Simulation as Logistic Support to Handling in the Warehouse: Case Study

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***Abstract* – Manipulation processes represent an important part of the material management in a company. These processes run inside a company and represent an integrated chain of material flow. The current situation regarding the material manipulation is evaluated using the manipulation indicators which may serve as the basis for manipulation system rationalisation designs. The present case study is focused on the determination of an appropriate number of forklift trucks in a given operation and consists of three sections. The introductory section deals with the evaluation of forklift activities while applying the selected analysis and the selected indicators. Analysis results subsequently served as a basis for the calculation. The calculated number of trucks must be properly verified; the verification should be focused on whether the given number of forklifts is actually sufficient for the performance of the current activities. The activities were verified while applying the simulation. A simulation model was created using the Technomatix Plan Simulation software.**

***Keywords* – Manipulation, evaluation, indicators, simulation, model.**

1. Introduction

Modern industry is dependent on the speedy and efficient movement of materials of all descriptions to and from their places of production, storage and distribution [1]. Nowadays, the great attention has to be paid to warehouses. Theoretical analysis shows the need to optimize their activities [2]. A warehouse is a location from where raw material, semi-product and finished products are received, transferred or put away, picked, sorted and accumulated, cross-docked and shipped in [3].

The above mentioned activity - manipulation with materials is a cost item but it does not provide any added value to the materials. The primary purpose of the material flow management is to minimize manipulation with materials. To make the manipulation with materials cost-efficient, the following principles must be adhered to: manipulation should be reduced to the minimum, material movement distances should be as short as possible, smooth material movement with minimum interruptions is required, manipulation devices must be standardized, their structure should be cost-efficient, purposeful, and multi-purpose [4].

The most frequent device used for material manipulation in warehouses is a forklift truck. Forklifts can be classified by different methods including the power source, operator position, and load engagement method [2].

In the literature, several authors present various problems regarding the forklift truck operation, e.g., Multi-Criteria Optimization of the Selection of Transportations Means [5], optimizing forklift activities [2], the working condition and energy flows of the forklift [6], the optimal range of parameters for an operator during his control of a forklift, within which he doesn't get into non-physiological work postures associated with discomfort [7], a forklift safety system [8], an environmental life cycle assessment of forklift operation [9], performance evaluation [10], etc.

An important problem in the operation is the correct determination of the number of used forklifts, in terms of their utilization and related costs. Correct determination of the number of forklift trucks is most frequently based on formulas found in the literature [11]. Subsequently, it must be verified whether the calculated number is sufficient for the performance

DOI: 10.18421/TEM71-13
https://dx.doi.org/10.18421/TEM71-13

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Received: 11 November 2017.
Accepted: 07 February 2018.
Published: 23 February 2018.

of the required activities. The verification is usually carried out using simulation.

The simulation is an experimental method in which we replace a real-world system with a computer model. Such model may be used for number of experiments which are subsequently evaluated or, potentially, optimised and the results are then applied to the real-world system. The first step within the simulation is the creation of a simulation model of the real system. The following step is execution of experiments using the simulation model; experiment results must then be correctly interpreted and applied [12].

2. Methodology and calculations

Determination of the required number of trucks and verification thereof using the simulation is carried out in three stages.

Stage 1 – evaluation of forklift activities in the operation. Evaluation of activities within the use of forklift trucks was carried out in four steps:

1. selection of relevant indicators,
2. "shift snapshot" preparation - observation, measurements, and recording,
3. processing of the measured values and calculation of indicators,
4. assessment of the current status.

This stage comprises of analysis of trucks and their activities in the operation while applying the selected technical and economic indicators.

Stage 2 – determination of the required number of trucks, using the formula [11]:

$$Z_p = \frac{Q_{vh} \cdot t_{cp}}{3600 \cdot M_d} \qquad \text{[pc]} \qquad (1)$$

wherein

Q_{vh} – required transport efficiency, [t/h] [pallets/h],
t_{cp} - average forklift operation cycle time, i.e. the time of transporting and loading operations [s],
M_d – average weight of a single dose (pallet) [t].

Required hourly transport efficiency is determined by the formula:

$$Q_{vh} = \frac{Q_{vs} \cdot k_{nh}}{T_{ps}} \qquad [\text{t.h}^{-1}] \qquad (2)$$

wherein

Q_{vs} – required scope of manipulation operations per shift [t],
k_{nh} – coefficient of hourly irregularity of operations during a shift,
T_{ps} – productive time fund of a shift [h].

The total average forklift operation cycle time is determined by the formula:

$$t_{cp} = t_1 + t_2 + t_3 + ... + t_n = \sum_{i=1}^{n} t_i \qquad \text{[s]} \qquad (3)$$

t_i – time intervals of individual partial actions within an operation cycle [s],
n – number of individual partial actions within a single operation cycle.

Duration of a complete closed operation cycle usually consists of the following time intervals [11]:

- time required for adjusting a tool to a position necessary for loading (a pallet),
- time required for loading (a pallet),
- time required for adjusting a tool to a position appropriate for travelling (usually an elevation),
- time required for travelling over the transport distance (travel time, with a load),
- time required for adjusting a tool to a position necessary for unloading (a pallet),
- time required for unloading (a pallet),
- time required for adjusting a tool to a position appropriate for travelling (lowering the fork),
- time required for travelling over the transport distance (travel time, without a load).

For the purpose of calculation the operation cycle time, the above specified formula can be simplified as follows:

$$t_{cp} = t_1 + t_2 + t_3 + t_4 \qquad \text{[s]} \qquad (4)$$

wherein

t_1 – represents the time of all manipulation and loading operations (e.g., forking a pallet, putting a pallet into a racking compartment, fork adjusting, etc.) [s],
t_2 – forklift travel time there and back (with and without a load) [s]

$$t_2 = \frac{2 \cdot L}{v} \qquad \text{[s]} \qquad (5)$$

t_3 – time of lifting loaded fork and lowering the unloaded fork [s]

$$t_3 = \frac{2 \cdot h_s}{v_z} \qquad \text{[s]} \qquad (6)$$

wherein

L – average transport distance in one direction [m],
v – average transport velocity of the forklift [m.s^{-1}],
h_s – average fork elevation and lowering height

(average height of storage - retrieval) [m],
v_z – average fork lifting and lowering velocity [m.s^{-1}],

t_4 – time losses incurred during the operation cycle [s].

Number of forklift cycles per hour:

$$p_c = \frac{3600}{t_{cp}} \quad [-] \quad (7)$$

The total number of forklift trucks Z_c is determined by increasing the number calculated using the formula (1) in the capacity reserve for scheduled and unplanned repairs and regular maintenance of forklift trucks [11]:

$$Z_c = Z_p \cdot \left(1 + \frac{r}{100}\right) \quad [pc] \quad (8)$$

wherein
Z_c – total required number of forklift trucks [pc],
r – determined capacity reserve for scheduled and unplanned repairs and maintenance of forklift trucks [%].

Stage 3 **-** verification of whether the calculated number of trucks is sufficient for the performance of currently required activities by applying the simulation, using the selected simulation tool.

3. Case study

The above described method was applied to a company warehouse. The warehouse activities include common warehouse activities: goods acceptance, storage, and dispatch on the basis of orders placed by customers and subsequent dispatch. Goods are dispatched for two types of orders: orders received and orders with direct goods collection (customers come personally to the company's subsidiary to purchase the goods). These activities are carried out in two shifts.

In the warehouse, there are 7 forklift trucks available. Table 1 lists the activities performed in the warehouse by shifts and the number of used trucks.

Table 1. Activities in the warehouse and number of used trucks by shifts

Shift	Number of trucks	Activities
1	7	- removal of prepared goods by loading them onto means of transport, on the basis of orders received - unloading and racking of the ordered goods, - removal of goods for customers with direct goods collection
2	3	- unloading and racking of ordered goods, - removal of goods for customers with direct goods collection, - preparation of goods to be distributed the following day, according to the received orders, and placing them in the dispatch area - material transport inside the warehouse.

Observation of a normal operation revealed that the trucks used in the first shift are not sufficiently used and there are frequent downtimes; the company thus considers reducing the current number of used forklifts.

Stage 1 – analysis of forklift activities

The analysis of activities engaging individual forklifts was carried out on the basis of the determination of the utilisation factor, while applying the method described in the paper [13, 14]. Data required for the utilisation factor calculation were obtained while applying the "shift snapshot" time study method. The shift snapshot method is based on continuous monitoring, recording, and evaluation of forklift trucks during the entire shift. Several parameters were monitored within this method: time parameters, e.g., loading time, unloading time, downtimes, number of travels, amount of transported goods, and travelled distance.

Snap-shooting was carried out for the first shift, as during this shift activities are carried out to a larger extent. If the calculated number of trucks is 3 and more, the given quantity will be sufficient for the second shift as well, as shown in Table 1.
Average values obtained by snap-shooting for the selected period for individual trucks are listed in Table 2 (*F1…F7- forklifts, 1 - Operation time [min], 2 - Downtime [min], 3 –Worked time [min], 4 - Transported amount [kg], 5 - Average transport distance [m])*.

Table 2. Average values obtained by snap-shooting of the shift 1

	F1	F2	F3	F4	F5	F6	F7
1	435	435	480	480	480	435	480
2	203	217	292	234	319	270	341
3	232	218	188	246	161	165	139
4	39.3	24.5	16.44	18.86	14.15	7.89	9.2
5	3.60	2.84	1.55	1.86	560	1.14	750

Values contained in Table 2 were used for the calculation of utilisation factor while applying the selected method [12]. Figure 1 presents the forklift utilisation factor values for shift 1.

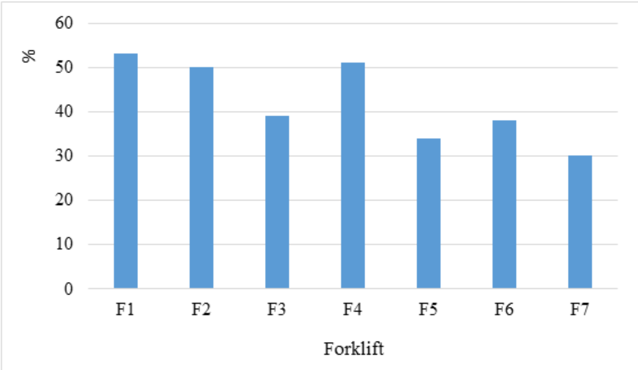

Figure 1. Utilizations factor values

On the basis of the data contained in Figure 1 we can state that the shift 1 utilisation factor is low; its values range between 34 and 53%, on average 42 %. The data obtained by measurements and calculation of the utilisation factor confirmed common observations from the operation. What number of trucks would be required in shift 1 to increase their utilisation at least up to 75%?

Stage 2 – determination of the required number of trucks

The required number of forklift trucks was calculated using formulas (1) and (8). Input data for the calculation were the data from the "shift snapshot" measured data. The values used in the calculation and the calculated values are listed in Table 3.

Table 3. Input values for the calculation and the calculated values

Forklift truck	Q_{vs} [t]	t_{cp} [s]	M_d [t]	k_{nh} [-]	T_{ps} [h]
Shift 1	130	490	0.5	0.75	7
Forklift truck	R [%]	Q_{vh} [t/h]	Z_p [pc]	Z_c [pc]	
Shift 1	50	13.92	3.79 ≐ 4	6	

On the basis of the calculated results we can state that in shift 1 it is necessary to engage 4 forklift trucks, i.e. 3 forklifts less than those used at present. The total number of forklift trucks at the 50% capacity reserve is calculated as 6 pieces for shift 1. After the calculation of the required number of trucks, it is necessary to properly verify whether the given quantity is actually sufficient for all the activities.

Stage 3 - verification of activities of the calculated number of trucks

The calculated number of trucks must be properly verified; the verification should be focused on whether the given number of forklifts is actually sufficient for the performance of all current activities. The activities were verified while applying the simulation. A simulation model was created using the Technomatix Plant Simulation software.

Plant Simulation is one from among the available software tools for logistics, developed by Siemens PLM Software for modelling, simulation, analysis, visualization and optimization of production systems and processes, material flow and logistics operations. Using Tecnomatix Plant Simulation, users can optimize material flow, use of resources and logistics for all levels of planning production facilities. This software tool allows a comparison of complex production alternatives, including process logic, computer simulation [15,16].

Model creation consisted of several steps; their simple order is shown in Fig. 2. Fig. 3 presents created routes in the warehouse layout [13].

The verified simulation model was used in experiments simulating the activities performed in the warehouse. Experiments for the current status

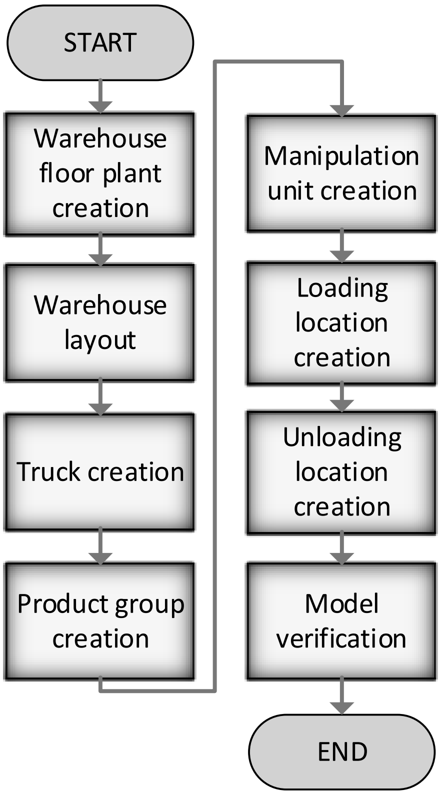

Figure 2. Simulation model creation procedure

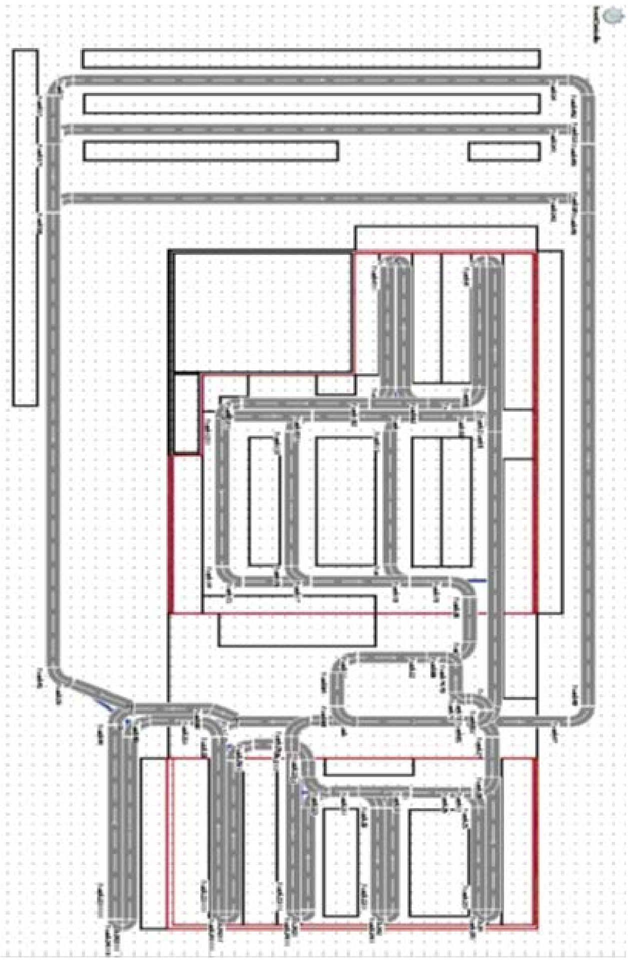

Figure 3. Manipulation routes

confirmed the comparable utilization factor values calculated in stage 1.

Subsequently, experiments were performed for the calculated number of trucks. Table 4 displays the comparison of results obtained in the experiments.

Table 4. Comparison of simulation results

Parameter	Current status	Suggested values
Number of forklifts	7	4
Forklift utilisation factor	46.30	81.45
Number of inputs and outputs	485	485
Travelled distance [km]	12.46	18.79

Comparison of the results indicates that forklift utilisation factor at the reduced number of forklifts will increase for 35% on average. However, the total travelled distance at the reduced number of forklifts is higher. It is attributable to the fact that at the current status of manipulation devices, the forklifts were allocated for the reserved section of the storage area, whereas in the design simulation the trucks were moving and performing activities all over the storage area. The simulation indicated that the reduced number of forklifts will be sufficient for the currently performed activities.

4. Conclusion

On the basis of the utilization factor determination and the calculation verification by simulation it was concluded that forklift trucks are used in the operation in less than 50%. The data obtained by observation carried out directly in the operation were used as the input data for the calculation of the required number of forklift trucks which was verified by simulation.

Acknowledgements

This article is a part result of the project VEGA 1/0577/17 Transfer of knowledge from laboratory experiments and mathematical models in the creation of a knowledge based system for assessing the quality environmentally friendly conveyor belts and project KEGA 009 TUKE-04/2016 – Design of the specialized training Concept orientated to the development of experimental Skills within the frame of education in the study branch Logistics.

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