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SIMULATION MODEL FOR THE ANALYSIS OF LOGISTIC SERVICE REQUIREMENT OF MAINTENANCE ACTIVITIES

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Abstract: *With the rapid increase in the number of our technical devices, and the technical complexity of individual equipment, the issue of maintenance becomes an increasingly important factor. A prominent feature of the use of industrial and service equipment is maintainability and repairability. Especially in the case of high-performance production equipment, where the construction and operation of an effective maintenance system is essential to maintain continuous operation, the analysis of maintenance processes is a particularly important task. It seems like an obvious solution to use various simulation methods for this purpose, but the randomness of the maintenance processes, or due to other features that are difficult to take into account, we can only perform the necessary tests with the help of complex models. In this article, a simulation model that can be used to examine the material handling activities of maintenance systems is presented, with the help of which the real characteristics of various maintenance operations can be accurately determined, and also the characteristics of the handling devices needed to serve them.*

Key words: *Maintenance logistics, simulation, logistic requirement, system analysis.*

1. INTRODUCTION

With the rapid increase in the number of our technical devices and the increase in the technical complexity of individual devices, the issue of maintenance is becoming an increasingly important factor. Some consumer devices are disposable, which usually does not require maintenance or repair activities, but the main feature of the use of industrial and service devices is maintainability and repairability. This is especially true in the case of high-performance production equipment, where the establishment and operation of an effective maintenance system is essential for maintaining continuous operation, and the examination of maintenance processes is a particularly important task.

The application of various simulation methods for this purpose seems to be an obvious solution, but due to the randomness of maintenance processes and other characteristics that are difficult to consider, we can only perform the necessary tests using complex models.

This article presents a simulation model that can be used to examine the logistic activities of maintenance systems, with the help of which the real characteristics of various maintenance operations and the properties of the devices required for their servicing can be precisely determined.

2. MATERIAL HANDLING DURING MAINTENANCE PROCESSES

Wear-and-tear of technical equipment is a natural procedure, which causes various negative changings. To avoid the consequences, we must apply a suitable maintenance process, which involves the control, maintain and repair activities related to the given equipment (machines, devices, vehicles, etc.) [1]. Some decades ago, maintenance was a simple, internal task within the production hall, which was realized by special teams, settled close to the manufacturing

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machines. In the last quarter of the twentieth century, diagnostic methods appeared in the maintenance processes, which opened new directions in the control of the machines. (Reliability Centred Maintenance, Total Productive Maintenance, see [2]).

As many other service processes, maintenance also requires material handling activities, so the task of maintenance logistics is to ensure the availability of the materials, elements, devices and operators required by the maintenance processes [3]. This paper focuses only the material handling activities related to the elements, materials and devices required by the maintenance processes.

Material handling requirements arise during each maintenance task (transportation, loading and storage activities). From a service perspective, maintenance can be divided into four distinct phases:

F1. Disassembly and inspections
F2. Repair
F3. Assembly and operation tests
F4. Tasks that arise after maintenance is completed

In order to meet the logistical needs of the maintenance processes, it is necessary to have an accurate knowledge of the maintenance needs, which - depending on the maintenance methods used - may contain significant randomness. If the necessary data are available, the logistic service parameters can be determined in the individual phases [4, 5].

2.1. Material handling equipment needs

In this article, we only deal with the delivery of physical objects, which can be parts (to be repaired, replacement, or scrap parts), materials, auxiliary materials, assembly, or repair tools and other waste. To determine the required logistic device capacity, we use the following general formula based on the theoretical model described in [6]:

$$C_{Df} = \sum_{i=1}^{N_{Af}} n_{Afi} \cdot V_{Afi} + \sum_{i=1}^{N_{Ef}} n_{Efi} \cdot V_{Efi} \tag{1}$$

where

C_{Df} – material handling equipment capacity needs in phase $\boldsymbol{f}$ [m^3],
N_{Af} – number of transported material types in phase $\boldsymbol{f}$ [pcs],
n_{Afi} – quantity of transported material $\boldsymbol{i}$ in phase $\boldsymbol{f}$ [pcs],
V_{Afi} – volume of transported material $\boldsymbol{i}$ in phase $\boldsymbol{f}$ [m^3],
N_{Ef} – number of transported device types in phase $\boldsymbol{f}$ [pcs],
n_{Efi} – quantity of transported device $\boldsymbol{i}$ in phase $\boldsymbol{f}$ [pcs],
V_{Efi} – volume of transported device $\boldsymbol{i}$ in phase $\boldsymbol{f}$ [m^3].

With a given handling device capacity, the number of necessary transport equipment in each phase can be calculated as follows:

Phase F1 (Disassembly and inspections)

- at $\boldsymbol{i}$ transport task, if there are no overlapping (see [6]):

$$N_{D1i} = \frac{C_{D1i}}{V_D}, i = 1 \dots n_1 \tag{2}$$

- at ***i*** transport task, if there are overlapping (see [6]):

$$N_{D1i(ov)} = \frac{C_{D1i} + C_{D1i(ov)}}{V_D}, i = 1 \dots n_{1(ov)} \tag{3}$$

where
V_D – capacity of the material handling equipment [m^3],
n_1 – number of transport tasks in phase ***F1*** [pcs],
$n_{1(ov)}$ – number of overlapped transport tasks in phase ***F1*** [pcs].

Phase F2 (Repair)

- at ***i*** transport task (in one direction, see [6]):

$$N_{D21i} = \frac{C_{D21i}}{V_D}, i = 1 \dots n_{21} \tag{4}$$

- at ***i*** transport task (in two directions, see [6]):

$$N_{D22i} = \frac{C_{D22i}}{V_D}, i = 1 \dots n_{22} \tag{5}$$

where
n_{21} – number of single transport tasks in phase ***F2*** [pcs],
n_{22} – number of double transport tasks in phase ***F2*** [pcs].

Phase F3 (Assembly and operation tests)

- at ***i*** transport task (see [6]):

$$N_{D3i} = \frac{C_{D3i}}{V_D}, i = 1 \dots n_3 \tag{6}$$

where
n_3 – number of transport tasks in phase ***F3*** [pcs].

Phase F4 (Tasks that arise after maintenance is completed)

- in case of integrated transport (see [6]):

$$N_{D4} = \frac{C_{D4}}{V_D} \tag{7}$$

2.2. Realization of the logistics tasks

Servicing maintenance tasks is usually not an easy task. In simpler cases, the main difficulty is the utilization of material handling equipment, since in the case of few tasks, the equipment is waiting for most of the useful working time. In the case of low utilization, a solution to reduce costs is to use external material handling equipment (e.g. forklifts handling the production needs), but this means a significant extra organizational task, or in some cases, it can increase the duration of maintenance (waiting for the release of devices). This problem does not occur in complex maintenance systems, because in the case of many tasks, own handling tools must be used in each case, but at the same time, the coordination of the service needs of parallel maintenance tasks raises similar problems. In the case of several material handling devices, it is also necessary to dispose of individual equipment, which may mean additional tasks [7].

Due to the above problems, a thorough and detailed examination of the operation is indispensable for the optimal implementation of logistics of maintenance systems, for which the application of simulation methods can be an excellent tool [8]. However, the peculiarities of the maintenance processes (randomness, complex delivery tasks, parallelism, etc.) require the creation of a unique simulation model.

3. Simulation model for the analysis of logistic activities of maintenance systems

To create the simulation model, a general but simplified handling system was used related to maintenance activities as a basis (Fig. 1), where the following restrictions and conditions are applied:

- there is one maintenance site, which also includes repair areas, warehouses and a waiting area for transport equipment,
- the location of the parts warehouse is given, the source point is always the same,
- a specific maintenance location can be characterized by two delivery destinations (there and return delivery),
- only one route is considered for a delivery task,
- transport and loading times are taken into account with constant values,
- the service device can be characterized by a predefined delivery volume,
- the maintenance requirement is generated by a failure date,
- several types of malfunctions may occur with one piece of equipment,
- there is a specific installation and repair scheme for every failure,
- the necessary parts and times are recorded in the given schemes,
- failures, or error types can change randomly,
- individual transport phases are completely separated,
- other external influences do not affect the model.

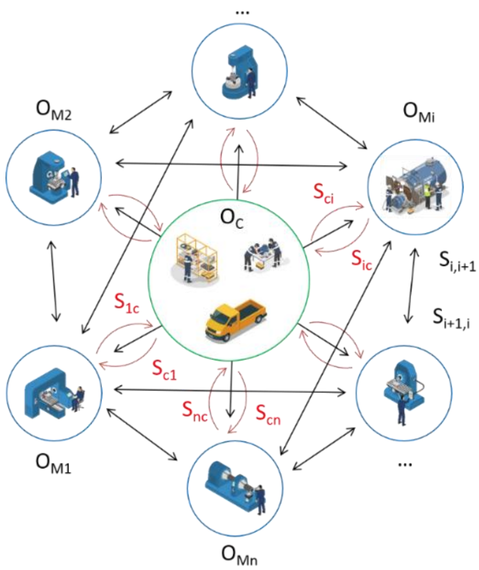

Figure 1. Structure of simulation model (O – objects, S – transport tasks)

The service phases are completely separated in the model, we do not create combined delivery tasks only within the individual phases.

Phases considered in the model:

1. Disassembly and inspections
   A. delivery of predefined service needs
   B. delivery of additional service requests (one or several phases)
2. Repair (one or several phases)
3. Assembly and operation tests (one or several phases)
4. Tasks that occur after the completion of maintenance.

The algorithm shown in Fig. 2 is used as a basis for determining the material handling needs of maintenance tasks. This algorithm contains only the activities necessary to serve one maintenance task, in the case of several tasks, the algorithm must be implemented separately for each maintenance task.

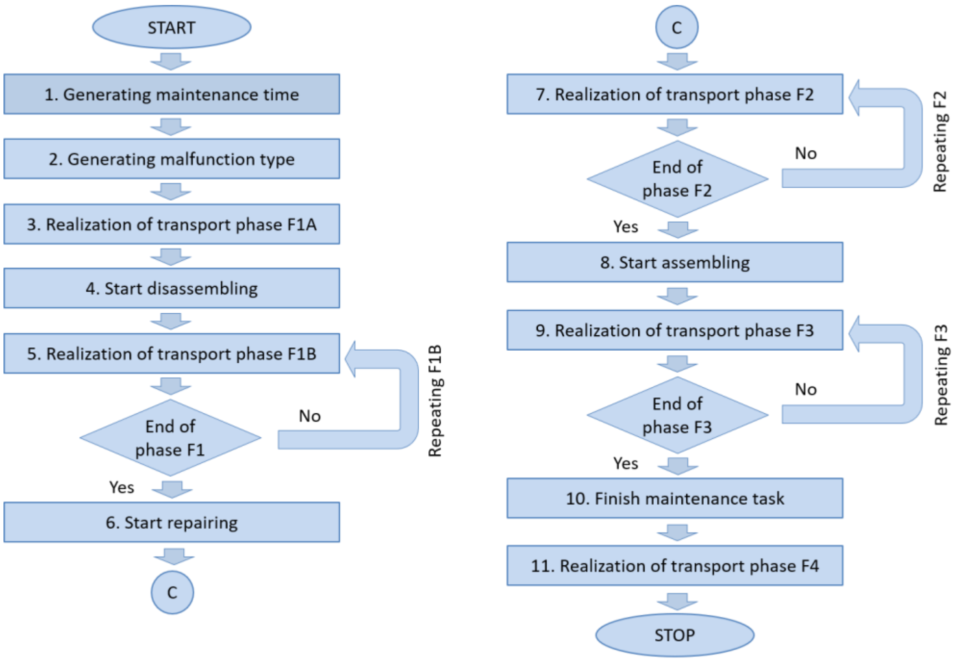

Figure 2. General algorithm of the simulation model

4. EXAMPLE SCENARIO

In order to verify the operation of the above algorithm, a practical example was prepared in which a maintenance process of two equipment characterized by specific maintenance behaviour was a basis. In the example, a specific case is presented where the parts are transported with one material handling device.

For the tests, a simple production system was built (with 2 technological equipment, one maintenance centre, one storing area for parts and devices and one waste handling point) in the Technomatix PlantSimulation environment [9], served by one transport truck, the physical arrangement can be seen in Fig. 3.

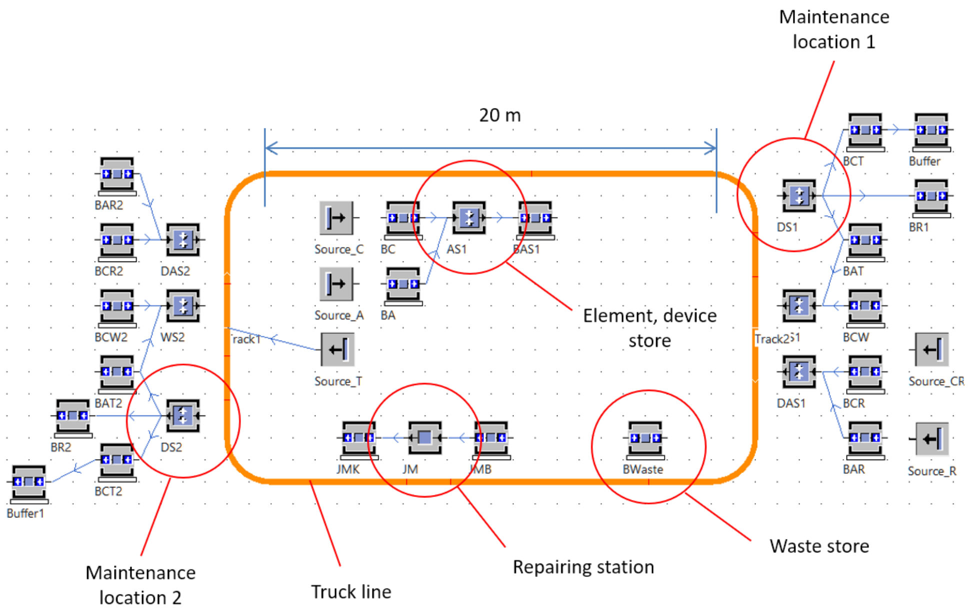

Figure 3. Structure of the example system in PlantSimulation

Using the mathematical relations described in the previous chapter, and the algorithm presented in Fig. 2, we simulated the individual phases of the maintenance process and the delivery of materials, parts and tools necessary for the randomly generated maintenance activities of the two maintenance locations running in parallel. The primary purpose of the tests was to demonstrate the functionality of the model, so the results of the runs are not compared, they serve purely for demonstration purposes.

The relationship between the phases of the randomly generated maintenance tasks and the associated delivery tasks is shown in Table I in chronological order. During the example task, there was no demand for materials in the assembly phases, so only waste transportation was connected to them.

After running the simulation, the time evolution of the actual implementation of each maintenance task was produced, which can be seen in Fig. 4 and 5.

Fig. 4 and 5 clearly show how the theoretical time required for the execution of maintenance tasks (the durations shown in the maintenance phases) has changed depending on logistic service tasks and the waiting phases (times elapsed between the start of each phase).

The actual evolution of the material handling tasks can be seen in Fig. 6 (the length of each section in the diagram includes the useful delivery times and the loading time requirements).

Table I.
The randomly generated maintenance tasks and the associated delivery tasks

Maintenance			Transport	
No.	**Task**	**Phase**	**No.**	**Material**
1	Previous transport	F1A	C1	For dismounting
2	Previous transport	F1A	C2	For dismounting
1	Disassembling	F1B	C3	For dismounting
2	Disassembling	F1B	C4	For dismounting
1	Disassembling	F1B	C5	For repairing
2	Disassembling	F1B	C6	For repairing
2	Repairing	F2	C7	For repairing
1	Repairing	F2	C8	For repairing
2	Repairing	F2	C9	For building
1	Repairing	F2	C10	For building
2	Assembling	F3	C11	Waste
1	Assembling	F3	C12	Waste

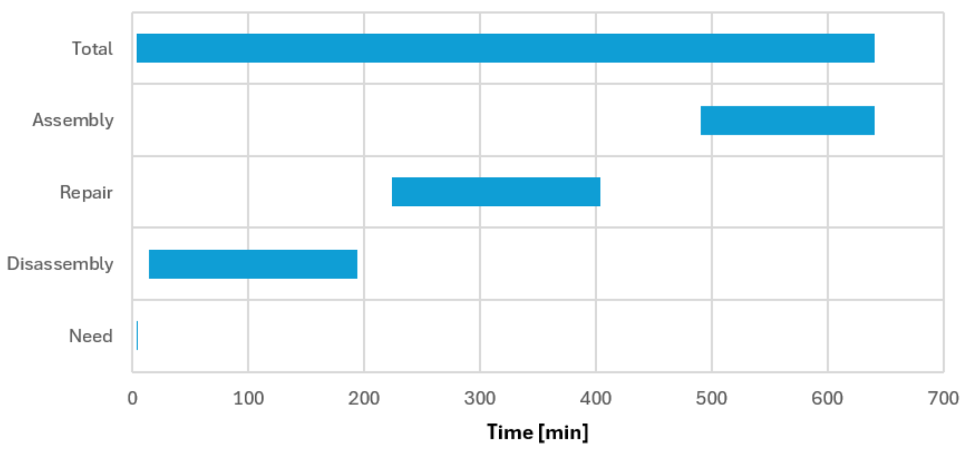

Figure 4. Realization of the phases of maintenance task 1

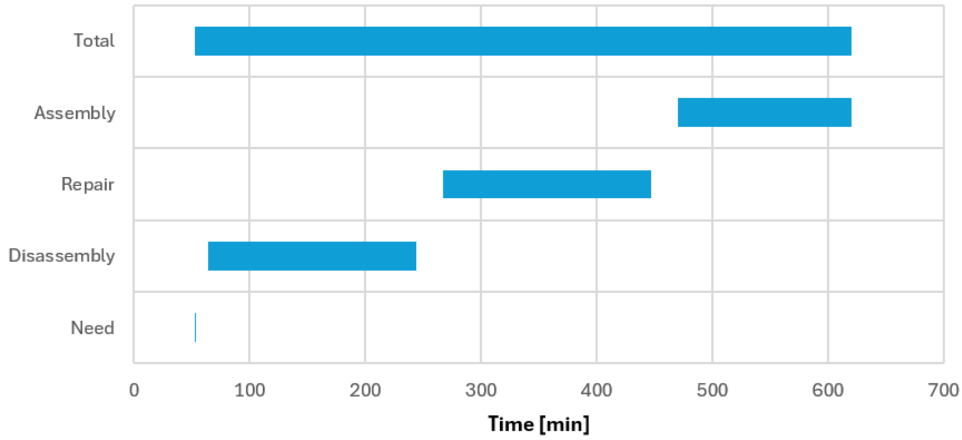

Figure 5. Realization of the phases of maintenance task 2

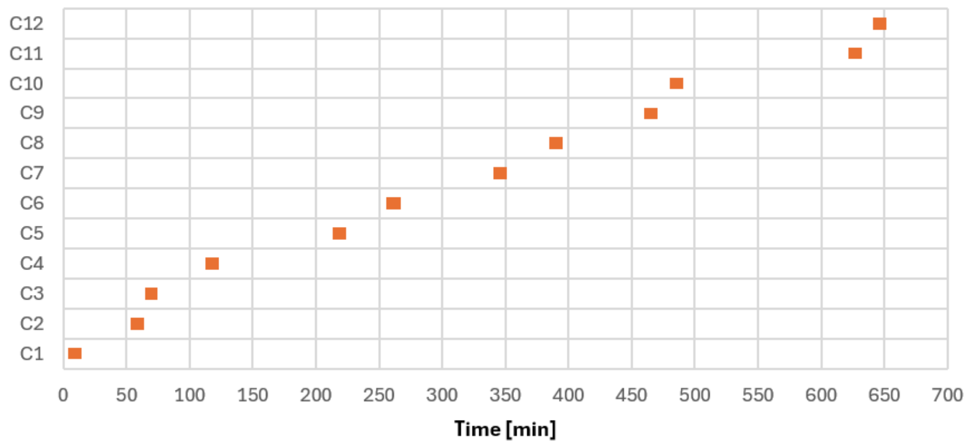

Figure 6. The realization of the material handling tasks in time

From the above diagrams, or from the additional results of the simulation, the different characteristics of each maintenance task and the detailed data of the service can be precisely determined, which enables the various purposes of analysis the logistic service of the maintenance systems.

5. Conclusions and Discussion

In the case of high-performance production equipment, where the construction and operation of an efficient maintenance system is essential to maintain continuous operation, the inspection of maintenance processes is a particularly important task. It seems like an obvious solution to use various simulation methods for this purpose, but the randomness of the maintenance processes, or due to other features that are difficult to consider, we can only perform the necessary tests with the help of complex models.

In this article, the general elements (structure, basic relationships, calculation algorithm) of a simulation model that can be used to examine the logistic service of maintenance systems have been presented. In the last chapter of the article, an example for the realization of the model in Technomatix PlantSimulation environment was presented, and also the real system data obtained as a result of the runs were detailed.

The results clearly illustrate the operation of the model, and its usability in simulation tests of maintenance service systems, where the following system parameters can be generated and analysed [10]:

- the ratio of theoretical and real maintenance times (time required for individual phases, total time required, etc.),
- service requirements (device capacities, device numbers, etc.),
- spare parts supply indicators (stock levels, etc.),
- maintenance tool usage indicators (utilization, occupancy, etc.),
- the characteristics of the material handling devices (utilization, availability, etc.),
- characteristics of logistic service problems (e. g. waiting times), etc.

The main goal of this article was to demonstrate the functionality of the model, so the results of the runs served purely for demonstration purposes. With the help of the model, complete maintenance system structures can be built, which enable, for example, the examination of the logistic service characteristics of individual maintenance methods.

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