail profile – over-consumed elements of the trolley travel, jammed bearings, axles, gears, etc. due to improper lubrication, wear of the rope sheaves and other receiving system parts as a result of overuse, worked out (by consumption) or corrupted (invalid operation) steel wire ropes, backlash in gears and couplings – due to excessive wear, improper assembly of elements – for example improperly meshing gears, the irregularities on working surfaces of the brakes as a result of incorrect adjusting, worn brake linings, worn edges of the trolley wheel rims, worn tires, faulty installation of power supply, short-circuiting of the electrical system, damaged cover of the power cords, failure on terminal contacts, damaged safety switches, damaged limit switches, faulty sensors, incorrect wiring, damaged control equipment, etc.

Maintenance tasks on the terminal equipment are usually carried out by a separated organisational cell within the business unit. The relevant department is responsible for the efficiency and safety of the equipment as well as for preparation and implementation of the maintenance strategy across the terminal. Their responsibility include monitoring the current state of the objects, carrying out periodic inspections and remove faults. In the event of a serious failure it is recommended to consult the manufacturer before proceeding with the repair work. In some cases technical supervision of the manufacturer may be necessary. These activities are based on the recommendations provided by the OEM in the operational and maintenance manuals.

The manual usually contains the suggested service and repair tasks for the entire machine and individual systems for the production series. This consist in identification of the key, from the point of view of maintenance, parts and components, and then defining the schedule and scope of maintenance tasks (minimum renewal). Among the recommended activities usually prevailing are the tasks of ongoing diagnostics, that is the inspection and control of the state as well as preventive measures, laid out in the form of time intervals for each subsystem. Under normal operating conditions, the principle of incomplete renewal applies, as the characteristics of the damage intensity function resembles the actual activities of the maintenance and repair for a container terminal.

4. DEFICIENCIES OF THE TYPICAL STRATEGIES

In the context of the maintenance of container terminals' equipment and infrastructure, a certain phenomenon should be noted. Namely, by their nature they function on a twofold level of interaction with the surroundings. On the one hand, the terminal is a place that interface between various elements of the transport industry on a global level and thus a way to unify solutions on a global scale is sought (the containerization phenomenon). The terminal must be able to accept containers, ships, logistic solutions, etc. partners operating from all over the world. This is then further strengthened by the equipment manufacturers' stance. Small volumes of machines in production batches encourages efforts towards standardisation of the technical solutions. This approach gives the manufacturers a chance of reduction of costs associated with research and development, unification of production processes and minimize the risk of errors.

On the other hand, each container terminal is different, distinguished by their own peculiarity, conditions in which they operate and individual requirements. Each is located in certain surroundings of complex nature and dependencies. These factors include, for example:

- Climatic conditions (temperature range and their variations, the presence of strong winds, ultraviolet radiation, etc.),
- Geographical location and geophysical features (seismically active areas, corrosiveness of the atmosphere, etc.),
- Economy and financial features (the economic situation in the region, transport and communication infrastructure, business relations over-national (e.g. membership of a terminal network), the presence and the power of trade unions, the political situation in the region, competition, bureaucracy, etc.),
- Business aspects (terminal workload, reputation),
- Technical preparation in the area of (the presence of industry, occupational background, 3rd level education, administration and management).

Despite the variety of sophisticated models of theoretical maintenance methods, in reference to container terminals, they often prove not to be very practical. In reality, the basic general strategies: corrective and preventive tend to dominate, though usually mixed in certain proportions. There are at least several causes of this phenomenon [24]. On a general level, the following factors should be noted.

a) A high degree of complexity of the system which a container terminal is, and its functioning as a whole, as well as the individual elements and the dependencies between them are the source of the limited application of more sophisticated methods. This is them further deepened due to multifaceted differences between the terminals. Each terminal, though it aims to accomplish a similar mission, functions in unique circumstances. Different are their capabilities and limitations. So are also the internal dependencies between elements and the influence of external factors. Management style, including maintenance policy, that works in one case may be inefficient in others. Theoretical models should be adapted to the specific circumstances, taking into account local specificity. All the possible variations and mutual relationships make it a highly complicated system, requiring careful analysis.

b) The objectives of maintenance are based heavily on current operational information of the device. The ability of data collection, its processing and interpretation is of fundamental importance for the effective management of technical objects. The modern maintenance theories postulates shifting towards the integration of the information system and maintenance management system in order to increase the company performance [14]. Furthermore, literature points out at benefits of application of the modelling and simulation (M&S) and statistical tools. These would allow for scenario testing, what-if analysis, evaluating contributing factors, and identification of root causes. However, for application of these tools, all the relevant operational and maintenance data must be available, and due to the highly stochastic nature of container terminals, the data entities and its values should be presented in parametrised form [12].

   The relevant database of terminal parameters is necessary to develop adequate strategies effective in a given circumstances. In reality, however, the universal and reliable operating data is rarely available. One source of the problem is the difficulty with obtaining the data, another – the question of processing and interpreting it. Also the insufficient communication and the data exchange between the user and the manufacturer exacerbated this issue, which is particularly evident for the developing countries. “Lack of adequate and relevant data for modelling maintenance decision problems – this is particularly true in developing countries” [4]. There is indeed noted increased awareness of operational and maintenance data collection, which also benefits from the development of information and communication technologies, but attempts are, in general, characterised by a lack of coordination, proven scheme and earned methodology.

c) The OEMs position reinforces this trend. One of the manufacturing practices is a process optimization through product standardization and the creation of production batches. Equipment of container terminals is on one hand highly specialized to perform designated tasks, but on the other hand, it must work under certain conditions, which can vary significantly. Manufacturers' recommendations and instructions for operation and maintenance are developed for a particular class of machinery. They describe the general and standard maintenance policy, spare parts management and corrective action. They do not always include the influence of the environmental factors or local specificity. This phenomenon is also strengthened by the use of components and subsystems from specialized 3rd party suppliers, which in turn are often serial products and have their standard characteristics of operation and maintenance.

These remarks demonstrate that the solutions offered by manufacturers can therefore diverge from the expectation of the end users. Further study is required. Due to the lack of available relevant data, necessary is application of qualitative methods to diagnose the problem and to conduct further research considerations. With respect to the asset management and maintenance of the technical infrastructure of container terminals, an insight into the considered phenomenon and processes taking place can be embraced by analysis of real and theoretical cases. This approach will allow to perceive the uniqueness of circumstances extending beyond typical patterns as well as to take into account the wider context [23]. Selected cases are not necessarily representative of the whole population. Rather, they represent relevant example illustrating the phenomenon [5]. The following notes to a large extent, have been developed on the basis of professional activity, participate in discussions, own observations and analysis of the market.

Scenario 1 – environmental conditions.

Geographical location has a significant impact, directly and indirectly, on the state of technical objects and the operation of the terminal. Examples of such effects are: climatic conditions (abnormal temperature, diurnal and annual variations of temperature, wind, etc.), high corrosiveness of the atmosphere (apart from high salinity typical for the location of the intermodal terminals, an additional effect can also have the presence of industry e.g. chemical), the intensity of UV radiation (sub-tropical countries) and dustiness (e.g. the impact of the mining industry or the occurrence of sandstorms – the Middle East countries).

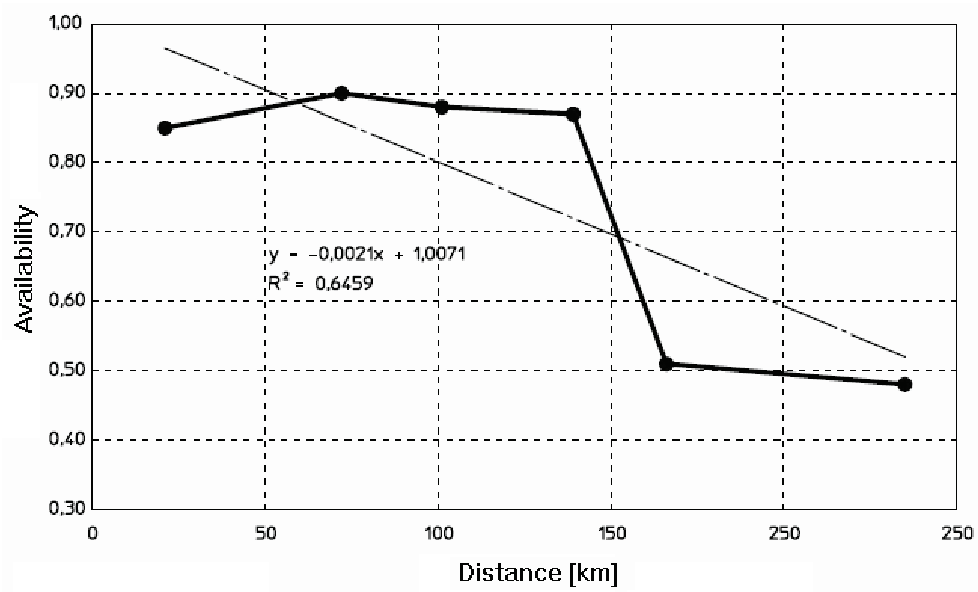

Fig. 6. Dependence between availability and the distance between the place of operation and the place of production. Reproduced from: [17].

Environmental conditions have a significant impact on maintenance and availability of the machines. For example, they may cause accelerated wear of protective coating and degradation of materials, like plastics, the need for periodic replacement of oils and lubricants (summer / winter), more frequent maintenance routine with a greater accent on surface protection as well as replacement of consumable parts (e.g. air filters). Possible is also accelerated degradation of the structure as a result of the stress caused by the temperature fluctuation. Consequently, standard strategy may require modifications, such as: adjusted intervals of the preventive maintenance and time allocated for maintenance tasks as well as spare parts and consumables policy.

Scenario 2 – location and distance from manufacturers.

Geographical distance from the manufacturers or distributors to the place of operation may have an impact on the processes of optimum service and maintenance. It may be also manifested in relation to the state of the local infrastructure or the political situation (e.g. customs, the arms embargo).

There are circumstances where the cost or time of delivery of the recommended spare parts is not economically justified, especially for special parts manufactured in small batches, and often on order. Large distance between the place of production and the place of operation promotes also the phenomenon of cannibalism, in which the good parts are taken from other machines (fig. 6.) [17].

Also, some repair works (e.g. under the warranty) require the supervision of the producer representatives – a considerable distance limits the availability of such personnel, extends repair time and increases the losses associated with downtime. In remote or difficult to reach areas access to technical resources (auxiliary equipment and materials) may be also limited.

History and experience show that sometimes it may be reasonable to assume, yet at the equipment design stage, the use of certain non-optimal parts and then take into account the local availability of the substitutes. As a result, it may be more effective to use lower quality parts and then replace them more frequent. Similarly, if the existing machinery a certain type of parts or consumables is used, it may be justified to use the same parts for new machines, even if they are not ideal, and thus not to complicate inventory management.

Consequences for maintenance include, for example: modified spare parts management (inventory stock (which may later prove to be unnecessary), and additional storage space and administrative organisation), maintenance strategy (preventive and corrective) may need to be modified, additional training and preparation of the technical staff.

Scenario 3 – personnel qualification

Technical background of the personnel is associated primarily with the educational system.

Significant role plays also the level of economic development of the region, the presence of similar businesses in the region, etc. These issues project on the quality of the use and maintenance of the assets. This is an important factor requiring consideration at the strategic, tactical and operational level [10].

The study on the causes of damages to road vehicles (referred to herein due to a lack of reliable data devices operating container terminals and because of the analogies of failure indicators characteristics) showed that a significant percentage of damage results from improper handling, including, among others, "*the use of improper consumables, incorrect installation, failure to detect or negligence of damage at an early stage during maintenance, failure to perform maintenance tasks indicated by the manufacturer (...) or derived from the general rules of use (...) not respecting repair techniques and lack of replacement of components showing excess of the allowable wear"* [6]. These remarks can be related directly to the container terminals machinery and equipment.

Potential service errors due to insufficient technical training may affect the maintenance processes of the facilities and machines. Consequences for maintenance are, for example, the need for additional specialized training or adaptive allocation of time for planned and unplanned downtime.

Scenario 4 – fleet management

Equipment of container terminals are destined to carry out tasks for a specific workload, assumed during its design and expressed by the duty classification. Overexploitation can lead to faster wear of parts and components. Also, exceeding single or average load intensifies the process of technical degradation.

In addition, such categories as the quality of the facilities (workshops and tools), the number of spare devices, operational directives of the terminal (e.g. concern of serving the customers treated with priority to the planned maintenance works), may have an impact on strategic and tactical fleet management and the intensity of their use. This in turn results in their maintenance profile.

5. MAINTENANCE STRATEGY CUSTOMISATION

In light of the foregoing, recognized is the incompleteness of the standard maintenance solutions provided by the OEMs to the practical needs. Although, from a practical point of view, the standard approach is satisfactory for the majority of cases, there are situations where their peculiarity is not captured in the general solution. A typical solution may not perform to a sufficient extend, be irrelevant or may even turn out to be harmful. There may arise circumstances when factors occurring locally (environmental conditions, operating determinants, etc.), are not considered in the standard policies and procedures, but nonetheless having an impact on the operation and maintenance of terminals. A characteristic feature of complex systems is that each is unique and each requires an individual approach. "*The selection of the optimal strategy depends on many factors, including among others:*

- *objectives of the technical object maintenance process,*
- *types of available resources – logistical and technical,*
- *conditions of the realised operational process,*
- *operating environment of the object"* [15].

General manufacturers recommendations are often modified by the maintenance departments of the end users to meet their own needs. This takes into account the determinants that occur locally. It should be noted, however, that the modifications due to the influence of environmental factors are often made regardless of the manufacturers. The lack of coordination in this aspect (e.g. access to operational data or feedback this information to the manufacturer) leads to individualisation of strategies applied in different terminals and further intensifies the problem.

6. CONCLUSION AND FINAL REMARKS

The question of the tailored maintenance strategies is nothing new, but, surprisingly, it seems to be grossly neglected especially for complex and non-uniform systems like container terminals. Container transport is developing in the direction of ever greater productivity characterized by the highest possible number of containers handled. Additionally, within enterprises observed is also a paradigm shift resulting in increased awareness of maintenance issues in recent decades.

However, sophisticated models presented in scientific publications do not always seem suitable for the practical needs in all cases. "*The models implementation reveals its practical validity, but in fact maintenance deals with highly diverse problems even in firms within the same productive sector, due to this is very difficult to design an operating methodology of general applicability*" [13]. In numerous situations one can see discrepancies between theory and practice maintenance, specifically the differences in the expectations of end users. Presented in this paper scenarios show that the standard maintenance strategies, even for the same class of devices, are not universal. There are situations caused by local environmental factors, which may significantly affect the processes of maintaining machinery and the enterprise as a whole.

Knowledge base build up and improvement have progressed by taking into account repeated patterns observable in practice. The presented herewith considerations, as well as the examplary situations highlight the impact of the local factors on the implementation of the maintenance tasks. The paper put up a postulate that the maintenance strategies should be designed for specific cases. There is a valid demand for revision of the principles of the maintenance strategy design. It seems natural that further development of the existing solutions and methodologies will go towards the supplement of the conditions and context-specific requirements occurring in specific situations taken into account. The concept of customization of the product should also include the strategy for its maintenance and operation tailored to the actual needs. This phenomenon requires further study. The recommended following research objectives include, for example, identification and isolation and of the port equipment parameters; local determinants parameterisation and quantification of their impact on maintenance; gathering and processing the reliable data about the current condition of the object.

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