Supplying of Assembly Lines Using Train of Trucks

Zdeněk Čujan and Gabriel Fedorko*

DOI 10.1515/eng-2016-0057
Received July 6, 2016; accepted August 1, 2016

Abstract: The typical supply system conceptions, i.e. the concepts “Just-in-time” (JIT) and “Just-in-sequence” (JIS) are very important factors with regard to a fluent operation of the assembly lines. Therefore the contemporary intra plant transport systems are being replaced by a new kind of the transportation technology, namely by means of the trains of trucks. The trains of trucks are used in two possible operational modes: either with a driver or without driver (fully automated). The trucks of the logistic trains are also cheaper and they are able to carry a larger volume and mass of the material at once. There are reduced in this way not only the investment costs, but also the operational expenses.

Keywords: Supplying; logistic flow; fluency of production; assembly lines; train of trucks

1 Introduction

Efficiency of production systems depends on correct settings of the logistic flows and on suitably chosen method of material supply [1, 2]. At present, a solution of the horizontal transport by means of the trains of trucks is one of the important tasks in most of the industrial plants. The logistic trains, which are driven personally – by the drivers or are operating in automatic regime, offer a lot of advantages in the area of intra plant logistics, predominately [3]. The train of trucks enables to transport an increased amount of the material or components required for the final assembly using a reduced number of the individual runs in comparison with the forklift trucks and this process can be performed without the driver [4–6]. The logistic trains offer many advantages, namely in the area of the production logistics and in expedition. The most of savings, resulting from the application of the train of trucks, is relating to replacement of the forklift trucks and to the increase of supplying efficiency not only in the production, but also in the process of supplying the assembly lines [7]. The trains of trucks are able to operate at a smaller area and in this way there is loose a larger area disposable for the production itself. Also the noisiness of the logistic trains is reduced compared to the forklift trucks on condition that there is applied a suitable towing vehicle (puller).

The real selection of the train of trucks depends on various factors [8]. There is important not only a kind of the transported material, but also amount of the material, i.e. intensity of the material flow. These facts are relevant with regard to a proper selection of the towing vehicle and type of the towed trucks that are necessary for assembly of the logistic train [9–11]. Another relevant question is the maximal number of the trucks integrated into the train of trucks. The next important aspect is the specifications of the train of trucks operation, i.e. frequency of the individual runs, number of the stations, width of the transport routes, dimensioning of the curve radii, solution of the turnouts, etc.

2 Analysis of the present situation

All the components, which are necessary for the final assembly of the escalators or travelators, are stored in the central storage and they are transported from this storage to the individual workplaces or to the assembly lines by means of the forklift trucks (Figure 1).

Presently, there are applied eight forklift trucks for supplying of the production devices and the assembly lines, whereas one forklift truck is transporting only one palette. The demands, concerning delivery of the required material or components to the production or to the individ-
Supplying of Assembly Lines Using Train of Trucks

The next data were obtained according to the analysis of the individual forklift truck movements (see Figure 2 and Figure 3) in Table 1.

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>black</th>
<th>violet</th>
<th>red</th>
<th>green</th>
</tr>
</thead>
<tbody>
<tr>
<td>runs.day$^{-1}$</td>
<td>10</td>
<td>30</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>m.run$^{-1}$</td>
<td>400</td>
<td>100</td>
<td>600</td>
<td>400</td>
</tr>
<tr>
<td>m.day$^{-1}$</td>
<td>4000</td>
<td>3000</td>
<td>18000</td>
<td>1200</td>
</tr>
</tbody>
</table>

Analysis of the forklift truck movements, which was performed during a two-shift operation within one month, offers the following values that are valid for one forklift truck and relating to one assembled unit (Table 2).

Disadvantages of the present forklift truck transport system can be eliminated by means of the logistic train, which enables:

- to perform a suitable configuration of the whole transport so that the all production lines and the assembly lines could be supplied at the right time with an optimal amount of the material, which is delivered on the determined points,
- to create a proper supplying system using optimal amount of the unloading points with optimal sequence of them (Figure 4).
Table 2: Values valid for one forklift truck and relating to one assembled unit.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average speed of the forklift truck $v$</td>
<td>$9.6 \text{ km.h}^{-1}$</td>
</tr>
<tr>
<td>Total passed distance $d$</td>
<td>$550 \text{ km}$</td>
</tr>
<tr>
<td>Total amount of the transported pallets</td>
<td>$1400 \text{ pcs}$</td>
</tr>
<tr>
<td>Number of the transported pallets per day</td>
<td>$70 \text{ pcs}$</td>
</tr>
</tbody>
</table>

4 Target Function

Applicability of the logistic train realisation has to be considered by means of the suitably chosen target function $F_x$. The main task of the target function solution is a minimisation of it:

$$F_x = \sum_{i=1}^{n} d_i + \sum_{j=1}^{m} t_j + \sum_{k=1}^{p} i_k \rightarrow \min$$  \hspace{1cm} (1)

where is:
- $d_i$ - the distance passed by the $i$-th train,
- $t_j$ - the value of time, which exceeds the permissible maximal supply time determined for delivery of the component to the $j$-th unloading point,
- $i_k$ - the number of requirements for transport of the $k$-th component to the assembly line without the allocated logistic train.

There was applied the genetic algorithm of the simulation tool Plant Simulations in order to optimise the solved supplying problem (Figure 5). The Graph on Figure 6 illustrates development of the chosen target function (1) in the case of the individual performed simulations.

Calculation of the optimisation process was realised for twenty following generations.

The histogram on Figure 6 is useful for evaluation of the process, namely for determination of the transported material amount and real capacity of the present and proposed system (Figure 7). The horizontal axis $x$ in the histogram describes number of the pallets transported per hour and the vertical axis $y$ describes the frequency of occurrence.
5 Mathematical model

Application of the logistic train in the supplying area is a method, which is more suitable with regard to the real requirements. This method includes (for every unloading point) a time interval, which is assigned with off-take of the necessary material or components from the central storage and the time interval, which is required for delivery of the given material and components to the production or to the assembly lines. It is necessary to know not only the distance \( d_{ij} \) between the individual loading and unloading points, but also to dispose of information about the transport times \( t_{ij} \) among the all implemented points, i.e. in the production and in the assembly lines. Afterwards, the mathematical model can be written in the next form [15–17]:

\[
f_z = \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} x_{ij} \rightarrow \min \tag{2}
\]

on the next terms:

\[
\sum_{j=1}^{n} x_{ij} = 1, \text{ for } i = 1, 2, \ldots, n, \tag{3}
\]

\[
\sum_{i=1}^{n} x_{ij} = 1, \text{ for } j = 1, 2, \ldots, n, \tag{4}
\]

\[
u_i - u_j + nx \leq n - 1, \text{ for } i = 1, 2, \ldots, n, \text{ for } j = 2, 3, \ldots, n, \text{ for } i \neq j, \tag{5}
\]

\[
x_{ij} \in \{0, 1\} \text{ for } i, j = 1, 2, \ldots, n, \tag{6}
\]

where:

\( n \) is the number of the points determined for arrival of the logistic train, including the central logistic storage (supermarket), which is signed with the index „1” and \( d_{ij} \) are the distances between the points \( i \) and \( j \).

The \( x_{ij} \) value is a bivalent variable. Its value is \( x_{ij} = 1 \) in case of passing of the logistic train from the point \( i \) to the point \( j \) and \( x_{ij} = 0 \) in the opposite situation. The limiting conditions (3) and (4) ensure that each of the points is visited by the logistic train only once (Figure 8).

The set of equations (5) and (6) with the variables \( u_i \) are the limiting conditions in order to avoid a possible creation of the partial cycles.

6 Simulation model

The simulation tool Tecnomatix Plant Simulation was used for modelling and creation of the simulation model, which describes the process of supplying in the production and assembly lines using the logistic train. This software is one of the most often applied products utilized for simulation and analysis of the logistic processes in the various industrial areas.

The Plant Simulation enables to create digital models of the logistic systems, whereas the developed model of the real system can be characterised and analysed in order to optimise the system performance. The simulation software is equipped with the various analytical tools determined for analysing and evaluation of the simulated solutions with regard to a proposal of the optimal variant (Figure 9).

Creation of the simulation model in the given software surrounding is based on a suitable application of the simulation blocks, together with a possible usage of the supplementary simulation language SimTalk, which enables to simulate the individual processes in more detail.

The conception of the simulation model creation is divided into the three basic groups:

- simulation of the material loading in the supermarket,
- simulation of the material transport from the supermarket to the point of unloading,
- simulation of the material unloading in the determined point.

There was assumed a simple process during creation of the simulation model, which describes a real operation
in the supermarket area (Figure 10). The empty transport units will be removed from the automated logistic system and at the same time the full transport units, which are filled with the required material, will be inserted back into the given system (Figure 11).

Figure 10: Part of the software created in the simulation language Sim Talk; unloading of the components.

Figure 11: Simulation model of the logistic train in the point of unloading.

7 Evaluation of the proposed

There were simulated twenty various situations and the variant with two logistic trains was definitely recommended and chosen after finishing of this simulation process, i.e. it is the variant with two towing vehicles and with the various towed trucks modified according to the real requirements concerning the shape or weight of the transported material; taking into consideration also other parameters, including safety of the whole transportation process (Figure 12).

Figure 12: Exploitation of the towed trucks.

The maximal number of the towed vehicles, which was considered during simulation of the supplying process, is six in this case. This number is limited due to a real profile of the transport trajectory arranged among the individual objects of the central storage, production hall, assembly hall, taking into consideration the process of control, packaging and expedient of the final products, as well.

Today there are utilized 8 forklift trucks in order to supply the production and assembly lines, i.e. it is necessary to employ 8 drivers and another 3 persons are employed in the storage in order to perform the order picking activities that are necessary for operation of the forklift trucks.

The new solution, which consists in implementation of two logistic trains, requires only 2 drivers of the towing vehicles instead of 8 drivers of the forklift trucks and only 1 storage handler, who ensures a continuous operation of the logistic train, instead of 3 workers necessary for the order preparation of the forklift trucks (Figure 13).

Figure 13: Number of workers necessary for operation of the forklift trucks and logistic train.
8 Conclusion

Application of the logistic train in the intra plant transport increases value of the transport system capacity and it reduces the movement frequency of the transport-handling devices. In this way it reduces a risk level of possible accidents, too. Thanks to a higher operational safety there are also decreased the costs concerning the unexpected repairs compared to the forklift truck operation.

There are applied the specific E-frames for the material transport. These frames are especially manufactured according to the client’s requirements. This kind of frames enables to transport pallets with the dimensions from 1000 × 600 mm to 1600 × 1200 mm. Some of these special E-frames are also able to transport the large pallets 1800 × 1200 mm safely and quickly. Elimination of the forklift truck operation is bringing a higher safety level of the material transport, together with savings of the personal costs and increased transport capacity. Another kind of the frame, namely the B-frame is designed for a considerably better loading and unloading from both sides. These frames are used for supplying of the production lines and assembly lines. The main task of every logistician is a question of cheaper, more reliable and safer material transport. The logistic solution presented in this article reduces not only the operational costs, but it also eliminates the transport collisions and possible damage of the trucks or production equipment.

Acknowledgement: This work is a part of these projects VEGA 1/0258/14, VEGA 1/0619/15, VEGA 1/0063/16, KEGA 006STU-4/2015, KEGA 018TUKE-4/2016.

References