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ELECTROMOBILITY IN THE SLOVAK REPUBLIC: A GREEN APPROACH

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Keywords: electromobility, charging, charging infrastructure, network analysis
Abstract: Nowadays, influenced by technology and new technologies in the automotive industry is increasingly experiencing the production of electric or hybrid cars. With the development of the automotive industry, the number of electromobiles operated is increasing. Electricity in the world is steadily growing. Several countries in the world are evolving forward in electromobility, dealing with alternative drive policies and applying it to transport strategies. The Slovak Republic does not develop sufficiently in electromobility as it lags behind the surrounding countries. Electromobiles in operation do not eliminate CO and CO2, which means they are more environmentally friendly.

1 Introduction

The development of electromobility in the Slovak Republic began in 19th century. In this century, at the Royal Academy in Bratislava, Professor of Physics and priest Anián Jedlik worked [1]. This physicist, in the years 1827-1829, first invented the electric motor model and, of course, demonstrably participated in the development of cars powered by electric power. In 1842, Anián Jedlik dealt with the construction of accumulators and galvanic cells and used the electromobiles to drive the cart on the rails. With the development of a power-driven car, the MicroEko project started in 1994 in Slovakia. Thanks to this development, an electromobile was created, which won the Gold Medal in Brno at the engineering fair and fulfilled the conditions for production. Its production was never started and it was the end of the first Slovak electric car. After 2010, mass production electromobility in Slovakia begin to be introduced. Volkswagen Automobile company, just to Bratislava, placed the production of the first serially produced electrictromobile [1,2].

The Slovak Republic belongs to the list of countries with the highest production of cars. Regularly, the highest number of vehicles produced per capita is achieved.

In addition to direct producers, the automotive industry in Slovakia is formed by several subcontractors, involved in employment. The Slovak Republic must keep up with the evolving trends in the automotive industry in order to maintain its position. The application of electromobility has a positive impact on the quality of life and a significant reduction in emissions and noise emanating from transport. The Slovak energy system produces electricity with the lowest CO_2 emission factor, which means that the benefits of electromobility would reduce emissions today [3]. The Slovak Republic should turn the current undeveloped electromobility to make the country a regional leader. This situation is based on the automotive industry system, on economic and social demands and on economic growth. In 2012, an association called Slovak Electric Vehicle Association (SEVA) was established in Bratislava [3,4]. The main priority for this association is the promotion and representation of transport infrastructure and the development of transport for electric vehicles in Slovakia. Their goal is to create an appropriate communication and partnership with foreign partners, public authorities and businesses involved in the preparation of documents and plans for the development of electromobility.

2 Charging stations for electromobiles

Prosperous charging stations create special needs for the integration of charging connectors, plugs and their placement in electric cars. In countries, the voltage and current characteristics are individually determined to determine the type of charging stations associated with the charging time of an electric car [1].

The charger is built-in electromobile or external. This unit is connected to the battery system during charging and recharges the vehicle's battery. Recharging of electric cars is governed by IEC 61851: 2001, it is actually charging electric cars via conducting an electric car, cable, with a power grid [2].

There are three ways to place the connectors that are used to connect an electric car with the charging station, which include them [4]:

- the connector is located only on the side of the station, the cable is fixed with the electric car charging unit (Fig.1 - 1a),
- the connectors are located on both sides of the cable (Fig.1-1b),
- the connector is only becoming electromobile, the cable is fixed with the charging station (Fig.1- 1c) [3].

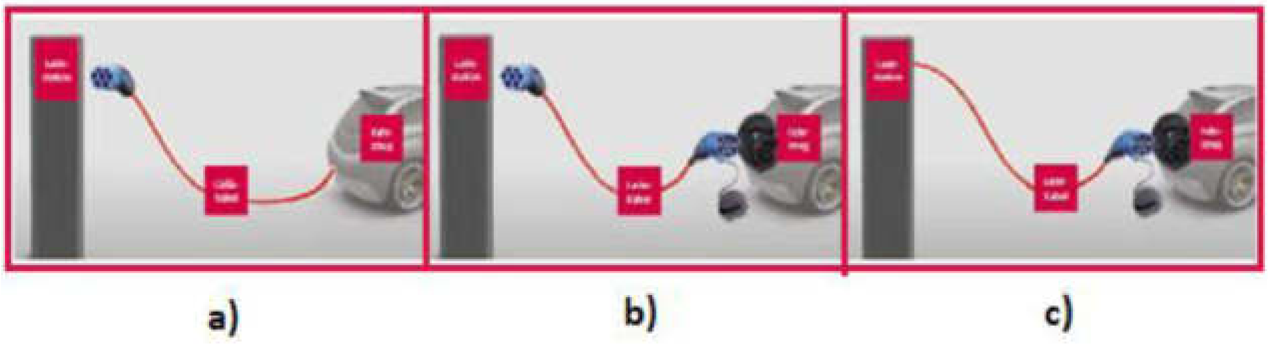

Figure 1 Connector location concept [1]

2.1 Sharing of charging stations according to the charging system

Accumulator batteries are usually charged with DC (Direct Current) but also AC (Alternating Current), which changes to DC while charging. Charging stations, according to the type and size of the current, are distinguished by [1,3]:

- AC Slow Charging:
  - ✓ It is a slow charging, alternating single phase (three-phase) current, 16 A (32 A),
  - ✓ it is usually used for home charging with a time of 5 to 8 hours,
  - ✓ the cost of operating such a charging station is relatively low.

- AC Fast Charging:
  - ✓ It is a fast charging, alternating current, with a value of 32 to 64 A,
  - ✓ is usually 2 to 4 times faster than slow charging.

- DC Slow Charging:
  - ✓ it is slow charging,
  - ✓ The charging power is 38 kW and 80 A DC.

- DC Fast Charging:
  - ✓ it is fast charging with a direct current,
  - ✓ The charging unit that is built into the station has a power output of 50 to 250 kW,
  - ✓ Electric car charging takes approximately 15 to 30 minutes,
  - ✓ Operating costs are higher than for DC charging stations [1].

AC chargers up to 22 kW are only connectors that transfer the current to the charger in the electric vehicle. In this case, the chargers are in the vehicle, i.e. on-board chargers. In the charger, this is located in the electric car, the alternating current changes to DC and is transferred to the rechargeable battery [1].

DC charging stations above 22 kW are chargers, from which the DC current is no longer transferred to the on-board charger but directly to the rechargeable battery. Mostly they have a power of 44 to 50 kW. These fast charging stations include the Supercharger Tesla super charger, the CHAdeMO fast charging station, and the news includes Combo Charging System Combo - CCS (Combined Charging System) [2].

3 Rechargeable infrastructure in the Slovak Republic

In the Slovak Republic, various pilot projects supported by the state are also being developed, which deal with the rechargeable infrastructure for electric vehicles. One of these projects is the VIBRATe project – BRATislava e-mobility Mobility. The main objective of this project is to build a charging infrastructure for charging stations between Bratislava and Vienna. Fast charging stations are built in the car parks in front of shopping malls, making this link to the highlights an ecological character. This project has so far not achieved much success, as it has been anticipated, since in 2014 only 119 electric vehicles were registered in the Slovak Republic [5].

For the development of electromobility, the following three parts are considered to be essential for achieving the objectives [6].

These basic pillars include:

- Public transport - Temporary financial and non-financial support from public institutions and governments is needed to reduce the risks of customers purchasing electric cars. Such support should take the form of financial subsidies or some tax exemptions. The automotive industry and the national government should strive to improve customer awareness, remove barriers to entry for new customers, adjust the area for reducing greenhouse gas emissions from transport, and set stricter CO_2 emission standards. These are all conditions for investment in electromobility in the Slovak Republic [2].

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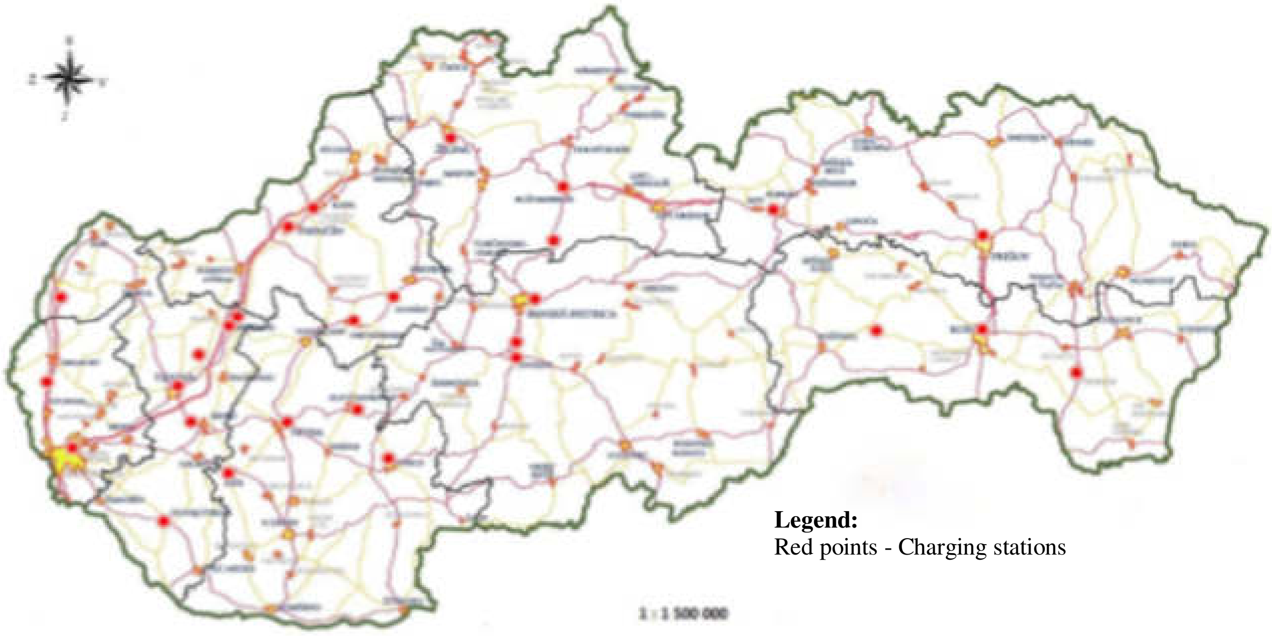

Figure 2 Charging stations in Slovak republic (high speed charging stations infrastructures including) [3]

In the Slovak Republic there are charging stations of various power and voltages. A network of fast charging stations, as well as slow-charge alternating current charging stations, is being created in the territory. These stations are 22 kW and a 32 A charging current. It cannot be built in any part of the country by the station and by high performance, but only in the places where the distribution network allows it. Fast charging stations need high power, for example, four charging stands from Tesla Motors require an input of approximately 265 kW. Because of this, Tesla Motors builds its own transformer stations, which they use to operate their charging stations. At higher power charging stations, an electric car is charging much faster than at a low-power station. Therefore, electric car owners use more power charging stations because they do not want to wait a few hours while charging at a slow charging station [1].

About 80 to 100 public and non-public charging stations are located in Slovakia. An average electric vehicle is 180 km, charging slowly in 11 to 13 hours, and charging at a fast charging station in about 15 to 20 minutes at 80% capacity. Fast charging stations are mostly located near highways, shopping centres and restaurants. Some stations, such as the fast charger in Partizánske, are only used to charge taxis. Public AC charging stations are less, because more chargers are used more quickly due to the charging rate. Slovakia is the second country in Europe through which the electric car can go across the territory. The following figure (Figure 3) shows the map of the Slovak Republic showing the locations where the public charging stations are located [3]. Charging station locations are color-coded according to their performance. Red points indicate fast charging stations with a power output of 44 to 50 kW. Blue points feature public AC charging stations with a power of 22 kW. The green dot with a colour ring indicates a charging station where you do not have to stay in order to charge, so it is a public charging station and the colour of the ring means what kind of charging it is. The black dot indicates the Supercharger Zvolen. It is the only Tesla Motors charging station in Slovakia. The light blue points on the map indicate charging stations with a power of 11 kW or less and are secured with a type 2 connector. Presented white points are for 16 A, 32 A sockets or home sockets.

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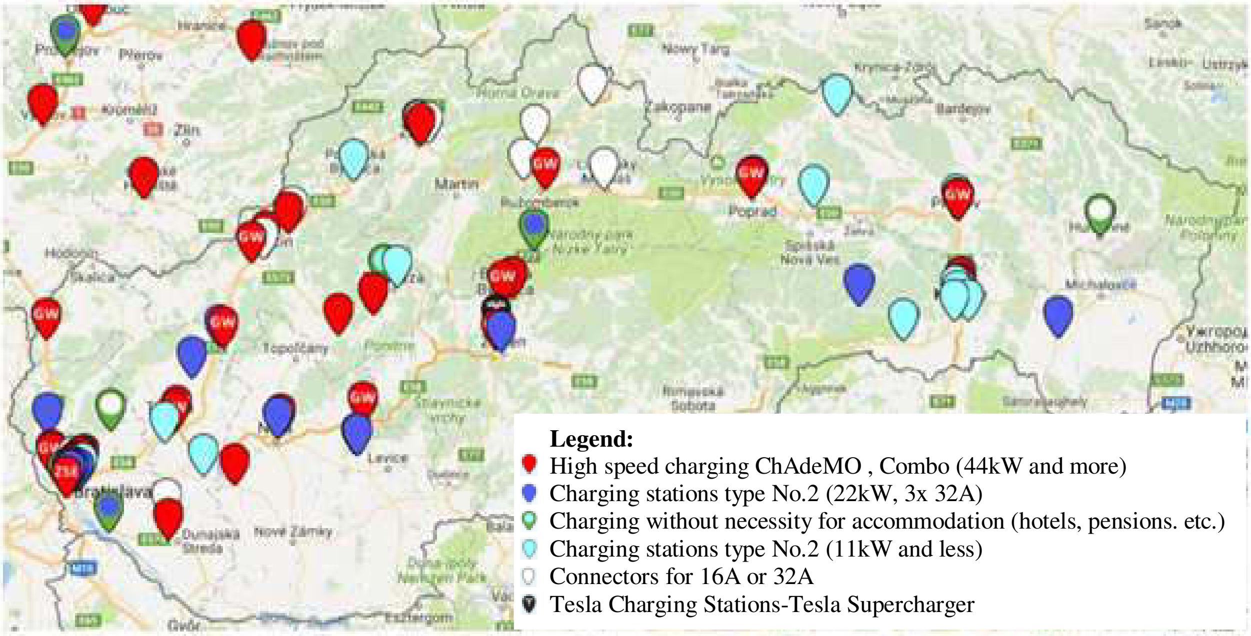

Figure 3 Charging stations situation in the Slovak republic [3]

There are different charging station operators in Slovakia, whether they provide public or non-public charging of electric vehicles. The network of fast charging stations is mainly provided by GreenWay. The list of major charging station operators is shown in the following table (Table 1). Operators are mainly divided according to the charging identification used to ensure charging performance and speed, as well as access. Table 1 describes overview of charging station operators in Slovak republic [6]. The Government of the Slovak Republic does not yet provide any benefits to the owners of electric vehicles. The Ministry of Economy of the Slovak Republic plans to implement a strategy to support electromobility. The main priority of this strategy is to promote the sale of vehicles, forgiveness of road tax and toll roads or to favour parking [2]. This support is intended to attract more low-emission, greener cars.

Table 1 Charging stations operators in Slovak republic [3]

Charging stations operators	**GreenWay**	**Východoslovenská energetika-RWE**	**Západoslovenská energetika**	**Slovenské elektrárne**	**Tesla Motors**
Parameter					
Capacity	44 kW	22kW	50 kW	44 kW	135 kW
Charging speed	more as 200 km/h	108 km/h	224 km/h	200 km/h	490 km/h
Connection	only for identified persons	all users	card	all users	only for Tesla
Identification	card	none	card	RFID	none
Price	fee including	for free	for free	for free	for free

4 Advantages of electric vehicles

The advantages of electric vehicles are:

- Compatible torque characteristics of the drive, due to the higher torque that acts from zero revolutions,
- The electric motor has a high performance in a wide range.
- Electricity production to drive an off-road electric car, use of renewable energy sources, the use of solar panels on the roof of the charging station to produce the energy needed to recharge the electric vehicle while reducing the dependence of the country on the import of the oil, [1,3].

- Do not pollute the environment, thanks to zero emissions.
- The efficiency of the combustion piston engine (n = 35%) is lower than the efficiency of an electric car (> 90%), the electric car does not shrink when power is used to drive a car [4].
- Virtually no maintenance costs (no emissions on MOT, no oil change required).
- An electromotor does not require as much space as a combustion engine in a classic car.
- A part of the electric car is a sound generator due to the low operating noise that mimics the sound of the classic engine and thus serves as a warning for pedestrians to have electric cars in their vicinity.
- The cost of production and the weight of a car are reduced due to the lack of a multi-stage gearbox and a clutch coupling [5,7].

5 Conclusions

The creation of recharging infrastructure, for electric vehicles, has a very positive impact on society, not only by changing the concept of car transport but also by bringing it together with nature.

The basic advantages of electric vehicles are:

- the low transport costs and the environmental benefits of using renewable energy sources,
- reducing noise, emissions and dust particles.

A prerequisite for a significant reduction in the price of electric cars is that such vehicles are produced in series. According to research of the development of electromobility in the Slovak republic it can be constant:

- Lack of development in the surrounding countries.
- Cost-oriented economy at the expense of quality.
- Inadequately developed research and development, inadequate foundation of the automotive industry.
- The lack of greening and new solutions, the undeveloped infrastructure for charging electric vehicles.
- The harmonization of standards.

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RAW MATERIALS INVENTORY MODEL APPLIED BY REGIONAL ENTERPRISES OF THE INDUSTRIAL CLUSTER

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Keywords: regional industrial cluster, raw materials inventory, inventory control, mathematical model
Abstract: For the effective functioning of the industrial enterprises and optimization of the production capacities it is necessary to predict the optimum inventory level of a production line on the basis of logistical approaches and studying the demand for products. Studies were conducted using the example of one industrial enterprise from the Udmurt Republic and there was proposed the inventory control model with the help of exponential smoothing and confidence interval.

1 Introduction

In the constantly changing business environment there is a need for implementation of logistical approaches for managing cluster formations. In Russia there is a great interest in clusters as the mechanism of regional development [1-3]. Today there is a growing need for logistic management approach implementation [4]. The formation of the regional industrial cluster in the Udmurt Republic makes it possible to consider federal and regional interests in addressing problems of military-industrial complex, filling idle capacities and preserving employment [5].

2 Technique of inventory control model development applied by the regional industrial cluster

Different resources are needed for the continuous production of innovative products: the metal of certain grade, hard alloy, labour power, electricity and other resources. This involves significant financial cost, because raw materials must be purchased and stored somewhere. Consequently, there is a need for the proper management of raw materials inventory control system, which will help to reduce production costs and release some working capital. There is data on the demand for the enterprise products in 2017-2018 (Table 1, Figure 1).

Table 1 Data on the demand for the products of the regional enterprise belonging to the industrial cluster in the Udmurt Republic

Date	01.2017	02.2017	03.2017	04.2017	05.2017	06.2017	07.2017	08.2017
Demand volume	260	300	290	310	270	250	290	280
Date	09.2017	10.2017	11.2017	12.2017	01.2018	02.2018	03.2018	04.2018
Demand volume	320	300	280	290	270	280	300	310
Date	05.2018	06.2018	07.2018	08.2018	09.2018	10.2018	11.2018	12.2018
Demand volume	280	300	270	260	290	310	300	290

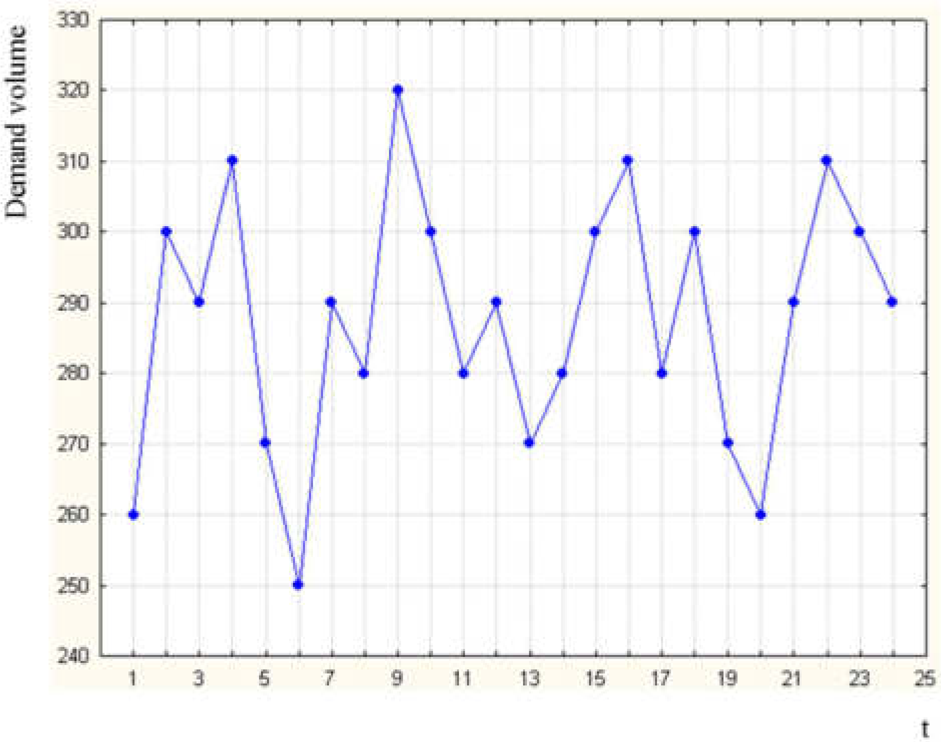

Figure 1 The demand chart for the products of the regional enterprise belonging to the industrial cluster in the Udmurt Republic

Before developing the control system for raw materials inventory, it is necessary to choose one of the factors determining the volume of raw material stocks, which will be used in the analysis. The main indicator that determines the volume of raw material stocks is the volume of the demand for manufactured products. In our case, the demand can be considered to be a random value.

It should also be noted that not the current level of demand, but its predicted value plays an important role in deciding volume of raw materials stocks. Therefore, it is necessary to predict the volume of the demand for products at least for one period of time ahead, based on the available data on the demand volume for several previous periods.

One of the most popular methods for time series analysis is exponential smoothing (in our case, demand values are linked to the periods of time, which means they can be considered as the time series).

A simple time series model is designed according to the following formula (1):

$$x_t = b + \varepsilon_t \tag{1}$$

Where b - constant and ε_t - accidental error.

The b constant is relatively stable at every period of time, but may also change slowly over time. One of the clear ways to distinguish b is to use moving average smoothing, in which weights applied to each of the past observations decrease exponentially.

Simple Exponential Smoothing is designed in such a way that weighting factors decrease exponentially, but unlike moving average all past observations are considered.

The formula of Simple Exponential Smoothing is as follows (2):

$$S_t = aX_t + (1-a)S_{t-1} \tag{2}$$

When this formula is calculated recursively, then each new smoothed value (which is also a prediction) is calculated as a weighted average of the current and smoothed time series. It is clear that the result of the smoothing depends on the parameter (alpha). If α = 1, then the past observations are completely ignored. If α = 0, then the current observations are ignored. Values ofαbetween 0 and 1 can show intermediate results. Empirical studies have shown that very often simple exponential smoothing can give a fairly accurate prediction [6].

We will use the software product «Statistica 6» developed by StatSoft Inc. to forecast values of the demand.

We will use values of the demand level in 2017 as the baseline data. Firstly, we will predict the demand value in January 2018. After that, we will have not 12, but 13 values, and we will predict the 14th and so on by the 24th (December 2018). In the future, these data will help us in drawing up a plan for the raw materials purchase. Initial data are shown in Figure 2.

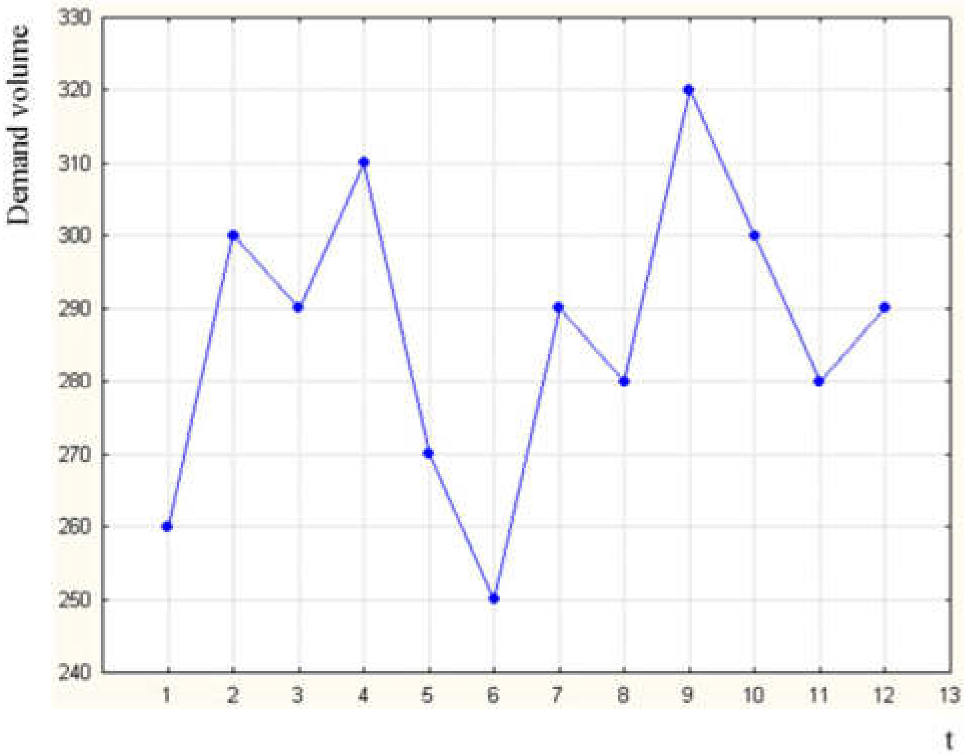

Figure 2 The demand volume for the products of the regional enterprise belonging to the industrial cluster in the Udmurt Republic

The chart shows that the time series doesn't have upward trend or down trend, or seasonality, therefore for our prediction we will use exponential smoothing without consideration of trend or seasonality factors.

There are following results made by the program after data entry and doing calculations (Figures 3 and Table 2).

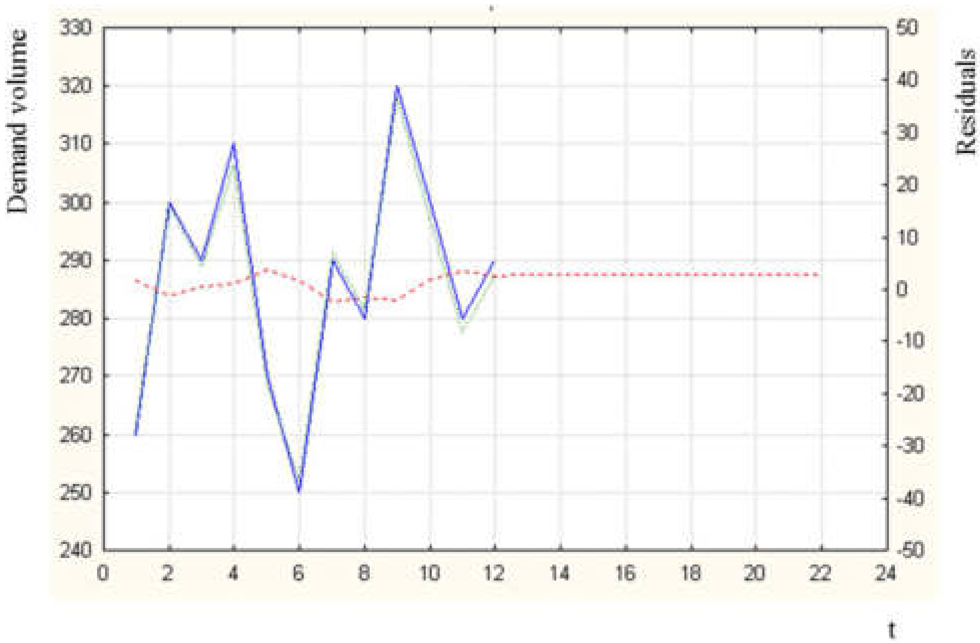

Figure 3 Exponential smoothing of the dynamic demand relations from a time series

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Table 2 Values of the smoothed and residuals series

Observations	Y	Smoothed series	Residuals series
1	260	286,6667	-26,6667
2	300	284,0000	16,0000
3	290	285,6000	4,4000
4	310	286,0400	23,9600
5	270	288,4360	-18,4360
6	250	286,5924	-36,5924
7	290	282,9332	7,0668
8	280	283,6398	-3,6398
9	320	283,2759	36,7241
10	300	286,9483	13,0517
11	280	288,2543	-8,2543
12	290	287,4281	2,5719
		287,6853	

According to the results, a number of past observations is more significant for the prediction than the current value of the indicator (α = 0.1). And the most important thing in these results is the predicted value of the demand equal to 287.6853.

In this case, it is about the number of ordered items, and it cannot be a fractional value, therefore, the number 287.6853 needs to be rounded to the whole, thus, the predicted demand value is 288 units. However, this number cannot satisfy us either, since there's a 50% chance that the demand value will exceed 287.6853 and the same chance that it will not.

To fill this knowledge gap we have to produce a confidence interval for the prediction. We will use the 95% confidence interval. This means that there is a 95% probability that the demand value in a future period lies within the interval.

According to the residuals chart data (Figure 4), it can be concluded that the residuals are normally distributed, which allows us to apply «Student's t-Distribution Table» for confidence limit calculating.

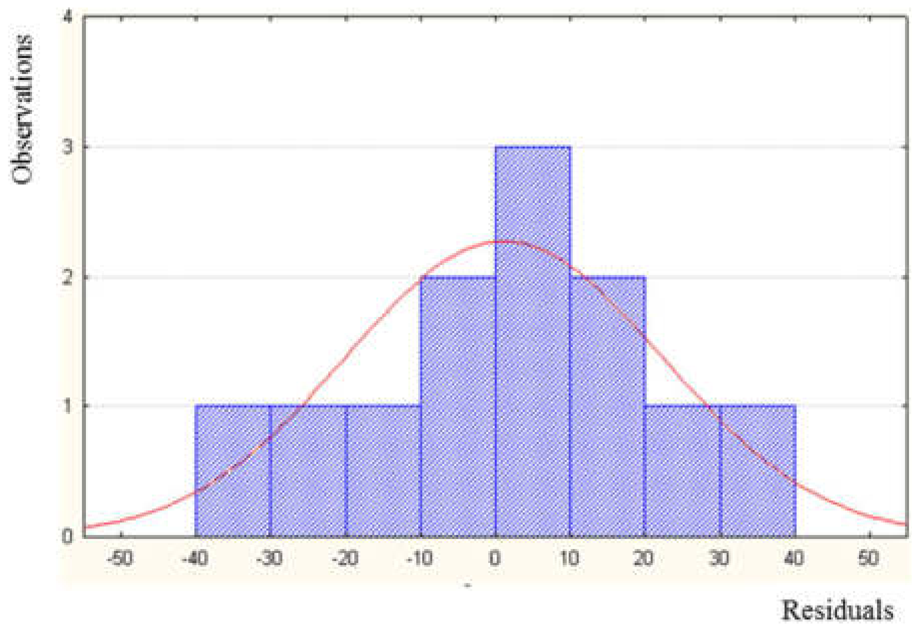

Figure 4 The residuals chart data

The confidence interval for the prediction is calculated as follows (3):

$$S_{t+1} = S_t \pm t_{\beta,p} S \sqrt{1 + \frac{\alpha}{2-\alpha}} \tag{3}$$

where:
S_{i+1} - predicted value,
S_i - latest calculated value,
$t_{\beta,p}$ - value from the Student's table at significance level β and p degrees of freedom,
$p = n - 1$, n–number of observations,
S – standard deviation (4),
α – smoothing constant.

$$S = \sqrt{\frac{\sum_{t=1}^{n}(X_t - S_t)}{n-1}} \tag{4}$$

where:
X_t - observing value.

Calculation data for 12 observations are as follows:

$S_t = 287$;
$t = 12$;
$\beta = 0{,}05$;
$p = 11$;
$t_{\beta,p} = 2{,}201$;
$S = 21{,}1$.

The confidence interval for the prediction:

$$S_{13} = 287 \pm 2{,}201 \cdot 21{,}1 \cdot \sqrt{1 + \frac{0{,}05}{2 - 0{,}05}} = 287 \pm 46{,}9$$

But since the quantity of products must be a whole number:

$$S_{13} = 287 \pm 47$$

For studying application, the model, we will use the data on demand for products in 2017-2018. Provided that 1 billet is needed for every product manufacturing, we can use data of the Table 1 as the level of raw materials costs needed for every product manufacturing in 2017-2018.

Let us calculate the level of raw materials which are required for other months in 2018. The results are shown in Table 3.

Table 3 Calculated level of required raw materials

Date	01.2018	02.2018	03.2018	04.2018	05.2018	06.2018
Raw materials, pcs.	305	304	303	304	306	305
Date	07.2018	08.2018	09.2018	10.2018	11.2018	12.2018
Raw materials, pcs.	306	305	304	304	305	305

Now, when we have the data on the required volume of raw materials stocks, as well as actual data on the volume of raw materials in the enterprise (Table 4), we can assess the effectiveness of the models under consideration.

Table 4 The level of raw materials stocks at the beginning of the month (actual data)

Date	01.2018	02.2018	03.2018	04.2018	05.2018	06.2018
Amount of stock	740	850	1090	790	480	950
Date	07.2018	08.2018	09.2018	10.2018	11.2018	12.2018
Amount of stock	870	780	720	990	980	900

Table 5 shows actual data on the raw materials stocks replenishment at the enterprise in 2018.

On the whole, in 2018 the company purchased 3,330 units of raw materials.

Let us consider how would the structure of the replenishment of raw materials stocks look like, if the enterprise applied cost prediction model on the basis of exponential smoothing (Table 6).

If the enterprise applied this model, then in 2018 they would have purchased 2758 units of raw materials, and the demand would be satisfied. And finally, Table 7 shows the data on the structure of the raw materials stocks replenishment when using Brown's Exponential Smoothing model.

Negative values in the “Residuals” column indicate the level of unmet need for raw materials.

If the enterprise used this model, then 2723 units of raw materials would have been purchased in 2018, while in April and October the company would not have been able to meet the demand due to the fact that the predicted level of the demand for the products (raw materials costs) happened to be less than the actual.

Table 5 The structure of the raw materials stocks replenishment

Date	Inventory at the beginning of the month	Purchase	Actual expenses	Residuals
01.2018	740	380	270	850
02.2018	850	520	280	1090
03.2018	1090	0	300	790
04.2018	790	0	310	480
05.2018	480	750	280	950
06.2018	950	220	300	870
07.2018	870	180	270	780
08.2018	780	200	260	720
09.2018	720	560	290	990
10.2018	990	300	310	980
11.2018	980	220	300	900
12.2018	900	0	290	690

Table 6 The results of applying cost prediction model on the basis of exponential smoothing

Date	Inventory at the beginning of the month	Cost prediction	Purchase	Actual expenses	Residuals
01.2018	740	334	0	270	470
02.2018	470	333	0	280	190
03.2018	190	329	139	300	29
04.2018	29	328	299	310	18
05.2018	18	330	312	280	50
06.2018	50	331	281	300	31
07.2018	31	329	298	270	59
08.2018	59	330	271	260	70
09.2018	70	330	260	290	40
10.2018	40	326	286	310	16
11.2018	16	326	310	300	26
12.2018	26	328	302	290	38

Table 7 The data on the structure of the raw materials stocks replenishment when using Brown's Exponential Smoothing model

Date	Inventory at the beginning of the month	Cost prediction	Purchase	Actual expenses	Residuals
01.2018	740	305	0	270	470
02.2018	470	304	0	280	190
03.2018	190	303	113	300	3
04.2018	3	304	301	310	-6
05.2018	0	306	306	280	26
06.2018	26	305	279	300	5
07.2018	5	306	301	270	36
08.2018	36	305	269	260	45
09.2018	45	304	259	290	14
10.2018	14	304	290	310	-6
11.2018	0	305	305	300	5
12.2018	5	305	300	290	15

3 Conclusion

According to the results of calculations, the model developed on the basis of logistic approaches leads to cost reduction, prevents the possibility of unmet demand, which in the future can lead to a decrease in the number of customers, and that will reduce the profit of the regional industrial cluster in the Udmurt Republic.

Therefore, when developing the inventory control structure in the production of innovative products by enterprises of the regional industrial cluster in the Udmurt Republic, we should use the model which is based on predictions with the applying of exponential smoothing and confidence intervals.

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USE OF GENETIC ALGORITHM IN LAYOUT DESIGN

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Keywords: layout design, genetic algorithm, material flow, metaheuristics

Abstract: Within the design of production layout, the planners are often confronted with complex, sometimes conflicting demands and a number of restrictive conditions, which encourages their efforts to develop new, progressive approaches to the development of production layouts. The purpose of the innovative approaches in this field is to provide users with better, elaborated designs in less time, while they are able to implement various restrictive conditions and company priorities to the design. One of the ways is a use of metaheuristic algorithms by space solution optimisations of manufacturing and logistics systems. These methods have higher quality results compared to classical heuristic methods. Genetic algorithms belong to this group. Main goal of this article is to describe the Genetic Algorithm Layout Planner (GALP) that was developed by authors, and its experimental verification and comparison with results of the classical heuristic.

1 Introduction to layout design

Process of layout design requires data from construction and technological preparation of production. Data for the manufacturing and logistics systems design can be divided into two basic groups [1]:

- Numerical data - information about products, production processes and resources [2].
- Graphical data – represent visual display of individual elements of the manufacturing and logistics system which are used mainly in layout design, modelling and simulation of the resultant system.

When we know the need of individual resources of the designed system, material flows and other connections among individual elements, we can begin to design an ideal spatial arrangement of the manufacturing or logistics system.

Proposing an ideal arrangement is advantageous to use optimisation methods and algorithms, which can be classified as follows [3]:

- Graphical methods (Sankey chart, spaghetti diagram, relationship diagram, etc.);
- Analytical methods (linear and non-linear programming, transport problem, methods of dynamic programming, etc.);
- Heuristic methods that includes construction procedures (CORELAP, ALDEP, PLANET, MAT, MIP, INLAYT, FLAT, etc.), change procedures (CRAFT, MCRAFT, MULTIPLE, H63, FRAD, COFAD, etc.) and combined procedures (BLOCPLAN, LOGIC, etc.);
- Metaheuristic methods (genetic algorithms, simulated annealing, Tabu search, Ant Colony optimisation, etc.).

2 Genetic algorithms

Genetic algorithm (GA) belongs to one of the basic stochastic optimisation algorithms with distinctive evolutionary features. Nowadays, it is the most used evolutionary optimisation algorithm with a wide range of theoretical and practical applications [4,5].

General procedure of genetic algorithm:

1. Initialisation – creation of initial (zero) population, that usually consist of randomly generated individuals.
2. Start of a cycle - thanks to a certain selection method, a few individuals with a high fitness function are selected from a zero population.
3. New individuals are generated from selected individuals via the use of basic methods (crossover, mutation and reproduction), new generation is created.

4. Competence calculation of new individuals (fitness function calculation).
5. End of a cycle - decision-making unit:
    - as long as the finishing criterion is not completed, move on to the point no. 2,
    - if the finishing criterion is finished, algorithm is completed.
6. End of algorithm - individual with the highest competence represents the main algorithm output and the best possible solution found.

Selecting the appropriate presentation of a problem is the most important application part of genetic algorithm. In a case of genetic algorithm, space of real problem is transformed to space of strings. These could be for example bit-strings, which were one of the first used representations. Real-valued vector representation is most commonly used for practical issues. In case of direct spaces, integer vector could be selected.

Constant population size is regulated in two ways. It is a so-called generation model that replaces the whole population by offspring (via mutation or recombination). Second option is to keep one part of the previous generation. This is done by elite selection or in other words by individuals with the highest fitness function. By selecting this way, it is guaranteed that the competence of the best individual will continue to improve [6].

3 Integration of genetic algorithm into design process of manufacturing systems

Design approach of manufacturing disposition with use of genetic algorithms, proposed by authors from this article, requires realisation of the following basic phases [7,8]:

1. Preparation phase for the disposition arrangement proposal - preparation of numerical data for analysis and layout optimisation, graphical data for 2D and 3D model creation of manufacturing system.
2. Application phase of genetic algorithm - algorithm core - optimised block layout is its output. The core works in the following steps:
    - requirement specification and input value assigning for GA,
    - optimisation of space arrangement with GA use,
    - GA procedure conclusion.
3. Processing phase of designed disposition arrangement in CAD system - transformation of proposed block layout into detailed 3D model of manufacturing system.
4. Phase of proposed solution's static verification - verification of a proposed solution based on calculation and analysis of material flows.
5. Phase of proposed solution's dynamic verification - verification of a proposed solution with use of software simulation.

The next chapter of this article contains detailed description of phase 2, based on basic structure of used genetic algorithm and verification of algorithm functionality and comparison of achieved results with classical heuristics application.

4 Layout optimisation using genetic algorithm

Proposed genetic algorithm for layout optimisation consists of the following steps
(Figure 1):

- requirement specification and input value assigning for GA,
- core of GA - optimisation of space arrangement,
- GA procedure completion (finishing requirements).

4.1 Solution requirement specification and input value assigning

In first part of the solution it is necessary to define basic requirements for proposed manufacturing disposition. These requirements come from a previous phase of process and analysis of input data. For optimisation purposes and GA use it is necessary to set following parameters [9]:

- number of placed workplaces, machines and devices,
- mutual relations and intensity among workplaces,
- A,E,I,O,U,X coefficients for relation evaluation,
- ration of fitness function intensity and mutual relations,
- specification of entry-exit places of manufacturing system,
- specification of machines and devices,
- specification of hall dimensions and potential construction restrictions (walls, columns, corridors).

It is also necessary to set parameters of genetic algorithm as [10]:

- maximum number of generations (iterations),
- number of individuals (solutions) in generation,
- selection types, crossover and mutation of their probability,
- required value of fitness function (optional information),
- maximum solution time (optional information),
- maximum number of generations without solution improvement.

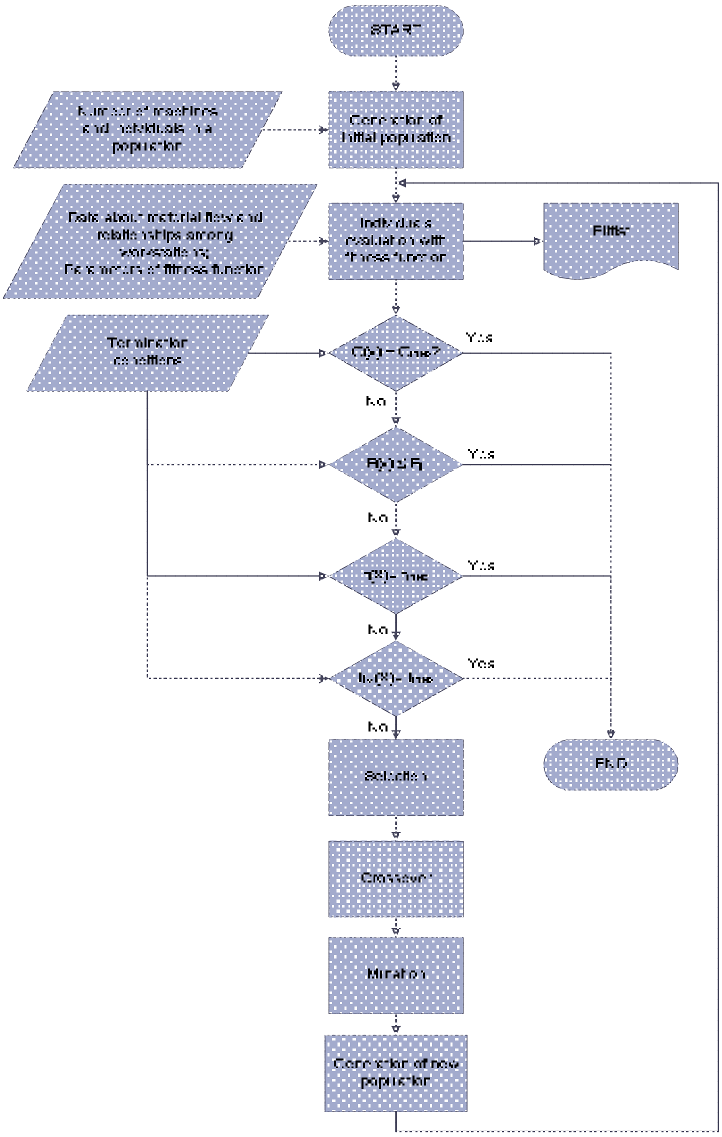

Figure 1 Own genetic algorithm for layout optimisation

4.2 *Optimisation of space arrangement using genetic algorithm*

After specification of all input data, own optimisation of space arrangement follows with the help of genetic algorithm. Basic parts of GA core will be explained in the following text.

1. Generation of initial population:

First step is to create a population that represents a group of solutions which will be further developed. In this solution, an individual is created by genes in the quantity that is equivalent to value of placed machines. These can have a value of 1 up to n, where n is equal to number of deployed machines. Sequence of individual genes corresponds with sequence where machines will be placed in the proposal. Next, there is one gene in each individual reserved for a pattern definition by which workplaces will be included in the proposal. Total matrix dimension corresponding to population in one generation, therefore [9]:

NUMBER OF INDIVIDUALS IN GENERATION × (NUMBER OF PLACED MACHINES + 1).

2. Individual evaluation of fitness function:

After having created a population, it is necessary to evaluate a fitness function. Resulting fitness function was designed as a sum of 2 components with verified weight. Verification was done according to the intensity of material flow and distance (fID) and according to relations and distance (fV).

Evaluation according to the intensity and distance (1) [10]:

$$f_{ID} = \sum_{i,j=1}^{i,j=n} D_{ij} \times I_{ij} \tag{1}$$

Evaluation according to relations and distance (2) [10]:

$$f_V = \sum_{i,j=1}^{i,j=n} V_{ij} \times D_{ij} \quad \text{for } V_{ij} \geq 0 \ OR$$

$$f_V = \sum_{i,j=1}^{i,j=n} \frac{V_{ij}^2}{D_{ij}} \quad \text{for } V_{ij} < 0 \tag{2}$$

where:
n – number of placed machines,
D – right angle distance between workplaces i-j (D_ij=|x_i-x_j |+|y_i-y_j |),
I – intensity between workplaces i and j,
V – evaluation coefficient of a relation between workplaces i and j.

Final fitness function value (3) is set as:

$$\min: \ f = \alpha \times f_{ID} + (1 - \alpha) \times f_V \tag{3}$$

where:
α - ratio coefficient of partial fitness functions (α ∈⟨0;1⟩).

Various restrictions are checked in layout construction and algorithm itself (overlapping objects, length, width and height of a production hall, transport street arrangement, position of fixed objects in a production hall, etc.).

After evaluating all individuals by a fitness function, the best solution is identified and saved in given generation - elite individual with his or her reached value and average value of fitness population. This data could be displayed during algorithm operation after each generation, in order to track solution progress. After completion, it is also possible to display a progress graph of average and elite fitness value.

3. Decision-making blocks:
In this step, it is necessary to compare specific conditions for algorithm termination in 4 decision-making blocks. Current solution state:

- To reach maximum number of generation (iteration) Gmax,
- To reach or exceed the highest permissible fitness value fp,
- To reach maximum solution time tmax,
- To exceed set iteration number (Imax) without improving of reached solution.

When meeting any out of four stated conditions, genetic algorithm is completed.

4. Selection:
In case none of the finishing criterion was fulfilled, the algorithm continues by selection, in other words by selecting individuals who will crossbreed and eventually mutate between each other. For such solution, roulette rule has been selected. Probability selection was proportional to an individual's achieved suitability. This form was chosen based on better possibility to search complex set of solutions when later combining parents and their evaluation as well as their calculation speed [11]. To prevent early convergence, suitability of individuals was integrated into algorithm via the help of sigma scaling.

After selecting, pairing follows, where Parent 1 and Parent 2 will be randomly selected from chosen individuals. These should make Offspring 1 and 2.

5. Crossover:
In order to prevent duplicate of identical machines in crossover or omission of same machines from genetic chain, mechanism of partially matched crossover was designed. This type of crossover has within its procedure implemented measures. These guarantee that each coded solution will have its machine only once [12].

6. Mutation:
After the crossover, mutation follows. However, in this type of solution encoding, traditional mutation or in other words value change of a random gene is out of the question. This would automatically require remedial measures to eliminate duplication or not classified machines. That is why mutation via the help of inversion or exchange was selected. Due to inversion rather big intervention into solution, probability was divided for exchange or inversion in 80:20 ratio [13].

7. Making of a new generation:
Following the genetic operator activity, parents are replaced by offspring. In case elitism is used in suitability evaluation and the best possible solution has been saved, this individual replaces one of the offspring with the worst suitability.

After this step, algorithm goes back to evaluating new individuals through the help of fitness function. Furthermore, algorithm keeps repeating in cycles until one of the finishing conditions is fulfilled [14].

8. Genetic algorithm finishing:
In decision-making blocks, each genetic algorithm cycle checks whether one of the finishing conditions has not been fulfilled:

- achieving the maximum number of generations (iterations),
- achieving or exceeding the highest permissible fitness value,
- achieving the maximum solution time,
- exceeding the set number of iterations without improvement.

If some of the finishing conditions were fulfilled, activity of genetic algorithm will finish. After completion of its activities there are generated outputs in user interface:

- block layout,
- achieved fitness value and information in which iteration was achieved,
- graph showing progress of average and elite fitness population values.

In the final phase, user will decide whether the solution proposed by genetic algorithm fulfilled all its requirements. If not, it is necessary to closely specify requirements and repeat generation of optimal layout. If requirements were fulfilled, methodology continues by result processing in CAD system.

5 Experimental verification of genetic algorithm and result comparison with use of classical heuristic

In order to check the functionality of the proposed GALP algorithm (Genetic Algorithm Layout Planner) series of experiments were carried out. These results were then compared with optimisation results with the help of heuristic according to Murat (sequence-pair approach). Heuristic according to Murat has been selected because it is believed the heuristic approach is implemented in Factory PLAN/OPT module, which is a part of software Siemens Tecnomatix. Final PLAN/OPT and GALP algorithm proposals were subsequently compared in FactoryFLOW software. A common characteristic for both algorithms is the block layout output. Both algorithms require finishing requirement and total time of algorithm functioning. For more complex result comparison, experiments were carried out for 1, 5, 10 and 20 minutes. Own experiments were carried out for 2 types of inputs:

- Case 1 - simple manufacturing system: 3 manufacturing families, 24 workplaces,
- Case 2 – complex manufacturing system: 9 manufacturing families, 60 workplaces.

Case 1 results are shown in the table 1. These experiment results indicate that GALP achieved better results in all cases than PLAN/OPT algorithm, which due to unknown reasons did not even keep workplace dimensions in some cases. GALP has also proposed solutions preferring singular direction of material flow with minimum crossing or backward material flow. Due to comparing both algorithms, no restrictions have been imposed on workplace arrangement. However, GALP algorithm enables basic restriction definition in the layout (production hall dimensions, height of spaces, material component arrangement, fixed installations or transport corridors in the layout).

Table 1 Experiment Result Comparison for Case 1

	Time calculation	GALP			PLAN/OPT		
		Distance (m)	Costs (EUR)	Time (min)	Distance (m)	Costs (EUR)	Time (min)
Achieved results	1 min	571 360.33	25 434.76	69 708.00	669 925.47	25 746.26	70 146.72
	5 min	510 552.24	25 023.22	67 682.66	633 664.26	25 668.70	70 281.26
	10 min	441 472.39	24 825.88	67 536.68	548 718.83	25 284.36	68 976.65
	20 min	430 341.00	24 755.86	67 214.88	529 770.15	25 214.38	68 811.54
Comparison GA – PLAN/OPT	Time calculation	Distance (m)	Costs (EUR)	Time (min)	Distance (%)	Costs (%)	Time (%)
	1 min	-98 565.44	-31.50	-438.72	-14.71	-1.21	-0.63
	5 min	-123 112.02	-645.48	-2 598.60	-19.43	-2.51	-3.70
	10 min	-107 246.44	-458.48	-1 439.97	-19.54	-1.81	-2.09
	20 min	-99 429.15	-458.52	-1 596.66	-18.77	-1.82	-2.32

Table 2 Experiment Result Comparison for Case 2

Parameter	GALP	PLAN/OPT	Difference	Difference (%)
Distance covered (m)	2 877 483.27	4 654 622.41	-1 777 139.14	-38.18
Costs (EUR)	83 939.38	91 344.13	-7 404.75	-8.11
Time (min)	230 818.14	253 032.38	-22 214.24	-8.78

Experiment results were consequently verified also taking into account complex solution of manufacturing system (Case 2) and solution time was set to 5.5 hour (solution time 1000 task generations in GALP). Advantages of genetic algorithm became evident in a more extensive problem. Final material flow is directed with minimum crossing. However, in case of PLAN/OPT algorithm, there is a crossing, where material flow keeps coming back and there is not any technology island creation in manufacturing system. Genetic algorithm proposed layout with greatly lower value of transportation performance (38.18%) than heuristic algorithm in a PLAN/OPT module. Experiment result comparison is stated in table 2.

6 Conclusions

The main aim of this article is to describe the use of genetic algorithm in manufacturing layout optimisation. The article describes the basic algorithm structure and its experimental verification. It also compares algorithm outputs of traditional heuristic application. Experiment results show the proposed GA provide saving of transport performance in case of less complex problems, which is 15-20% compared to classical heuristic results. When problem complexity increases, saving from the GA use continues to increase (Case 2 - saving more than 38%). Also, disposal arrangement generated by GA leads to a solution with easier and directed material flow. Proposed genetic algorithm is a part of complex project methodology of manufacturing dispositions and its basic steps are described in chapter 3. Furthermore, this proposed GA enables the user to consider practical restrictions when arranging space in layout optimisation, that is a shape and production hall dimensions (length, width and height) building block placement (e.g. columns), fixed installations, transport corridors, input and output spaces of manufacturing system, etc. Therefore, this means that layout that has been designed by a genetic algorithm requiring the minimum number of corrections that do not represent significant deviations from optimal parameters of material flows.

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TRANSPORTATION OF EURO PALLETS SOLVED AS A SPLIT DELIVERY VEHICLE ROUTING PROBLEM

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Keywords: split delivery vehicle routing problem, Euro pallet, vehicle routing problem, heuristics, CPLEX

Abstract: The article is aimed at the logistic problem of the company transporting Euro pallets to its customers. The main focus is on finding more effective routes for pallets distribution in terms of the total distance. The real instance can be solved as the vehicle routing problem. In many cases, splitting of the customer demand into several routes, can significantly improve the solution. The real problem consists in the pallets distribution from the depot to twelve customers. For solution, model in MPL for Windows is formulated and solved in CPLEX. Because of NP-hardness of the problem, it is necessary to propose heuristic algorithms for getting the effective feasible solution instead of unreachable optimum solution.

1 Introduction

In the Vehicle Routing Problem (VRP), capacitated vehicles must serve a set of customers with their demand quantities. In [1], mathematical models and methods are presented for many variations of VRP. Baldacci et al. [2] offer a survey of problems under vehicle and time window constraints. Because of NP-hardness of VRP, heuristic algorithms must be used for real instances [3]. In the Split Delivery Vehicle Routing Problem (SDVRP), customer demand can be splitted into several routes. The problem and corresponding savings were introduced in [4] and [5]. Applications and computational results can be found in [6]. Advanced heuristic algorithm is proposed in [7].

In the article, SDVRP with the identical capacitated vehicles, placed at one depot, is studied. The aim is to suggest the solution for the instance with twelve customers. The solution is compared with the existing strategy of the company and with the solution obtained from the optimization model of VRP.

Figure 1 shows the advantage of the formulation of the problem as SDVRP instead of VRP. In the example, the depot is located in node 1, customers are located in nodes 2, 3 and 4. In boxes, their demands are specified, the vehicle capacity is 10 units. Cost values are assigned to all arcs. While VRP offers 3 routes with the total cost of 60, SDVRP offers 2 routes with total cost of 45.

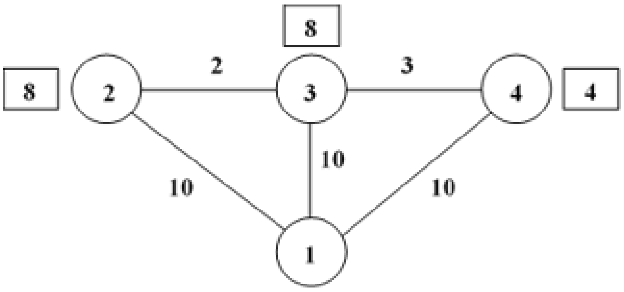

Figure 1 VRP vs. SDVRP

2 Vehicle Routing Problem

In the standard formulation of VRP, a number of vehicles located at one depot is supposed to be generally unlimited. They have the identical transportation capacity V. Let n be a number of locations in the distribution network, depot is placed at location 1. Demand of customer i is denoted by $q_i < V \ (i = 2,3,...,n)$. For each pair of locations, their distance is given as $c_{ij} \ (i, j = 1,2,...,n)$. Binary variable x_{ij} is equal to 1, if a vehicle visits location j after visiting location i, 0 otherwise. Mathematical model of VRP originates from [1]:

$$z = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij} \rightarrow \min, \tag{1}$$

$$\sum_{j=1}^{n} x_{ij} = 1, \quad i = 2,3,...,n, \tag{2}$$

$$\sum_{i=1}^{n} x_{ij} = 1, \quad j = 2,3,...,n, \tag{3}$$

$$u_i + q_j - V(1 - x_{ij}) \le u_j, \quad i = 1,2,...,n, \quad j = 2,3,...,n, \quad i \ne j, \tag{4}$$

$$u_i \le V, \quad i = 2,3,...,n, \tag{5}$$

$$u_1 = 0, \tag{6}$$

$$x_{ij} \in \{0,1\}, \quad i, j = 1,2,...,n, \tag{7}$$

$$u_i \in R_0^+, \quad i = 1,2,...,n. \tag{8}$$

The objective function (1) aims at minimizing total distance. Respecting constraints (2) and (3), each customer is visited exactly ones. Inequalities (4), containing variables u_i, are load balance constraints. Each route must respect vehicle capacity (5). At the depot, vehicle load is set to 0 according to (6). Although model (1) – (8) is proposed to pick up problem, it can be used for delivery problems. However, we must be careful about the interpretation of obtained results, especially values of load variables.

3 Split Delivery Vehicle Routing Problem

If there is at least one demand exceeding the vehicle capacity, it is necessary to solve the problem as the SDVRP. Because of the computational complexity of the problem, in real instances it is often necessary to use heuristic algorithms. First, the exact approach is offered.

3.1 Mathematical model

In the model of SDVRP, third index k must be introduced for the identification of the vehicle which serves the customer. Variable x_{ij}^k is equal to 1, if the vehicle k goes from location i to location j, 0 otherwise. Variable Q_i^k is associated with the part of demand of customer i delivered by vehicle k. Let us suppose K vehicles located at the depot. Then, the mathematical model of SDVRP, based on [7], can be formulated as follows:

$$z = \sum_{k=1}^{K} \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}^k \rightarrow \min, \tag{9}$$

$$\sum_{j=2}^{n} x_{1j}^k \leq 1, \quad k = 1, 2, \ldots, K, \tag{10}$$

$$\sum_{i=1}^{n} x_{ij}^k = \sum_{i=1}^{n} x_{ji}^k, \quad j = 2, 3, \ldots, n, \quad k = 1, 2, \ldots, K, \tag{11}$$

$$u_i^k + Q_j^k - V(1 - x_{ij}^k) \leq u_j^k, \quad i = 1, 2, \ldots, n, \quad j = 2, 3, \ldots, n, \quad i \neq j, \quad k = 1, 2, \ldots, K, \tag{12}$$

$$u_1^k = 0, \quad k = 1, 2, \ldots, K, \tag{13}$$

$$0 \leq Q_i^k \leq u_i^k \leq V, \quad i = 2, 3, \ldots, n, \quad k = 1, 2, \ldots, K, \tag{14}$$

$$\sum_{k=1}^{K} Q_i^k = q_i, \quad i = 2, 3, \ldots, n, \tag{15}$$

$$0 \leq Q_i^k \leq q_i \sum_{j=1}^{n} x_{ij}^k, \quad i = 2, 3, \ldots, n, \quad k = 1, 2, \ldots, K, \tag{16}$$

$$x_{ii}^k = 0, \quad i = 1, 2, \ldots, n, \quad k = 1, 2, \ldots, K, \tag{17}$$

$$x_{ij}^k \in \{0, 1\}, \quad i, j = 1, 2, \ldots, n, \quad k = 1, 2, \ldots, K. \tag{18}$$

Similarly, to model of VRP, the objective function (9) represents the total length of all routes. Inequalities (10) allow each vehicle to leave the depot maximally once. Equations (11) assure that the vehicle entering any location must also leave it. Compared to the model of standard VRP, balancing constraints (12) contain load variables with additional index k. Using (13), all vehicle loads at the depot are set to 0. Because all loads on each route must respect vehicle capacity, inequalities (14) are introduced. Equations (15) assure that partial deliveries will meet demand of each customer. Constraints (16) have two meanings. If vehicle k does not serve customer i, i.e. there is no travel of this vehicle from the location of this customer, the corresponding partial delivery Q_i^k must equal to 0. On the contrary, if partial delivery is positive for vehicle k, it must leave customer i on this route.

3.2 Heuristic algorithm

In [5] the following approach is proposed. At the beginning, it is necessary to find any feasible solution of VRP, i.e. the solution without splits. Such solution can be found using any heuristic algorithm described in [1] or using the mathematical model (1) – (8). Let us suppose, there are three routes in the solution. The vehicle on the first route has free capacity V_1, and the vehicle on the second route has free capacity V_2. On the third route, there is customer s, for which demand q_s it is given:

$$q_s \leq V_1 + V_2, \tag{19}$$

i.e. demand can be splitted into two routes mentioned above.

Further, let us denote, in the original solution, i_1 and j_1 two successive locations on the first route, i_2 and j_2 two successive locations on the second route, i_3 immediate predecessor of location s and j_3 its immediate successor (Fig. 2).

The sum of all distances related to the above-defined locations can be expressed as follows:

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$$z_1 = c_{i_1 j_1} + c_{i_2 j_2} + c_{i_3 s} + c_{s j_3} \,. \tag{20}$$

On Figure 2, the corresponding travels are highlighted in bold arrows.

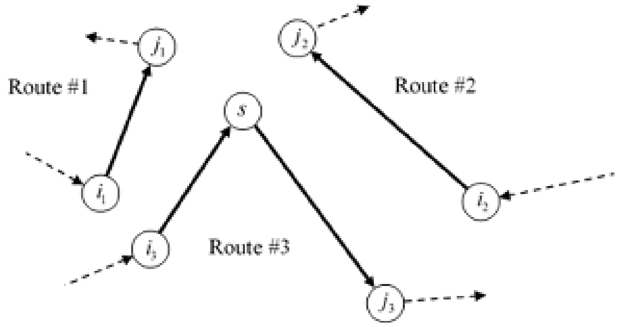

Figure 2 Solution without splits

Respecting (19), let us split demand q_s into routes #1 and #2 (Fig. 3). New sum of distances is calculated as:

$$z_2 = c_{i_1 s} + c_{s j_1} + c_{i_2 s} + c_{s j_2} + c_{i_3 j_3} \,. \tag{21}$$

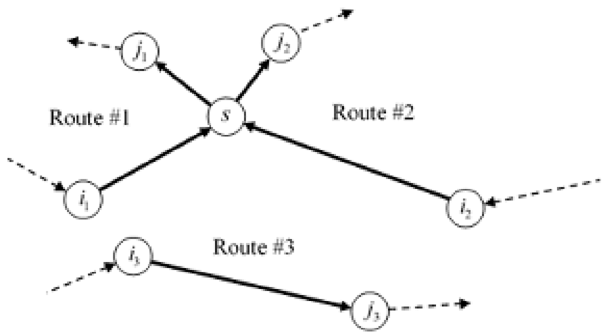

Figure 3 Solution with splits

If $\Delta z = (z_1 - z_2) > 0$, proposed change brings savings in distance and it is realized. This procedure can be repeated while the solution can be improved in terms of the total length of all routes.

4 Application

The main goal of the analysis is to solve the logistic problem of the company transporting Euro pallets to its customers. In the real instance of the company located in Bystrany, twelve customers are located in north-western region of Bohemia and Saxony. Demands of customers are listed in Table 1. For the transportation, the vehicle with the capacity of 70 pallets is used.

Table 1 Demand of customers

	Location	Demand
1	Bystrany	-
2	Teplice	45
3	Decin	33
4	Roudnice nad Labem	85
5	Kostany	17
6	Usti nad Labem	19
7	Bilina	26
8	Litvinov	37
9	Zim	11
10	Most	28
11	Drazdany	89
12	Dubi	12
13	Louny	16

In Table 2, distances (in km) between all pairs of locations can be found.

Table 2 Distances between locations

Location	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	4.9	42.8	43.4	11.6	22.2	17.5	28.5	12.3	33.4	70.0	10.8	38.7
2	4.9	0	44.4	46.3	7.7	18.5	12.6	23.5	15.2	29.1	71.0	5.9	34.7
3	42.8	44.4	0	65.0	53.0	25.9	59.3	68.8	39.8	66.6	71.5	50.7	72.8
4	43.4	46.3	65.0	0	51.1	48.1	53.6	66.0	31.1	57.6	97.1	47.9	55.4
5	11.6	7.7	53.0	51.1	0	27.2	15.3	17.5	23.4	29.9	70.9	5.3	37.4
6	22.2	18.5	25.9	48.1	27.2	0	31.4	46.6	13.9	44.1	66.2	28.5	53.9
7	17.5	12.6	59.3	53.6	15.3	31.4	0	28.3	22.5	15.9	83.0	19.4	22.1
8	28.5	23.5	68.8	66.0	17.5	46.6	28.3	0	36.2	12.4	84.9	18.1	35.5
9	12.3	15.2	39.8	31.1	23.4	13.9	22.5	36.2	0	43.2	66.0	18.1	43.6
10	33.4	29.1	66.6	57.6	29.9	44.1	15.9	12.4	43.2	0	96.4	29.6	33.7
11	70.0	71.0	71.5	97.1	70.9	66.2	83.0	84.9	66.0	96.4	0	66.8	106.5
12	10.8	5.9	50.7	47.9	5.3	28.5	19.4	18.1	18.1	29.6	66.8	0	39.7
13	38.7	34.7	72.8	55.4	37.4	53.9	22.1	35.5	43.6	33.7	106.5	39.7	0

In existing solution, six routes are realized with the total length of 683.7 km (Tab. 3). Deliveries are splitted in Teplice, Bilina, Roudnice nad Labem, Usti nad Labem and Drazdany. While in case of Roudnice nad Labem and Drazdany it is necessary to split delivery, for other locations the splitting is optional.

Table 3 Existing solution

Route	1	2	3	4	5	6
Locations	Bystrany Teplice Bilina Louny Roudnice Bystrany	Bystrany Bilina Most Litvinov Bystrany	Bystrany Kostany Dubi Teplice Bystrany	Bystrany Usti Roudnice Zim Bystrany	Bystrany Drazdany Bystrany	Bystrany Drazdany Decin Usti Bystrany
Total length	138.4	74.3	27.7	113.7	140.0	189.6
Total load	69	69	70	70	70	70

Although the occupancy of vehicles is perfect, the company's management examined whether designed routes are cost-effective. For the application of mathematical models, the system MPL for Windows 5.0 and solver CPLEX 11 were used. Heuristics were designed in VBA for Excel. All calculations were executed in the Intel Core i7 Processor, 2.3 GHz, with 8 GB of RAM, running Windows 10, 64-bit OS. All results, compared with the existing solution, are listed in Table 4. Firstly, the optimum solution of VRP (1) – (8) was found with 2 direct fully-loaded-travels to Roudnice nad Labem and Drazdany. Of course, this in-advanced splitting (specifically 70+15 and 70+19) could be changed and investigated. The total length of all routes is 693.9 km, i.e. approximately 10 km worse than the existing solution.

Then, the model of SDVRP (9) – (18) was applied. Due to the computational complexity of the problem, the optimal solution was not reached even after 24 hours of run. The objective value of the best found feasible solution is 680.5 km, with the lower bound of 635 km. Finally, above-suggested heuristic algorithm was applied for the feasible solution obtained using Clarke and Wright savings heuristic [8]. Both heuristics were developed in VBA for Excel. The total length of all routes is 712.2 km.

5 Result, discussion and conclusion

For solution of real instance with the transportation of Euro pallets, various approaches were applied. If direct travels are used for customers with the demand exceeding the vehicle capacity, remaining deliveries can be included in routes optimized as VRP without possible splitting. More effective access is the application of mathematical model of SDVRP. However, the computational complexity of the problem is the obstacle to obtaining optimal solution even for small-sized real instances. Therefore, heuristic algorithms are used for such situations.

For comparison of all solutions to analysed instance, see Table 4. Although the optimality of the solution obtained by the application of model SDVRP cannot be proved, the solution might be optimal. Anyway, it is the best found solution (Tab. 5) which length is more than 3 km shorter than the existing solution. With the comparison of the solution obtained using model VRP, there are also two fully-loaded-travels to Drazdany and Roudnice nad Labem. However, the total length of all routes is more than 13 km shorter what shows the advantage of splitting, even in cases the vehicle capacity is higher than demand of each customer (optional splitting in Teplice and Usti nad Labem)

Table 4 Comparison of solutions

	Company's solution	Model VRP	Model SDVRP	Heuristic SDVRP
Total length	683.7	693.9	680.5	712.2
Number of routes	6	7	6	6

Table 5 Best found solution

Route	1	2	3	4	5	6
Locations	Bystrany Drazdany Bystrany	Bystrany Roudnice Bystrany	Bystrany Teplice Dubi Kostany Bystrany	Bystrany Teplice Litvinov Most Bystrany	Bystrany Teplice Bilina Louny Roudnice Zim Usti Bystrany	Bystrany Usti Decin Drazdany Bystrany
Total length	140.0	86.8	27.7	74.2	162.2	189.6
Total load	70	70	68	70	70	70

The solution of real problem can be improved introducing vehicles with different capacity [9]. In such situation, cost evaluation of vehicles must be defined in the objective function.

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METHOD FOR OPTIMIZING MAINTENANCE LOCATION WITHIN THE INDUSTRIAL PLANT

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Keywords: maintenance, logistics, optimization, logistic delay
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

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):

$$c_{ij} = u_{ij} \times v_{ij} \quad (1)$$

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

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

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

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

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

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

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.

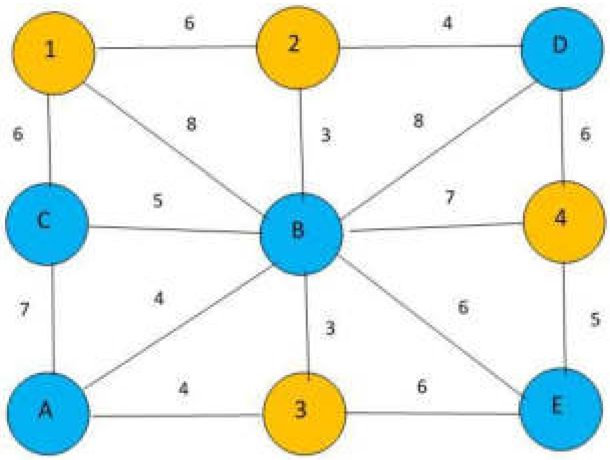

Figure 1 Graph of network projection of devices and unit locations

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).

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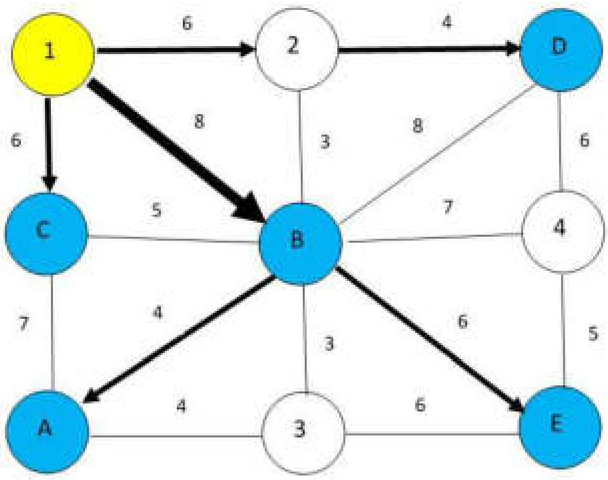


Figure 2 Representation of logistic routes to devices from maintenance stations 1

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

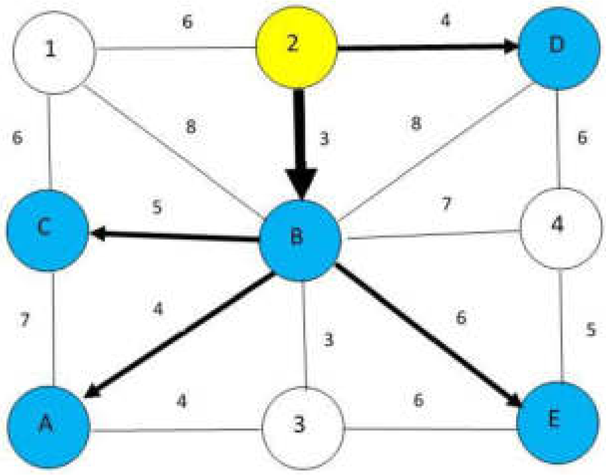


Figure 3 Representation of logistic routes to devices from maintenance stations 2

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

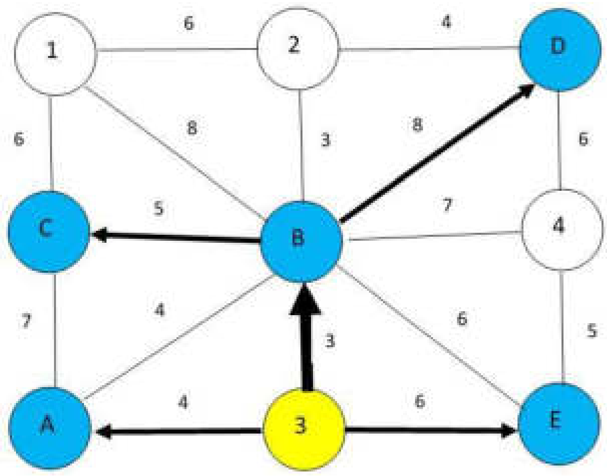


Figure 4 Representation of logistic routes to devices from maintenance stations 3

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

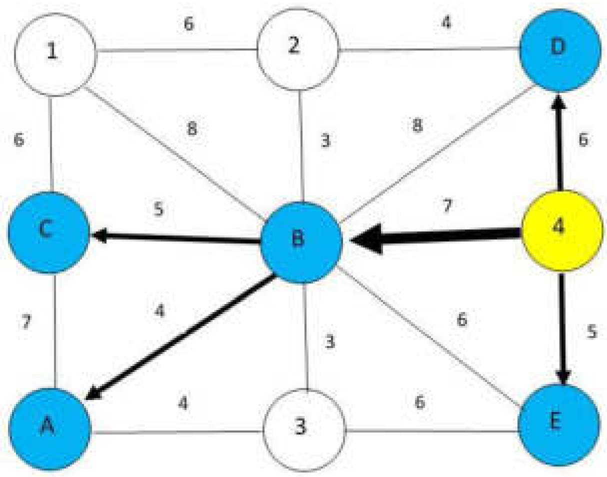


Figure 5 Representation of logistic routes to devices from maintenance stations 4

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.

$$c_i = n_i \times u_i \times v_i \tag{5}$$

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).

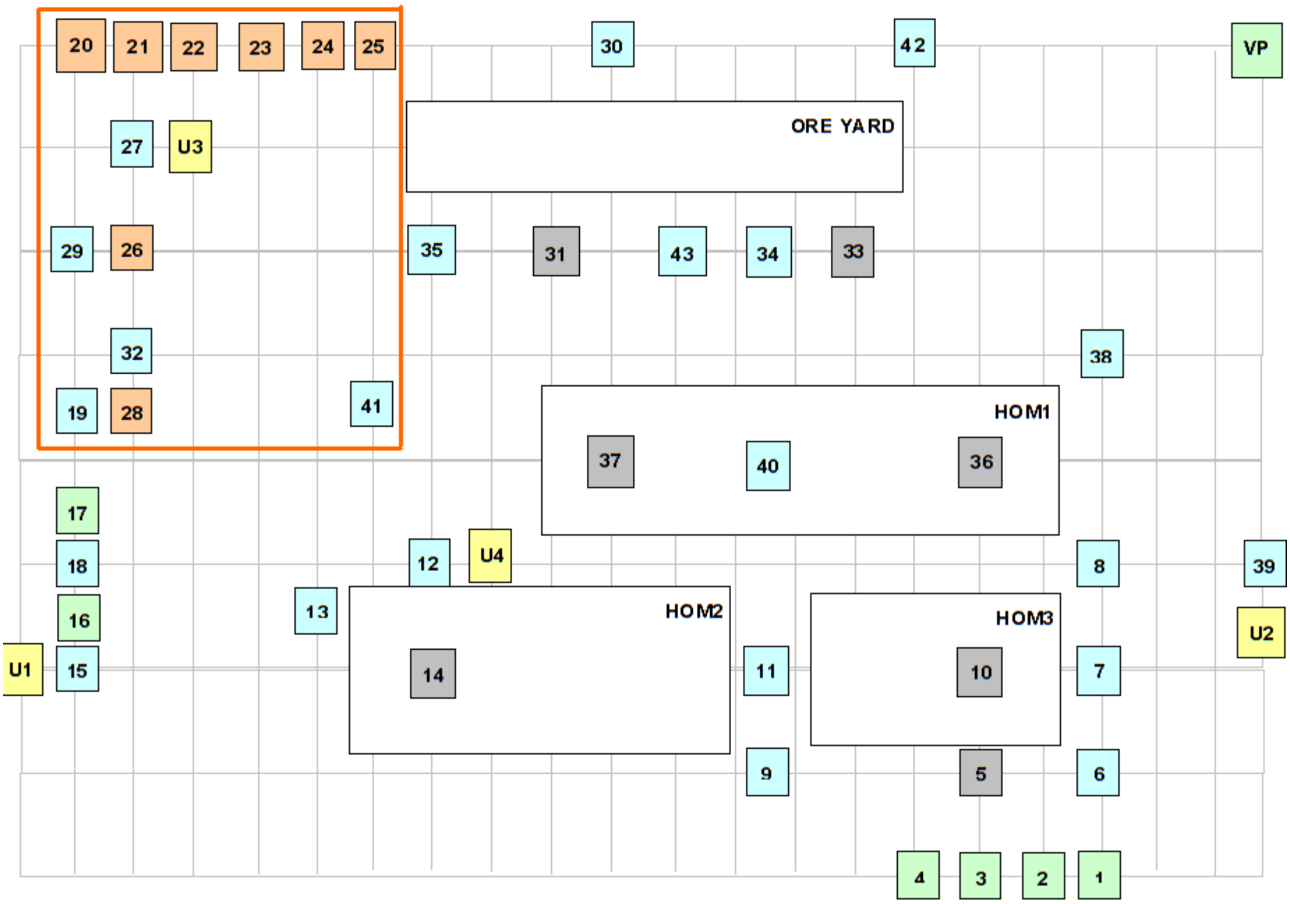
$$s = 6 \times e^{(-3{,}5 \cdot |tg(\theta)+0{,}05|)} \quad \text{[km/h]} \tag{6}$$

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

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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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