Research Article

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Implementation of the logistics train in the intralogistics system: A case study

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Abstract: Intralogistics contributes significantly to the proper functioning of business processes. When designing and solving intralogistics systems, it is necessary to take into account the specific conditions in the given enterprise. The technical design, as well as the composition of the trolleys in the design of the transport system, must respect the specificities of the goods transported as well as shelf life and quantity. The study presents, for example, the implementation of a tugger train into an intercompany system with a solution procedure that is adapted to specific operating conditions and ensures the smooth functioning of the supply process. It is a principle based on the use of a simulation model. During its creation, three original sequences were developed in the programming language SimTalk. Their application decreases the use of blocks from the simulation program by up to 65% and it was possible to model more detailed processes that would not be possible in terms of functionality by using classical blocks. Fifteen directions of the language SimTalk were applied in their creation. Two variables of the type Integer, two variables of the type Object, and one variable of the type Real were defined.

Keywords: intralogistics, transport, tugger (logistics) train

1 Introduction

Tugger trains have become an important transport element in internal logistics [1]. The supply of production and assembly lines became more efficient after their

introduction. Compared to the forklifts originally used, tugger trains are faster, safer, and usually run at regular intervals.

As Kolář states in his study [2], the reason for the implementation of tugger trains for internal logistics is greater efficiency of the supply process. The higher efficiency is due not only to both large time and financial savings, but also due to the requirements arising from the supply of parts and materials to production and assembly lines in the just-in-time mode. One tugger train system can supply multiple workplaces, saving several additional means of handling technology.

The use of a tugger train for internal logistics increases the volume of goods transported and handling performance [3]. Neradilová describes the logistics process of supply using a tugger train for smoother transport in smaller handling units [4] in the just-in-time and just-in-sequence modes. As an added value, Neradilová mentions a lower risk of accidents and thus greater [4] safety, which is due to the one-way operation of the train. Another advantage of the tugger train is the possibility of driving on narrower transport routes and thus saving the area for production needs.

Beinschob et al. [5] compare tugger trains with the originally used forklifts. Tugger train systems always carry more goods in a single route compared to a single trolley, during which time there is a smaller number of transport equipment in operation [6]. Usually, train systems run in a predefined route at regular, predictable time intervals. The use of tugger train systems also has a large share in ensuring a safer environment in the production hall compared to the number of forklifts originally used.

The tugger train system consisting of a tractor and tow trucks (trolleys) can be more efficient in supplying production and assembly lines than the fastest forklift, says Petřík [7]. One train system that supplies material to multiple workplaces can then save several additional means of handling technology, which is usually oversized for the given use [8]. When using a tugger train to supply multiple workplaces, the train becomes an integrating element between individual technological operations [9]. In addition to replenishing supplies, it can

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deliver the parts to the assembly line for assembling. Tugger trains can be used wherever individual workplaces have to be supplied with materials and intermediate products at regular [10] intervals.

The use of tugger trains can significantly reduce the costs associated with the material operation of production and assembly lines [11]. In addition to saving labor, tugger trains save investments, which can then be used to modernize service handling technology and simplify the logistics processes in production. It is clear that the current trend in internal logistics is toward the implementation and use of automated robotic systems in processes where manual labor is still used [12]. Usually material is manually handled and transported to production and assembly lines. The automation of these activities is in line with the requirements for increasing product performance and efficiency, compliance with time and production schedules, including the requirement to reduce production costs [13].

The use of towing tugger train systems both in storage and production contributes to simplifying and streamlining material flows [14]. In production premises especially, it eliminates the use of forklift trucks and thus increases operational safety. Tugger train systems, combined with internal logistics (intralogistics systems), have become a part of lean logistics [11].

The increasing interest in tugger train systems is an incentive for various technological innovations, such as increasing load capacity and towing force, extending the

travel time on a single charge, improving the controllability of the tractor, as well as maneuverability of the whole system [15]. Thanks to the higher maneuverability, the tugger train system will pass through narrower aisles and space can be used more efficiently. The contribution presents the procedure for choosing a route using a tugger train in the field of internal logistics in automotive conditions.

2 Intralogistics systems

Intralogistics systems, or internal logistics systems, are based on the concept of lean production. Tugger trains are increasingly becoming an integral part of them. Tugger trains, also named smart logistics train systems, are equipped with trolleys with various internal logistics systems that increase the performance, sustainability, and continuity of material flows, including ensuring higher quality and safety of operation.

A smart logistics train system (Figure 1) can be created using a suitably chosen composition of internal logistics systems, which ensures a smooth flow of material and semi-finished products, both to production lines and the flow of components to assembly lines. The choice of standard internal logistics systems depends on many factors that are decisive for the optimal composition of smart logistics train systems. The main factors are the

Figure 1: Example of a logistics train used in intralogistics [16].

quantity, dimensions, and frequency of the transported material and semi-finished products to production lines and components to assembly lines.

When choosing internal logistics systems, how cargo will be transported is usually a decisive factor:

- platform trolley concept – the load or cargo unit is placed directly on the trolley,
- taxi concept – handling trolleys can be loaded from both sides, and
- retractable concept – the transport unit is moved to the handling trolley.

At the same time, it must take into account the operating conditions in which the logistics train will be operated. In doing so, it must take into account various factors, such as the distribution of supply objects and positions, or transport performance requirements. This is followed by other criteria such as the power and performance of the towing device and the organization of the transport route. Standardized systems are very often used in the operation of tugger trains in internal logistics.

Standardized internal logistics systems consist of trolley chassis with different types of frames, which by their technical solution facilitate the transport of various materials, semi-finished products, and components.

2.1 Driving torque on the axle of the tractor

The automatically controlled tractors of the tugger train move using the driving torque M_h , by which the electric motor acts on the rear axle of the tractor (Figure 2).

Figure 2: Automatic tractor scheme.

From the balance of forces and moments to the center of gravity when neglecting the friction of the trolley is

$$\Sigma X = 0; F - G \cdot \sin \alpha = 0 \text{ [N]}, \quad (1)$$

$$\Sigma Y = 0; G \cdot \cos \alpha - N_1 - N_2 = 0 \text{ [N]}, \quad (2)$$

$$\Sigma M = 0; N_1 \frac{1}{2} F \cdot h - N_2 \frac{1}{2} = 0 \text{ [N]}. \quad (3)$$

From the balance of forces in the X-axis, the driving force is equal to

$$F = G \cdot \sin \alpha \text{ [N]}. \quad (4)$$

After installation and adjustment, it gets the power torque size of the electric motor on the shaft of the rear axle in the form of

$$M_h = F \cdot \frac{D}{2} = F \cdot r = G \cdot \sin \alpha \cdot r \quad (5)$$

$$= m \cdot a \cdot \sin \alpha \cdot r \text{ [N m]}.$$

After adjustment, the driving torque of the electric motor on the rear axle shaft is

$$M_h = r \cdot m \cdot a \cdot \sin \alpha \text{ [N m]}. \quad (6)$$

The moment of a pair of forces is always the size, which is determined by the result of the strength and the distance between them:

$$M_h = F \cdot r \text{ [N m]}, \quad (7)$$

where F is the size of the force in pairs (the second is the same size) and r is the distance of vector lines of the acting forces.

The driving torque thus determined is the basic starting point for the selection of the towing device, the determination of the number of standardized systems in

T – centre of gravity of the trolley [mm]

G – force of attraction [N]

$N_{1,2}$ – normal forces from axles [N]

F – driving force [N]

l – axle distance [mm]

h – distance of the centre of gravity from the floor [mm]

Figure 3: Examples of standardized systems used in internal logistics [17,18].

the vehicle combination (Figure 3), and the choice of the transport route. It will help implement a tugger train into the internal logistics system.

3 Implementation of tugger train into the intralogistics system in automotive

The implementation of the tugger train system (in terms of the choice of transport route) into the inter-object

transport system within the framework of internal logistics will be presented through the example of an automotive component manufacturing company. The demands on supply in this industry are enormous as it uses a large quantity of material from a few millimeters long to items that are tens of centimeters long. The location of production facilities in several separate buildings does not contribute to efficient supply flows. The study dealt with the premises of a company, which was located on a flat surface and contained a fairly well-built network of roads, which had to be used as the transport routes of the tugger train. There are a total of four buildings in the area, as can be seen in Figure 4. As can be observed, transport also

Figure 4: Premises of the company during the deployment of a tugger train.

Figure 5: Plastic tray with workpieces and plastic EURO crate.

took place in an open environment, when choosing a transport route it was also necessary to take into account the issue of used packaging.

3.1 Packaging used for the transport of components

When using the tugger train system, the material handled and its packaging must be considered. Handling material used in the manufacture of automotive components is often a complex process. These are small components that are susceptible to weathering, electrostatic environment, humidity, and last but not least, the way they are handled. Quality is essential for the transported products in this industry. Abrasions and scratches on the products are not tolerated. To meet these requirements and to

speed up and simplify handling, the material is often repackaged in another packaging. The purpose of the packaging is to simplify handling, but it also has a protective function.

When handling these components different types of plastic crates and boxes are used (Figure 5). Some transported components need to be packed in their packaging using specially designed plastic pallets. These plastic trays are also dimensionally compatible with the plastic boxes in which they are inserted in a large number of cases. As already mentioned, finished products are often packed in special packaging. These packagings have dimensions compatible with the EURO pallet or even the pallet supplied to the customer.

In addition to packaging another factor that must be taken into account while operating a tugger train outdoors is the existence of various risks and risk points.

Figure 6: Points of collision and proposal for solutions to the problem of collision points.

3.2 Risk areas

A fundamental risk factor that will have to be taken into account while designing the model of this inter-object transport is the movement of various transport products on the premises. Of course, it is not only tugger trains that move on the premises. Transport on the premises is also provided by vehicles, which bring and take away material. Parking places are very important for the employees of the company, which are also located on the premises.

It follows that, in this case, it is necessary to cross the routes of the various means of transport. This crossing is clearly shown in Figure 6. It is possible to see that there are four risk points on the premises where a collision could occur if drivers are negligent.

Risk point No. 1 is located at the external warehouse and entrance to the premises. At this point, there are intersections of trucks delivering material needed for production, as well as vehicles transporting finished products with tugger trains supplying production. There are no intersections of employees' and visitors' vehicles at this point. This is the main supply route of the company. Risk point No. 2 is located at the ramp of the supply point of object No. 1. At this point, there are intersections of the tugger train route supplying objects with employees' vehicles. The vehicles of visitors should not be at this point, because it is back parking where they do not have reserved parking. However, it is a point where pedestrians can also be present. After parking the vehicle in the parking place, employees must move on the pavement along the road to the building, thus crossing the route of the tugger train and the vehicles of employees. Risk point No. 3 is on the "T" shape intersection, between objects Nos. 1 and 2. This is a busy place as there are visitors' vehicles, employees as well as tugger trains. There is a risk at this point from both sides. The point is also located where the parking place is located. So

there is a risk of a collision involving pedestrians. Risk point No. 4 is located in front of the supply ramp of object No. 2, where the routes of employees and visitors' vehicles intersect with the tugger train moving to the given building. The section is quite busy and has an increased risk of delaying tugger trains during supply operations.

The risks of collisions due to carelessness and human error are relatively high in the sections mentioned above. To prevent such incidents responsible trained staffers are needed in tugger trains in addition to measures to prevent such possibilities. Of course, drivers entering the premises cannot be trained by employees always. So it seems reasonable to use classic traffic signs and signs warning drivers of the risks of moving vehicles and persons on the premises as shown in Figure 6.

The first measure in solving the problem of safety and traffic flow in the area should be to determine the right of way rule. The main activity of the company is the continuous production of automotive components, which requires a continuous supply of the materials needed for production. As a result, the right of way rule will have a tugger train in the premises. Vertical traffic signs and a traffic mirror will ensure this right of way rule for the tugger train as well as traffic safety.

4 Model of supply of objects by one tugger train

One way to ensure material supply and the transport of finished products of individual production objects is to serve both buildings with one train. This solution is also possible in the case of malfunction of one of the trains and it would not be possible to supply both objects independently. As it is possible to see in Figure 7, the route of the train depends essentially on the object to which the

Figure 7: Supply of object variants A and B.

supply begins. If the supply begins with object No. 1, the train route is easier and faster because it has the ramp of object No. 4 in which contaminated packaging is unloaded and clean one is loaded on the way to building No. 3, which represents an external warehouse.

In this case of a supply emergency, when one tugger train has to serve both objects, its route will depend primarily on the requirements of individual objects that they will have for the supply of components. Priority will be given to an object with zero inventory or inventory close to zero.

To determine the number of trains that will be needed to be purchased for the supply of objects, it is needed to calculate one of the time quantities. For example, it is possible to choose the time needed to transport finished products and deliver new pallets for finished production. This means that every hour the train must be able to transport the exact number of pallets of finished products from each of the objects while bringing the same number of pallets for further production.

4.1 Use of simulation model with an additional programming of sequences

Computer simulation was used for this case study for determining time and the analysis of possible solutions for supplying workplaces. It is currently a well-validated and reliable method that is commonly used for the solution of intralogistics tasks.

The use of this method requires a considerable way of creative approach and originality. The creation of a simulation model is always conditioned by the specifics of the problem. For this reason, to capture the specific conditions within the described example of an intralogistics transport problem, it was necessary to create and program a logistics train loading process.

The Tecnomatix Plant Simulation program was used to create the simulation model, which has a sufficient set of tools for modeling the supply processes of logistics systems. The study will not describe in detail the simulation model, but only its completed parts, which were

```
(SensorID : integer; Front : boolean)
is
  i,c:integer;
  vozik:object;
do
  if sensorID=1 and @.name="Tractor1" or @.name="Tractor2" then
    @.stopped:=true;
    waituntil Poziadavka_R1=0 and Poziadavka_B1=0 and Poziadavka_G1=0 prio 1;
    vozik:=@;
    for i:=1 to pocet_vozikov loop
      vozik:=vozik.RearMU;
      if vozik.name="T1" and Poziadavka_R1=0 and vozik.empty then
        wait(2);
        buffer.cont.move(vozik);
        RED:=RED+1;
      elseif vozik.name="T2" and Poziadavka_B1=0 and vozik.empty then
        wait(2);
        buffer1.cont.move(vozik);
        BLUE:=BLUE+1;
      elseif vozik.name="T3" and Poziadavka_G1=0 and vozik.empty then
        wait(2);
        buffer2.cont.move(vozik);
        GREEN:=GREEN+1;
      end;
    next;
    @.stopped:=false;
  end;
end;
```

Figure 8: Created program sequence of the logistics train for loading.

developed by the authors of the study. These are original program sequences that can also be used to create other models aimed at simulation of logistics trains within intralogistics systems. Therefore, they are published in the full format so that they can be used by other researchers. Specifically, it will be a sequence for modeling the loading, unloading of goods, and a sequence that is designed to display and compare the results obtained during simulation experiments.

The process of loading is modeled with the help of a specific block in the program. However, this was unsatisfactory and insufficient for the case described in this case study. Therefore, an original sequence was created using the SimTalk language (Figure 8), which can be implemented in the simulation model. This simulated the process of loading, which is a mirror image of the real state within the company's logistics processes. The creation of this sequence was based on the assumption that it was designed universally and could be used for other similar cases. The creation used statements for the definition of partial conditions "wait until" and "wait," which were used for the definition of time parameters. This created and debugged sequence is universal and can be used for a wide range of logistical problems. The presented solution brings savings to the classic block, which represents 65%. At the same time, 15 statements of the program SimTalk were used for pro-

gramming, two variables of the type "Integer," two variables of the type "Object," and one variable of the type "Real."

Similarly, a sequence was proposed for material unloading from the set of logistics trains. This sequence was also created in the language SimTalk and it has general validity. The sequence allows simulating unloading of the optional number of sets of logistics trains (after modification). Their definition is realized by the term "Tractor," to which the relevant serial number of the trains is assigned. The sequence is formed with the possibility of a constant or different number of driving peripherals. The letter "T" was used for their determination with the appropriate number. The created sequence allows the realization of unloading gradually in parts (cost terms) or all at once. Therefore, this sequence has general validity and can be used in other simulation models (Figure 9).

Another important task that was solved in this case study is the collection, processing, and evaluation of data. Of course, the simulation program has this functionality, but for the needs of the case study, it was necessary to develop its address solution. In this case, it is a presentation of the number of transport requests from workstations, that the intralogistics system has to implement and their mutual ratio in percentage.

This function is possible by the original program sequence (Figure 10) which consists of simple mathematical

```
(SensorID : integer; Front : boolean)
is
  vozik:object;
do
  if sensorID=2 and Poziadavka_R1=0 and T1>0 and @.name="Tractor1" then
    @.stopped:=true;
    vozik:=@;
    vozik:=vozik.RearMU;
    repeat
      if vozik.name="T1" then
        vozik.cont.move(buffer3);
        wait(2);
      else
        vozik:=vozik.RearMU;
      end;
    until buffer3.full;
    @.stopped:=false;
  end;
end;
```

Figure 9: Created program sequence of the process of unloading of a logistics train.


```

is
  Sucet:real;
do
  Sucet:=RED+BLUE+GREEN;
  Pomer_R1:=RED/Sucet;
  Pomer_B1:=BLUE/Sucet;
  Pomer_G1:=GREEN/Sucet;
end;

```

Figure 10: Program sequence and method of its visualization.

formulas and variables. The obtained calculations are then visualized using a graph which helps to obtain a quick and simple overview of the outputs of the simulation. It is also necessary to properly configure the output graphs. This solution is not an automatic part of the simulation program, but it is created using programming in SimTalk language.

The mentioned sequences were subsequently implemented into a simulation model which was used for the case study solution (Figure 11).

All mentioned sequences were created as part of the research and attempts to find solutions to the questions raised in this case study. Emphasis was placed on simplicity and variability. The created sequences can also be considered universal and can be used for research by other authors in future.

5 Results

Computer simulation is currently a complex engineering method that is used for a wide range of research problems. However, in its implementation, because of the increasing complexity and complexity of the solved tasks, it is necessary to use not only the common tools used by individual simulation tools, but it is also necessary to use additional programming. The study presents the result of the design of original program sequences for the solution of intra-plant transport in SimTalk. The obtained results expand the findings presented by Deng *et al.* [19]. These authors used SimTalk in modeling production processes in the field of metallurgy. The proposed sequences presented in the study together with the conclusions [19] enable the creation of a complex simulation model of the logistics process. At the same time, it is possible to implement the results presented in the study in the field of IoT in terms of logistics train management. Lin *et al.* deal with this issue in more detail [20] and the proposed completed

Figure 11: Part of the simulation model used in the case study.

sequences can thus be used to model a complex intra-plant transport system that will use IoT. At the same time, the proposed sequences can be used in conjunction with genetic algorithms, as presented by Chen and Huang [21] to optimize intra-plant transport processes. Overall, it can be stated that the results presented in the study expand the knowledge in the application of the programming tool SimTalk and complement the knowledge presented in the works of other authors [22–24].

Logistic towing systems or tugger trains, which are equipped with suitably selected internal logistics systems, are increasingly used in the field of supplying production and assembly lines. Compared to the original systems, logistics systems show several advantages. Starting with increased transport performance and a reduction in the number of internal transports, operational safety has increased significantly and operating costs have been reduced.

Various applications of innovative solutions have had a positive impact on internal logistics. As an example, the increase in the maneuverability of the trolleys with steered axles allows logistics systems to be used to supply narrower aisles and then use the space saved more efficiently. Loading and unloading of pallets for internal logistics systems of E-frames and C-frames. The newly developed B-frame allows loading and unloading of pallets from both sides, making it easier to supply production and assembly lines.

The current trend in internal logistics is toward automating activities that add no value to the product, that is mainly material handling. The motivation for automation is usually nonavailability of labor, less error rate, and the possibility of long-term use, especially in multi-exchange or continuous operations. There is a consensus among professionals that the gradual automation of all logistics processes is irreversible.

The efforts to find solutions suitable for inter-object transport systems are progressing in mile-long steps. Automated systems that do not need manning will most likely eliminate the human factor eventually.

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