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# DYNAMIC SETTING OF SHIPPING POINTS IN LOGISTICS SYSTEMS WITH MULTIPLE HETEROGENEOUS WAREHOUSES

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This study aims to model a planning process of handling outbound deliveries from a set of geographically dispersed warehouses. The model incorporates parameters observed in real-life supply chains and allows simulation of various variants of process supporting decision making of current shipment management, as well as strategic planning of distribution network. A heuristic algorithm that can be used for planning source warehouses for shipments is proposed. The model is built and tested on real business data and its performance proves to be better than the one currently used by a reference company.

**Keywords:** *supply chain planning, distributed warehousing, internal logistics, warehousing policies*

## 1. Introduction

Last years' planning has become a major aspect of conducting logistics business. The focus of decision making and processes design has been shifted from single operations management within specific business units towards a holistic vision of material flows, where production plants, vendors, warehouses, and customers form an integrated network. In a modern logistic system, every operation associated with materials needs to be checked in the process design phase. Even short-distance movements of products within a company's premises (production plant, warehouse) or within a supply chain (vendors, logistics operators, customers) start to play an important role.

Companies that have several warehouses in various localisations face the problem of proper allocation of stored goods. When considering decisions, they must take into account aspects like types of materials (such as raw materials or finished products), storage capacity or handling options, like the possibility to build heterogeneous pallets or service only full single-material pallets. In the process of material allocation and

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warehouse performance planning, all such general constraints must be considered, alongside the local characteristics of each company.

In this study, an approach is made to model a planning process of handling outbound deliveries from a set of geographically dispersed warehouses. The model incorporates parameters observed in real-life supply chains, especially warehouse capacity and throughput, technical handling capabilities, and range of materials stored in each store, as well as external factors, like customer's order service level (possibility to split a single delivery and supply it from different localisation or option to merge orders within periods to form aggregated shipments). Most studies in the area of warehouse outbound logistics focus on considerations of picking process in a single storage area, like a warehouse. The main stress is put on the description of policies of goods placement in picking locations, path optimisation for order collection and work split between workers responsible for operations. Another field for logistic research considering the process of order supply changing is focused on tactical planning of material distribution among different logistics objects (see Table 1 for review of various research concerning the subject). The author has not encountered any studies that concern both – tactical and operational challenges in the process of decision making for redistribution products from logistics objects. The key contribution of this paper is the identification of a set of parameters that appear in such problems and a proposal of a heuristic procedure that allows optimisation and can be implemented by the business.

## 2. Literature review

Research in a company's internal logistics involved in outbound processing can be roughly grouped into three sections: description of policies of goods placement in picking locations, path optimisation for order collection, and work split between workers responsible for operations. The main aspect of the first consideration focuses on choosing a proper organisational strategy that allows storing a product in a way that minimises collection time spent by a worker, thus minimising the cost and maximizing the customer service level. There are two main approaches used in storage management strategies. The first, so-called randomly storage policy, reduces the time needed to place material in its destination, but often significantly increases the time needed to pick it. According to such a policy, a product is stored in a place that is currently empty. Workers receiving materials into the warehouse place them in random locations, usually as close to the entrance point as possible – a strategy known as closest open location [6]. The second main storage approach is based on fixed location assigned to each material, or a group of materials – so-called assign storage policies. Various levels of details can be represented – each material can have a dedicated place, or a group of materials sharing the same properties are stored in the same warehouse area. The first is usually less effective as it reserves more space to hold enough stock for peak picking periods [6]. Shared storage policies can lead to higher performance levels. Commonly used ABC classification based on Pareto's method divides the items by turnover values. Usually, A represents fast-moving/high-volume materials, B is the next category for slower-moving/less-volume, and so on. The assignment of classes to materials takes place periodically to ensure that any changes in turnover be reflected. The locations for each class (as well as for each material in the case of dedicated places) can be established based on a variety of parameters but the most important is that materials with the highest rotation (A) should be placed as close as possible to warehouse issuing points to minimise the time needed for picking [9, 14, 15].

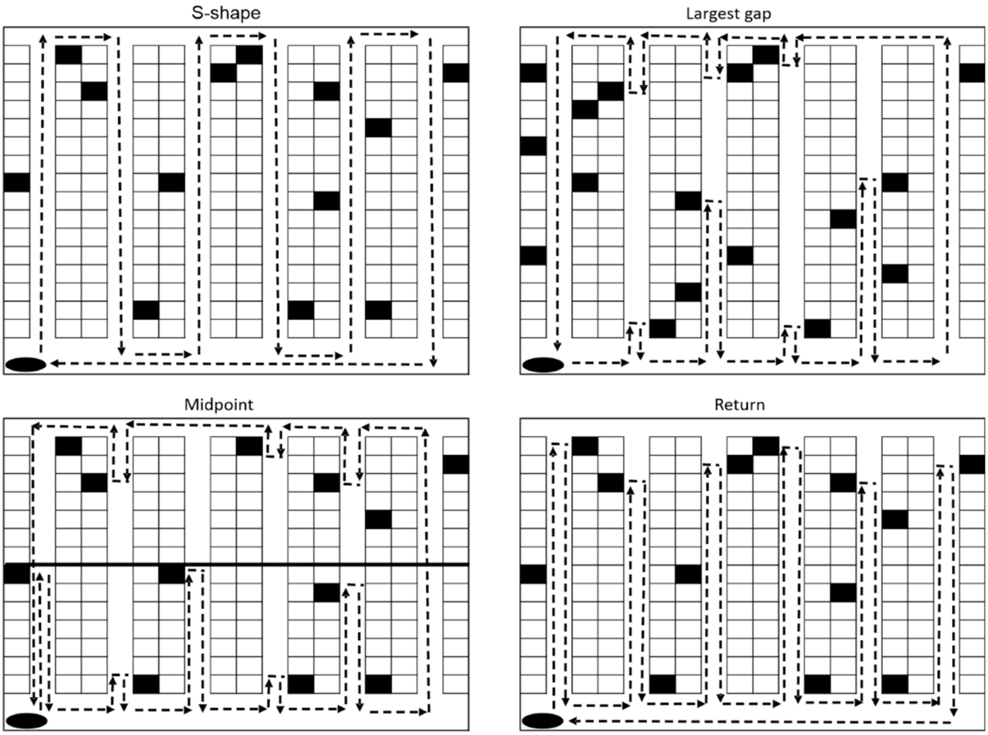


Fig. 1. Routing heuristics – source: Sabo-Zielonka and Tarczyński [27]

Path optimisation strategies for material picking (so-called routing policies) are among the most frequently researched area of increasing the effectiveness of warehouse operations. Numerous algorithms try to find the optimal path but the most popular approach is using heuristics. This is caused by the simplicity of the application as well as the fact that the produced results are similar to exact algorithms [26]. Exact algorithms are limited by the number of variables that must be taken into considerations and the constant need of building new models for each new selection of picking lists. The most commonly described methods for path optimisation, according to Sabo-Zielonka and Tarczyński [27] are: S-shape (the worker goes through alleys all the way there and back), midpoint (warehouse is logically divided into two parts or halves – the worker enters an alley and picks the goods only until logical half – if any material is in the other half, it is picked on the way back), largest gap (similar to midpoint but the worker can enter the alley further than the midpoint, as long as (s)he encounters the largest gap between materials; such gap is represented as a direct distance between two materials in the same alley, between the lower main corridor and first picking material or between the upper corridor and last material. If such distance is met, then the worker should go back to the corridor where (s)he has started), return (the worker enters each alley as long as (s)he picks the last item there and goes back to enter the next alley in the same direction). A brief illustration of each method is shown in Fig. 1.

In the warehouse, where a shared storage policy that allows placing the same material in many distinct locations, the algorithm may need to take into account additional parameters. The quantity of material in each location will influence the decision to choose a location, where there is enough material to satisfy the whole requirement or to allow partial picks in more places (more information can be found in [11]). Another factor influencing the choice are the properties of batches of the same material – for materials with a shelf-life period, it will determine the picking sequence (just to mention FIFO – first in-first out or FEFO – first expired-first out strategies). Depending on previous options' selection, a picking location must be chosen, taking into consideration the distance that the worker ought to travel to complete the order. Certainly, the path should be as short as possible to minimise the time spent on travelling.

Table 1. Research fields for warehouse outbound logistics

| Main areas of warehouse out-bound logistic in literature | References |
|---|---|
| Storage management strategies | De Koster et al. [6], Diaz [7], Frazelle, Apple [9], Glock, Grosse [10], Jakubiak, Tarczyński [14], Kłodawski, Jacyna [15], Li et al. [19], Manzini et al. [20], Tsamis et al. [32] |
| Picking path optimisation | Bustillo at al. [5], Hsieh, Huang [13], Kulak et al. [16], Li et al. [18], Moeller [22], Ratliff, Rosenthal [26], Sabo-Zielonka, Tarczyński [27], Scholz, Wäscher [30] |
| Process parallelisation | Anderson et al. [2], Bratcu, Dolgui [4], Henn, Wäscher [12], Mutingi, Mbohwa [23], Pan et al. [24], Scholz et al. [29] |
| Planning of material distribution | Agrawal et al. [1], Avci, Selim [3], Lau, Nakandala [17], Paterson et al. [25], Schmitt et al. [28], Stanger et al. [31], Van Wijk et al. [33] |

The third area of study considers the process of splitting the work between workers to minimise the time needed to collect each order. Detailed research is described in works like Anderson et al. [2], and Bratcu and Dolgui [4]. Another field for logistic research considering the process of order supply changing is focused on tactical planning of material distribution among different logistics objects. The works are concentrated on problems concerning material flows between warehouses and material allocation in many geographically distributed storages. The cost of operations is the main optimisation criteria taken into account. Such considerations can be found in [1, 3, 25, 27, 32]. Table 1 groups the source literature for the subject by research fields:

In this paper, the process model and heuristic algorithm is presented. A business case is used to model the process of planning outbound deliveries from a set of geographically dispersed warehouses, a set of parameters that influence such process is identified and a heuristic algorithm that can be used for planning of source warehouses for shipments is proposed.

## 3. Business case

The initial need for the research was raised by a company that has faced problems with the proper distribution of goods within its warehouses. The international company working in the area of construction chemical products has three production plants in Poland – all involved in domestic and export order fulfilment (in the process only out-bound part is researched). Each plant has a finished goods warehouse – two of them have fairly simple warehouses used for storing goods produced in respective plants, both capable of handling full pallets only (a combination of high rack and floor bulk storage, goods placed with random policy and issued according to FEFO). The third warehouse is the biggest and more complex – it can receive finished goods from all three production plants, as well as trading goods bought by the company (Fig. 2 illustrates the layout of this warehouse). Besides the handling of full pallets, single unit and mixed pallets orders are serviced there. Full pallets are stored on high racks (goods are put away to the first empty bin) and issued based on FEFO. Goods for picking of partial quantities are stored in dedicated bins that are assigned based on ABC classification and reviewed every 3 months. Replenishment of dedicated bins is done up to the maximum allowed when planned orders reserve full quantity stored. The picking process is organised with the S-shape approach and one order can be split among several workers for simultaneous processing. Business growth and change of processes (e-commerce and need for more flexible service) caused the need for optimisation. A simulation was designed to model the company's distribution problems and to help to find better methods for the management of customer outbound deliveries.

In the process of new distribution network, the design of several cost properties is analysed, including land and workforce costs, taxes, as well as factors supporting local economic growth (i.e., special economic zones), and location attributes, like accessibility to various transport modes (like roads or railways), distance to communication nodes (highways, airports, ports, etc.), and availability of communal services [21]. Each of the planned logistics network objects can be assigned a proper role and built in a way that maximises its performance. In this particular example, the company's warehouses are already existing, so the redesign process must be based on their current capabilities.

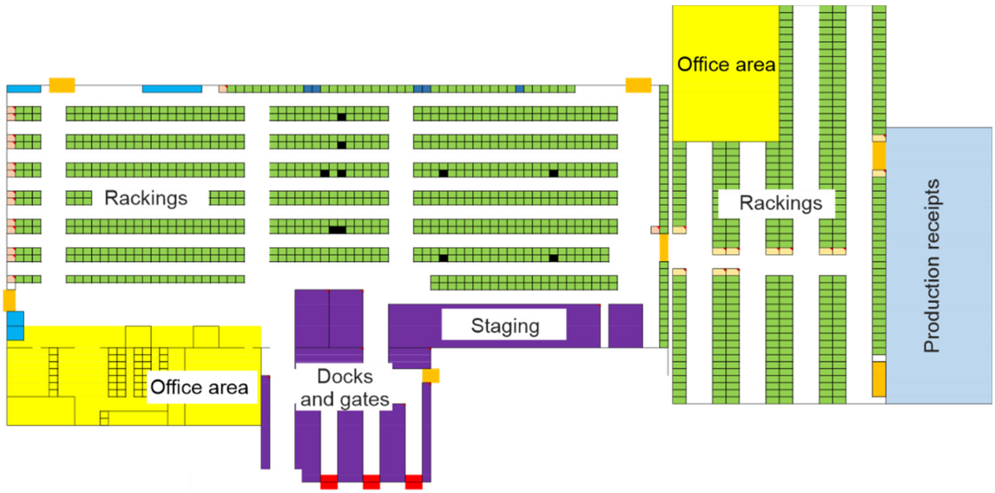


Fig. 2. Main warehouse layout

The following assumptions and limitations have been considered:

• The number of shipping points was known/limited – in the simulation two warehouses were used.

• Each warehouse was described with properties – ability to prepare mixed pallets, ability to issue full pallets, ability to process both types,

• Each warehouse was assigned with a list of materials that can be stored there – because of environmental hazards some combinations of materials are not allowed together.

• Each customer is described with a set of parameters – orders can be split, i.e., one order can be supplied from more than one warehouse and orders can be aggregated within certain periods – for instance, if the customer places several orders during one day, then they can be combined and shipped together. Additionally, the customer can be assigned the default shipping location.

• Conversion data is provided for each material allowing calculation of full pallet number, i.e., how many pieces form a pallet.

• The cost of delivery is not considered directly, but the most favourable option is to supply as many materials/pallets from a single warehouse as possible, thus reducing fragmentations.

• Stock levels of respective materials available in each warehouse are sufficient to fulfil the customer's needs.

## 4. Algorithm proposal and simulation run

In the described environment, the process starts when the customer places an order. It is directed to the company that is considered only as an agent that uses a set of rules (the described algorithm) to distribute orders among proper warehouses. It is shown in Fig. 3.

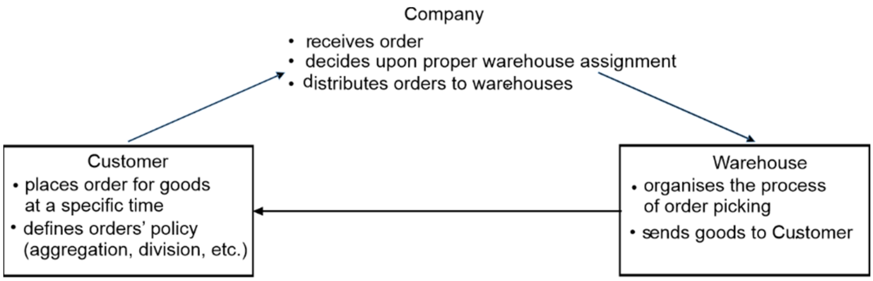


Fig. 3. Illustration of the proposed supply chain network

There are two main strategies for a decision-making model that can be applied for simulation – optimal and heuristic. An optimal solution is obtained by defining an objective function that minimises the cost or maximises logistics throughput. Numerical calculations in such a case (called an NP hard problem) can become much time consuming, as more combinations are included. The heuristics model can help to solve the problem without giving the optimal solution but with a solution that is accepted within time constraints. Such models can be used as practical rules in a decision-making process.

The simulation is to be run for order or groups of orders, on specific days based on the algorithm that considers internal and external limitations described above. The programme was designed in a way that allows the use of single customers' orders as well as orders' aggregations. An additional optimisation option was implemented that uses a cost-based algorithm that proposes a source warehouse. With the assumption that orders from each customer can be aggregated in a defined time (one day was taken as default) and orders can be freely split and supplied from separate warehouses, after defining a set of control cost parameters, it is possible to determine the combination of shipments with least total cost. The following cost types are proposed:

• C1 – the cost of sending a full homogenous pallet from a warehouse capable of handling only full pallets without the possibility of creating heterogeneous (i.e., mixed) units (later referenced as FPW or full pallet warehouse),

• C2 – the cost of sending a full homogenous pallet from a warehouse capable of creating heterogeneous (i.e., mixed) units as well as full pallets (later referenced as MPW – mixed pallet warehouse),

• C3 – the cost of sending a mixed pallet from a warehouse capable of creating heterogeneous (i.e., mixed) units – MPW,

• CA – the cost of orders' aggregation – each time two orders or order and previously created combination are shipped together – this cost is applied,

• CS – the cost of split – each time order or combination of orders are shipped from two different warehouses together this the cost is applied,

• CF – the cost of a fine for order split for customers that do not allow division of orders for partial deliveries. Although in business case description it is not allowed for some customers to split the deliveries – this cost parameter is introduced to the procedure as high value serving the same purpose. It is possible, however, to simulate the effect of minimisation of this value (in the case of renegotiation of the business contract with such customer) on the simulation result. A simplified flow diagram is shown in Fig. 4.

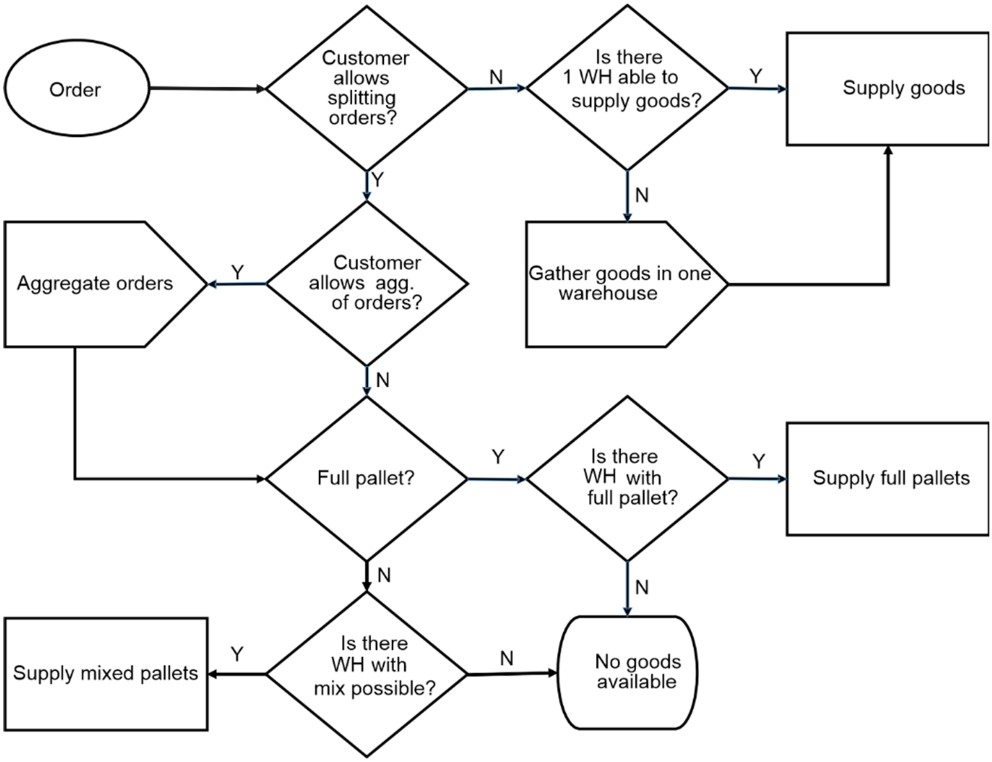


Fig. 4. Simplified algorithm flow

An additional optimisation algorithm was implemented with the following steps:

1. For each pair of customers and date gather all orders.

2. Filter out full homogenous pallet orders – they can be serviced with minimal cost without any aggregations or splits on their own.

3. Create the list of *n*-element combinations of orders, where *n* can have values between 1 and the number of non-full pallet orders for the customer on the respective date. In this case, the one-element combination means that separate orders would be shipped, two-element means that two orders are combined, and so on. The list is sorted by an increasing number of orders in combinations:

3a. Heuristics 1 – if the number of orders taken into account is greater than control parameter P_LEVEL, reduce the number of combinations by erasing two to (*n*-P_LEVEL) element combinations. Take, for instance, that in a sample of data, 10 separate orders are to be shipped – in case P_LEVEL parameters are set to 8 – all orders combinations containing two elements (pairs) and three elements (triplets) will be neglected due to assumption, that higher rate of aggregation will be achieved with more orders combined.

4. Create the list of all combinations of combinations of orders (CCO), so each of them contains all orders:

4a. Heuristics 2 – if the number of orders in the next CCO is greater than the desired number of orders in a current loop, omit the next combinations in the branch and move to the next in sequence.

5. Determine the CCO with the least cost – if there are more of CCOs with the same cost, prefer the ones with a smaller number of splits and aggregations.

Because of practical considerations, the decision was taken to employ the heuristics approach for simulation of the process rather than finding the best theoretical result of the objective function. Simulation has been prepared in SAP ECC 6.0 environment with a program written in ABAP (Advanced Business Application Programming) language by the author. ABAP is a 4GL programming language created by SAP AG to develop a platform for their ERP system SAP R/3. The language and system were chosen mainly because of the possibility to test the solution directly on real business data as the company uses SAP S/4 HANA. The simulation was designed along with ABAP best practices, and it consisted of:

- report/program responsible for running simulation – providing a user interface for parametrisation, running of calculations, and display of results,
- set of classes for object-oriented representation of algorithms used by main program processing data from a database,
- set of database tables representing materials, customers, customer's orders, and simulation outputs – instead of using standard ERP tables, a new set of tables has been prepared to allow data anonymisation and database access optimisation.

After adaptation, the prepared set of classes can be included in ERP processing and used for productive planning of source warehouses for shipments.

The simulation was run in three variants:

• S1 – direct application of rules as described in the Business Case chapter. This variant represents the same process of handling shipments as currently used by the company.

• S2 – theoretical process, where all orders can be aggregated and split freely between warehouses. It represents lower bond restraint, a benchmark showing the least cost theoretically possible if no constraints are applied.

• S3 – application of optimisation algorithm to find the least cost combination of shipments of customer's orders.

To allow a comparison between all variants they were called with the same cost values – the costs were estimated roughly, as based on current workforce cost and represented as cost units. The reference cost calculated for S1 and S2 was compared with the result of S3 (run 0). Later, the S3 variant was run several times with the cost of sending a full pallet from MPW (C2) gradually reduced to the level of cost that represents the cost of sending a full homogenous pallet from an FPW – a warehouse capable of handling only full pallets (C1). For the sake of simplicity, an assumption was made that the costs can be reduced only in this warehouse, as the processes are most complex and, accordingly, most expensive, giving higher potential for process and cost optimisation. All the costs used are shown in Table 2 (Run 0 was taken as the reference for S1 and S2).

Table 2. Costs used for simulation runs

| Cost type | Cost units | | | | |
|---|---|---|---|---|---|
| | Run 0 | Run 1 | Run 2 | Run 3 | Run 4 |
| C1 | 7 | 7 | 7 | 7 | 7 |
| C2 | 15 | 13 | 11 | 9 | 7 |
| C3 | 30 | 30 | 30 | 30 | 30 |
| CS | 5 | 5 | 5 | 5 | 5 |
| CA | 1 | 1 | 1 | 1 | 1 |
| CF | 50 | 50 | 50 | 50 | 50 |

## 5. Results

The simulation was run three times with the described variants of parameters on a sample of around 450k order lines placed by customers of an existing company over a sequence of 9 weeks. The results of the analysis are shown in two dimensions:

• Item – the number of order items that represent full pallets sent from MPW, full pallets sent from FPW, more than a full pallet of the same material sent from MWP, more than a full pallet of same material split and sent from FPW and MPW.

• Pallet – the number of pallets: full pallets sent from MPW, full pallets from FPW, partial pallets (in case of mixed shipments) from MPW and filling ratio.

Table 3. Items for each variant of simulation

| Week | MPW full pallet | | | FPW full pallet | | | MPW more than 1 full pallet | | | FPW split of more than 1 full pallet | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 |
| 1 | 15 | 0 | 15 | 342 | 354 | 339 | 14 | 0 | 14 | 129 | 147 | 138 |
| 2 | 57 | 0 | 55 | 792 | 846 | 792 | 32 | 0 | 30 | 309 | 345 | 317 |
| 3 | 47 | 0 | 47 | 821 | 858 | 820 | 37 | 0 | 37 | 311 | 355 | 314 |
| 4 | 35 | 0 | 35 | 867 | 892 | 865 | 32 | 0 | 32 | 293 | 334 | 299 |
| 5 | 47 | 0 | 47 | 806 | 847 | 805 | 49 | 0 | 50 | 297 | 353 | 305 |
| 6 | 39 | 0 | 40 | 716 | 754 | 720 | 28 | 0 | 28 | 261 | 291 | 263 |
| 7 | 30 | 0 | 27 | 551 | 576 | 550 | 28 | 0 | 30 | 156 | 188 | 157 |
| 8 | 44 | 0 | 43 | 819 | 858 | 820 | 51 | 0 | 52 | 272 | 328 | 274 |
| 9 | 70 | 0 | 69 | 1021 | 1083 | 1032 | 69 | 0 | 69 | 406 | 481 | 406 |
| Total | 384 | 0 | 378 | 6735 | 7068 | 6743 | 340 | 0 | 342 | 2434 | 2822 | 2473 |

There are small fluctuations of values between S1 and S3. One can observe that in some cases, order items previously presented as a full pallet item in S1, after aggregation with another order lines are moved to one of more than full pallet items (Table 3). Orders in S2, as defined in simulation, are always delivered from FPW in the case of full pallets and MPW from partial pallets.

Table 4. Pallets for each variant of the simulation run

| Week | Full pallet from MPW | | | Full pallet from FPW | | | Partial pallet from MPW | | | Fill ratio [%] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 |
| 1 | 15 | 0 | 15 | 1123 | 1182 | 1125 | 1103 | 967 | 967 | 64.4 | 73.2 | 73.2 |
| 2 | 57 | 0 | 55 | 2311 | 2495 | 2321 | 2469 | 2145 | 2206 | 67.4 | 77.4 | 75.3 |
| 3 | 47 | 0 | 47 | 2540 | 2704 | 2542 | 2641 | 2162 | 2178 | 64.1 | 78.2 | 77.6 |
| 4 | 35 | 0 | 35 | 2475 | 2618 | 2476 | 2812 | 2206 | 2335 | 61.7 | 78.7 | 74.3 |
| 5 | 47 | 0 | 47 | 2481 | 2671 | 2482 | 2669 | 2086 | 2123 | 61.1 | 78.0 | 76.7 |
| 6 | 39 | 0 | 40 | 1982 | 2106 | 1982 | 2449 | 2050 | 2096 | 65.2 | 77.9 | 76.2 |
| 7 | 30 | 0 | 27 | 1462 | 1559 | 1462 | 2076 | 1704 | 1733 | 64.4 | 78.4 | 77.1 |
| 8 | 44 | 0 | 43 | 2405 | 2616 | 2406 | 2665 | 2279 | 2304 | 67.9 | 79.4 | 78.5 |
| 9 | 70 | 0 | 69 | 3011 | 3293 | 3014 | 3921 | 3114 | 3189 | 65.0 | 81.8 | 79.9 |
| Total | 384 | 0 | 378 | 19790 | 21244 | 19810 | 22805 | 18713 | 19131 | 64.6 | 78.6 | 76.9 |

From a pallet number perspective (Table 4), it is visible that FPW is favoured in the case of sending full pallets – in S3 fewer full pallets are sent from MPW than in S1. The biggest improvement is seen, however, in the number and fill ratio of partial pallets – there is just 1.7% difference between S3 and benchmarking run S2, comparing to 14.2% between S1 and S2.

Table 5. Cost comparison

| Week | Cost units | | |
|---|---|---|---|
| | S1 | S2 | S3 |
| 1 | 42 928 | 38 685 | 38 971 |
| 2 | 95 658 | 85 214 | 87 915 |
| 3 | 102 080 | 87 246 | 88 553 |
| 4 | 106 819 | 88 454 | 92 900 |
| 5 | 102 969 | 85 056 | 87 072 |
| 6 | 91 817 | 79 480 | 81 481 |
| 7 | 75 869 | 6 4551 | 65 833 |
| 8 | 102 512 | 90 121 | 91 937 |
| 9 | 146 724 | 121 569 | 125 384 |
| Total | 867 376 | 740 376 | 760 046 |

Costs calculated by optimisation run S3 are always closer to benchmarking run S2 than to the currently used method (S1) showing its advantage.

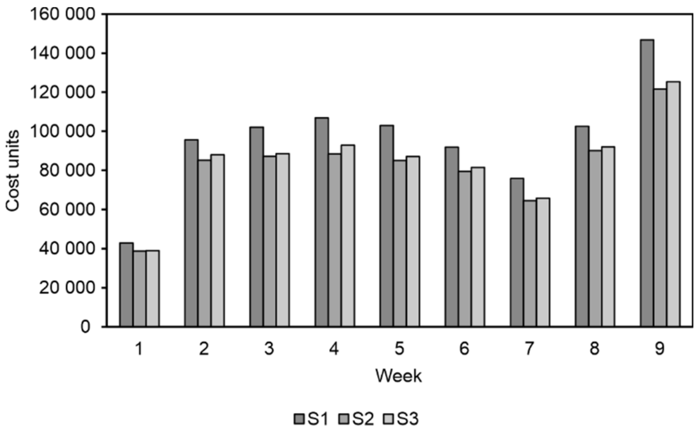


Fig. 5. Cost comparison chart

Table 6. Runtime and cost calculated for P_LEVEL parameter

| P_LEVEL | Time [s] | Cost units for S3 |
|---|---|---|
| 3 | 271 | 799917 |
| 4 | 279 | 785552 |
| 5 | 351 | 774348 |
| 6 | 377 | 766586 |
| 7 | 2388 | 760046 |

Control parameter P_LEVEL has been set to 7 after several test runs on smaller samples of data. This value is a trade-off: although the higher number would lead to better results, the time of simulation significantly grows. Additionally, the increase in accuracy is not in line with the time increase. Table 6 shows the runtime and total cost calculated for the whole dataset in variant S3.

Figure 6 shows scaled values of runtime and cost – the cost function is almost linear – as P_LEVEL increases, the cost is minimised, going toward benchmarking value, whereas the time function reassembles exponential function, increasing the time as P_LEVEL increases. The runtime for S1 was 236 s and for S2 – 232 s.

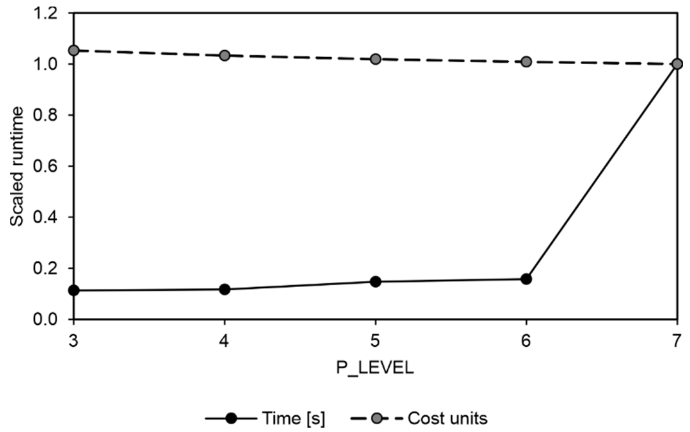


Fig. 6. Dependences of time and cost on P_LEVEL

Later, the simulation was run for multiple values of cost C2, ranging from the initial value (15) to the value of cost C1 – the cost of sending pallet from FPW (7). Results are shown in Table 7 for the pallet number perspective and Table 8 for the cost perspective.

Table 7. Number of full pallets sent from MPW and FPW depending C2

| Week | Full pal from MPW | | | | | Full pal from FPW | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C2 = 7 | C2 = 9 | C2 = 11 | C2 = 13 | C2 = 15 | C2 = 7 | C2 = 9 | C2 = 11 | C2 = 13 | C2 = 15 |
| 1 | 1040 | 109 | 79 | 57 | 15 | 142 | 1073 | 1103 | 1125 | 1125 |
| 2 | 2303 | 332 | 230 | 188 | 55 | 192 | 2163 | 2265 | 2307 | 2321 |
| 3 | 2449 | 298 | 212 | 170 | 47 | 255 | 2406 | 2492 | 2534 | 2542 |
| 4 | 2304 | 282 | 200 | 149 | 35 | 314 | 2336 | 2418 | 2469 | 2476 |
| 5 | 2294 | 271 | 217 | 189 | 47 | 377 | 2400 | 2454 | 2482 | 2482 |
| 6 | 1908 | 247 | 179 | 132 | 40 | 198 | 1859 | 1927 | 1974 | 1982 |
| 7 | 1385 | 196 | 130 | 97 | 27 | 174 | 1363 | 1429 | 1462 | 1462 |
| 8 | 2242 | 313 | 257 | 218 | 43 | 374 | 2303 | 2359 | 2398 | 2406 |
| 9 | 3016 | 421 | 340 | 301 | 69 | 277 | 2872 | 2953 | 2992 | 3014 |
| Total | 18941 | 2469 | 1844 | 1501 | 378 | 2303 | 18775 | 19400 | 19743 | 19810 |

This simulation aimed to determine the level of target cost of C2 when planning future logistics processes. As Figure 7 shows when C2 is between 7 and 9 cost units, the sourcing warehouse for the shipments changes from FPW to MPW.

Table 8. Total cost of shipments for S3 for various C2 values

| Week | C2 = 7 | C2 = 9 | C2 = 11 | C2 = 13 | C2 = 15 |
|---|---|---|---|---|---|
| 1 | 37965 | 38548 | 38721 | 38857 | 38971 |
| 2 | 85158 | 86627 | 87133 | 87551 | 87915 |
| 3 | 85902 | 87378 | 87845 | 88227 | 88553 |
| 4 | 90354 | 91823 | 92259 | 92608 | 92900 |
| 5 | 84390 | 85827 | 86288 | 86694 | 87072 |
| 6 | 79324 | 80528 | 80920 | 81231 | 81481 |
| 7 | 64247 | 65119 | 65407 | 65639 | 65833 |
| 8 | 89142 | 90498 | 91040 | 91515 | 91937 |
| 9 | 121492 | 123424 | 124162 | 124808 | 125384 |
| Total | 737974 | 749772 | 753775 | 757130 | 760046 |

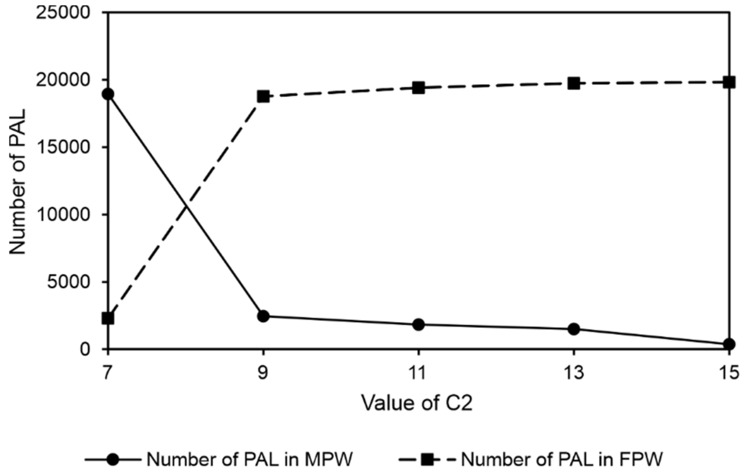


Fig. 7. Dependences of source warehouse on cost C2

The simulation proves that the proposed heuristic algorithm outperforms the currently used policy. With proper control of parameters, it can provide better results with the acceptable overhead of runtime. Simulation of cost variants can be used for future planning of supply chain networks [8]. After considering data for longer periods, this simulation could potentially suggest that for this particular company it is more advisable to invest in a central distribution centre capable of playing the role of FPW and MPW simultaneously, rather than keeping a network of distributed warehouses. Another managerial implication is that it proves to influence non-warehousing costs included in the model – costs of orders' splits (both standard and fine) and aggregations. After proper estimation of their levels, a decision can be made to renegotiate the contracts with customers to enforce agreements that will allow a more elastic way of planning sourcing warehouses. An example of such an agreement could be an additional discount for buying full pallets.

## 6. Conclusion

A model for goods distribution has been proposed and verified. Simulations on a set of real business data positively verified its potential for optimisation of supply chains with multiple warehouses with different handling capabilities. Definition of further constraints representing more costs and/or penalties would make the model even more realistic, however, at the same time, it would make the calculation process more complex. Using heuristics makes the decision process faster and widely possible for implementation – either directly in ERP system or indirectly as a part of decision support system. The second area of application of results of simulation would be an influence on customers' contracts negotiations – with predicted shipment cost it is easier for both parties to agree on a pricing scheme, favouring full pallet shipments over partial units. After enriching the algorithm, it can easily be applied to incorporate full-truck or bulk deliveries discounts as well. Future research could be performed to find the best and the most exact solution to this problem and to compare times of execution to test the possibility for everyday applicability into logistics management.

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