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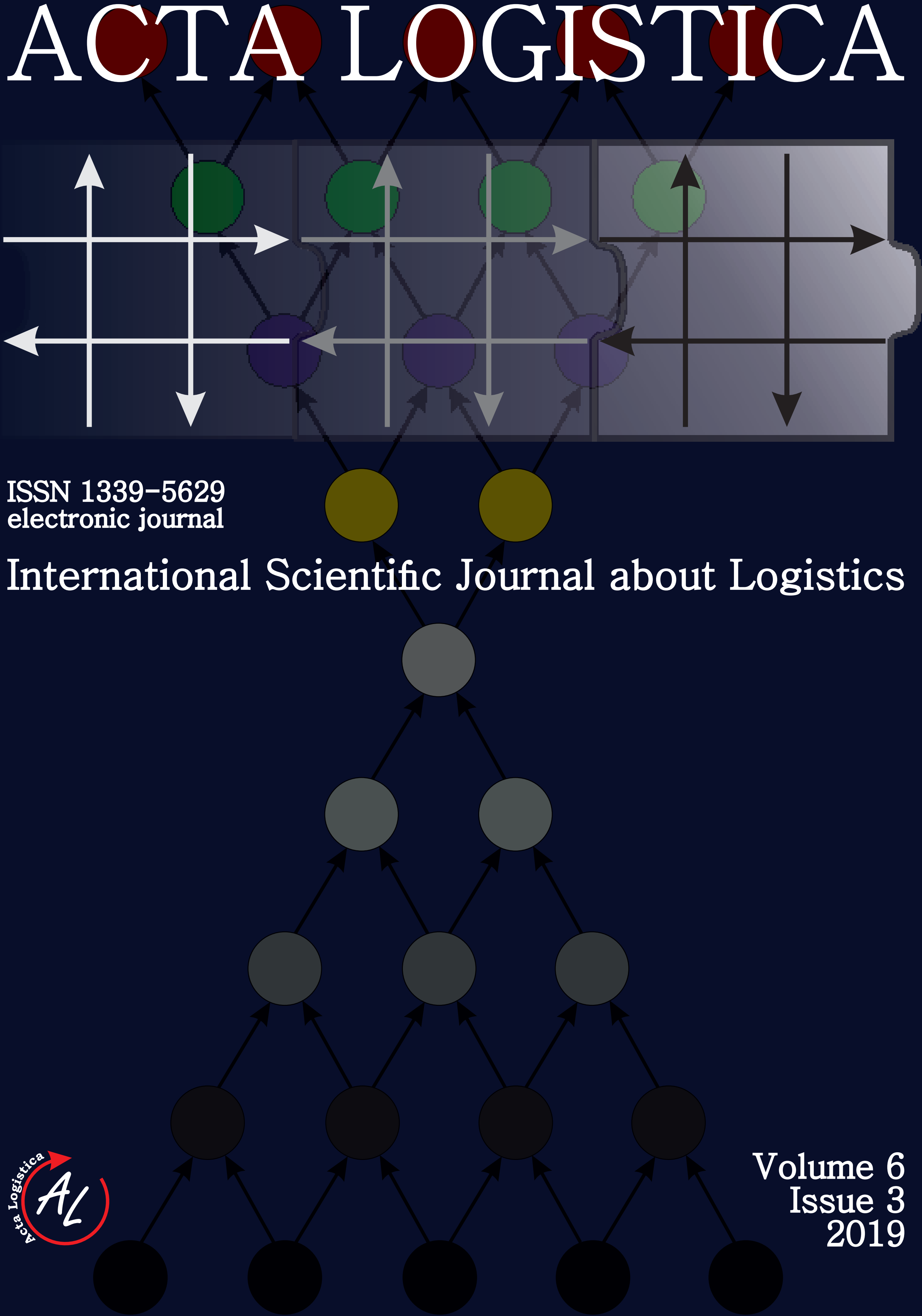

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MODELLING OF ELECTRONIC KANBAN SYSTEM BY USING OF ENTITY RELATIONSHIP DIAGRAMS

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Keywords: Electronic Kanban, ERD, information systems, design
Abstract: The Entity Relationship Diagrams are often used at the design stage of information systems to identify all elements of the future system and their relationships and dependencies. This stage is the most important phase of information systems designing as the future structure and functionality depends on it. The publication deals with the analysis of the applicability of the Entity Relationship Diagrams for the design of the enterprise information system, electronic Kanban system.

1 Introduction

The utilization and active use of Kanban system has been increased in the last decades. Traditional Kanban is gradually replaced by implementation of electronic Kanban system due to technical development. Electronic Kanban belongs to the area of enterprise information systems. There are a lot of methodologies available for the modelling of enterprise information systems. One of the tools for visual representation of data is The Entity Relationship Diagram (ERD). ERD focuses on conventions which express how the data is related. The ERD uses symbols representing the main entities of the system and their interdependencies. This tool mostly belongs into the field of software engineering when working with complex databases.

2 ERD and its basic elements in relation to designing enterprise information system

The Entity Relationship Diagram consists of basic elements and elements which are based on these basic elements. Basic elements are represented by entities, attributes and relationships between entities (Fig. 1) [1,8].

Figure 1 Graphic representation of basic elements of The Entity Relationship Diagram

Entities represent defined elements of the system such as person, object, or event which the stored information is concerned with. Entities can be combined into classes. Classes are a structured description of system components sharing common attributes. Weak entity represents a special kind of entity (Fig. 2). Existence of weak entity is dependent on existence of basic entity [2,6]. This entity cannot be identified by its own attributes.

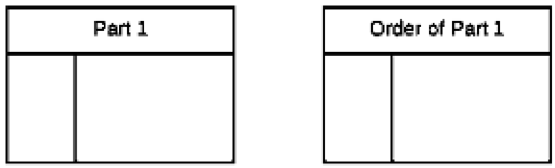

Figure 2 Entity – Part 1 and its weak entity – Order of Part 1

Attributes are specific features of entities and they characterize entities. There is no specified maximum number of attributes pertaining to one entity. It is possible to identify specific attributes for individual entities. These attributes are referred as compound attributes, e.g. compound attributes for attribute transport box could be height, width and depth of transport box. Another kind of attributes represents derived attributes. Derived attributes depend on existence of other attributes and occurrence of these attributes is rare in the Entity Relationship Diagram. Attributes can have also a certain specification where Primary Key (PK) attributes and Foreign Key (FK) attributes are distinguished (Fig. 3). Primary Key Attributes are a special kind of attributes that define a unique database entry. This specification is unique value which applies to a specific attribute. Foreign Key attributes are the opposite of Primary Key attributes, where attributes do not represent unique values. Multiple entities can share the same attributes [1,4].

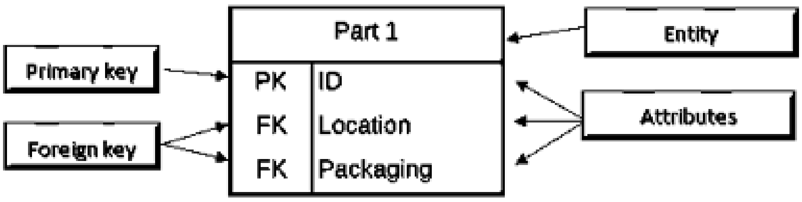

Figure 3 Attribute of entity -part

Another important basic feature of Entity Relationship Diagrams are relationships. Relationships in ERD are represented by the term cardinality of relations.

2.1 Cardinality of relationships in context of Entity Relationship Diagrams

Cardinality within the ERD expresses the relationship between two entities in a graphical - numerical form. With the aid of cardinality of relations, the occurrence of an entity which is in association with the occurrence of another entity is identified [1,6,9]. There are several notations in terms of graphical visualization of cardinal relationships, Table 1.

There are three basic cardinal relationships and these are one-to-one cardinality, one-to-many cardinality, and many-to-many cardinality. One-to-one cardinality is used to divide an entity for purpose of its simplification. Figure 4 a) expresses an example where a unique Kanban card is created for a unique part. No other Kanban card belongs to this particular part. One-to-many cardinality identifies the relationship between two entities A and B. The instances of entity A can be associated with multiple instances of entity B while the instances of entity B are associated with only one instance of entity A. At Figure 4 b) is a Kanban card for one workstation but the workstation uses multiple Kanban cards as it uses several parts. Many-to-many cardinality expresses the relationship between entities A and B where entity A is associated with multiple instances of entity B and vice versa. According to Figure 4 c) the part can be used by several workstations and at the same time one workstation is using several different parts.

Table 1 Notations of Cardinality of Relationships

Symbol	Meaning
	**One**
	**Many**
	**One or more**
	**One and only one**
	**Zero ore one**
	**Zero or many**

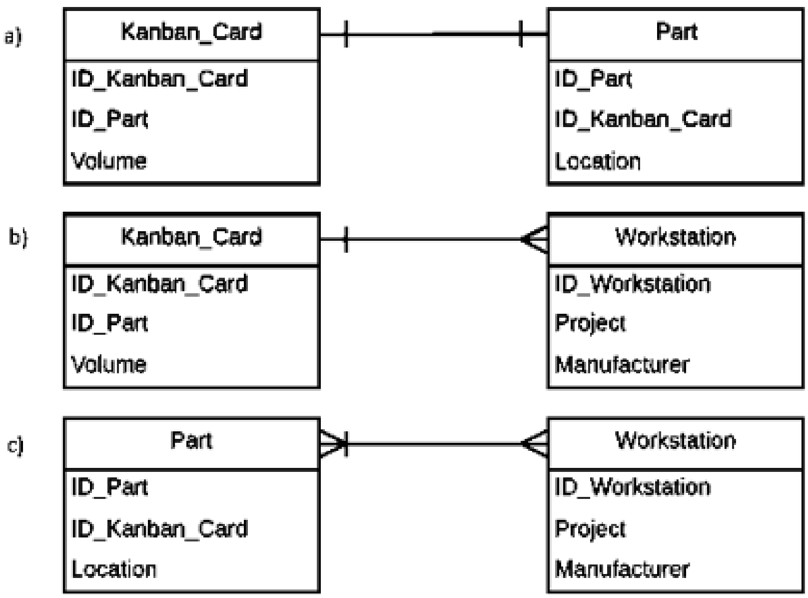

Figure 4 Basic types of cardinal relationships a) one to one b) one to many c) many to many

2.2 *Basic models for ERD visualization*

Three types of models are used to display the Entity Relationship Diagram. Each of them contains the core elements of the ERD. The difference lies in the meaning for which they are created and the target groups for which they are intended [5,7].

Table 2 Comparison of Conceptual, Logical and Physical Model

Features of ERD	Conceptual model	Logical model	Physical model
Entity	YES	YES	YES
Relationship	YES	YES	YES
Attributes		YES	YES
Type of Attributes		OPTIONAL	YES
Primary Key			YES
Foreign Key			YES

Based on the comparison of the individual features of the Entity Relationship Diagram mentioned in Table 2, for the needs of designing of the enterprise information system electronic Kanban it is possible to state the following:

- The conceptual model provides only a basic overview of the principle of system operation by identifying basic entities and their relationships,
- The logic model also deals with the identification of attributes of entities but does not allow them to be categorized more precisely,
- The physical model allows to create real image of the future system through the detailed identification of the elements of the system and their relationships.

The conceptual model is designed to provide an overview of the system by identifying business objects in the system. These models lack specific details but provide an overview of the content of the project and express how the data correlate with each other. The logical model represents a more detailed analogy of the conceptual model. This model fully captures and illustrates specific attributes and relationships. The model focuses mainly on business activities. Physical design of the system is created by physical model. This model is based on a logical model and deals with specific implementation of the system (Fig. 5) [2,3,6].

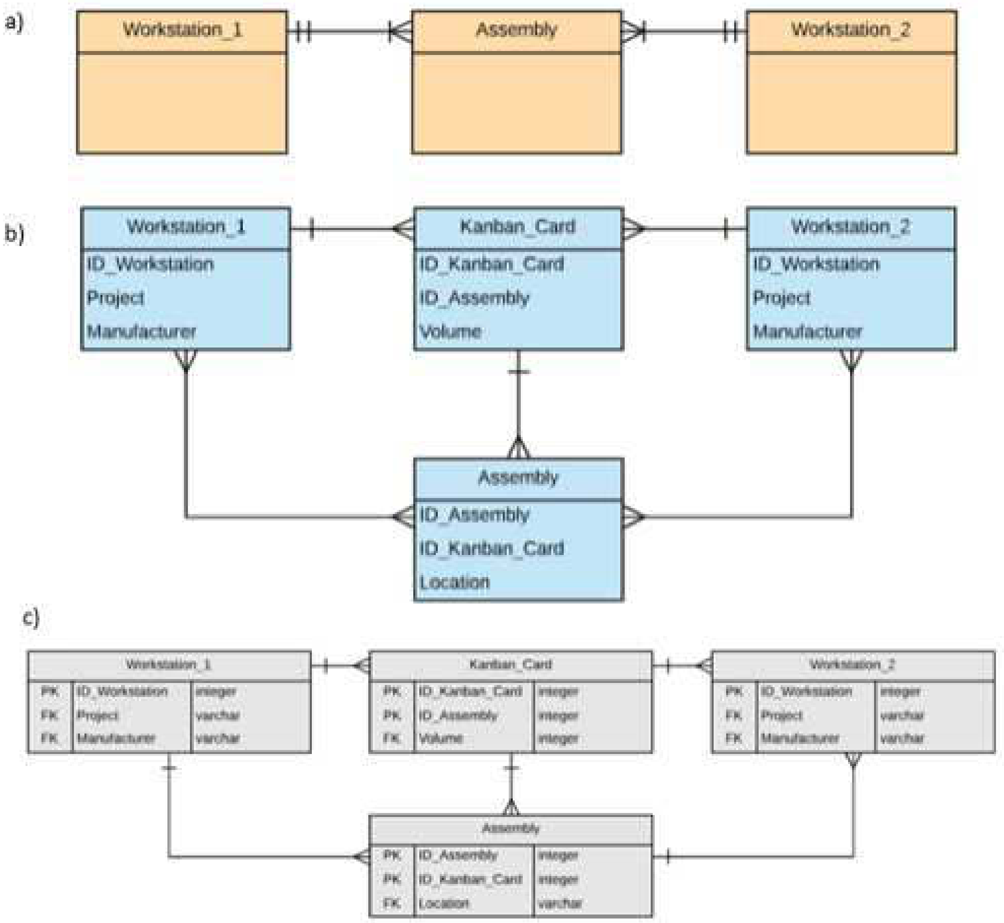

Figure 5 Using the ERD diagram to create an electronic Kanban system: a) conceptual model b) logical model c) physical model

3 Conclusion

Proper understanding and usage of Entity Relationship Diagram enables correct design of the electronic Kanban system as well as management and maintenance for the correct functioning of future enterprise information system.

Based on comparison of conceptual, logical and physical models used in Entity Relationship Diagram is possible to conclude that only physical model appears to be an appropriate tool for detailed design of electronic Kanban system. It captures a detailed description of the objects, its attributes and relationships within future information system.

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EVALUATION OF IPT SYSTEMS APPLICATION USING SIMULATION

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Keywords: AGV, simulation, Simul8, Inductive Power Transfer
Abstract: In this paper a comparison is presented for different battery charging concepts of Automated Guided Vehicle (AGV) systems using simulation models. In the focus of our investigation was, what kind of benefits can Inductive Power Transfer (IPT) for an AGV-based material handling system have, which is increasingly applied today. The proper application of IPT systems lets the reduction of the necessary number of AGVs and balances their utilization level.

1 Introduction

Logistics is the science of planning, execution, and control of the procurement, movement, and stationing of personnel, material, and other resources to achieve the objectives of a campaign, plan, project, or strategy. It may be defined as the 'management of inventory in motion and at rest' [1].

In manufacturing plants, the main task of logistics is to supply the raw materials and parts to the workplaces. On the one hand, the precise delivery of finished products to the delivery point, and on the other hand, the movement of semi-finished products between manufacturing cells.

If we look ahead to development, besides traditional push-type production strategies pull-type systems have been concepted as well. Currently, both systems co-exist, and companies search for the right balance, as stated in the article by A. Puchkova, J. Le Romancer, D. McFarlane [2].

During push-type production, the main focus is to forward the workpieces to the next workstation as quick as they can, to avoid unutilized production capacity. This has advantages but also disadvantages, like high inventory holding costs and low inventory turns. The pull-type system drives production based upon customer demand. This kind of perception and service strategy brings the modified material handling structure of raw materials and semi-finished products to the Just In Time (JIT) and Just In Sequence (JIS) manufacturing processes. As a result, servicing the production machines requires increasingly flexible machines, which can be adjusted based on the ever-changing needs.

By simultaneously automating manufacturing and manufacturing logistics, and then managing it with an integrated process control system, it is possible to create a fast and relatively flexible production system that works efficiently, where process technology and material flow can be easily and accurately monitored and controlled.

In these production and related material supply services, multiple shifts are increasingly required. This increased amount of continuous work cannot be met manually. In the long term and in large quantities this can only be achieved using automation. This is one of the reasons why demand for automatic guided vehicles (AGVs) has become more and more important in the last 60 years [3].

Due to the development of computing and sensors, practically every conceivable material handling task can be automated in some way using mobile robots, and a properly designed automated system can also greatly increase efficiency and work safety by excluding human error factor [4].

AGVs have been playing an important role in the material flow during the past 60 years. The first automated guided vehicle was developed in the early '50s [3]. A tugger truck was converted by Barrett Electronics to assist in warehousing operations. This vehicle was very primitive in comparison with today's techniques: it led to a ground-fed wire that could be followed by the electromagnetic field sensing device. Its construction costs were relatively high, as it had to use so many wires and to lay out the direction in which the truck had to go. A computer controlled which line would be powered to be followed by the vehicle.

In the following 20 years, the applied technique did not change significantly. More and more towing AGVs were being used, and in 1973, Volvo developed a computer controlled system with 280 pcs of AGVs in a Swedish factory. They tried to find a suitable alternative to conventional conveyor line assembly.

The first major breakthrough took place in the mid-'70s: first unit load AGVs were introduced. They have gained popularity because they have not only been able to tug carts, but also have been fitted with the proper accessories as a workbench. AGVs of this type are widely used in warehouses, factories, mills, hospitals. In this article, we will look at the material handling model of a system built from such kind of mobile workstations.

The article by Kabir, Q.S., Suzuki, Y. [5] has pointed out how important the battery and battery management is. By completely agreeing with the content, we outline that a well-built IPT system can be very effective. One critical issue lies predominantly in the AGV's power supply. So, in order to operate an AGV system efficiently, we need to effectively address the current energy supply problems.

2 Energy management in AGVs

In simpler systems, users should change AGV batteries manually after a shift, depending on the degree of utilization. Considering that these drive batteries can weigh more than 10kg, we can assure, that these solutions cannot be said to be user-friendly, but we also need to know that they are factually the cheapest. The article by Kabir, Q.S., Suzuki, Y. [5] has pointed out as well that these solutions require twice as many batteries and, it has special expectations, taking into account the design of the charging bay, and the replacement of the batteries will also pose a serious threat to the workers.

Ergonomics is now becoming more and more important for the AGV manufacturers, so it is no coincidence that a growing number of companies offer automatic charging for this type of systems. In smarter systems, when the truck's battery voltage drops below a certain level, the truck automatically accesses the charging station and informs the supervisor system. This solution is considerably more user-friendly than the first one with the manual replacement, however, there is a disadvantage that while the truck is charging, it cannot perform a material handling task, therefore, in this case, we will need more AGVs, which will result in significant investment costs.

The article by Kabir, Q.S., Suzuki, Y. [5] has also pointed out that Inductive Power Transfer can be used to build up an AGV system without batteries. However, this kind of system is not very flexible, because the AGV can drive only above the Inductive Power Tape. Modifying the track is also very expensive. There are solutions as well where using the Inductive Power Transfer technology, the batteries of the AGVs can be charged contactless, either on the go, or even while standing [6].

As a summary, advantages of IPT systems can be stated as follows:

- Using no moving parts is an advantageous solution regarding long time reliability.
- The absence of live electric contacts increases workplace safety.
- Environmental issues are also significant because IPT enables smaller or the complete absence of batteries, as charging is carried out on longer sections during operation.

In our research topic, we were looking for the possibility of using IPT technology for AGV systems, and if so, which topology and utilization mode would deliver the best benefit for the user.

It should be noted here that there is an increasing demand for the modernization of traditional production structures (e.g. production lines). The reason for this is that the product range on a production line is widening, the material handling processes are becoming more and more complex, leading to bottlenecks over time. Thus, it can be seen that these traditional production structures need to be developed. One of the pioneers of this is the introduction of a more modular manufacturing structure, which is being tested in a wider range.

The idea behind it is production without assembly lines, broken down into the individual work stations. The new assembly stations are occupied by one or two workers. Unlike today, they work steadily at a continuous pace because they no longer have to adapt their activities to the speed of the line. And they do not have to move with the car on a conveyor; they can work in one place. The transport of the components between the stations in modular assembly is taken over by AGVs [7].

The planning methodology of this new type of production systems is extensively described in the paper by Kern, W., Rusitschka, F., & Bauernhansl, T. [8].

In these systems, besides the manufacturing and material handling machines, the importance of the accessorial components like sensor networks is increased as described in the paper by Konyha, J., & Bányai, T. [9].

There are also mixed assembly line models possible as described in the paper by Keckl, S., Abou-Haydar, A., & Westkämper, E. (2016) [10]. As concluded from the literature, new type of production structures exists. Material supply can be advantageously implemented using AGV systems. As stated above, AGV systems need efficient power management for the AGVs, used in a flexible production structure, unlike the fixed charging points, an extensive IPT network can be an effective solution.

To be able to prove our assumption, we have developed a simulation model for that kind of AGV-systems, because simulations can be used to examine the behaviour of such kind of material handling systems. Application of simulation in logistics has extensive literature. Straka et al. [11] point out in their paper that in simulation modelling the appropriate first step is the creation of a formalized structure, which can be converted into components of the used simulation software. Neradilova, H., & Fedorko, G. [12] describe the important role of computer simulation used in the Industry 4.0 systems. In the work of Kesen, S.

E., & Baykoç, Ö. F. [13] a comprehensive description of several existing AGV simulation models can be found.

So we have developed a simulated production system where material handling is carried out by AGVs. Simulation models are capable of modelling both conventional and IPT charging.

Current research is in the framework of our H2020 project called "EPIC," and the research was supported by the National Research, Development and Innovation Fund of Hungary under grant no. ED_18-22018-0006.as well.

3 Functioning and simulation modelling of IPT systems

As modelling of IPT systems for AGVs is the main speciality of the proposed simulation model, a short description of the IPT technology follows. Detailed description can be found in [14-16].

In the IPT systems the incoming AC current is first converted to DC and fed to the wave generator. The wave generator has oscillators through which the current flows and this generates microwave electromagnetic radiation. This will be emitted by the transducer antenna, and received by the "rect-antenna" on the another side, and the energy will be re-converted to DC power, which can be used according to the application (Fig. 1).

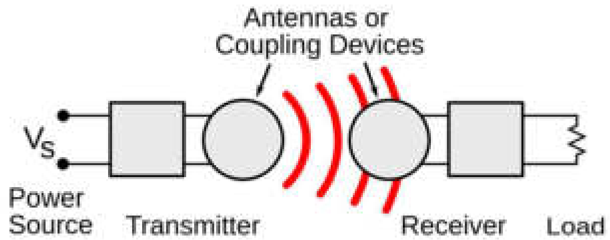

Figure 1 Functionality of IPT [17]

However, the energy transfer works only if the mobile vehicle follows the track closely. Even in case of a small deviation, we can calculate with reduced energy transfer.

The following figure (Fig. 2) shows, on the left side, the ratio of the vertical position deviation and the received power, and on the right side, the ratio of the horizontal position deviation and the received power.

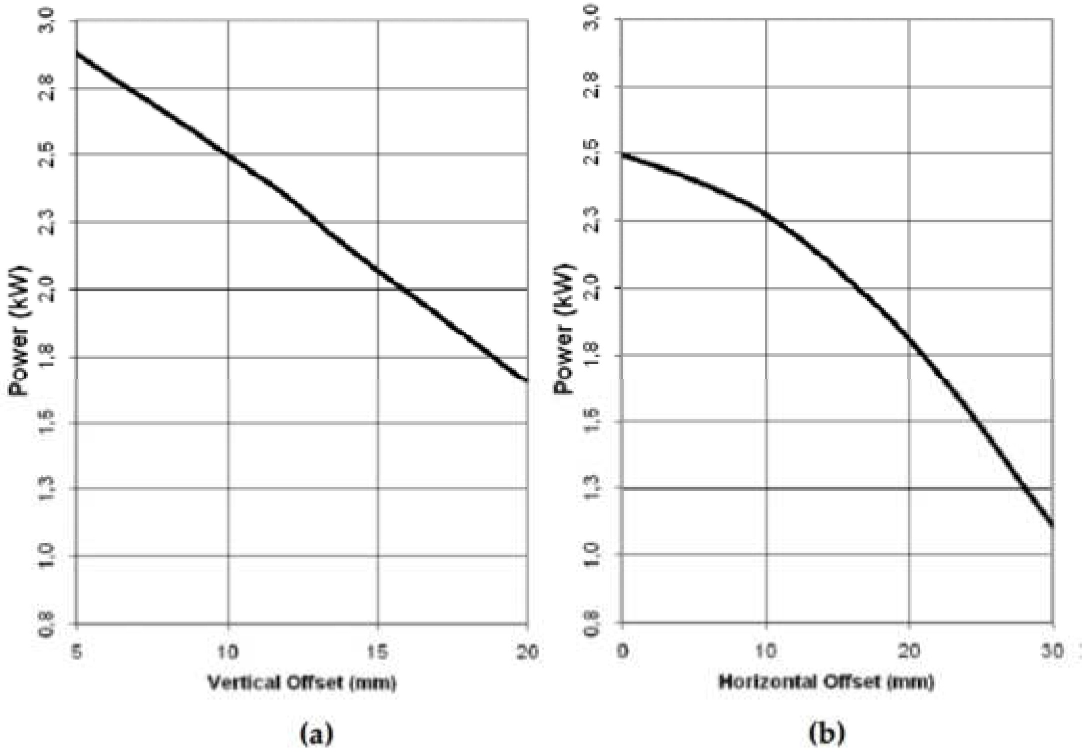

Figure 2 Ratio between the offsets and the power [18]

Figure 2 (a) shows that at a 15 mm vertical offset, there is a drop in power by about 15%, and in case of 20 mm vertical offset, this value is more than 30%. The system is even more vulnerable to horizontal lateral deviation, as shown in Figure 2 (b). At a 10 mm deviation, there is roughly 10% loss of power, at a deviation of 20 mm there is almost 30% of power loss, while in case of a 30 mm deviation, there is a drastically reduced performance by more than 50%. However, we did not model this during our simulation.

Contrary to popular belief, the IPT system can reach a very high DC-DC power efficiency of 96%, while batteries have approximately 80% of charging efficiency, as described in [15]. This is one of the reasons why AGV systems without batteries have also been justified.

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This means, IPT systems can be modelled also as a continuous charging system component. The transmitted capacity is proportional to the time of staying near to the inductive wire.

According to the above, modelling of the IPT system corresponds to a track-type component during which the capacity of the battery changes. By neglecting the machines' idle power consumption, the used energy is proportional to the travelled distance. The charged energy is, however, proportional to the time of the machines' stay or movement above the track segment. If the machine travels along an inductive path of length L, the change of battery capacity can be formulated as follows:

$$\Delta C = a_{const}\frac{L}{v} - b_{const}L \tag{1}$$

where a_{const} is the degree of charging [W/sec], b_{const} is the degree of energy consumption [W/m], and v is speed [m/sec].

If

$$\Delta C > 0 \tag{2}$$

the system is self-supporting, if

$$\Delta C < 0 \tag{3}$$

the system has to be supplemented by additional charging stations. If, during the period of movement, the amount of charged energy does not cover the consumption, then the equipment must be stopped for a shorter or longer period(s) at certain charging points. Of course, this is not necessarily a problem, because IPT systems can also be built up where the AGV can be charged over time while waiting for workpieces next to the workstations.

We should mention one more simplification, which is important regarding the result of our simulation. We have neglected the fact that AGVs have a higher energy demand when they are loaded, than when they are unloaded.

4 Development of AGV Simulation Model

The model has been developed using a widely accepted Discrete Event Simulation (DES simulation) model (with Program Simul8). The following figure (Fig. 3) shows the layout of the created simulation model of an AGV system with conventional charging method.

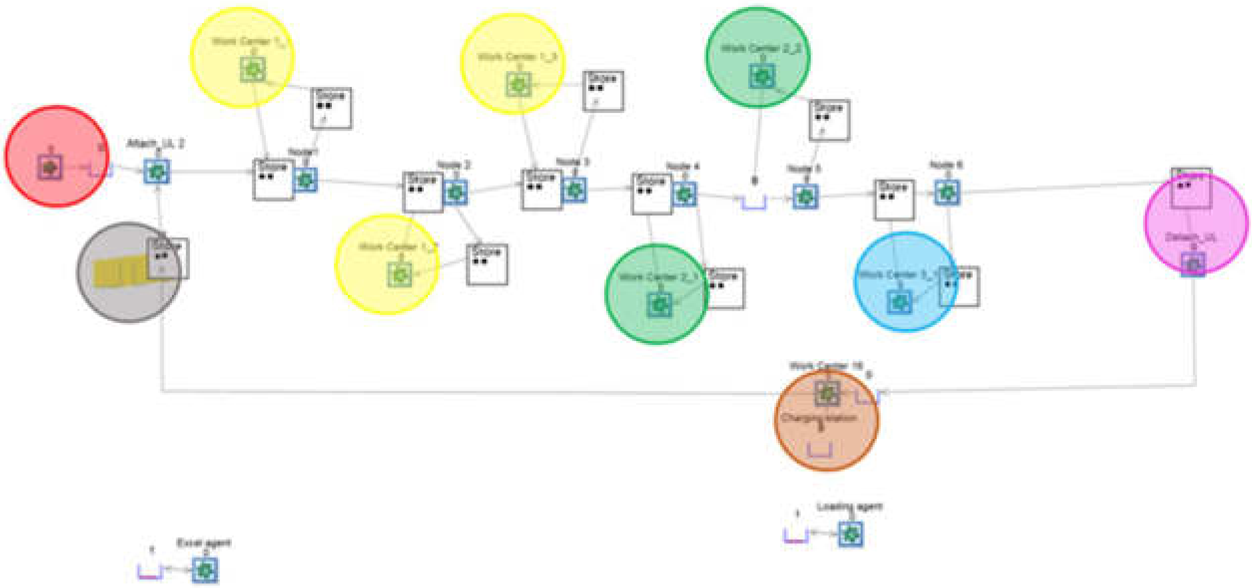

Figure 3 AGV system model in Simul8

This simulated production facility is a modularly designed manufacturing system, using a pull principle. Cycle times in the system are decreasing in the later phases, which helps Work in Process level (WIP level) to be kept at a minimum. This way the number of AGVs in the system is kept at minimum level.

The raw material is generated at a rate of 2.5 min, following a normal distribution with 0.5 min deviation on the input side (red circles) of the manufacturing system. These will be transported by AGVs to the first step of manufacturing (yellow circle). In our simulation, we created three such production cells for the first step. Routing has been defined so that all three cells are equally used. Next, the finished workpieces are taken by the AGVs to the 2nd stage machines (green circles). There are two machines in this phase in order to suit the demanded capacity. The model routes the products so that utilization is equal. Finally, the AGVs deliver the material for the 3rd workstation (blue circle). There is only one work station in this phase. Finally, the AGVs carry the finished product to the output side (purple circle) and then drive back to the beginning of the system where they wait (grey circle) for the next task.

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It is also important to note that the AGVs are waiting on each production site while the workpiece is ready. When determining the consumption data of the AGVs, it was taken into account that the batteries should be discharged with a ratio, to be able to operate the AGV at least one shift without recharging.

At the first run of the simulation, the following logic was applied for the charging of the AGVs: if the charge level of the AGV is 20% or less, the AGV will be removed from the system at the charging station (brown circle) until it was recharged up to 100%.

However, it was to be recognized that with such a simple charging logic, the system cannot be self-sustaining with automatic charging, as all AGVs are discharged at approximately at the same time. Thus, they are simultaneously removed from the system due to charging, which causes that no more free AGVs will remain in the system to do the material handling. So, with the initial set of AGVs and with such a high material flow, the system can only perform its function if, after each shift, the AGVs' batteries are manually replaced.

If more AGVs were to be used (based on industry experience, the AGV manufacturers and distributors usually recommend + 100% for continuous operation), there would be enough free remaining capacity in the system, that would allow to take out AGVs from the system for recharging. In that case the material handling system with automated recharging would work. Of course, this investigation has a significantly higher investment cost, often the companies are unwilling to pay for it.

In order to keep the number of AGVs at a more constant level, in the second simulation run, a modified charging logic is applied. In this case there is a given number of AGVs at the loading station. If a transport machine arrives at the station, and the number of the AGVs at the station is below a certain level, and the machine is not fully charged, then it goes to the charging station.

So with the simulation we also tried to find out what kind of charging logic should be used, and how many extra AGVs have to be added to the system to perform this kind of automatic charge.

From this point of view, it is conceivable that if this system were to be complemented with an IPT system, we would have to take out the AGVs for less time "from the battle line" for charging.

We have, therefore, investigated two types of IPT systems.

First, we tested the IPT system installed on the long straight sections, so the AGVs could be recharged on the go. This IPT loop is shown as the blue loop in Figure 4.

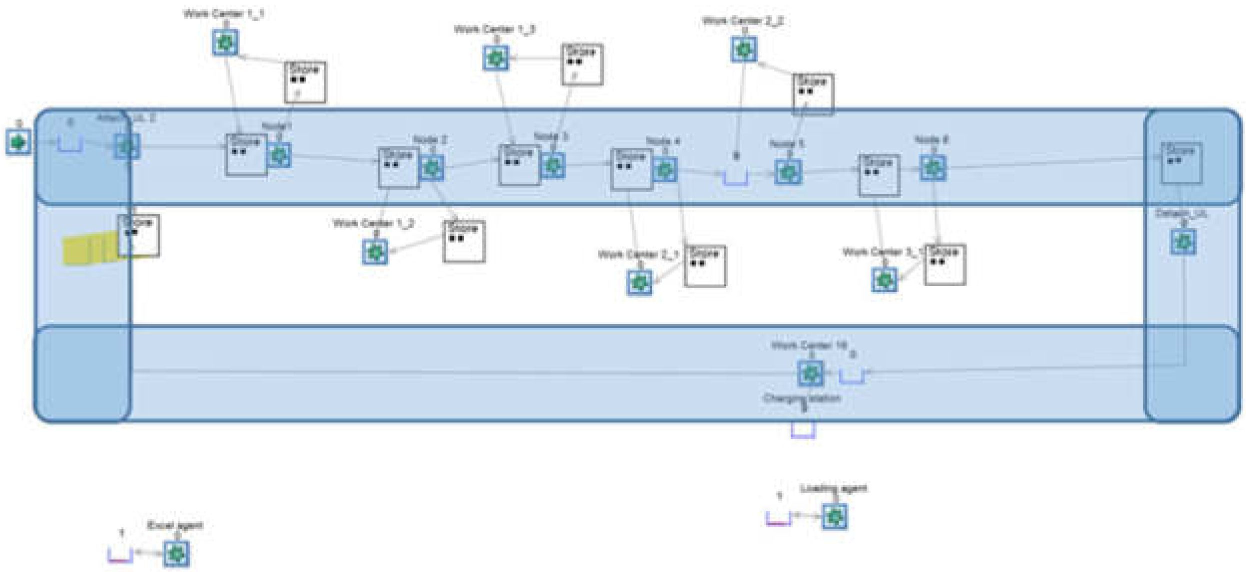

Figure 4 AGV system model in Simul8

Second, we have created a simulation in which the IPT system has been designed to recharge the batteries of the AGVs whenever they wait for the workpiece on each manufacturing cell. This can be seen in Figure 5.

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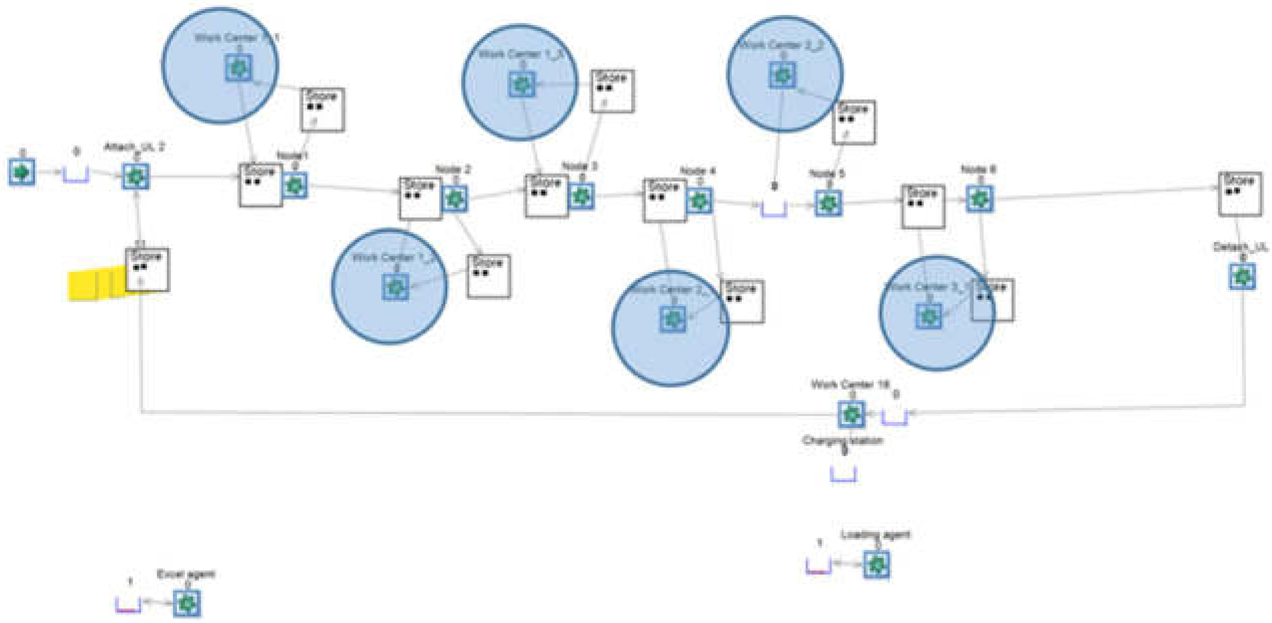

Figure 5 AGV system with IPT charging stations at the work cells

5 Simulation results

Main output of the simulation runs is the judgement if the system is capable of handling the amount of incoming material flow. This can be measured by the amount of incoming, queueing work items of the model. If this amount increases steadily then, there are too few AGVs in the system. The value must be observed over a longer period in order to ignore the distortion coming from initial charging. There is a single input parameter of the different simulation runs: the number of AGVs in the system. Optimal number of AGVs has been determined in an iterative way, by increasing the number of AGVs to the limit where the number of awaiting work item has no increasing trend.

5.1 Simulation results for the AGV system with conventional automatic charging

As we have seen, with the simple, conventional automatic charging logic, the system was unable to carry out continuously the material handling tasks. This is why we were looking for a better charging logic to be able to operate the system, and parallel with that we investigated the number of AGVs required to the material flow.

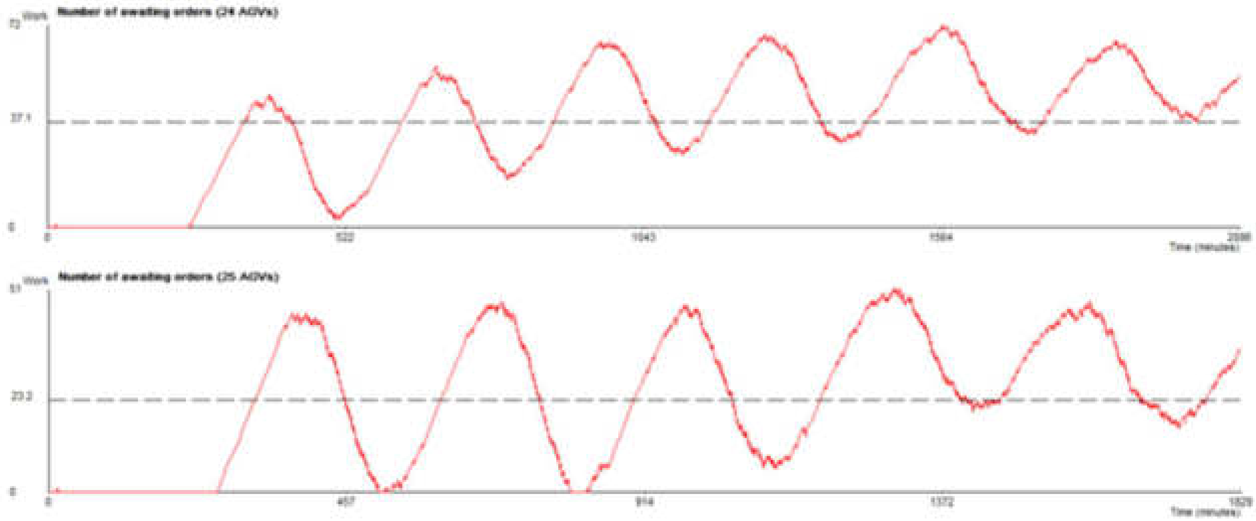

Figure 6 Number of awaiting work items at the input side

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We tested several charging logic, and finally the following one was proved to be most useful: We do not let the AGV run until the batteries were totally (20%) exhausted, but if the charging level of the AGV is below 80%, the AGV will be removed from the system and recharged. This can only be done if there are sufficient amount of AGVs to perform the material handling tasks. The system was sustainable for over a long time when it consisted of at least 25 pc's of AGVs (Fig. 6).

The above results make up the reference values for the inductive power transfer models. The question is therefore, how large reduction can be achieved regarding the number of AGVs compared to the previously stated 25 pieces.

5.2 *Simulation results for the AGV system with additional IPT-loop charging*

In this case the AGVs are charged on the tracks, therefore discharging has a lower rate. Additional charging track is, however, cannot be avoided like in the conventional case. The number of necessary AGVs is, however, much lower. Simulation results have shown that the necessary number of AGVs are 15.

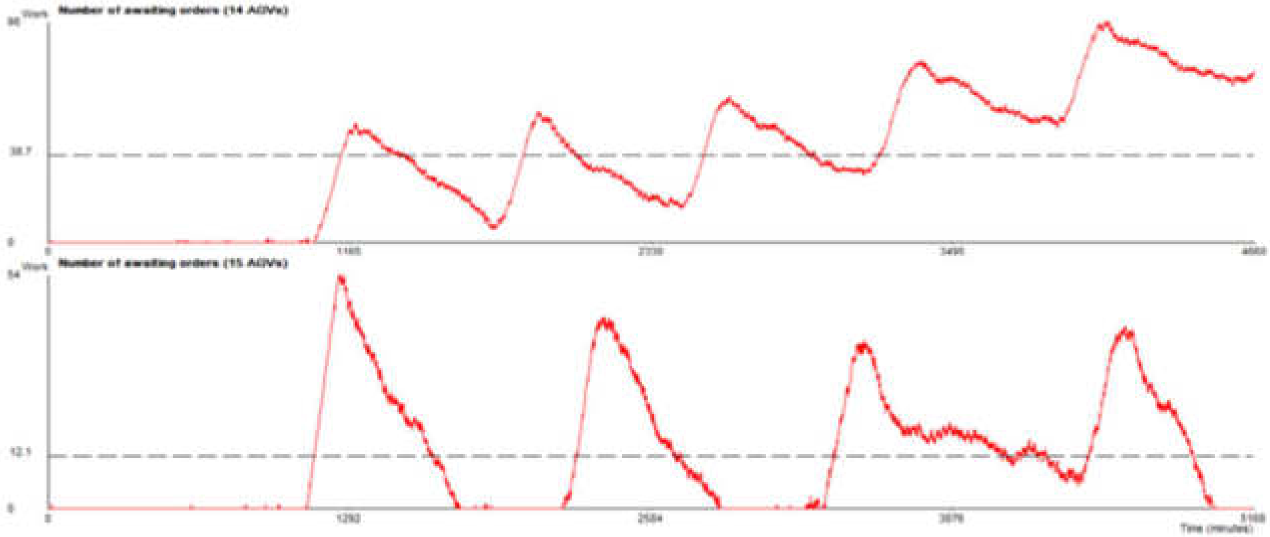

Figure 7 Number of awaiting work items at the input side using IPT tracks

In Figure 7 we can see that the time when the capacity drops under 80% and the AGVs massively depart for extra charging occurs later (around 1202 min instead of approx. 430 min, see Figure 6 for 25 AGVs) using an IPT system, because of the charging along the routes. Figure 7 for the case of 15 machines clearly shows that the system is capable of actively reducing the number of awaiting incoming orders periodically to zero. We remark that the amount of fluctuation can be reduced by a more strictly controlled material flow when not all AGVs are let out for auxiliary charging at the same time.

5.3 *Simulation results for the AGV system with additional IPT charging stations*

In this case during the movement, the capacity decreases, and the battery is charged at the separate charging stations and at the work centres. The simulation runs have proved that in this case 15 AGVs are necessary as well. Results can be seen in Figure 8. in which we can observe that 14 machines are still not enough.

These results made us drawing further conclusions because the simulation runs couldn't decide preference of either IPT systems. We found that if the sum of processing times would be significantly more than the time of related AGV motion than the application of charging stations is preferred. In our example these values were chosen approximately and accidentally almost for same.

There are however other factors which should be considered by the decision of which system to apply. The track type IPT system costs more than the charging stations, so a parallel calculation of these costs is also necessary.

Finally, it should also be considered how significant changes can be expected regarding the layout. If it can be matched to the existing IPT track sections then it brings a great advantage, because repositioning of charging stations causes significant costs.

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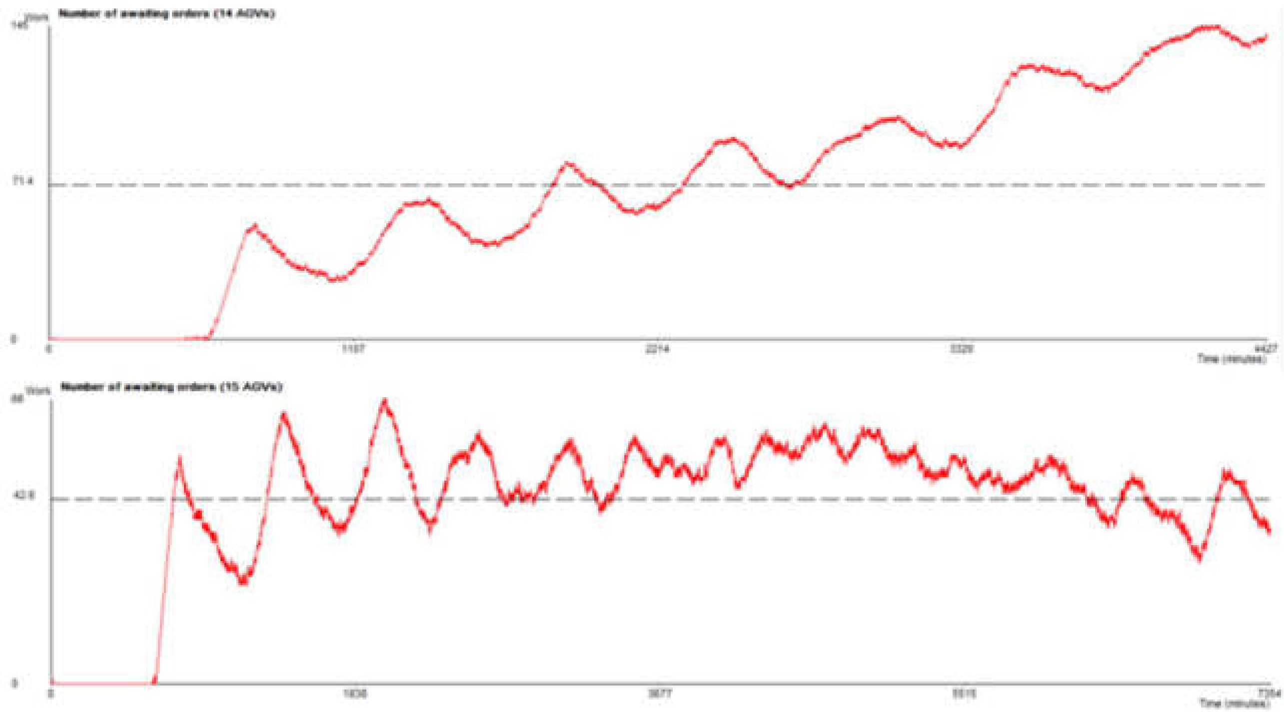

Figure 8 Number of awaiting work items at the input side using additional IPT stations

6 Conclusions

Our simulation proved that first of all, with a well-chosen charging logic, we can achieve serious investment saving, and simulation can effectively support these planning and analysis activities as well. Secondly, using an IPT system for additional charging of AGVs can be used effectively to increase the system capacity. It was also pointed out that both charging stations and tracks can be advantageous depending on the model parameters. This issue can be later an important basis for further examinations. The above scenarios depicted a static scenario that means the incoming material flow is stationer and homogeneous.

Further research concentrates on inhomogeneous and instating material flow which means, the AGVs handle simultaneously multiple different transport tasks, during which the generated path consist of IPT and no charging sections. This requires complex planning to which a theoretical model is needed. Next task of research aims development of this model.

7 Appendix A – Acronyms table

AGV – Automated Guided Vehicle;
IPT – Inductive Power Transfer;
DES Simulation – Discrete Event Simulation;
WIP level – Work in Process.

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REACTION TO RISK IN LOGISTICS COOPERATION – RESULTS OF EMPIRICAL RESEARCH

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Keywords: cooperation, risk, risk transfer, risk reduction, logistics service provider
Abstract: The risk of cooperation with service provider is associated primarily with non-performance of outsourced tasks or with performance not in line with the expectations of principal. Significant factors that affect the risk of cooperation with service provider result from the attitude of parties to cooperation, and also from the external conditions of this cooperation. Undistorted cooperation with logistics service provider, as well as undisturbed flow of goods play a special role in the delivery of goods to recipients. The objective of this article is to present the results of empirical research on reaction to the risk of cooperation with logistics service providers. It is part of the results of a wider research on management of the risk of cooperation with logistics service providers. The research is based on the assumption that attitudes of cooperating parties play a key role in dealing with risk.

1 Introduction

The risk of cooperation with service provider is associated primarily with non-performance of outsourced tasks or with performance not in line with the expectations of principal. The effects of risk may be related to disruptions in relationships with suppliers and recipients cooperating with the client of service provider (described in this article also as principal) and consequently may also result in the increase of logistics costs of principal [1]. Significant factors that affect the risk of cooperation with service provider concern insufficient experience in contract preparation, limited access to information, tendency of parties to opportunism, high specificity of assets used in cooperation, as well as external changes in conditions related to legal regulations, policy and economy [2,3]. The problem of risk management in logistics cooperation including the issue of reaction to risk factors concerning relationships between parties is widely discussed in literature. It is considered particularly in the context of cooperation with logistics service providers [4-7], as well as in the area of cooperation in supply chains [8-11]. Phenomena related to the natural environment also affect the activity of both principal and service provider [12,13].

Undistorted cooperation with logistics service provider, as well as undisturbed flow of goods play a special role in the delivery of goods to recipients. Among the main factors related to logistics, influencing the competitiveness of suppliers of such goods, efficiency management, organization of flows, capital investments (in infrastructure and equipment), focus on searching and implementing innovations, and the ability to forecast demand are distinguished [14]. Cooperation with suppliers is often associated with long-term contracts, based on joint improvement of the parties' activities. The assumption of a long period of cooperation is related to the ability of cooperating parties to adapt to changing conditions in the environment [12,13].

The objective of this article is to present the results of empirical research on reaction to the risk of cooperation with logistics service providers. It is part of the results of a wider research on management of the risk of cooperation with logistics service providers. The research is based on the assumption that attitudes of cooperating parties play a key role in dealing with risk. *(The publication was financed from the resources allocated to the Management Faculty of Cracow University of Economics under the grant for the maintenance of the research potential).*

2 Methodology

The article presents the results of research carried out in enterprises cooperating with logistics service providers. In the research, suppliers of goods for customers, logistics operators, as well as freight forwarders were included. The data presented was collected using a questionnaire addressed to representatives of enterprises operating in Poland, responsible for ordering and further monitoring of the service. The activities of the surveyed enterprises included production, trade, comprehensive logistics service and forwarding. Most of them have at least several years of experience in cooperation with suppliers of specialized service in the area of logistics. The obtained data was analyzed using the assumptions of the FMEA method. The research was of a pilot nature.

In general, risk factors affecting cooperation with providers of logistics service can be divided in two groups. The first group includes factors representing the performance of logistics service: errors, damages and delays in deliveries [15]. The results discussed in this article concern the second group of factors, related mainly to the attitude of employees representing principal and provider of logistics service. The occurrence of these factors may be related to changes in parties' approach to cooperation as a result of new, unforeseen changes in the environment of cooperation. They can be considered as factors influencing further problems in the area of logistics performance. The identification of factors related to parties' attitude to cooperation is based on the typology of transactional, operational and strategic risk factors presented in literature [16,17]. The typology of risk factors prepared for research is also based on opinions of employees responsible for cooperation with logistics service providers in enterprises.

In this article, the point of view of principal is considered. It includes factors related to general terms of cooperation with service provider, as well as factors caused by logistics service provider. However, it should be noted that factors shaping the terms of cooperation are usually the result of joint decisions of principal and service provider. Depending on the relationship between these parties, the influence of each party on shaping the terms of cooperation may differ significantly.

Presented assumptions of risk factors taken into consideration in the research, as well as threats influenced by these risk factors and potential consequences for cooperation are presented (Table 1).

Table 1 Risk of cooperation with logistics service provider, threats and consequences for client [16,17]

Risk factors	Potential threats	Potential consequences for cooperation
Tendency of provider to take advantage of opportunities for his own interest, affecting the disruption of deliveries to principal and his recipients.	Differences between provider's offer and his real ability to perform the assigned tasks, excessive dependence of client on the service provider, conflicts between partners destroying cooperation.	Complaints from principal, his suppliers and recipients regarding cargo safety, way of transport in supply and distribution, possibility of reducing the scope of cooperation or loss of principal's recipients.
Opportunistic limitation /obstruction of principal's access to information held by service provider regarding the performance of the outsourced service.	Differences between offer of logistics company and its real ability to provide service, limiting the knowledge of principal, his suppliers and recipients about the quality of order fulfilment by service provider.	Low quality of service, complaints from principal, his suppliers and recipients concerning cargo safety, way of transport in supply and distribution, possible loss of recipients by principal.
Dependence on the provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation (this applies for example to adaptation of loading and unloading points to the methods of goods flow used by provider).	Long period of time for coordination of activities and solving problems in cooperation with provider, reduced influence of principal on the adjustment of the service provider to changes in the principal's logistics needs.	Difficulties in planning activities by principal, possibility of losing the ability to make independent decisions on further activity of principal, possibility of market loss by principal.
Insufficient commitment of logistics service provider to improvement of cooperation with principal.	Failure to notice disturbances and errors in principal's business, too slow development or lack of development of principal's activity.	Delays in adapting to new requirements of suppliers and recipients of principal, difficulties in planning of activities, weakening market position of principal.
Insufficient experience of principal in cooperation with logistics service provider.	Difficulties in understanding mutual expectations of parties to the contract, difficulties in determining the expected effects of cooperation.	Too long negotiations of the terms of cooperation, possibility of losing the ability to make independent decisions on further activity of principal, insufficient quality of service provided.
Lack of assignment of responsibility for updating information about logistics service market and new offers of providers addressed to employees /organizational units of principal.	Lack of knowledge about current state of offers, excessive costs of obtaining the expected quality of service (if there are units on the market that offer similar quality at a lower price).	Long period of time to acquire new service provider after termination of cooperation with the existing one, difficulties in providing the expected level of logistics service.
Differences in risk perception and assessment between principal and provider of logistics service.	Problems in communication of risk between partners, misunderstanding of mutual expectations by parties to the contract.	Disruptions in the implementation of the terms of cooperation, conflicts with service provider related to disruptions.

As one of the most important results of the research conducted, the significance of the impact of each risk factor on cooperation between principal and service provider was estimated. It should be added that factors with previously estimated insignificant impact on cooperation, without requirements to take any actions in response, may also gain more importance in further period of cooperation. Therefore, the occurrence and strength of the impact of individual risk factors should be monitored on an ongoing basis. Although the reaction in response to the increase in their impact mainly consists in limiting the effects of occurrence, the lack of any reaction may result in significant additional costs.

The next step of the research was to determine important actions taken in response to the risk of cooperation with logistics service provider. These actions can be treated as a response to identified risk factors (Table 1). Taking into account these risk factors, the principal may independently take specific actions affecting the behavior of service provider or may also undertake activities jointly with service provider. Activities in response to risk may be of a different nature. Using the typology of risk management methods proposed for the concept of risk management in project management, the following general types of risk response can be distinguished [18,19]:

- acceptance of risk and its potential effects as they are – this approach is characteristic for factors with estimated low impact (taking action to reduce the impact of risk factor would be associated with the need to incur higher expenses than the costs associated with the results of this risk factor),
- reduction or complete elimination of the probability of occurrence of risk factor and its consequences – it concerns situations where it is possible to influence the source of risk so that the risk factor does not arise or despite the lack of influence on the risk source it is possible to limit the likelihood of occurrence of a threatening factor,
- transfer of consequences of the risk factor influence on principal's activities – by insurance, guarantees or the division of outlays on the implementation of activities between cooperating units, appropriate for the risks which can be insured; it is important to compare the costs of insurance and of the risk effects,
- reducing consequences of impact (determining the activities that will be implemented if the risk factor occurs, related to the development of the so-called contingency plans) – such actions do not affect the probability of risk occurrence, but reduce its potential effects by minimizing the time necessary to respond to a specific event.

It should be added that due to the subject of the conducted research, the first type of response to risk (accept risk and take no actions in response) was not included in further part of the discussion.

According to the characterized types of response to risk, different types of activities representing different types of risk responses were included in the questionnaire. A typology of actions was developed based on the approaches presented in literature [12,13,20-24]. It also included consultations with logistics managers of the surveyed enterprises to determine adequate activities, taking into account the specificity of the logistics service market and logistics itself in achieving and maintaining a competitive advantage.

3 Results of research

The results of the first part of research concerning the significance of risk factors, as well as the results of further part of the study related to identification of the importance of particular actions in reaction to each risk factor were reported in other separate publications. In this article, the relevance of individual actions appropriate for response to each risk factor is presented.

Table 2 The importance of types of reaction to risk factors in logistics cooperation

Position	Type of action taken in response to the risk
1.	Renegotiation resulting in changes of cooperation terms with existing service providers.
2.	Extending the scope of control of tasks performed by service providers.
3.	Complementary training of employees of principal cooperating with provider.
4.	Extending the scope of tasks of employees representing principal in cooperation.
5.	Changes in internal procedures concerning logistics activity of principal.
6.	Starting cooperation with a new service provider.
7.	Termination of cooperation with existing service provider.
8.	Involving additional staff from other organizational units of principal in cooperation.
9.	Transfer of selected responsibilities of logistics employees to other organizational units of principal.
10.	Learning from an experienced service provider.

Based on information concerning the frequency of use of individual types of actions in response to each risk factor included in the study, a summary of risk-response activities was made in order from the most to the least used actions. It is presented in prepared ranking of individual types of actions in Table 2. The higher position (lower number) in the table means that the considered action is more often used.

Based on the types of actions listed in Table 2 it can be stated that the most commonly used response to risk in cooperation with logistic service providers is renegotiation resulting in changes of cooperation terms with existing service providers. This type of action has been identified in the research as suitable primarily in conditions of the appearance of such risk factors as:

- difference in risk perception and assessment between principal and provider of logistics service,
- insufficient experience of principal in cooperation with logistics service provider,
- dependence on the provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation,
- opportunistic limitation/obstruction of principal's access to information held by service provider regarding the performance of the outsourced service,
- tendency of provider to take advantage of opportunities for his own interest, affecting the disruption of deliveries to principal and his recipients.

Renegotiation and changes in cooperation terms with existing service providers represent the types of attitudes to risk such as risk transfer or reduction of risk results. Renegotiation resulting in transfer of risk is associated with the need to change the scope of each party's commitment to cooperation and the resulting need to increase the level of benefits for partner who bears more risk. This approach is related to preparation for future risk factors. Negotiation of existing terms of cooperation may also be aimed at eliminating current problems occurring in day-to-day cooperation. In this situation, the considered action is implemented to reduce the results of risk factors that have already occurred.

Another type of action in response to the risk of cooperation with service provider included in the study is extending the scope of control of tasks performed by service providers. This action is considered appropriate in response to the following risk factors:

- difference in risk perception and assessment between principal and provider of logistics service,
- insufficient commitment of logistics service provider to improvement of cooperation with principal,
- opportunistic limitation/obstruction of principal's access to information held by service provider regarding the performance of outsourced service,
- insufficient experience of principal in cooperation with logistics service provider.

According to the results of the conducted research, the type of action mentioned above is applied less frequently in response to such risk factors as tendency of provider to take advantage of opportunities for his own interest, affecting the disruption of deliveries to principal and his recipients, as well as dependence on the provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation. This type of action usually represents an attitude based on efforts to reduce the effects of risk occurence. It means, therefore, striving to reduce mistakes made by service provider, resulting in disruptions in principal's activity and dissatisfaction of his recipients and suppliers. Extended control of provider's performance is usually a reaction to already ocurring risk factors. However, under certain conditions, it may be treated as a way to reduce the probability of occurrence of cooperation risk in the future, when the principal considers provider's experience to be insufficient.

Another kind of action used in response to the risk of cooperation with provider of logistics service is complementary training of employees of principal cooperating with provider. This applies particularly in reaction to such risk factors as:

- difference in risk perception and assessment between principal and provider of logistics service,
- lack of assignment of responsibility for updating information about logistics service market and about new offers of providers addressed to employees/organizational units of principal,
- insufficient experience of principal in cooperation with logistics service provider.

The considered type of action is less frequently undertaken in response to other risk factors such as dependence on logistics service providers associated with the costly involvement of principal in infrastructure adaptation to the needs of cooperation and opportunistic limitation/obstruction of principal's access to information held by service provider regarding the performance of the outsourced service. This type of action is also occasionally used as a reaction to such risk factors as insufficient commitment of logistics service provider to improvement of cooperation with principal or the tendency of provider to take advantage of opportunities for his own interest, affecting the disruption of deliveries to principal and his recipients. Emphasizing the complementary nature of training of employees involved in cooperation with service provider it can be concluded that it represents the type of response to risk defined as a reduction of risk results.

The action regarding the extension of tasks of client's employees in cooperation with service provider is a solution implemented much less frequently than other actions presented so far. This applies to taking over by these employees some broader tasks related to preparation and coordination to ensure greater integration of cooperation. This is usually a reaction to such risk factors as:

- difference in risk perception and assessment between principal and provider of logistics service,
- lack of assignment of responsibility for updating information about logistics service market and about

new offers of providers addressed to employees/organizational units of principal,
- dependence on the provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation.

The action presented here plays a minor role in the case of reaction to such factors as insufficient commitment of logistics service provider to improvement of cooperation with principal, opportunistic limitation/obstruction of principal's access to information held by service provider regarding the performance of the outsourced service, insufficient experience of principal in cooperation with logistics service provider, tendency of provider to take advantage of opportunities for his own interest affecting the disruption of deliveries to principal and his recipients. The considered action represents the type of reaction to risk reducing the results of risk occurrence. It can also serve as a tool to reduce the probability of occurence of risk factors in future cooperation.

According to the results of the conducted research it can be concluded that extending the scope of tasks of the client's employees cooperating with service provider, as well as changes in procedures of principal's internal logistics activity are of similar importance in response to the risk of cooperation with logistics unit. Extending the scope of tasks performed by principal's logistics employees may be related to the need to implement adjustments to existing procedures and to the need to develop new procedures. Changes in procedures of principal's internal logistics activity play a special role in responding to such risk factors as:
- dependence on the provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation,
- insufficient experience of principal in cooperation with logistics service provider.

The considered type of action is less frequently used as a reaction to the lack of assignment of responsibility for updating information about logistics service market or in the case of new offers of providers addressed to employees/organizational units of principal. Occasionally it is also a reaction to the tendency of provider to take advantage of opportunities for his own interest, affecting the disruption of deliveries to principal and his recipients. This action is the least likely reaction to such risk factors as a difference in risk perception and assessment between principal and provider of logistics service, insufficient involvement of the logistics service provider in improvement of cooperation with principal and opportunistic limitation/obstruction of principal's access to information held by service provider regarding the performance of the outsourced service.

The previously presented types of actions reflect mostly the reactions to risk related to transfer of risk and reducing the consequences of risk factors. Changes, and in particular improvement of internal procedures of principal's logistics activity, reflect focus on reducing the probability of occurrence or even complete elimination of risk factors and their consequences. Although errors in procedures can be revealed through errors and misunderstandings in actions, an improvement of these procedures makes it possible to eliminate sources of risk.

The results of the conducted research also indicate types of actions used less frequently in reaction to the risk of cooperation. The example is cooperation with a new service provider. It is implemented especially as a reaction to such risk factors as:
- insufficient commitment of logistics service provider to improvement of cooperation with principal,
- opportunistic limitation/obstruction of principal's access to information held by service provider regarding the performance of the outsourced service,
- tendency of provider to take advantage of opportunities for his own interest, affecting the disruption of deliveries to principal and his recipients.

The considered solution is also occasionally used as a reaction to difference in risk perception and assessment between principal and provider of logistics service and as a reaction to dependence on the provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation. Starting cooperation with new service provider represents the orientations based on risk transfer and on reduction of the results of risk occurence. New service provider may also take over the responsibility for cooperation of principal with his existing suppliers and recipients of goods. Cooperation with new service provider can also be a way to discipline existing service providers.

The aforementioned solution consisting in undertaking cooperation with new service provider may be the consequence of another type of action concerning termination of cooperation with existing service provider. The greater usefulness of the previously presented type of action indicated in the research means that it is more widely used than the termination of cooperation with existing service provider. The termination of cooperation is characteristic as a reaction to such risk factors as:
- insufficient commitment of logistics service provider to improvement of cooperation with principal,
- dependence on the provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation,
- tendency of provider to take advantage of opportunities for his own interest, affecting the disruption of deliveries to principal and his recipients.

The presented solution in response to the risk of cooperation is also used, but less frequently, as a result of difference in risk perception and assessment between principal and provider of logistics service, in the case of dependence on provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation, as well as in the case of opportunistic limitation/obstruction of principal's access to information held by service provider regarding the performance of the outsourced service. The action consisting in termination of cooperation with existing service provider most often represents an attempt to reduce the results of the risk factor occurence.

According to the results of the conducted research, among the least used solutions in response to risk in logistics cooperation is the involvement of employees of other organizational units of principal's company in relationship with service provider. This solution was indicated as significant in conditions of the provider's tendency to take advantage of opportunities for his own interest, affecting the disruption of deliveries to principal and his recipients. On the other hand, such a response is rarely taken into account in the case of a difference in risk perception and assessment between principal and provider of logistics service, insufficient commitment of logistics service provider to improvement of cooperation with principal, in the cases of dependence on the provider of logistics service related to costly commitment of principal to infrastructure adaptation to the terms of cooperation and opportunistic limitation/obstruction of principal's access to information held by service provider regarding the performance of the outsourced service. Little interest in the application of such a solution results in particular from its specificity and focus on increasing the level of integration of the activities of principal and provider of logistics service. Such an integration may be a manifestation of approach concerning reduction or even complete elimination of the occurence of risk factor.

The type of action which is occasionally implemented is the transfer of some responsibility from logistics employees to employees of other organizational units of principal's enterprise. It has been used as a reaction to such risk factors as lack of assignment of responsibility for updating information about logistics service market and about new offers of providers addressed to employees/organizational units of principal, and also as a reaction to insufficient experience of principal in cooperation with logistics service provider. The considered type of action may represent the orientation towards reduction or elimination of the probability of the occurence of risk factors. More often, however, it is a reaction to already occurring problems, associated with improper allocation of aforementioned competences and errors when establishing and conducting cooperation resulting from principal's lack of experience in cooperation with provider of logistics service.

According to the results of the conducted research, the type of action that is rarely used but seems to be currently up-to-date, especially in terms of focusing on organizational learning, is the response to risk defined as learning from an experienced service provider. Such a response is taken into account in the circumstances of insufficient principal's experience in cooperation with a logistics service provider. It may reflect the orientation towards reduction of the results of the risk factor occurence. However, this action can also be treated as being undertaken in order to reduce the probability of risk occurrence or to completely eliminate the source of risk.

4 Discussion and conclusion

The significance of response to risk of cooperation involving renegotiating the terms of cooperation with existing logistics service providers may result from considerable experience and knowledge of respondents of problems and disruptions in cooperation related to changes of service providers. Due to the importance of logistics in achieving and maintaining competitive advantage, these problems can significantly affect the satisfaction of suppliers and recipients of goods from principal. The focus on continuation of cooperation, even in conditions of mistakes made by service provider, also confirms the frequency of extending the scope of control of tasks performed by service providers.

According to the results of the conducted research, the improvement of cooperation with logistics service provider is also related to the development of principal's employees and extending the scope of tasks of employees involved in relationship with logistics service provider. This approach reflects the importance of human resources in ensuring lasting and undistorted cooperation. It may be accompanied by improvement in the organization of cooperation, which is reflected in changes in the internal procedures of principal's logistics activity.

The fact that termination of cooperation with existing service provider, sometimes followed by the start of cooperation with a new provider, is used much less frequently than other aforementioned types of actions may indicate significant maturity of participants of the research and their experience in cooperation with providers of logistics service. Independently it should be added that starting cooperation with a new service provider, while maintaining relations with existing providers may result from the decision to increase the scope of cooperation.

Focus on concentration of responsibility for cooperation with service providers among employees of principal's logistics activity may be reflected in little interest in involvement of additional staff from other organizational units of principal in this cooperation, as well as little importance of transfer of selected responsibilities of logistics employees to other organizational units of principal's company.

Research results presented in the article, regarding the application of considered types of actions in response to identified risk factors may be useful for practice of cooperation with logistic service providers. These results reflect opinions of respondents regarding the effectiveness of each type of action. However, results obtained in the research have some limitations. Further research may refer to attempts to determine suitability of identified types of actions in response to risk, depending on the scope of logistics activities performed by service provider, expected period of cooperation with this provider, as well as market conditions in the environment of cooperation between principal and service provider.

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THE OVERLOOKED DEPENDENCIES OF MATERIAL FLOWS ON QUALITY AND QUALITY ASSURANCE

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Keywords: material flow, material handling, quality, inspection errors, yield rates

Abstract: The flow of materials is a major constituent of in-plant logistics and similar factors govern resource requirements and material flows. In particular, quality factors and the configuration of the quality assurance – the inspections' system. Nonetheless, no study considers the association between and the dependencies of material flows on quality levels and the configuration of the inspections' system. The configuration of the inspections' system affect the structure of the material flow network by adding nodes – inspection stations, to it and changing the paths, accordingly. In addition, the quality levels, the configuration of the inspections' system, and inspection error rates significantly affect the volumes of material flows. These effects are quantified, demonstrated and discussed in this study.

1 Introduction

"Material handling is of extreme importance to logistics and manufacturing industries as it accounts for a large percentage of the operation."[1] This work is concerned with the flow of materials in manufacturing processes which can be conducted either inside a single facility or be distributed between several links of a supply chain. Material flows are a primary input to facilities' design and to the design of the material handling (MH) system, and the flows, the layout and the MH system significantly affect the performance of the entire system – production or service system [1-7].

Even larger attention has been drawn to quality issues, but the vast majority of the quality and operations systems research, naturally focuses on operations management. Still, the dependency of the volumes processed in production/manufacturing facilities and consequently, of capacity and resource requirements on quality has been noticed in the facilities' design literature. However, while similar factors govern resource requirements and material flows, no study associated quality and the configuration of the quality assurance system with material flows and the design of the MH system. This is the aim of this work: to study and characterize the association between and the dependencies of material flows on quality and on the configuration of the quality assurance – the inspections' system.

2 Literature survey

To locate this study within the existing body of literature, it is best to refer to the description in [2], where two approaches for facility design are discussed. Both approaches involve complex processes, but in both there is a single origin, which provides the necessary input information for the whole design process. In the first approach, it is termed 'material flow calculations', while in the second this initial phase is decomposed into two steps: 'input: production data' and 'handling relations'. Similarly, in the well-known systematic layout planning (SLP) methodology [4,5,7], the design begins with input data collection from which material flows and resource requirements are derived. This study is concerned with these initial steps, more accurately, with the translation of the production data into both material flow calculations and handling relations and, in particular, with the dependencies of material flows on quality issues.

Quality issues have drawn large attention, but the vast majority of the quality and operations systems research, naturally focuses on operations management. Operations are managed in an existing system where the capabilities and capacities of the resources are given, at least for the near future. Resource availability constrains and often limits system's operation. The question is, then, what is the best that can be done with, or how to best utilize, the available resources. This is often termed throughput analysis (e.g., [8]). However, there are other, no less important questions, including the question of what are the appropriate resources? What are the required capabilities and capacities? What amount of each resource will best satisfy the requirements? These issues are usually of concern with respect to production resources but are of no less significance with respect to MH resources (e.g., [9,10], which are 'throughput analysis' studies).

Resource requirements, quality and flows are central issues in the facilities design literature, which tells us (e.g., [3-6]) that extra capacity is required to compensate for yield losses due to imperfect quality. Yet again, the results are rather limited. First, "very limited work exists in analyzing assembly system quality when multiple products are produced in the same system" [11]. Quality issues, including inspection errors, like other components of manufacturing/production systems, are stochastic in nature. Stochastic models of production systems (e.g., [12,13]) are usually based on queuing theory and hence, consider processing and productive times, while here the production quantities are of concern. Some (e.g., [6,13])

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translate the changes in quantities to time by inflating processing times, but this approach is limited in its ability to cope with assembly systems of multiple products, which are of major concern in this study.

The work of Eben-Chaime [14] is, perhaps the first step in this direction (and note the difference between the analysis in [14] and the incomplete/imperfect analysis in Appendix A of [6]), but even in this work inspections and inspection errors are disregarded. A common method for coping with defective items is to make inspections (e.g., [15-19]). Nevertheless, focusing on quality, most studies on inspections (e.g., [17-19]) concentrate on error type II – missed defective units, while taking no notice of the waste which is associated with type I errors – false rejections. Very few studies, if any, consider assembly system quality with inspections and inspection errors of both types. Furthermore, while similar factors govern resource requirements and material flows, no study considers the association between and the dependencies of material flows on quality and the configuration of the quality assurance – inspections', system. The configuration of the inspections' system affect the structure of the material flow network by adding nodes – inspection stations, to it and changing the paths, accordingly. In addition, the quality level, the configuration of the inspections' system, and inspection error rates significantly influence the volumes of material flows. These effects are discussed quantified and demonstrated in the sequel.

3 Method

Without loss of generality, the dependencies of the material flows on the quality level and the configuration of the inspection system are demonstrated by several numerical examples. Basically, the method follows the principles in [14], yield rates are calculated in an opposite direction to material requirements (required quantities), the inversion of the input-output relationships, the actual yield (defect) rates of assemblies, etc. However, inspections are not considered in [14] and their inclusion require some modifications. First, the *product structure* does not include inspections and hence, should be replaced by another model. Besides, inspections are activities not components. Hence, to includes inspections, the description should be of the manufacturing/production process. Then, calculations of conforming rates and required inputs, similar to the calculations of material requirements and actual yield rates of assemblies, should be developed for inspections.

3.1 Process description

An excellent process description is the *operations process chart* (OPC), which is discussed briefly towards the end of [14]. "The operations process chart is one of the most useful techniques in manufacturing planning. ***Actually, it is a 'diagram' of the manufacturing process***. It has been used in many ways as a planning and control device. With the addition of other data, it can be extremely useful in manufacturing management" [3]. Moreover, the manufacturing/production process of each product can be described completely by a single OPC, even when the process is decomposed into sub-processes' which can be performed at different locations and/or by different organizations. The OPC of the product used in this study is portrayed in Figure 1 and includes the three most common activities: operations, which are represented by circles, inspections, which are represented by rectangular boxes, and material flows to which the arrows correspond. The arrows describe the flow of materials between subsequent activities and are directed according to the flow of the process. It should be noted that each branch – a series of operations, in an OPC correspond to a component of the product while operations with more than a single entry depict assemblies where the entering arrows correspond to the components. The activities are numbered to facilitate communication. These are the top numbers in the circles and boxes: 0 and 3 are assembly operations, 1, 2, 5 and 6 are inspections and the rest are regular (non-assembly) operation.

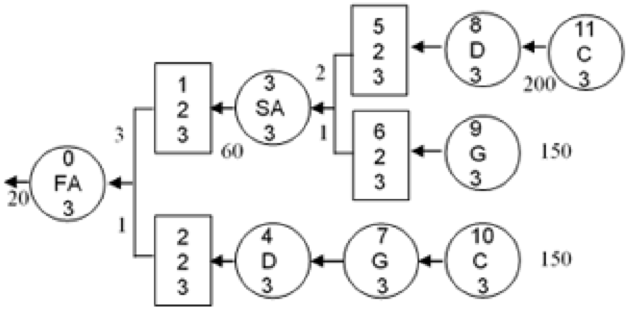

Figure 1 An extended operations process chart

The OPC in Figure 1 is an extended version, which contains additional information as suggested by Apple. The letter in the middle of each circle is the station type which has been chosen to do the operation, while the number on the circle's bottom is the mean defect rate, d_i, in percents, 3 = 3%. There is some freedom to choose the station type for each operation, which is highly significant, but the calculations need to be done for each combination of choices because the defect rate (and the processing time) depends on both the operation and the station where it is performed. In the sequel, let $d_{i,j} > 0$ only for the chosen station type. The numbers in the boxes, below the activity number, are the error rates: type I, α_i, in the middle and type II, β_i on the bottom. The single digit numbers by the arrows are the assembly ratios, which are specified in the bill of material of each product (e.g., [6,20], while the larger numbers are the number of units per material handling trip. Namely, in operation 3, two unit of the component which arrives from inspection 5 are assembled with a single unit of the other component and in operation 0, a single unit of the component on the lower branch is added to three sub-assemblies. Likewise, the assembled units moved from operation 0 onward in lots of 20 units, while the units on the lower branch are moved in lots of

150 units all the way from the raw material storage up to operation 0. Like the defect rates which depend on the choice of station, the number of units per trip depend on the choice of MH equipment. Thus, the configuration of the MH system has a significant influence on system's performance, but again, the calculations need to be done for each configuration.

3.2 Assumptions

The calculations in the next sub-section are based on certain assumptions, which are listed below. Of course, these assumptions do not hold completely, but even so, the results provide very good approximations.

1. The workstation has already been specified for each operation.
2. The operations are independent of each other.
3. The inspections are independent of each other.
4. The operations and the inspections are independent of each other.
5. All processes are statistically in control.
6. Defective units are detected only by inspections.
7. Each defective unit is removed as soon as it is detected.

As noted, there is some freedom to choose the station type for each operation, but the calculations need to be done for each combination of choices. Assumptions 2–4 are used in the calculations of the yield of serial processes and in the calculations below. These assumptions are quite reasonable, as different operations/inspections are performed at different stations. Assumption 5 implies that items turn defective due to random causes only, in an independent manner (e.g., [16]). Some defective units might be rejected not by inspections, but the numbers are small and assumption 6 greatly simplify the presentation. The calculations can be modified to handle cases where assumptions 6 and 7 do not hold. Finally, mean defect rates and mean error rates are used, since long-term performance of repeated processes are considered.

3.3 Calculations

First, recall the basic principle noted in [14]. Production planners know how many end items are needed and from these figures, order quantities are calculated backward – opposite to the direction of the OPC's arrows, as in material requirements planning [20]. Further, defective units cannot be used as intended. Hence, more units should be produce to replace any defective unit. Consequently, the simple input-output relationships, with imperfect quality: $Q^{out} = (1-d) \cdot Q^{in}$, where d is the mean defect rate, should be inverted:

$$Q^{in} = Q^{out}/(1\text{-}d). \quad (1)$$

In the sequel, the conforming or yield rate: $y = 1\text{-}d$, is used for convenience.

Recall also the actual yield rate, y_A^a, of assembly operations, which, for an assembly operation with K component types, assembly ratio $m(k)$, component conforming rates y_k and self defect rate d_A, is:

$$y_A^a = (1 - d_A) \prod_{k=1}^{K} y_k^{m(k)}, \quad (2)$$

where the self defect rate d_A in the portion of the units that turn defective during the assembly. Eq. (2) can be generalized to include non-assembly operation, too, by letting K be 1; i.e., a single component type, whose assembly ratio $m(1) = 1$, too. Accordingly, m(k) = 1 anywhere in Figure 1, unless a larger value is specified explicitly. Due to the use of the conforming rates of the components, these yield rates should be calculated first. Hence, yield rates are calculated forward – along the direction of the OPC's arrows.

An addition of this study, is the inclusion of inspections and inspection errors. By assumptions 6 and 7, above, units are removed from the process by inspections. Hence, inspections' output is smaller than the input. Assemblies' output is also smaller than the input but for a different reason – the join of several components to form a single (sub)assembly, and by assumption 6, the output of a regular operations equals its input. The units removed are of one of two types: defective units and falsely rejected units, due to type I errors. With the 'contribution' of type two errors, the approved units are also of one of two types: conforming units and missed defective units. Let d be the defect rate upon arrival to an inspection, α the type I error rate and β the type II error rate. Then, the portion of units that continues after the inspection is: $\beta \cdot d + (1-\alpha) \cdot (1-d)$ and the conforming rate upon leaving the inspection is:

$$(1-\alpha) \times (1-d) / [\beta \times d + (1-\alpha) \times (1-d)]. \quad (3)$$

However, inspections fix nothing. It is the removal of the defective units detected by the inspections that improves the outgoing quality. Further, usually one cannot tell whether a rejected unit is defective or a false rejection, whenever units are rejected more units must be produced to replace them – any rejected unit requires compensation. Hence, the required input of an inspection is:

$$Q/(1-\alpha) \times (1-d). \quad (4)$$

Following the description above, each OPC is traversed twice. First, with the direction of the arrows, conforming rates are calculated using the generalized Eq. (2) for operations and Eq. (3) for inspections. Upon arrival to the last activity, the overall yield rate of the whole process is obtained. Then, a backward traverse is conducted. The process yield rate is substituted in Eq. (1) to derive the required input to the last activity for the desired input. Then, going back on each arrow the required input for the activity in the arrow's head is multiplied by the assembly ratio on the arrow, $m(k) = 1$ if not specified otherwise, to determine the required output from the activity on the arrow's tail, and Eq. 4 is employed whenever an inspection is encountered.

4 Results

Key factors, as noted in the introduction, are the volumes of material flows, which are derived from the volumes of material requirements. Consequently, material requirements are considered first.

4.1 Yield rates and material requirements

Material requirements, as also noted, depend on the yield rates. Hence, the calculations begin with these rates. The calculations are demonstrated on a couple of simple cases – no inspection and a single, final, inspection after operation 0. No inspection means that the inspections in activities 1, 2, 5 and 6 are inactive. That is: $\alpha = 0$ and $\beta = 1$ for all four inspections. Assuming, for convenience only, that the arriving materials to operations 9, 10 and 11 are of perfect quality, the yield rate of each is 97%. Substituting this value in Eq. (2) for operations 7 and 8 result in 94.09% yield rate for both. Continuing from operation 7 to operation 4, the yield rate of the latter is about 91.27%. Passing over the inactive inspections 5 and 6, the yield rate of the assembly operation 3 is: $0.97 \cdot 0.9409^2 \cdot 0.97 \approx 83.3\%$, where the first 0.97 is the self defect rate of the assembly, while the 0.97 at the end corresponds to the component which arrives from operation 9. The term is the middle corresponds to the component that arrives from operation 8 and is squared because its assembly ratio is 2. Passing, again, over the inactive inspections 1 and 2, the yield rate of the assembly activity 0 can be calculated: $0.97 \cdot 0.9127 \cdot 0.8333 \approx 51.17\%$. Noteworthy are the assemblies' mutual effects – the dramatic drop of the yield rates in operations 3 and 0. In this example, the last value: 51.17% is the process yield rate, too – the outgoing quality. This implies that just a little less than half of the assembled units are defective. Consequently, in order to produce say, 1,000 conforming units, 1,000/0.5117 ≈ 1,954.4 units should be assembled, on average, knowing that on average, 954.4 of them will be waste.

Traversing back on the OPC, no assembly is conducted on the lower branch of the chart and hence, the same number: 1,954.4 units are required in operations 4, 7 and 10. Since 3 units of the sub-assembly, which are assembled in operation 3 are assembled in each unit in operation 0, about 5,863.3 sub-assemblies are required. The assembly ratio of the components which arrive through operation 9 is 1, 5,863.3 units are required of this component, while some 11,727 units are required of the other component, whose assembly ratio is 2. Note again the assemblies' mutual effects. Of the 1,954.4 units which arrive to operation 0 from operation 4, only about 8.7% or 170.6 units are defective, on average. Another 1,954.4 - 1,000 - 170.6 = **783.8** units, are conforming units which will either be assembled with defective sub-assemblies or the assembly will turn defective in operation 0. The same hold for the sub-assembly: 979.3 defective sub-assemblies arrive to operation 0, out of 5,863.3 and only 3,000 are required to assemble 1,000 units in operation 0. This leaves **1,884** conforming sub-assemblies, on average, which will either be assembled with defective mates (sub-assemblies) or defective unit of the other component, or the assembly turn defective in operation 0.

A simple, perhaps the simplest, way to improve the outgoing quality is to inspect the assembled units when leaving operation 0. Assuming that $\alpha = 2\%$ and $\beta = 3\%$, as specified for all the inspections in Figure 1, another 2% of the conforming assemblies will be falsely rejected. Thus, only $0.98 \cdot 0.5117 \approx 50.14\%$ of the assembled units will pass the inspections. In parallel, 3% of the defective assemblies, a bit less than 1.5% of the assembled units will be missed by the inspection. The resultant outgoing quality is, thus, 97.16% (roughly 0.5014/(0.5014+0.015), up to the rounding of the numbers). While this is a significant quality improvement, the required input has grown, according to Eq. (4), to 1994.3 units, on average, adding yet more waste.

Three more cases, where some in-process inspections are active, have been analyzed: inspection 1 and 2 are active; inspections 5 and 6 replace inspection 1, that is 2, 5 and 6 are active; and all four inspections are active. The results are summarized in Table 1. In the left column in the table, A#, the activity numbers are listed. In the next column, S#, the successor of each activity, the activity at the head of the arrow pointing out from the activity in A#, is shown. These activity-successor pairs play important role in analyzing material flows. In the column headed 'type', the station type chosen for each activity – the letter in its circle in the OPC, is shown. "I" in this column indicates inspection. In the column headed '$m(i)$', the assembly ratios are listed while In the column headed 'u/t', the numbers of units per MH trip are listed. The remaining columns are paired – a pair for each case. In the left column in each pair, which is headed 'volume' the material requirements are listed. The numbers calculated above appear in the two pairs on the left: no inspection and final inspection. In the right column of each pair the number of MH trips are listed. These numbers are obtained by dividing the corresponding volume by the corresponding number of units per trip. The number of trips on the row of operation 0, for example, are the corresponding volumes divided by 20.

Table 1 Material requirements and material flows

A	S				No inspection		Final inspect.		Inspect. 1+2		Inspect.2+5+6		Ins. 1+2+5+6	
#	#	type	$m(i)$	u/t	volume	trips	volume	trips	volume	trips	volume	trips	volume	Trips
0			1	20	1954.4	97.7	1994.3	99.7	1053.1	52.7	1149.3	57.5	1037.4	51.9
1	0	I	3	60					3870.2	64.5			3289.5	54.8
2	0	I	1	150					1177.4	7.85	1284.9	8.57	1159.8	7.73
3	1	SA	1	60	5863.3	97.7	5983	99.7	3870.2	64.5	3447.8	57.5	3289.5	54.8
4	2	D	1	150	1954.4	13	1994.3	13.3	1177.4	7.85	1284.9	8.57	1159.8	7.73
5	3	I	2	200							7478.3	37.4	7135	35.7
6	3	I	1	150							3627	24.2	3460.5	23.1
7	4	G	1	150	1954.4	13	1994.3	13.3	1177.4	7.85	1284.9	8.57	1159.8	7.73
8	5	D	1	200	11727	58.6	11966	59.8	7740.5	38.7	7478.3	37.4	7135	35.7
9	6	G	1	150	5863.3	39.1	5983	39.9	3870.2	25.8	3627	24.2	3460.5	23.1
10	7	C	1	150	1954.4	13	1994.3	13.3	1177.4	7.85	1284.9	8.57	1159.8	7.73
11	8	C	1	200	11727	58.6	11966	59.8	7740.5	38.7	7478.3	37.4	7135	35.7

The yield rates of the three cases on the right side of Table 1 – with in-process inspections, are: 94.96%, 87.01% and 96.4%, respectively. These values are less than the 97.16% of the final inspection but much higher than 51.17% with no inspection. Further, the corresponding scenarios involve much less waste as indicated by both the volumes – the material requirements, and the numbers of MH trips in the corresponding columns. In this example, the replacement of inspection 1 with 5 and 6 appears to be inferior – lower yield rate and higher waste, while the addition of 5 and 6 to 1 and 2 requires deeper examination since two more inspections are required to obtain rather small improvements. Cost factors might be incorporated in the analysis to facilitate resolution.

Another phenomenon in Table 1 are the empty cells. These cells correspond to inactive inspections and are associated with the structure of the material flow network, as discussed next.

4.2 Quality, inspections and material flows

In this section the goal of this study is arrived at: the association between and the dependencies of material flows on quality and the configuration of the quality assurance – inspections', system. Observe that, while few arrows can point into an activity, only a single arrow points out of each activity in Figure 1. This is a general observation, any OPC can have this attribute and if not, it can easily be decomposed into several OPCs, each of which has this attribute. As a consequence, the activity-successor association can be used and the relevant information to each arrow can be presented next to the activity on its tail, as in the columns headed $m(i)$ and 'u/t' in Table 1. An assembly ratio $m(i)$ associates each activity to its successor and the 'u/t' entry is the number of units per MH trip from the activity to its successor. However, several operations can be conducted in the same station type and materials flow between stations. For example, the arrow between operations 11 and 8 represents flows from station type C to station type D. Similarly, the arrow between operations 10 and 7 represents flows from C to G. This information can also be found in Table 1. Not in the example in Figure 1, but in general, there might be many arrows between the same station types, either in the same OPC or in different OPCs of other products which are produced in the same multi-product system. The MH system should handle total flows: the sums of the flows – of the numbers of material handling trips, on all the arrows between the same station types and in the same direction. This information and this discussion lay the foundations for material flow analyses.

Figure 2 is the core of this study. It portrays the material flow networks: structure and volumes, for the cases in Table 1; but while there are five cases in Table 1 there are only four networks in Figure 2, because in the network (a) both first cases of Table 1: no inspection and final inspection, are presented. This is done by displaying two volumes on each arrow: the smaller volumes correspond to the 'no inspection' case, while the larger volumes correspond to the 'final inspection' case. Since the 'final inspection' follows operation 0, it is not shown in the network (a) but the arrow pointing out of operation 0 either leads to the inspection or elsewhere – storage, etc.

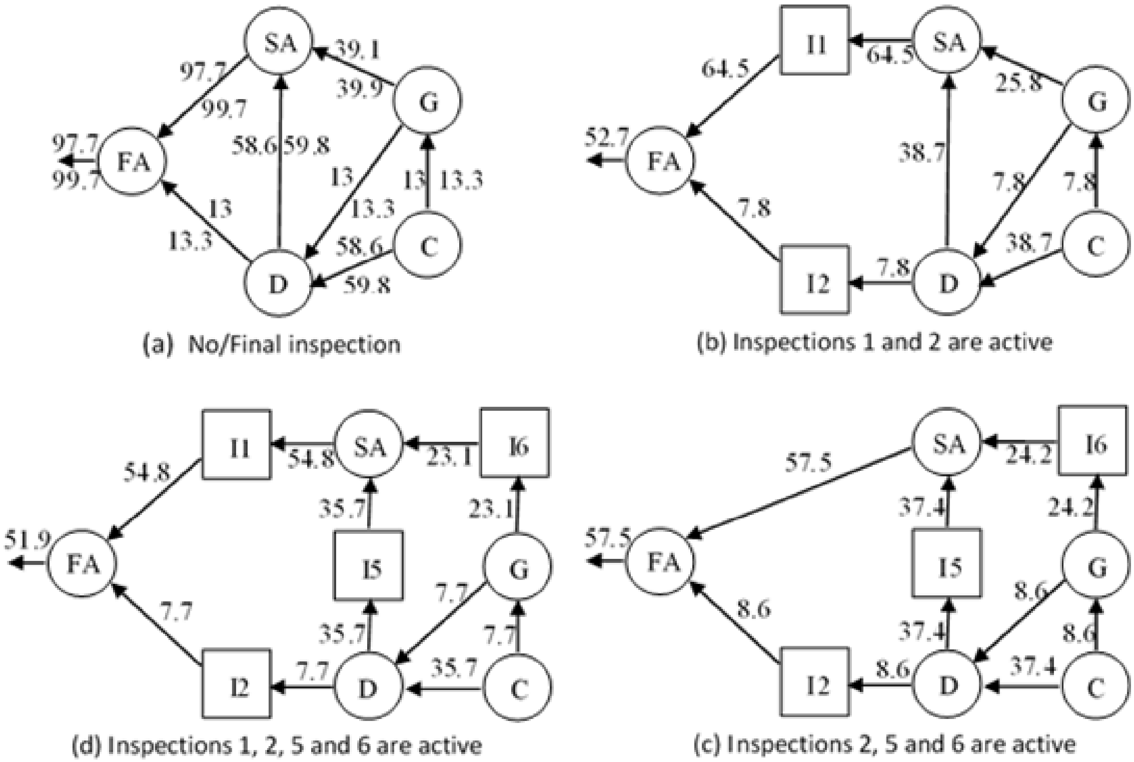

Figure 2 An extended operations process chart

A quick glimpse at Figure 2 tells the whole story. First, the structures of the four networks are different and second, the flow volumes are different. All these differences are ramifications of imperfect quality. Changes in quality levels – the yield rates, will result in different volumes. Moreover, imperfect quality forces the use of inspections and Figure 2 clearly demonstrates how the design of the inspection system affects both the structure of the material flow network and the volumes of the flows.

5 Conclusions

Comparing the numbers in Table 1 and the networks in Figure 2 reveals the complexity of the inspection system's design problem. To illustrate, consider the arrow from D to FA in the network (a). Inspection 2 splits the MH trips on this arrow – each trip is divided into two legs, but while the volumes on each leg is smaller than both values in the network (a), their sum is larger. The distances are out of the scope of this study but additional stations require additional space thereby lengthening the distances. In addition, each MH trip involves a load and an unload of the cargo, adding more work to the MH equipment. Consequently, the selection of the desired solution: where to improve the quality, where to place inspections etc., is a complex problem, and material flow is just one of its many facet.

While a single and very small example is used in the presentation above, the generality of the conclusions is easy to imagine. No system is perfect. In the quality literature, in particular, there is a distinction between 'in' and 'out of control', where even when a process is 'in control' the quality is not perfect, but within acceptable level; e.g., [15,16]. Hence, the questions at the end of the previous section always exist, including the implications on material flows and the MH system and its design. Surfacing these facets, which have been ignored thus far despite their significance, is a significant contribution of this study. In addition, the tools used above are generally applicable to analyze and design manufacturing/production systems of multiple products with assembly operations.

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OPTIMIZING LOGISTICS ROUTES IN THE FIELD OF MAINTENANCE

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Keywords: logistics, maintenance, optimization, Traveling Salesman Problem
Abstract: In the event that there is a requirement to provide maintenance with a service intervention somewhere in the area, it is necessary to select a service team which is optimal for the given task for all the assessed aspects. In this article, tests and methods based on TSP principles have been developed that are able to optimize route selection between key points. Due to the complexity of algorithm design, two approaches have been validated. The "Brute Force" method, which can provide information on the choice of the optimal route according to the specified parameters, and the "Nearest Neighbour" method, which is able to quickly calculate a large group of intermediate points, but only provides sufficient results. The aim was to create a methodology, guidance, and direction in evaluating route selection. That is why two basically opposed methods of TSP solution have been chosen, modified by the authors into a form suitable for implementation on virtually any platform. Although the design and program implementation was based on the MATLAB platform, no proprietary functions and libraries are used and the entire software design is implemented without the need for their use.

1 Introduction

Distribution logistics is an important part of logistics chain, as it enables the final distribution of products to a large number of end customers and the provision of related services.

The term distribution logistics refers to the circulatory processes provided by the enterprise. Distribution logistics is responsible for the location and determination of the type, equipment and number of warehouses, type of assortment, quantity of supplies, packaging of products, organization of transportation, etc. Last but not least, the determination of the logistics unit. The logistics unit is the largest amount of transportable goods that can be further subdivided. It plays an important role in international and domestic transport. Its unification achieves savings and accelerates the movement of goods.

The goal of distribution logistics is to ensure that the product is properly placed on the market in the best possible way, with optimal costs. Therefore, distribution logistics should only address a certain segment of a particular circulatory process, as one of the components of marketing logistics. The so-called distribution policy serves her. We can define it as a set, the process of all decisions that must be made in relation to a product or performance path from the manufacturer to the final consumer or processor. Thus, the role of distribution policy is to decide on how to create optimal relationships between production and consumption, as well as optimal distribution links.

2 Logistics in providing maintenance and service

The issue of distribution logistics must also be addressed in the area of maintenance and service processes. In particular, the following factors affect the organizational forms of maintenance and repair activities [1]:

- the number of independent manufacturing companies and firms and their size,
- territorial distributed units,
- the number of installed production facilities and their structure,
- the technical complexity of the equipment and the resulting complexity of technological, technical and economic preparation of maintenance and repair operations,
- the complexity and sophistication of operational control of maintenance and repairs.

Although practice very often seeks to define and subsequently apply some type of organizational solution - such a general and universal solution does not exist nor would such an organizational scheme be useful. There is no general system that could be used by small, medium or large enterprises, as well as by enterprises with advanced management or with completely underdeveloped management, or enterprises with already built technical repair facilities, or enterprises with incomparably lower equipment, because everyone it has its specifics both from a technical and technological point of view, and of course it has an influence on the system for maintenance and repair activities [2].

In order to effectively control multiple service groups on a large area, it is always necessary to choose which group will intervene. This decision depends on several conditions that need to be considered.

The most important decision factors are:

- Distance of service team from service area.
- Time of arrival to the place of service.
- Distance of service team from parent service centre after arrival to service area.
- Priority of service intervention.

If there are more service groups in the terrain or if there are several service centres in the area (Figure 1), the actual distance of the service team from the service intervention decides on the exit.

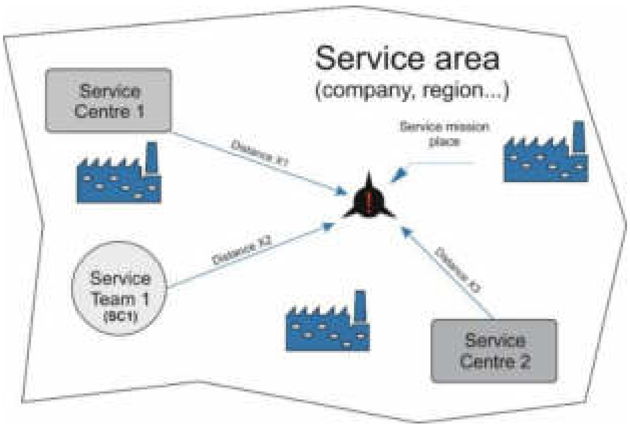

Figure 1 Evaluation of the distance of the intervention site from the current service team position

Of course, this value is important, but it says nothing about the real distance that a service team will offend. The parameters, that defines arrive time, must also take into account the route, that service team travel distance. This step has proved to be a very complex problem with a highly developed scientific background. In short, the issue of the so-called "sales representative" and the methods of solution is a large quantity [3].

It is also necessary to take into account that if the closest team is chosen as a suitable team, it can reach such a distance from its service centre that the total distance travelled is no longer profitable [4,5].

This is also related to the priority of the intervention (Figure 2), which will be crucial in evaluating the selection of a service team. Priority may be the urgency of the service action, the quantified loss on equipment, the quantified loss counting the entire logistics chain, etc. [6].

During maintenance management it is necessary to minimize the logistic delay of individual downtime and therefore it is also necessary to pay attention to logistics issues in the field of maintenance. For preventive maintenance, maintenance personnel must pay attention on various sites located in different parts of the enterprise. This requires planning the optimal path to ensure efficient use of service time. In the case of corrective maintenance, when multiple failures are reported in a single time period, the service team must decide on the sequence of restoring the failures to service. One of the partial factors of this optimization task is the magnitude of the logistical delay caused by transport to the place of intervention. To optimize routes, it is possible to take advantage of the traveling salesman problem. This method is a key parameter in minimizing the logistic delay, which significantly affects the total length of time the objects will be restored after a failure. This is positively reflected in the economy of the company [7].

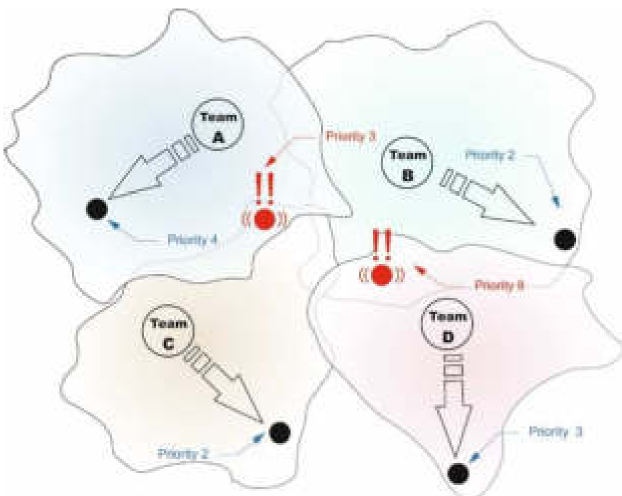

Figure 2 Prioritize service events

3 Traveling Salesman Problem

The issue of finding the optimal route is not just a domain of logistics. Traveling Salesman Problem (TSP) is very similar to the issue addressed by routing protocols in data networks. For low number of intermediate points, it is possible to apply simple algorithms [8-10], which are not very effective, but are fast, computational and low-memory and will fulfil their task. If you need to find out the optimal route, for example, using the "brute force" method, you will have to take into account the very high memory requirements, as well as the high CPU load. The "brute force" method passes through every possible option and selects from it the best parameters [11].

The TSP problem is, to say the least, the assignment that defines that business travellers must promote products in n cities (including the city where they live). After visiting each city (each city can be visited only once) it will return to the default city of departure (option of return with return to starting position). Suppose there is one way to connect each two cities. So what's the best way, with a minimum journey time? It has been shown that TSP is generally a complex problem, i.e. finding a time polynomial algorithm to achieve an optimal solution. TSP is easy to interpret, but it is very difficult to solve. This problem has been arousing the interest of many scientists for a long time, although it was presented in 1932.

However, so far no effective solution has been found. Although TSP is only the shortest circuit problem, there are many real TSP related problems in real life [12-14]. For a better understanding of the issue, possible examples will be explained in the following.

Example 1. - Mail route. Mail delivery is very closely related to the TSP issue. Suppose a mail car needs to collect mail in n locations. Under these circumstances, you can view the route using a drawing containing n + 1 nodes. One node means the post office, from where this postal car leaves and returns. The remaining n nodes are nodes that need to collect shipments. The aim is to find the shortest route while neglecting to optimize the route, taking into account the time lag, fuel consumption, or the need to pay tolls [15,16].

Example 2. - Mechanical Arm. When the mechanical arm is used to secure the nuts and bolts on the assembly line, this mechanical arm will move from its initial position (position where it is necessary to fasten the first nut) to each nut in the correct order and then return to its starting position. The path that moves the mechanical arm is the path that contains the nodes - individual assembly keys. The most economical route will allow the mechanical arm to complete its work in the shortest possible time.

Example 3. - Analog circuit of an integrated circuit. Often, thousands of separate electronic components need to be inserted during integrated circuit manufacturing. When switching from one electronic element to another, some energy is consumed. So how is it possible to arrange a production order for minimum energy consumption? This is also a solution for TSP.

In addition to the examples above, the issues associated with finding the shortest route are linked to issues such as the layout of the transport network, the choice of a walking path, the laying of the pipeline needed for city planning, and engineering structures, etc. Because finding a solution for TSP plays an important role in real life, much attention is being paid to this issue [17-19].

The mathematical description of problems TSP

$$min \sum d_{ij} \cdot x_{ij} \qquad (1)$$

$$\sum_{j=1}^{n} x_{ij} = 1 \quad i = 1,2,\cdots n \qquad (2)$$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad j = 1,2,\cdots n \qquad (3)$$

$$\sum_{i,j \in S} x_{i,j} \le |S| - 1 \quad 2 \le |S| \le n-2, S \subset \{1,2,\cdots n\} \qquad (4)$$

$$x_{ij} \in \{0,1\} \quad i,j = 1,2,\cdots n \quad i \ne j \qquad (5)$$

where d_{ij} is the distance between the city i and the city j, the decision variable $x_{ij} = 1$ is the route made by the business traveller (including the route from the city i and the city j), $x_{ij} = 0$ is the route not made by the passenger. | S | means the number of elements contained in the S set (1).

The objective function (1) defines the total minimum distance, z (2) shows that a business traveller can only leave the city once, (3) defines that a business traveller can enter the city only once. It can be seen from (2) and (3) that business travellers visit each city once, but do not exclude the possibility of any loop. Definition (4) specifies that a vendor should not create any loop in any subset of cities [20].

4 Evolutionary algorithm for TSP solution

As mentioned above, traditional algorithms used to solve TSPs have some significant limitations. With the advent of evolutionary algorithms, many new numerical optimization algorithms appear [21]. These algorithms are to some extent random search algorithms. ACA and PSO are typical parallel algorithms, although they cannot guarantee that they will obtain an optimal solution in limited time, they can provide a satisfactory solution within an acceptable time frame. In order to determine the effect of the solution for the TSP obtained by the optimization algorithm, it is necessary to consider the search capabilities of the search algorithm. For example, a strong optimization algorithm will have a better effect, while an algorithm that easily gets stuck in a local extreme often helps to obtain an optimal solution for a TSP of a local nature. An example of an evolutionary algorithm for solving TSPs is the Ant Antony Algorithm.

Ant Colony Algorithm (ACA) is a relatively new evolutionary algorithm presented by the Italian scientist Dorigo. He called it the "ant system" and achieved a relatively good experimental result with it. As for ACA, n represents the number of cities for TSP, M represents the number of ants in the colony, d_{ij} (i, j = 1,2,…, n) represents the distance between the city and the city j, $\tau_{ij}(t)$ represents the pheromone concentration on the route between cities i and j in time t. The initial condition at time $t = 0$ is the concentration of pheromone on each route equal, respectively $\tau_{ij}(0) = C$, where C is a constant. During movement in the colony, the ant ($k = 1.2,\ldots, m$) determines which direction to follow, according to the pheromone concentration on each route. $P_{ij}^{k}(t)$ represents the probability of movement (choice) of ant from city i to city j at time t (6).

$$P_{ij}^{k}(t) = \begin{cases} \frac{\tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t)}{\sum_{s \in allow_k} \tau_{is}^{\alpha}(t)\eta_{is}^{\beta}(t)} & j \notin prohib_k \\ 0 & \end{cases} \qquad (6)$$

where $prohib_k$ ($k = 1.2,\ldots m$) means that the ant has passed through the given city, with only one first at the beginning (default city). During the algorithm, the length of the $prohib_k$ variable increases gradually. The term allow $k = \{1,2,\ldots, n\}$ - $prohib_k$ defines another city, the direction that an ants are allowed to. The quantity η_{ij} represents visibility and is derived from the length of a given route between two cities *i* and *j*. The variables α and β affect the pheromone concentration τ and visibility η.

Over time, pheromones on each route lose their intensity. The ACA algorithm uses the principle of positive feedback, which accelerates the evolutionary process and also allows the native use of parallelization calculations.

The ongoing process of information exchange and communication between individuals helps to find a better, more effective solution. It is easy to focus on the local extreme when there is only one individual. Colony collaboration, however, allows several subsets of the solution space to be obtained that provide a better environment to implement another solution. The movement of individual individuals in the colony is random. In fact, the measures taken to exclude the possibility of local extreme occurrence slow down the speed of convergence. When the size of an anthill colony grows, it will take longer to find the best route. The principle of an ant colony is very popular today and many scientific papers are devoted to it. Many improvements and optimizations are available. However, it cannot be said that this algorithm was in the final stage of optimization. On the contrary, it seems that it is very suitable for the solution of TSP and is only at the very beginning of its journey [22].

5 Design of optimization method based on TSP principles

5.1 *Brute Force Method*

In principle, it is a method that can check all variations of routes and calculate their suitability index, resp. price, the English term "Cost". Each selected route has its own specific price. This is an analogy of data networks, where a route with the lowest cost is selected - cost, cost. This criterion was chosen as appropriate and therefore the cost of each route will be calculated. Both presented methods allow for a variable number of specific properties, parameters for each route, so there is no limitation in their number. However, the essential condition is independence from the direction of the selected route. The route price is therefore the same in both directions. This limiting condition is introduced for purely objective reasons, in a significant simplification of the algorithm. Directional constraint is very specific and not very utilized. Multiple algorithms can be created to calculate the path price. The current time, the dynamic path utilization, etc. can play a role. The cost of the trip in this case can be calculated, for example, by the relation (7).

$$c_i^{a\to b} = \sum_{k=1}^{n} w_k \cdot \sigma_k \tag{7}$$

where c_i is the price of the route between two points *a* and *b*, w_k the weight of the specific route parameter *i* and σ_k determines the value of the specific route parameter *i*. The specific property, parameter such as route difficulty, static load, toll etc. is multiplied by the appropriate weight and the sum of all parameters determines route price. It should be borne in mind that, for example, a faster route will show a lower price because the lowest cost of the route is the criterion of optimality. Only the length of the route is taken into account within the algorithm, other features and weights have been omitted for reasons of debugging and clarity. The route length was calculated in two-dimensional space according to formula (8).

$$\begin{gathered} l_i^{a\to b} = \sqrt[2]{dX + dY} \\ dX = (a_x - b_x)^2;\ dY = \left(a_y - b_y\right)^2 \\ c_i^{(a,b,\dots,n)} = \textstyle\sum_1^n l_i \end{gathered} \tag{8}$$

where $l_i^{a\to b}$ corresponds to the length of the route between points *a* and *b*, dX and *dY* are the distances between points in the *X* and *Y* axes, a_x, b_x, and *y*, would be the coordinates of the given axis for that point. Then the total length of the route ci between points *a* to *n* is the sum of the partial lengths l_i.

The generated algorithm generates key points in the desktop automatically and randomly for testing purposes. Fixed points can generate overly optimistic results, and the algorithm could gravitate to optimize for a given point array in the face. Thus, the random distribution of key points helps to test the developed algorithm. The number of parameters of each route is defined and the area size in which the optimal route is sought is determined. These values correspond to the size of the business, the area where the service teams are located.

Furthermore, the number of route points is defined, which significantly influences the solution time and the optimum route.

Subsequently, the coordinates of the individual through points of the route, which are in the range ⟨0; dimX⟩ and ⟨0; dimY⟩. The result is a three-dimensional matrix with the depth of parameter + 1 and the rank of dimX, respectively dimY.

The following is the *"%% Start and End Point Definition*" section, which aims to determine the starting and ending points of the route. No extra point is generated, both are selected from existing points.

In real-time deployment, the starting position would be the current location of the service team and the end point instead of service intervention. In this case, a random generator of both points is created.

A very important step is to create a matrix of all points (cities) on the map.

In fact, the map_1 variable represents the entire area at a given resolution, and only in places where there are through points is the cell value set to 1. Individual points, including coordinates, are stored in trace_1. The procedure that passes all points in the matrix map_1 and stores them in the new variable trace_1 is named *"%% Saving all* *waypoints to trace_1 without optimization*". Individual points are stored in the matrix in the order in which the procedure algorithm encounters them. The order of points is not optimized.

The algorithm for finding the optimal route itself is in the section called *"%% Finding the Shortest Way - BruteForce Method*". The aim of the method is to find the optimal route by analysing each individual route combination. The condition is that the individual waypoints are not duplicated and the route passes from the starting point to the end point. The computing complexity is $\frac{2^{n-2}}{2}$ operations, where n is the total number of through points. By simple calculation it is possible to find out that in case of 4 points of the route 2 combinations of points in the route will result. Two points are always fixed, that is, the starting and ending points.

There is a lot of material describing the issue of combinatory such as here [23,24]. However, the combination creation algorithm is not directly listed. The most complicated part of the "Brute Force" method was to create a complete combination matrix where each line would represent one unique route from the starting point to the end point. To this end, a binary math based combination matrix method has been developed. The method is not optimized, it can create duplicate routes, but it does not change the result. The principle is based on the binary notation of the sequence of numbers presented in on the left.

It is apparent from the binary notation that the ones and zeros create a pure combination structure. Thus, the method of the combination matrix method was that if the individual positions in binary expression were replaced by individual through points, it would be possible to effectively create their combination matrix. If we introduce binary expressions of numbers in the range ⟨0, n⟩ as a matrix (e.g. matrix A), individual cells at the level of weights represent through points [25]. If a value of 1 is entered in matrix A at weight level 1, the through point is shifted one position to the left to be exchanged with its neighbour. Basically, the "swap" function is performed on the adjacent two cells of matrix A. In this way, the individual through points are "bubbled" to the right places.

If the cell value of matrix A at the highest weight level is equal to 1, the outer cells are exchanged (right at Figure 3).

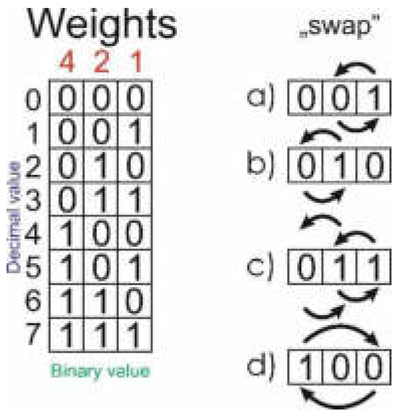

Figure 3 Display of decimal numbers in binary form and route point migration method

An example of the algorithm is shown in Figure 4, the coordinates of the through points are shown in Table 1 and an example of the combination matrix of the *x* values of the through points in Table 2.

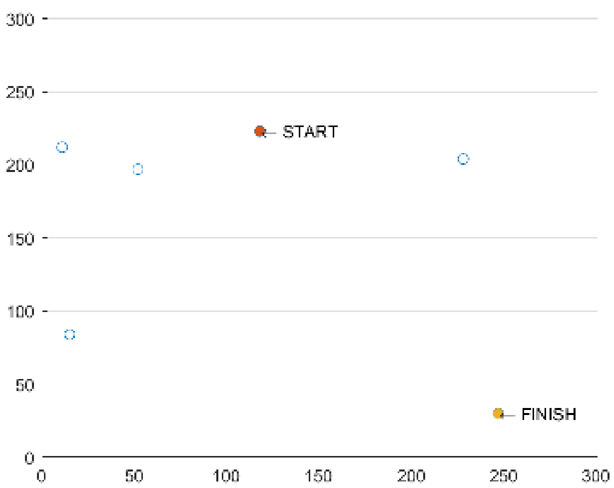

Figure 4 An example of the placement of 4 through points with the starting and ending points

Table 1 Coordinate of through points

Point order	Y-coordinate	X-coordinate
1.	10	5
2.	5	9
3.	8	2
4.	2	10

Table 2 Combination of x-coordinate of through points

A combination of X-coordinate points			
10	5	8	2
10	8	5	2
10	5	8	2
10	5	8	2

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The creation of the combinatorial matrix is dealt with in the program section called "%% Finding the Shortest Way - BruteForce Method".

The output of this part of the program is the variable var_mapx and var_mapy, where all combinations of *x* and *y* coordinates of through points are stored.

The following is the calculation of the length of the individual routes in the section marked with the heading "%% Calculate the length of individual routes". The lengths of each route are calculated according to formula (8). Path lengths are stored in the trace_2 variable unchanged.

The following is the shortest route ("%% Finding the shortest path") by a simple algorithm by browsing the individual path length records. The output of the algorithm is *mnm* and *mxm*. Examples of output routes when using the "Brute Force" method are see in the Figure 5.
Computational testing also took place as part of the verification. See Figure 6 for details. This method is suitable for a low number of through points. With the number of points, computational complexity increases, and from a certain threshold, the method on conventional machines is unusable. Its main advantage is finding the optimal route, according to the given criteria.

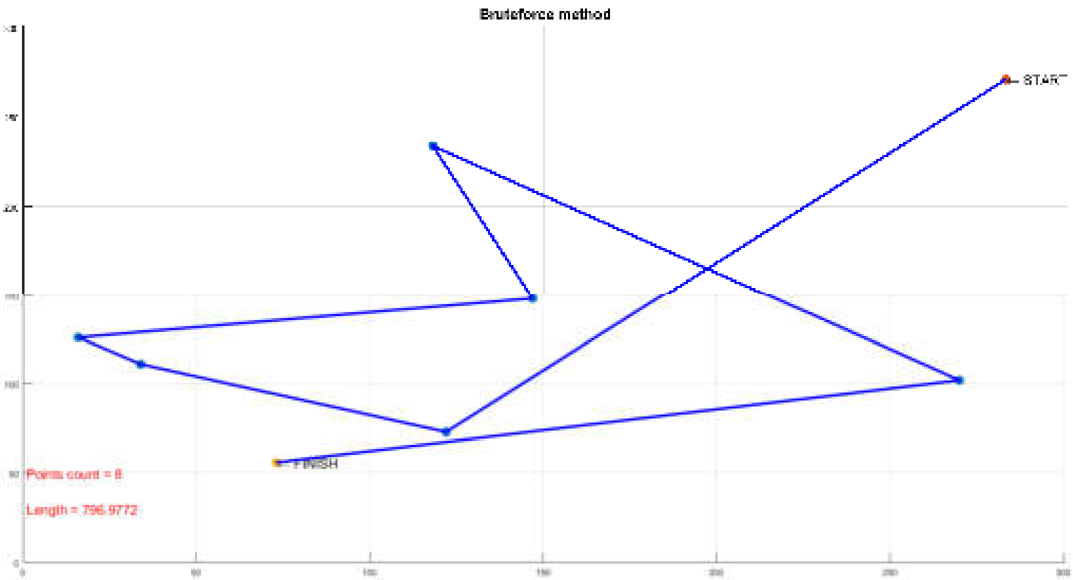

Figure 5 Example of output routes when using the "Brute Force"

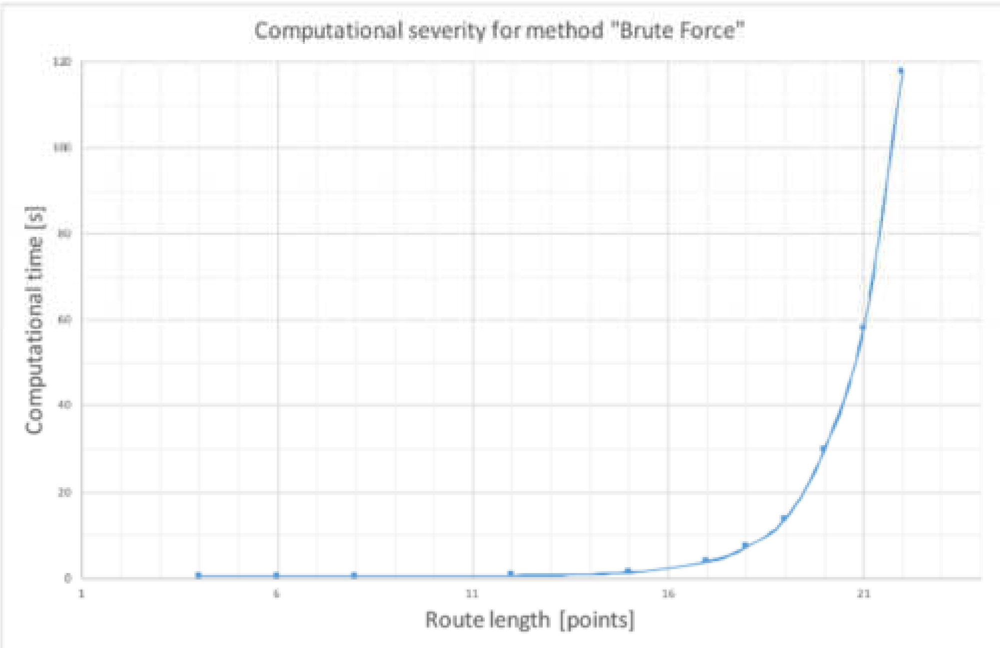

Figure 6 The computational complexity of the method "Brute Force"

5.2 Nearest Neighbour Method

Due to the limitations of the "Brute Force" method, it was also necessary to verify one of the methods, which, although not leading to an optimal result, will be applicable within certain compromises. One of these methods is the method called "Nearest Neighbour", respectively nearest neighbour. This method has been elaborated and modified for use by the author of this thesis to find the optimal path for the service team.

Again, as with the previous method, two endpoints, default and endpoint, are selected. The method is based on the assumption that the ideal route choice will be through the nearest next point.

The initial setting is the same as the previous method. A map of the area with through points is created. The area size is defined by the dimX and dimY variables. If there are not many through points (<6), they will be printed on the MATLAB application window. Following is the definition of the start and end points, the start and fin variables, then a simple matrix of all through points (trace_2) is created as they are stored, without optimization. Up to now, only the input data has been edited into an appropriate format for analysis. The core of the algorithm is the partition named *"%% Nearest Neighbour method*". In the cycle *"% Calculate the length between the waypoints*", the distance from the starting point to all the other points according to formula (8) is calculated. Only a simple distance between points is considered. Additional parameters are neglected. If these parameters are available, the calculation according to formula (7) and (8) is used. The nearest point (the *"% found shortest route*") to the starting point is marked as the starting point after the cycle is completed and the process is repeated. The output of this part of the algorithm is the newly arranged trace_3 matrix, where the route is already optimized. The following is the calculation of the total length of the route in the section called '% compute total route length' [26]. On Figure 7 are examples of output routes when using the "Nearest Neighbour" method.

Computational tests were performed as part of the verification. See Figure 8 for details. This method is suitable for both low and high throughput points. The number of points increases the computational complexity of the method linearly. Its main disadvantage is only approximate optimization of the route, according to the specified criteria.

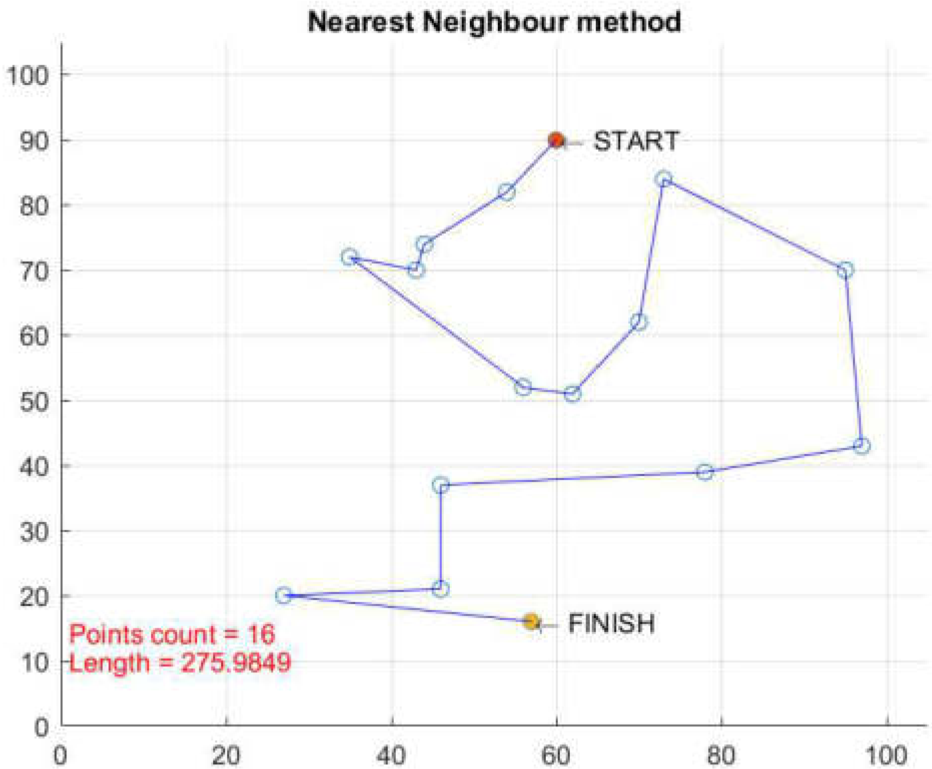

Figure 7 Example of output routes when using the "Nearest Neighbour"

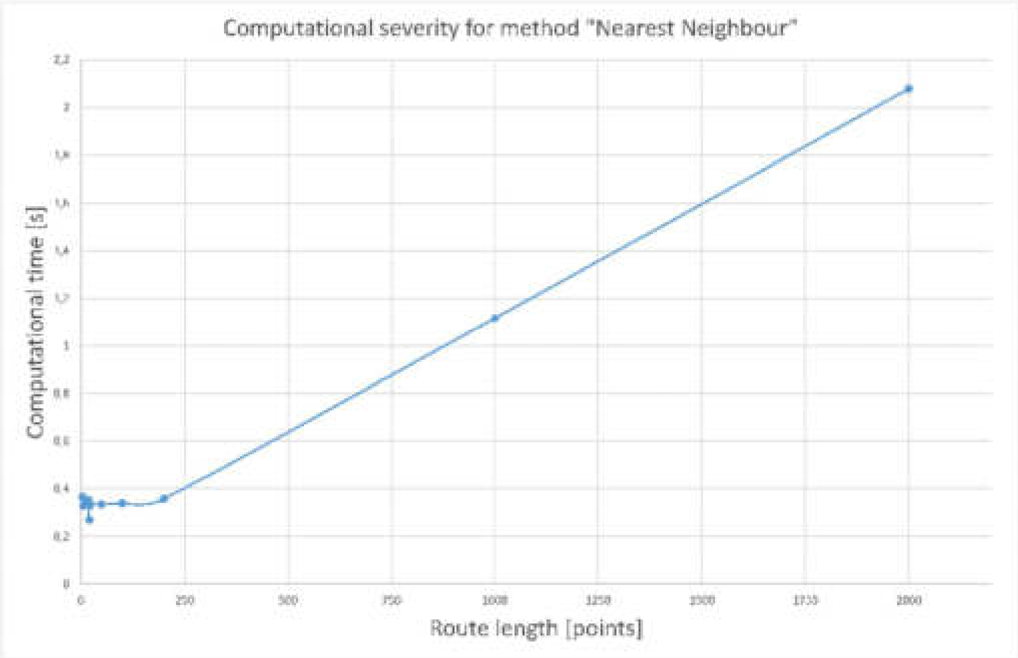

Figure 8 The computational complexity of the method Nearest Neighbour

6 Conclusion

In the paper, two approaches to the optimal route using TSP were presented. Two solutions were chosen, the "Brute Force" method and the "Nearest Neighbour" method. The "Brute Force" method provides better results from the optimal route selection, but is only suitable for low through points. The algorithm created in MATLAB was able to optimize the route with a maximum of 22 through points in reasonable time and with enough memory. The output of the algorithm is the optimal route, determined according to the parameters of individual routes between neighbouring points.

Although the "Nearest Neighbour" method does not provide the optimum route from the starting point to the end point compared to the "Brute Force" method, its computational complexity is of the order of magnitude and is also capable of handling thousands of waypoints.

As you can see from the pictures, the "Nearest Neighbour" method gives a good or a good comparable results with the Brute Force method for a low number of through points. A higher number of points shows insufficient optimization of the algorithm and a temporary jam in the local extreme.

It is important to realize that the data used was of random nature within objectivity and it is likely that the results of the Nearest Neighbour will be better when using real position data.

The aim is to transform the localization data into a simpler form, to create a time link to the location data and, in particular, to optimize the intervention of the service teams according to their current location and priority of the intervention. The output is a system of original algorithms and procedures that can be part of the maintenance process optimization. The developed methodology can be deployed in industrial and non-industrial processes. It can be assumed that good maintenance management with good work management can significantly reduce the likelihood of production equipment failures and prevent additional costs.

The data processing algorithms created are inherently unique, even though they are based on the previously described theories. Both presented optimization methods are adapted for the needs in the field of service team management (or in other areas where intervention is needed at given time with given priority). The methods are optimized (from the program code point of view) with regard to current needs and computational complexity, which is the main scientific contribution.

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