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CALCULATION OF LOGISTICS RESOURCE REQUIREMENT FOR INDIVIDUAL MAINTENANCE PROCESSES

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Abstract: *The maintenance activities are related to production objects, but the consideration of the parameters of the maintenance process during material handling requires a completely different approach. The most important difference compared to production processes is the randomly arising servicing needs. The research presented here aimed at establishing an integrated material handling model for the entire maintenance processes. In this article, a calculation method will be presented that seeks to minimize the handling equipment requirement by analysing the transportation tasks of individual maintenance process elements. The relationships related to satisfying maintenance material and device needs can be used to determine the various parameters of the material handling equipment and the size of the equipment park required for maintenance.*

Key words: *Maintenance logistics, logistic resource capacities, logistic operation times.*

1. Introduction

The logistics of service processes has always been different from the servicing of production processes, because the properties of service process elements can differ significantly from production process elements. This is especially true for maintenance services, in which tasks are strongly tied to production objects, but the parameters of the maintenance process require a completely different approach from logistics specialists. The most important difference compared to production processes is the randomly arising servicing needs, for which the logistics models developed for planned handling systems cannot be used.

This article presents a calculation method that does not aim at continuous and efficient service but rather seeks to minimize the material handling equipment demand by analysing the delivery tasks of individual maintenance process elements. The presented calculation method contains the relationships for satisfying the maintenance material and component demand, but by analogy, formulas that can be used for the delivery of maintenance equipment can also be described.

2. Logistic activities in maintenance processes

Wear-and-tear of technical equipment is a natural procedure, which causes different 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 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. Next step of the development was the Reliability Centred Maintenance (RCM), which is based on the reliability of the machines and their elements, and means a new point-of-view, at first

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mainly in the aircraft production. The last concept is the Total Productive Maintenance (TPM), which - similarly to the Total Quality Management (TQM) systems - tries to give the responsibility for certain tasks of the maintenance (keeping, observing, etc.) to the handling operators and introduces a general system concept for the maintenance to avoid malfunctions and crashes [2].

As many other service processes, maintenance also requires material handling activities, so the task of maintenance logistics is to take care about the materials, elements, devices and operators required by the maintenance processes.

During maintenance logistics different activities must be used to satisfy the requirements of the production companies [3]:

- material handling tasks related to the maintenance activities,
- storing (elements, devices, wastes),
- element and device supplying,
- waste management,
- scheduling and allocation of the logistic equipment and human resources, etc.

In this paper only the material handling activities [4] will be presented and detailed.

Material handling requirements arise during each maintenance task (transportation, loading and storage activities). From a material handling perspective, maintenance can be divided into three distinct phases (Fig. 1):

1. Disassembly and inspections
2. Repair and assembly
3. Tasks arising after maintenance is completed.

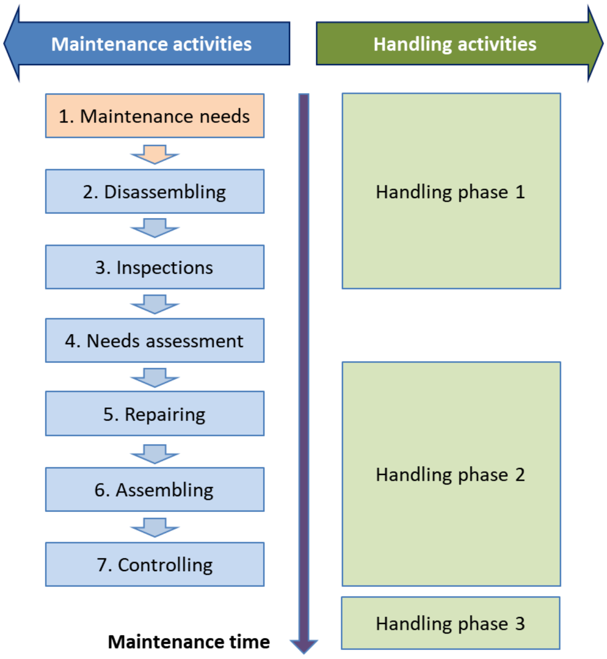

Figure 1. Relations of maintenance and material handling activities

To start maintenance activities, the appropriate operators and tools, as well as the necessary materials, must be delivered to the maintenance location. The logistic activities required for this must precede the physical start of maintenance. If the maintenance dismantling tasks can be divided into separate phases (or additional equipment and material requirements may also arise during the inspections), then the service tasks can also be divided into phases (e.g. carrying out several transport rounds). The exact resource requirements for maintenance are usually not yet available in this phase. Transport activities in this phase are only carried out towards the maintenance location.

The 2nd phase of service begins after the actual resource requirement has been determined and includes activities of different content and direction. From the logistics point of view, a distinction must be made between on-site repair and repair in the workshop. The delivery of several parts to be repaired at different times may require complex transport arrangements. Material handling activities include

- the delivery of replacement parts required to repair the defects,
- the delivery of operators and tools to the maintenance site,
- the delivery and return of repaired parts,
- the additional parts and tools required for assembly.

The importance and execution of material handling tasks after maintenance is completed differs from the previous two phases because the time requirements of the activities do not affect the maintenance time (downtime of the maintained device). The last service phase includes

- the return of unused parts and devices,
- the removal of defective parts and waste generated, and
- the transportation of operators to different destinations.

Mobile tools are usually returned at the same time, using the same means of transport. Waste can be removed in a separate cycle or integrated into the waste management process of the manufacturing system. Operators and larger equipment can be transported back to the source (site or warehouse) or to a subsequent maintenance location.

4. LOGISTIC SERVICE REQUIREMENT

To meet the logistical demands of maintenance processes, it is necessary to have an accurate knowledge of maintenance requirements, which - depending on the maintenance methods used - may contain significant randomness. In the case of high randomness (e. g. maintenance due to failure), the necessary data can only be generated using probability functions or statistical data.

If the necessary data are available, the handling parameters can be determined for the service phases defined in the previous chapter [5]. In order to plan the logistics of maintenance tasks, the following characteristics need to be determined:

- resource requirements in each phase (operator, material and equipment requirements),
- transport routes in each direction,
- maintenance time parameters in each phase, etc.

Using the above parameters, the material handling equipment requirements can be determined and logistic tasks can be scheduled.

4.1. Description of the maintenance system

Maintenance processes can be very diverse, as they are adapted to the characteristics of the monitored equipment and the operating environment, as well as the characteristics of the applied maintenance strategies. As a first approximation to determine the service needs, we outline a simple but generally applicable maintenance system model [6].

In the model (Fig. 2), we use a centralised site layout, a predefined route system and a homogeneous device structure (transport trucks).

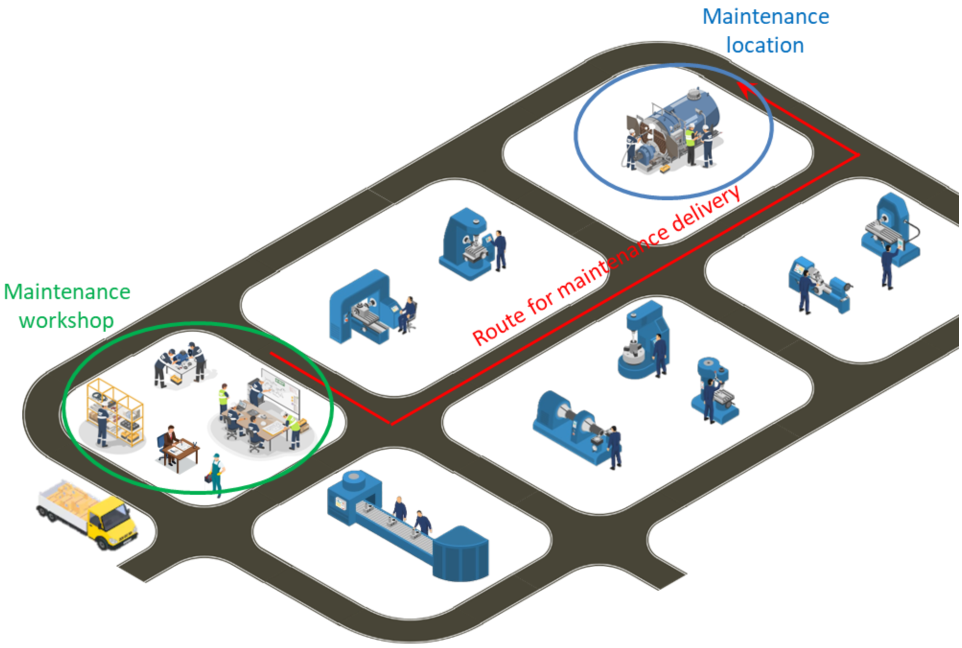

Figure 2. Structure of a maintenance system

When planning material handling tasks, we consider a predefined fleet of equipment and site starting points (warehouses and parking spaces are also on site).

4.2. Material handling equipment needs in Handling phase 1

The separation of the service phases is aligned with the resource requirements of the maintenance process. During the 1st handling phase, the resource requirement appears in two forms:

A. predefined operator, tool and material requirements based on estimates and previous experiences, which are already available at the start of maintenance,
B. resources arising during the actual handling phase based on new requirements arising during disassembly and inspections, the occurrence time of which is random and contingent.

In this article, only the relationships related to material and component transportation [7] will be presented. The determination of the service device requirement related to devices and operators is done similarly to that of components, but their joint examination requires an integrated service approach, which significantly increases the complexity of the relationships.

From logistics point of view, the number of handling devices and their scheduling are primary, but in simpler maintenance processes, only a few devices are usually required during material handling. For this reason, in the following, the question will be that the individual phases of a given maintenance task can be implemented by one material handling equipment or not.

When delivering predefined service needs (A), one handling device is sufficient if

$$C_{D1A} = \frac{\sum_{i=1}^{N_{1A}} n_{1Ai} \cdot V_{M1Ai}}{V_D} \leq 1 \tag{1}$$

where

C_{D1A} – predefined handling equipment needs in Handling phase 1,
N_{1A} – number of predefined materials and components in Handling phase 1 [pcs],
n_{1Ai} – quantity of predefined component i in Handling phase 1 [pcs],
V_{M1Ai} – volume of predefined component i in Handling phase 1 [m^3],
V_D – material handling equipment capacity [m^3].

When delivering additional service requirements (B), two basic cases can occur:

- single-level delivery: all requirements arising during disassembly or inspections can be delivered in one cycle,
- multi-level delivery: disassembly or inspections include several operations that build on each other (each operation requires new tools or materials).

In the case of multi-level additional material requirements, the delivery is made up of separate cycles.

When delivering additional service requirements, one handling device is sufficient if

- in the case of single-level delivery:

$$C_{D1B} = \frac{\sum_{i=1}^{N_{1B}} n_{1Bi} \cdot V_{M1Bi}}{V_D} \leq 1 \tag{2}$$

- in the case of multi-level delivery:

$$C_{D1Bi} \leq 1, i = 1 \ldots n_{1BF} \text{ and} \tag{3}$$

$$\sum_{i=1}^{n_{1BF}} T_{D1Bi} + (n_{1BF} - 1) \cdot T_V \leq T_{Lim1B} \tag{4}$$

where

C_{D1B} – additional handling equipment needs in Handling phase 1, in case of single-level delivery,
N_{1B} – number of additional materials and components in Handling phase 1 [pcs],

n_{1Bi} – quantity of additional component i in Handling phase 1 [pcs],
V_{M1Bi} – volume of additional component i in Handling phase 1 [m^3],
C_{D1Bi} – additional handling equipment needs of delivery level i, in Handling phase 1, in case of multi-level delivery,
n_{1BF} – number of additional delivery levels, in Handling phase 1, in case of multi-level delivery [pcs],
T_{D1Bi} – time requirement of delivery level i, in Handling phase 1, in case of multi-level delivery [min],
T_V – time of return of the empty handling equipment [min],
T_{Lim1B} – time limit for the additional deliveries in Handling phase 1 [min].

4.3. Material handling equipment needs in Handling phase 2

Two cases are also possible for delivery needs related to repair and assembly:

- single-level delivery: all necessary materials, parts, or tools can be delivered in one cycle,
- multi-level delivery: each need is met in a separate cycle.

The reason for the separation of service needs may be the stacking of operations, the acceleration of the maintenance process, the separation of tasks in time, etc. The structure of service cycles related to repairs may be:

- one-way transport (directed to the maintenance site – tools, replacement parts),
- two-way transport (to the maintenance workshop and return – repaired parts).

The structure of the service cycles only affects the material handling equipment requirement if the return transport is separate for each repaired part (in the case of two-way transport).

During the transport of the material requirement of a single-level delivery - similarly to relation (2) - one service equipment is sufficient if

$$C_{D2} = \frac{\sum_{i=1}^{N_2} n_{2i} \cdot V_{M2i}}{V_D} \leq 1 \tag{5}$$

where
C_{D2} – handling equipment needs in Handling phase 2, single-level delivery,
N_2 – number of required materials and components in Handling phase 2 [pcs],
n_{2i} – quantity of required component i in Handling phase 2 [pcs],
V_{M2i} – volume of required component i in Handling phase 2 [m^3].

In case of multi-level delivery - similarly to relation (3) - one serving device is sufficient if

$$C_{D2i} \leq 1, i = 1 \dots n_{2F} \text{ where} \tag{6}$$

$$n_{2F} = n_{21F} + n_{22F} \text{ and} \tag{7}$$

$$\sum_{i=1}^{n_{21F}} T_{D21i} + \sum_{i=1}^{n_{22F}} 2 \cdot T_{D22i} + \sum_{i=1}^{n_{2F}} T_{J2i} + n_{2V} \cdot T_V \leq T_{Lim2} \tag{8}$$

where

C_{D2i} – handling equipment needs of delivery level i in Handling phase 2,
n_{2F} – number of deliveries in Handling phase 2 [pcs],
n_{21F} – number of one-way transports in Handling phase 2 [pcs],
n_{22F} – number of two-way transports in Handling phase 2 [pcs],
T_{D21i} – time requirement of one-way transport i, in Handling phase 2 [min],
T_{D22i} – time requirement of two-way transport i, in Handling phase 2 [min],
T_{J2i} – total repairing time requirement of delivery level i, in Handling phase 2 [min],
n_{2V} – number of empty routes in Handling phase 2 [pcs],
T_{Lim2} – time limit for the deliveries in Handling phase 2 [min].

During the service, it is assumed that the travel time (T_V) of the idle runs is the same in both directions (towards the maintenance site or towards the maintenance workshop), and that the parts delivered to the workshop in one phase are also delivered to the site after repair in one phase. In the case of multi-level delivery, the number of idle runs depends on the ratio of one-way and two-way deliveries, as well as on the order of each delivery; in special cases, it can also take on a zero value.

4.4. Material handling equipment needs in Handling phase 3

Since the transport tasks that occur after the maintenance is completed do not affect the maintenance time, there is usually no time limit for service. In terms of material and component transport, the task is primarily the transport of defective components and waste materials, for which one service vehicle is sufficient if

$$C_{D3} = \frac{\sum_{i=1}^{N_3} n_{3i} \cdot V_{M3i}}{V_D} \leq 1 \qquad (9)$$

where

C_{D3} – handling equipment needs in Handling phase 3,
N_3 – number of delivered materials and components in Handling phase 3 [pcs],
n_{3i} – quantity of delivered component i in Handling phase 3 [pcs],
V_{M3i} – volume of delivered component i in Handling phase 3 [m^3].

During return transport, maintenance equipment is usually transported along with materials and parts, so these also affect the required equipment capacity.

5. EXAMPLE SCENARIO

To demonstrate the above relationships, a practical example has been prepared, based on the maintenance process of a given production equipment. The example presents a specific case where the delivery of the parts listed in Table I is implemented.

Using the relationships described in the previous chapter, we can determine the transport capacity requirements of each phase. Fig. 3 shows that each phase of the example process can be implemented using one serving device (in the case of a 100 dm^3 transport platform).

Table I.

Data of the example system

No.	Parts	Quantity	Volume	Needs start	Needs fulfilled	Repairing time	Delivery phase
		[pcs]	[dm^3]	[date]	[date]	[min]	
1.	Part 1	1	5	8:00	9:00		1A
2.	Part 2	1	10	8:00	9:00		1A
3.	Part 3	1	4	8:00	9:00		1A
4.	Part 4	2	8	8:00	9:00		1A
5.	Part 5	1	4	8:00	9:00		1A
6.	Part 6	1	3	9:30	10:00		1B1
7.	Part 7	1	2	10:00	10:30		1B2
8.	Part 8	1	7	10:10	10:30		1B2
9.	Part 9	2	15	11:00	11:30	0	211
10.	Part 10	1	20	11:00	11:30	0	211
11.	Part 11	1	10	11:00	11:30	0	211
12.	Part 12	1	25	11:00	13:00	30	221
13.	Part 13	1	12	11:00	13:00	30	221
14.	Part 14	2	9	11:50	13:20	0	212
15.	Part 15	1	21	12:40	14:20	30	222
16.	Part 16	1	30	13:20	14:40	0	213
17.	Part 17	1	23	14:00	15:40	30	223
18.	Waste 1	1	3	16:00			3
19.	Waste 2	2	5	16:00			3
20.	Waste 3	1	9	16:00			3

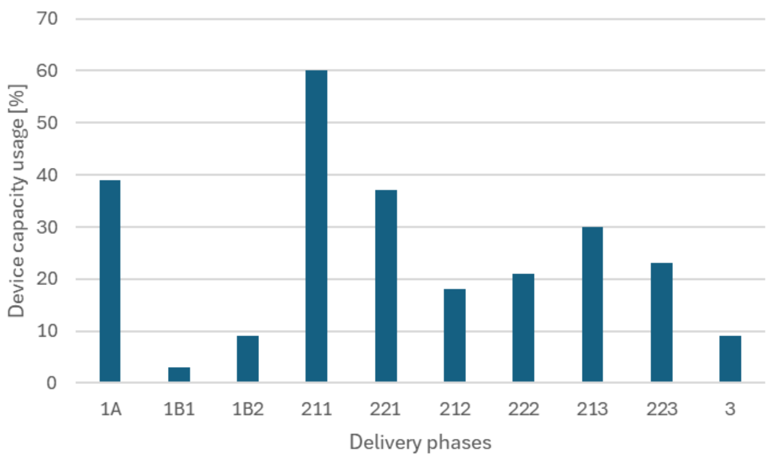

Figure 3. Capacity needs of the delivery phases

When carrying out the transport, time constraints must also be considered [8], which are shown in Table II in the case of the example maintenance system.

Table II.

Time limits of the example maintenance system

No.	Maintenance phase	Starting [date]	Finishing [date]	Handling phase	Time limit [min]
1.	Maintenance needs	8:00	9:00	Phase 1	180
2.	Disassembling	9:00	10:00		
3.	Inspections	10:00	11:00		
4.	Repairing	11:00	13:00	Phase 2	270
5.	Assembling	13:00	15:00		
6.	Controlling	15:00	15:30		
7.	Delivery after finishing	15:30	16:00	Phase 3	30

Using the relationships described in the previous chapter, we can determine the time requirements of each delivery phase [9]. Fig. 4 contains the time requirements of the delivery phases of the example system. In the case of a linear service scheme (successive deliveries, without overlap), the total time requirements of the three handling phases can be calculated by adding the individual values:

- in Handling phase 1: 1A + 1B1 + 1B2 = 72 min,
- in Handling phase 2: 211 + 221 + 212 + 222 + 213 + 223= 278 min,
- in Handling phase 3: 3 = 26 min.

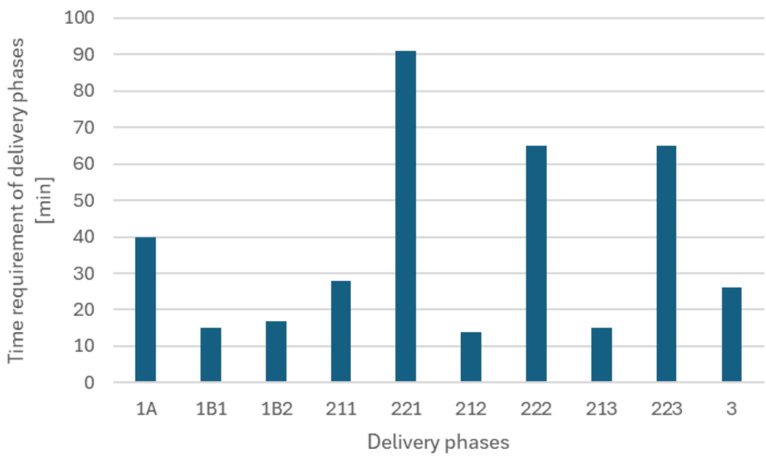

Figure 4. Time requirements of the delivery phases

Comparing the time limits involved in Table II with the total time required for each service phase, it can be concluded that in Handling phases 1 and 3, the use of one material handling device is sufficient to comply with the time limit, but in phase 2, the service time is 8 minutes longer than allowed.

In such cases, there are several options for modifying the handling parameters [10] (e.g., using a new device, merging the delivery phases, parallelization, etc.). In the present example, examining the deliveries related to repairs (Table I), we can see that the longest service phase is 221, which has a total handling time of 91 minutes. This phase includes a two-way parts delivery, of which 60 minutes is the repair time. Since the next one-way phase (212) can be implemented in time while the handling device is waiting, this reduces the total service time by 14 minutes. With this parallelization, the problematic time limit can be met.

6. SUMMARY

The tasks performed during maintenance services are strongly tied to production objects, but considering the parameters of the maintenance process during service requires a completely different approach from logistics professionals. The most important difference compared to production processes is the randomly arising service needs.

This article presents a calculation method that aims to minimize the service equipment requirement by analysing the transportation tasks of individual maintenance process elements. The relationships for satisfying maintenance material and component requirements can be used to determine the various parameters of the logistic equipment and the size of the equipment fleet required for maintenance. In the last chapter of the article, an example was presented for the method to determine the service equipment requirement, which, with minor modifications, is also suitable for examining the transportation of maintenance equipment.

The research, part of which has just been published, aimed at a comprehensive calculation procedure for the entire maintenance service. In the future, next steps will work on setting up an integrated model that includes the resource requirements for material, parts, equipment and operator transportation.

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