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METHOD FOR OPTIMIZING MAINTENANCE LOCATION WITHIN THE INDUSTRIAL PLANT

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Abstract: Nowadays, more and more emphasis is placed on the overall maintenance concept and strategy, not only in all industrial sectors, but increasingly, maintenance management is becoming part of a long-term strategy for both businesses and other institutions. One of the priority objectives of all types of maintenance is the return on investment that has been put into maintenance and, of course, the smooth operation of machines and equipment without failures that negatively affect the entire product manufacturing process. Obviously, a company with a poorly developed maintenance structure, will only be very hardly competitive in today's market, compared to a company with the same or similar manufacturing program, which, due to a more sophisticated maintenance system, often has lower maintenance costs. Less attention is paid to maintenance in industrial enterprises. In the article, it describes and characterizes this basic reliability feature and proposes a method for optimizing the maintenance location within an industrial enterprise. The proposed method is universal and can be used to support maintenance assurance management in both industrial and non-industrial sectors.

1 Introduction

Manufacturing companies are under increasing pressure to reduce production costs. They are forced to more optimize their production processes and increase the productivity of production processes and the use of machines, people and materials. This entails high demands on production management in terms of production management and planning. For decision making, it is necessary to have information on critical points in production. Know the real production capacities, bottlenecks, various downtime and losses that arise under specific conditions and combinations of variations. One of these factors is the location of maintenance that affects the logistic delay of the service.

2 Losses in production

Each production generates losses that do not allow for maximum theoretical production performance. It depends only on how responsible workers, mainly production managers, but also operators and operators on the lines, manage to reduce their incidence and size. Losses in production can be divided into four basic areas [1]:

- Planned losses: weekends, holidays, preventive maintenance, cleaning, development, tests, exams, etc.
- Operational losses: machine setting, production change, lack of material and people, poor service, outages, equipment, bottlenecks, errors, etc.
- Power losses: poor machine settings, deliberate deceleration, failure, extended production cycle
- Poor quality of production: material defect, production inaccuracy, repairs, etc.

Obviously, some production losses cannot be completely eliminated, but most losses can be significantly reduced or eliminated. Actual production performance depends on how the above losses can be avoided or substantially reduced [2].

There are some forms of wasting, which need to be eliminated in logistics area, for example [3]:

- Useless movement and manipulation of products and materials - is delivered too much or too little; unnecessary reloading, moving stock, people and material. By default, it has been confirmed that there are up to ten other activities per technology operation.
- Redundant documents and administration - excessive documentation related to logistics activities, manual recording of items, filling in too many types of documents, redundant records.
- Bad documents in logistics - incorrectly filled documents, incomplete specification, parts list errors and subsequent errors in the information system due to depreciation of finished production, poor material transfers.
- Searching for material and semi-finished products - the material is not where the system shows, the system shows a certain number of items and there is no material in the warehouse and vice versa, the system does not have the material, so it automatically orders it and is physically in the warehouse. Each of these

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situations is followed by a waste of time by a number of people looking for differences in the number of items and comparing the system with reality.

- Waiting - waiting for loading, waiting for unloading; waiting for material imports; waiting for the shipment to be completed, waiting for material to be released, or material composition.
- Errors in logistics activities - incorrectly loaded consignment, incomplete material supply, inventory differences, late delivery of material or semi-finished products [4].

As noted above, we will focus on minimizing logistic delays in service interventions. According to ČSN IEC 60050-192 [5], the logistic delay is defined as the delay, excluding administrative delay, provided for the provision of resources needed for maintenance action to proceed or continue.

In practice, this is the cumulative transport time to installed equipment and waiting for spare parts, experts, test equipment, information or suitable environmental conditions.

A graphical interpretation of the logistic delay [6] in service interventions is shown in Table 1. All the times mentioned in the figure are time intervals or time interval sequences.

Table 1 Maintenance times [5]

<table>
<tr><td colspan="9">Maintenance time</td></tr>
<tr><td colspan="5">Corrective maintenance time</td><td colspan="4">Preventive maintenance time</td></tr>
<tr><td rowspan="3">Logistic delay</td><td colspan="7">Active maintenance time</td><td rowspan="3">Logistic delay</td></tr>
<tr><td colspan="4">Active corrective Maintenance time</td><td colspan="3">Active preventive Maintenance time</td></tr>
<tr><td>Technical delay</td><td>Fault localization time</td><td>Fault correction time</td><td>Function checkout time</td><td>Technical delay</td><td>Preventive maintenance active time</td><td>Function checkout time</td></tr>
<tr><td></td><td></td><td colspan="3">Repair time</td><td></td><td></td><td></td><td></td></tr>
</table>

Note: All times mentioned in the Table 1 are time intervals or sequences of time intervals.

3 Method for optimizing the placement of maintenance

3.1 Method algorithm

For the issue of optimization of maintenance location or management of transport routes are developed various optimization methods based on different algorithms solutions and is described in numerous publications.

Paper [7] is to propose innovative condition-based maintenance scheduling methodologies by integrating complex data processing, feature extraction, prognostic algorithm, and maintenance scheduling optimization. The proposed framework of prognostic-based maintenance scheduling is able to provide trade-off analysis in terms of key performance metrics such as command possession rate, cost, and capacity expansion. The optimized maintenance schedule based on fleet health status will lead to higher aircraft availability, lower unscheduled maintenance cost, and meeting the continuous improvement initiatives

The paper [8] describes a mathematical programming model of the problem, as well as a shortest path dynamic programming formulation for a single part which solves the problem in polynomial time complexity.

Article [9] proposes an integrated product-service model to ensure the system availability by concurrently allocating reliability, redundancy, and spare parts.

Article [10] deal with an optimal reliability and maintainability design problem of a searching system with complex structures. The system availability and life cycle cost are used as optimization criteria and estimated by simulation. Authors want to determine MTBF (Mean Time between Failures) and MTTR (Mean Time to Repair) for all components and ALDT (Administrative and Logistics Delay Times) of the searching system in order to minimize the life cycle cost and to satisfy the target system availability. A hybrid genetic algorithm with a heuristic method is proposed to find near-optimal solutions and compared with a general genetic algorithm [11].

Our maintenance assurance solution is unique and use of the CRAFT method - the technique of determining the mutual position by calculation is used to determine the optimal relative position of the various elements in the arrangement of the whole. As a reminder, the essence of this method is that it is based on arbitrary locations of workplaces that are most advantageous in terms of material handling costs. The aim is to find an arrangement unit which would reduce the cost of material handling to a minimum.

For CRAFT calculation we need the following data:

n - number of departments;

v_{ij} - the number of load units (products, components) moving between i and j;

u_{ij} - the cost of moving the load unit per unit distance between the i and j;

l_{ij} - distance between centres of departments.

The cost of the whole product movement between units i and j per unit distance is then given by relations (1):

$$c_{ij} = u_{ij} \times v_{ij} \tag{1}$$

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which can be written in the form of a matrix (2):

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ \vdots & & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix} \quad (2)$$

Changing the layout of formations varies the distance between them. Distance between departments can be expressed through the matrix L (3):

$$L = \begin{bmatrix} l_{11} & l_{12} & \cdots & l_{1n} \\ \vdots & & \ddots & \vdots \\ l_{n1} & l_{n2} & \cdots & l_{nn} \end{bmatrix} \quad (3)$$

The cost of any solution of the deployment of the units is then expressed as (4):

$$A_L = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} \times l_{ij} \quad (4)$$

The goal of subsequent step is to minimized mentioned function (4). We proceed in such a way that you come out of the arbitrarily chosen initial deployment of the units (workplaces) and in the steps there are mutual exchanges of units, which are the most cost-effective for handling the material. We proceed until we find a solution that can be improved by any exchanges. When solving problems this method it is necessary to respect some given conditions, for example some workplaces must be side by side, workplaces have a fixed position and so on.

The method is calculated on a computer. Input data form material flows between departments, the cost of material handling is per unit distance, and any initial deployment.

For maintenance needs, the CRAFT method has been modified to address the task of optimizing maintenance location.

3.2 *Demonstration solution*

The following example illustrates the entire modification of the CRAFT method. Let us have the devices expressed by nodes A to E and the stations expressed by nodes 1 to 4 (Figure 1). We have to decide on maintenance points so that it is optimal from the point of view of service logistics and thus minimal logistic downtime.

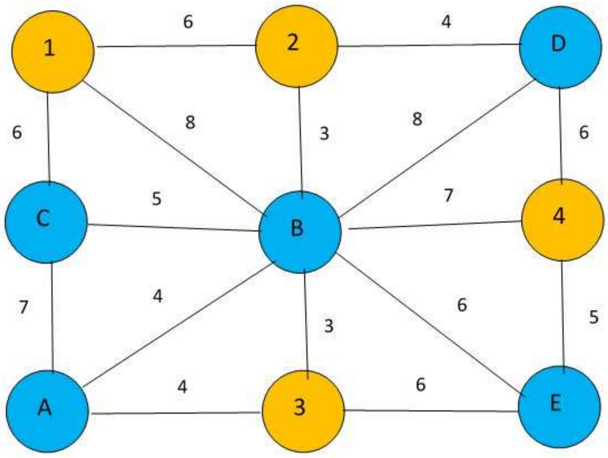

Figure 1 Graph of network projection of devices and unit locations

The distances between the nodes are replaced by the time data - the transfer times. Table 2 gives an example of the individual transfer times.

Table 2 Times of logistic delay - the transfer times [h]

	1	2	3	4	A	B	C	D	E
1		6				8	6		
2	6					3		4	
3					4	3			6
4						7		6	5
A			4				7		
B	8	3	3	7	4		5	8	6
C	6				7	5			
D		4		6		8			
E			6	5		6			

Subsequently, we define the individual logistic routes for each of the proposed maintenance stations (Figure 2 to Figure 5) and determine the logistic delay times for these logistic routes (Table 3 to Table 6).

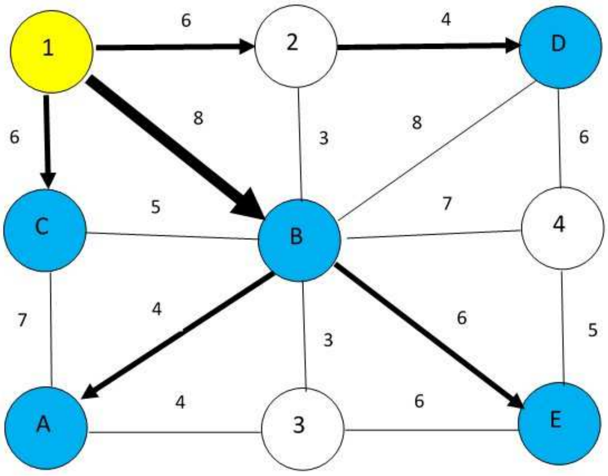

Figure 2 Representation of logistic routes to devices from maintenance stations 1

Table 3 Logistic delay times according to logistic routes for maintenance stations 1 [h]

	A	B	C	D	E
1	8+4	8	6	6+4	8+6

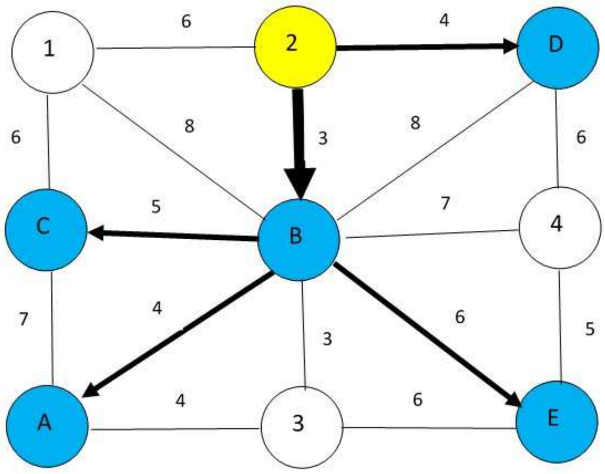

Figure 3 Representation of logistic routes to devices from maintenance stations 2

Table 4 Logistic delay times according to logistic routes for maintenance stations 2 [h]

	A	B	C	D	E
2	3+4	3	3+5	4	3+6

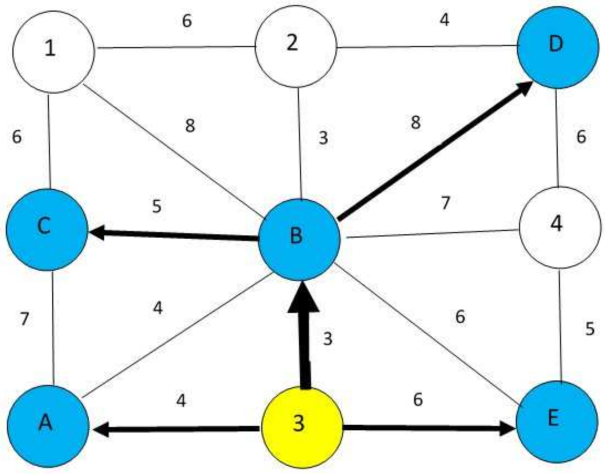

Figure 4 Representation of logistic routes to devices from maintenance stations 3

Table 5 Logistic delay times according to logistic routes for maintenance stations 3 [h]

	A	B	C	D	E
3	4	3	3+5	3+8	6

Table 6 Logistic delay times according to logistic routes for maintenance stations 4 [h]

	A	B	C	D	E
4	7+4	7	7+5	6	5

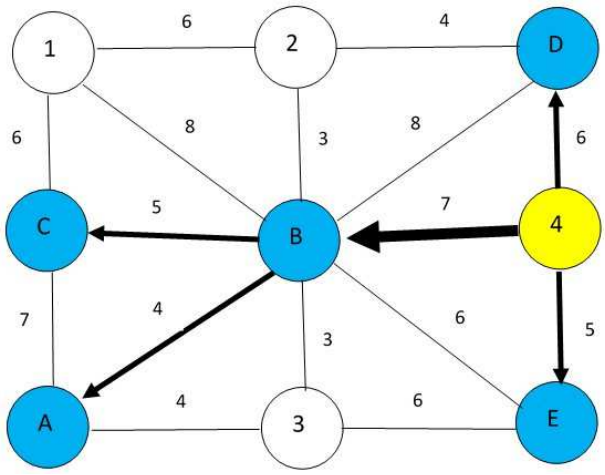

Figure 5 Representation of logistic routes to devices from maintenance stations 4

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The quantity v_{ij} - the number of units (products, components) moving between departments *i* and *j* has been transformed to the average number of maintenance workers which are ensuring maintenance. Table 7 is an example of the transformed value *v*, for the example chosen by us.

Table 7 Average number of employees in the maintenance of individual devices [without dimensional quantity]

	A	**B**	**C**	**D**	**E**
v	4	2	5	2	3

Similarly, the quantity u_{ij} - the cost of moving the unit of per unit distance between units *i* and *j* has been transformed into average hourly cost of maintenance personnel for the purposes of this modified CRAFT method to optimize the maintenance location within an industrial plant. Table 8 shows an example of the transformed value *u* for the chosen example.

Table 8 Average hourly costs of maintenance personnel [CZK / h]

	A	**B**	**C**	**D**	**E**
u	210	150	190	200	185

In addition, new we will now determine the average frequency of maintenance interventions on individual devices. We denote this variable n and in Table 9 there are values of this quantity for the chosen example.

Table 9 Average frequency of maintenance interventions on individual devices [without dimensional quantity]

	A	**B**	**C**	**D**	**E**
n	6	4	10	9	2

We then proceed with the CRAFT method - application of relation (1), but we will also modify this relationship. The result is a relationship (5) expressing the total hourly cost of personnel for the maintenance of each facility.

$$c_i = n_i \times u_i \times v_i \quad (5)$$

Table 10 shows the resulting cost vector $\boldsymbol{c_i}$ for the example we choose.

Table 10 Vector of Total of Hourly Cost of Maintenance Staff [CZK]

	Total hourly costs of maintenance workers
A	5040
B	1200
C	9500
D	3600
E	1110

The final procedure is the calculation according to the relation (4) - calculation of costs of any solution of deployment of departments - but for our purpose we calculate the cumulative costs due to logistic delay (Table 11).

Table 11 Cumulative costs due to logistic delay [CZK]

	A	B	C	D	E	Σ
1	60480	9600	57000	36000	15540	178620
2	35280	3600	76000	14400	9990	139270
3	20160	3600	76000	39600	6660	146020
4	55440	8400	114000	21600	5550	204990

The result optimal solution is the minimum sum of these cumulative costs. In Table 11 for our example, the resulting minimum value is indicated in yellow. This implies that for the specified conditions and given parameters, the location marked with the number 2 is optimal for maintenance.

4 Optimizing maintenance position on the sinter plant

The goal of optimization [12] is to decide on the optimal location of the sinter plant maintenance centre to minimize logistical delays in preventive and corrective maintenance interventions.

It is decision between 4 possibilities, which are in the technological diagram (Figure 6) and also marked with symbols U1, U2, U3 and U4.

For this optimization, the modified CRAFT method was used as described in the previous chapter.

The solution consists in the fact that the proposed model of the agglomeration plant according to the technological scheme was converted to a network model with nodes (Figure 6), where the individual machines and devices are represented by nodes, which were given an identification number and an identification symbol (the list of node marking is Table 12). Traffic routes between individual nodes (machines and devices) are represented by a network with parameters of 39 m/unit on the x-axis and 31 m/unit on the y-axis. These parameters were determined based on model and real system similarity.

For the determination of logistic delays times, i.e. transfer times between nodes, the average speed of the maintenance worker was first determined in operating conditions. This speed was determined according to [13], where it is assumed that the rate of walking of a person is determined by health status, motivation, terrain and other circumstances, and thus the walking speed depending on the slope of the terrain can be estimated by the Tobler function (6).

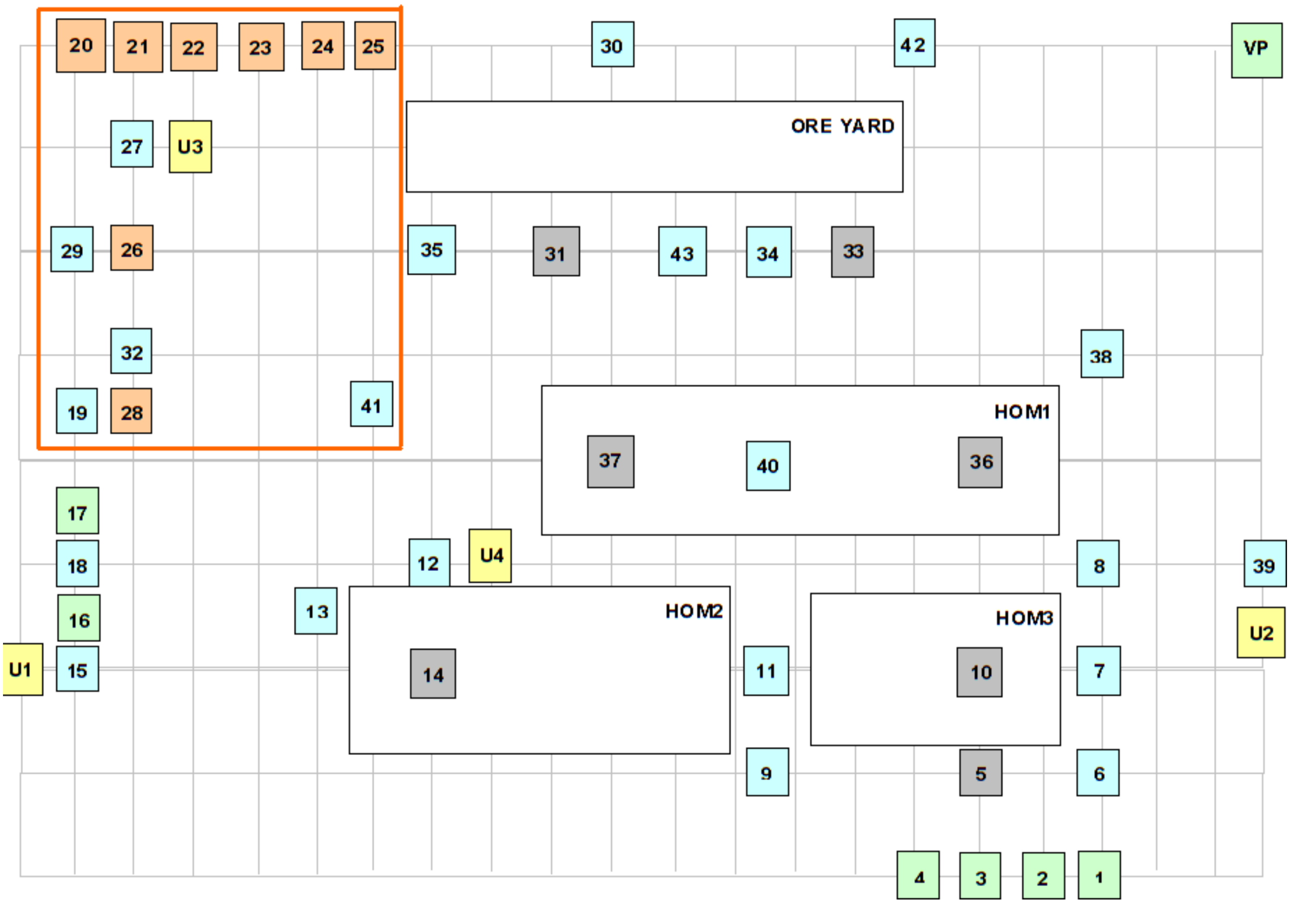
$$s = 6 \times e^{(-3{,}5\cdot|tg(\theta)+0{,}05|)} \quad [\text{km/h}] \quad (6)$$

where s is the walking speed of a healthy person on the well-tended path and θ is the inclination angle of this path (negative means descent, positive ascent).

The angle of inclination of the paths in the conditions of the sinter plant can be assumed to be zero while neglecting the movement between the floors in the buildings and halls. Also, the modification constant 3/5 of the Tobler function, which is used to move outside the well-tended path, has been neglected.

The speed of the maintenance worker in the conditions of the modelled of sinter plant was thus set at 5.036 km/h, after the conversion of 1.399 m/s.

Based on this data, logistic delay times were set between the planned maintenance centres and the individual machinery.



HOM1, HOM2, HOM3 is homogenization pile
VP is blast furnaces

Figure 6 Network of node model of the sinter plant

Table 12 List of node markings - equipment of sinter plant

Number	Symbol	Equipment	Number	Symbol	Equipment
1	V1	tipper	22	SP	sintering
2	RT	thawing tunnel	23	DR1	grinder
3	V2	tipper	24	TR1	sorting plant
4	V3	tipper	25	CH	cooling
5	J1	crane	26	ML	milling
6	P1	conveyor belt	27	P11	conveyor belt
7	P2	conveyor belt	28	DR2	crushing
8	P3	conveyor belt	29	P13	conveyor belt
9	P4	conveyor belt	30	P14	conveyor belt
10	N1	loader	31	J2	crane
11	P5	conveyor belt	32	P12	conveyor belt
12	P6	conveyor belt	33	J3	crane
13	P7	conveyor belt	34	P15	conveyor belt
14	Z1	collator	35	P16	conveyor belt
15	P8	conveyor belt	36	N2	loader
16	ZB	tray	37	Z2	collator
17	ZA	tray	38	P17	conveyor belt
18	P9	conveyor belt	39	P18	conveyor belt
19	P10	conveyor belt	40	P19	conveyor belt
20	TR2	sorting plant	41	P20	conveyor belt
21	MI	blender	42	P21	conveyor belt
			43	P22	conveyor belt

Subsequently, on the basis of the mean failure-free operation of the individual devices, the average frequency of maintenance interventions on individual installations is determined and the average hourly cost of maintenance personnel is determined.

Furthermore, it was necessary to determine the average number of personnel in the maintenance of the individual facilities for the purposes of optimizing the maintenance location within the sinter plant model.

From these values, the vector of total hourly cost of maintenance personnel was calculated according to relation (5).

Table 13 Cumulative costs due to logistic delays for individual planned maintenance centres

The maintenance centres	Cumulative costs due to logistic delays [CZK]
U1	207337
U2	249589
U3	176707
U4	137492

The final phase of the optimization is the determination of cumulative costs due to logistic delays on individual installations and subsequently to individual planned maintenance centres (Table 13) and cumulative costs were determined from these partial calculations due to logistic delays for individual planned maintenance centres.

The resulting optimal solution is the minimum sum of these cumulative costs. This implies that for to ensure maintenance of the sinter plant for the specified conditions and given the parameters, the optimal maintenance centre location is chosen U4 (Table 13).

The impact of CRAFT method on return on investment is to optimize the maintenance environment in a industry environment in that way to be minimized the amount of logistical delays in maintenance. This will reduce the time for preventive and corrective maintenance, which will be used for production. At the same time, production efficiency and productivity will increase. Other benefits of implementing of suggested method is an optimizing the number of maintenance workers associated with increasing their labour productivity. There is a reduction in wage costs while maintaining maintenance in the same resp. higher level.

5 Conclusions

The proposed method to optimize maintenance location within an industrial enterprise is one of the methods to support maintenance assurance management. This method is a modification of the CRAFT method. The CRAFT method is used to determine the optimal relative position of the various elements in the arrangement of the whole. The proposed modification consists in adapting the method to the conditions of maintenance management, ie. The individual input parameters of the method and steps are precisely defined in order to support the decision on the optimal location of the maintenance centre in the industrial enterprise so as to minimize logistic delays in preventive and corrective maintenance actions.

The proposed maintenance optimization method is implemented at the sinter plant. The agglomeration was chosen because it is an integral part of the metallurgical enterprise and consists of partial, diverse processes and facilities.

The results of the agglomeration plant model obtained and presented show that the proposed tools are suitable for supporting maintenance assurance management. They can be used, both in the maintenance assurance planning phase, whereby we can optimize the maintenance assurance process - both in terms of the appropriate maintenance location in the process, as well as the maintenance schedule and the number of maintenance personnel performing the intervention. In addition, they can be useful in the operational management phase, allowing us to quickly orient and support operational decision-making in managing maintenance of a technological process based on current status, while providing us with strong weaknesses in object reliability.

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