Integrated System for Combining Decisional Problems in a Distribution Centre

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Abstract The efficiency in distribution centres is conditioned by the management in the storage and picking process. To achieve this efficiency different coupled decisions have to be made for problems like storage, picking, truck-dock assignment and task assignment. The information of the activities, inside the facility and in the supply chain, is a key point to adapt the status of the process to the conditions of a changing environment. This paper describes a system to integrate information and decisions dynamically and validates it with a detailed simulation model. We show the results of the application in two case studies in actual facilities.

Keywords Distribution centre · Decisional system · Warehousing · Picking · Simulation · Operational efficiency

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1 Introduction

Efficiency in Supply Chains is mainly determined by the competence in operations management in the distribution centres. Different trends in manufacturing and distribution have made the order picking process more important and complex [1].

Although the Distribution Centres (DC) have a key role for the success or failure of supply chains [2] at the design stage, there is no systematic or scientific approach to the physical design of warehouses [3–5].

Order picking, the process of picking products from their storage locations to fill customer orders, is known as the most important activity in warehouses [6]. Order picking was identified as the most labour-intensive and costly activity for almost every warehouse long time ago; the cost of order picking is estimated to be as much as 55 % of the total warehouse operating expenses [1].

The warehouse design decisions are tightly coupled, and one cannot be analysed or determined in isolation from the others [7]. The integration of simulation, statistical analyses and meta-heuristic techniques is an effective and efficient way of optimizing a very complex logistic system such as the order picking systems [8].

An efficient warehousing management system could greatly reduce overall warehouse costs, which is achieved mainly by optimizing movements. Poor warehouse performance has different negative impacts in the warehouse and for the supply chains [9] with effects like: complex management, poor customer service and high logistics cost. Optimizing activities performed with transportation equipment could have significant impact on reducing energy consumption and CO_2 emission.

The paper is organized as follows: Sect. 2 describes the problem and the resolution steps. Section 3 is the literature review of the problems related to the paper. Section 4 is the methodology used to resolve the problem. Section 5 describes the case studies where the system has been applied. Section 6 shows the results obtained and at last Sect. 7 resumes the conclusions and the future work lines.

2 Problem Statement

In order to perform an efficient warehouse management diverse decisions have to be taken. The warehouse design decisions are tightly coupled, and one cannot be analysed or determined in isolation from the others [7]. Usually these decisions need information from different management systems: ERP, WMS, TMS, sometimes integrated, sometimes not. In the final stage the operator takes the decision with all the information at hand and his own experience.

The lack of experience in some cases and the weak integration of different IT systems could cause delays and inefficiencies in the processes, with the consequent cost in time and cost in terms of energy.

In order to solve these problems a system for combining decisional problems has been developed which integrates the main important operative problems in a distribution centre exploiting all the information available. The system is tested in two case studies, one with home appliance products and one with heavy industrial manufacturer.

In both cases there is a lack of efficiency detected. The decision process is mainly done based on experience and fixed rules with a WMS for registering the details of activities to operate the warehouse. Each company identified the warehouse as an opportunity to improve in the actual economic scenario.

The distribution centres selected, according to the classification of order-picking systems [1] could be classified as order-picking methods, employing humans, picker-to-parts, high level, and pick by order. The storage mode is stacked and conventional. The improvement strategy is to optimize the use of space and resources, minimize the loading time and to make the process as efficient as possible with the maximum service level.

3 Literature Review

Our research objective is to find a model to increase the distribution centre performance by the combination of different problems with a new IT system. With the combination of problems the evaluation of results becomes complex. Few authors address combinations of the decision problems. Yet, de Koster et al. in [1] say that this is necessary as there is interdependency in their impact on the order picking objectives.

Petersen and Aase in [10] have studied the impact of different combinations of the three previously mentioned operational policies developing a simulation model that considers fixed order sizes. Other authors [11–13] have also studied these strategies, but none of them took real demand information into account. Gu, Goetschalk and McGinnis in [7] state that there is a significant gap between academic research and practical application.

3.1 Storage Location Assignment Problem

The storage location assignment problem (SLAP) is to assign incoming products to storage locations in storage departments/zones in order to reduce material handling cost and improve space utilization. Different warehouse departments might use different SLAP policies depending on the department-specific SKU profiles and storage technology. The storage location assignment problem is formally defined as follows: Given information on the storage area, information on the storage locations and information on the set of items to be stored, determine the physical location where arriving items will be stored. The assignment is subject to performance criteria and constraints such as: Storage capacity and efficiency, picker capacity, response time and compatibility between products and storage locations [14].

Types of SLAP problems:

1. Storage location assignment problem based on item information (SLAP/II)

- Assignment Problem (AP)
- Vector Assignment Problem (VAP)
- Duration-of-Stay (DOS)

2. Storage location assignment problem based on no information (SLAP/NI)

- Closest-Open-Location (COL)
- Farthest-Open-Location (FOL)
- Random (RAN)
- Longest-Open-Location (LOL)

3. Storage location assignment problem based on product information (SLAP/PI)

- Dedicated Storage
- Random Storage
- Class-Based Storage

Different criteria can be used to assign a product (class) to storage locations. The three most frequently used criteria [2]:

- Popularity (defined as the number of storage/retrieval operations per unit time period).
- Maximum inventory (defined as the maximum warehouse space allocated to a product class).
- Cube-Per-Order Index (COI, which is defined as the ratio of the maximum allocated storage space to the number of storage/retrieval operations per unit time) (COI or turnover based storage location assignment rules include popularity and item size).

3.2 Order Picking

Picking is the most labour-intensive operation in warehouses with manual systems and a very capital-intensive operation in warehouses with automated systems so it is therefore a key process in warehouse design as it has a significant impact on capital and operating costs. Coyle et al. in [15] state that this activity's contribution could rise to 65 % of the total operating costs of a common warehouse.

Malmborg and Al-Tassan [16] describe four basic types of parameters influencing the operating performance of an order picking system, and these are the basis for the parameterization of the proposed dynamic models: Item features (transactions demand levels, item space requirements, and item assignment constraints); Storage equipment (vehicle route, speed and movement pattern); System operating rules (picking strategies, sequencing); and Physical configuration of storage area and unit load size (height, depth, number of storage aisles). To accurately model the operating performance of an order picking system in terms of its three fundamental measures of total space requirements, throughput capacity and service level, the interdependencies among these parameters must be reconciled. Simulation is an analysis tool that is capable of capturing these interdependencies.

Won and Olafsson [17] has highlighted that although previous research traditionally focuses on improving system throughput (total picking time and effective use of equipment), the primary concern of customers is often fast delivery of their orders (order maturity time). Nevertheless, it is possible that some initiatives to improve one of those performance measures might impact negatively on the other one. In this context, analysing performance evaluation trade-offs is an important task in order to align warehouse efficiency measures with customer requirements.

3.3 Truck–Dock Assignment

One of the key activities at distribution centres is the dock assignment for trucks. Trucks are assigned to docks for the duration of a time period during which the cargo and trucks are processed. Dock availability and times of arrivals/departures for each truck can change during the course of the planning horizon due to operational contingencies (e.g. delays, traffic control). Such changes in turn have impact on dock availability, since docks may become unavailable when required. Miao et al. [18] explains a model centred in cross docking operations to schedule docks well in order to increase the utilization and achieve better performance of the transhipment network. Most of the literature in this field has been published on cross docking operations like [19–21].

3.4 Workforce Assignment

The assignment of tasks to operators is one key point in the operational level strategy. Since interfaces between different processes are typically handled within the design problems at the strategic and tactical level, this implies that at the operational level policies have less interaction and therefore can be analysed independently [22]. The main decisions at this level concern assignment and control problems of people and equipment. Some of the main decisions are the assignment of replenishment tasks to the personnel and the assignment of picking tasks to order pickers.

3.5 Simulation

Simulation is a technique that uses the computer to model a real-world system, especially when those systems are too complex to model them with direct mathematical equations without disturbing or interfering with the real system [23]. The main advantages of simulation arise from the better understanding of interactions and identification of potential difficulties that simulation offers, allowing the evaluation of different alternatives and, therefore, reducing the number of changes in the final system. There are several simulation techniques; however, Discrete Event Simulation is the most commonly used [24].

4 Methodology

This paper proposes a methodology to integrate different decisional problems with a high degree of dynamism with an adaptive task dispatching system. The platform is integrated with online information from the IT systems and validated with a simulation model. This platform has been applied in two real companies from different sectors, which led to improvements in the efficiency in their DC. Two collaborative projects were launched with the operational department from each company. Diverse objectives were established. In addition to the operational cost in this paper we focus on indicators like the loading waiting times and the filling rate which are not widely considered in the literature.

All this information is available in the company IT systems but usually it is not considered in the day-to-day operations. The integrated system is based on a framework which combines information from different management systems. The information is used to improve the decision making process. Four main problems are merged in our system: The storage location assignment problem (SLAP), the Order-truck-dock assignment, the order picking and the workload assignment. These decisions have been selected because they have a high impact on the process cost and they are tightly coupled and one cannot be analysed or determined in isolation from the others.

The integrated system described in this paper is part of the AWARE platform from the work of the doctoral thesis from David Cipres. It is also one part of the research done under the national research project RAFUWARE.

4.1 Decision Problems

For the decisional problems we define a set of variables which could be measured from different IT systems and included in the algorithms. To achieve this goal we evaluate the following decision problems:

- **D1 Storage location assignment** (SLAP) concerns the assignment of incoming stock to storage locations. The objective is to assign incoming products to storage locations in storage departments/zones in order to reduce material handling cost and improve space utilization (Fig. 1).
- **D2 Order-Truck-Dock assignment**: This decision consists of the selection of the best shipment for the truck regarding the location of the load. The objective is to minimize the travels in the distribution centre respecting the constrains like filling rates or waiting times. An example is shown in Fig. 1 from the case II of this paper (Fig. 2).
- **D3 Order picking**: The process of picking products from their storage locations to fill customer orders. It is the most intensive task regarding resources and it is a directly related to the service level (errors and punctuality). Selecting the correct strategy and sequence has a big impact on the process efficiency.
- **D4 Workforce assignment**: In the DC there are different forklift operators for storage and picking activities. Initially, tasks were divided between teams, a team for storage and a team for picking. With the new IT system we combine actions. We assign the best action to each operator regarding his location and the task priorities. In addition, we consider auxiliary assignments to equilibrate the workloads (Fig. 3).

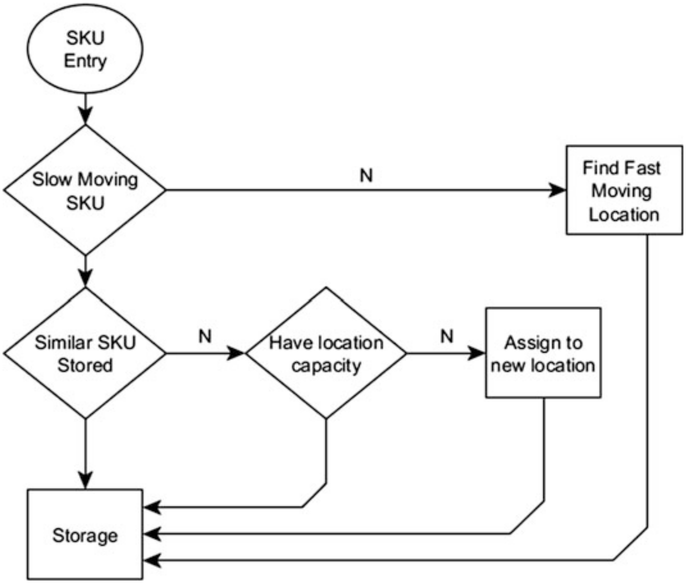

Fig. 1 Example of the order-truck-dock assignment schema applied in case I

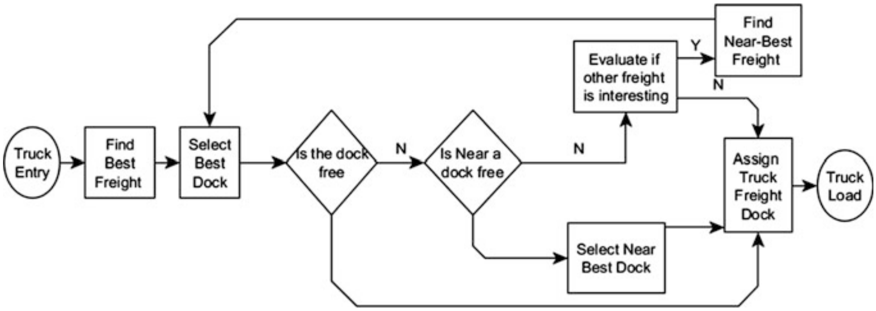

Fig. 2 Module relationships between the IT system, the algorithms and the simulation software

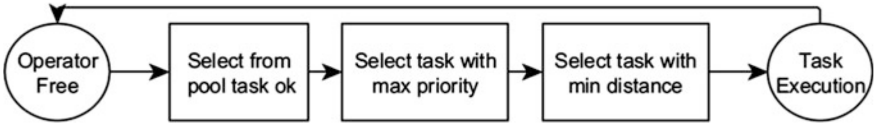

Fig. 3 Simulation model layout details

4.2 Priority Management

The precedent algorithms generate a collection of tasks, but the sequence is not specified. To determine the sequence of actions a balance between efficiency and urgency as indicates [9]. To be efficient, the WMS assigns a task to the operator which is near to its current position. Then it minimizes the empty travel distances between the tasks. Besides the travel distances the management system has to consider the urgency of the tasks. Urgency is not only caused by deadlines that need to be met, it may also be due to critical bottlenecks.

In our model we have designed a priority task schema which integrates constrains of the manufacturing process and the delivery scheduling. We defined a scale from 1 to 5 points. Lower values are assigned to the lower priority tasks. We group the task in three categories.

- Storage task: The priorities of these tasks are related with the status of the input buffer. If the buffer is below 50 % of the capacity, the priority is 2. Between 50 and 80 % the priority is 3, above 80 % the priority is 5, the maximum. The input buffer cannot be blocked; it will cause problems in the manufacturing process.
- Picking task: The priorities of these tasks are related to the waiting time of the shipment truck. If the waiting time of truck is below the 50 % of the OWT (objective waiting time), the priority is 3 and above 50 %, the priority is 4. A picking task has never a priority of 5; it is reserved for the storage actions.

- Secondary task: This category groups actions which have to be done in the DC but they are not directly connected to the material flow, like changing item locations or organize the items inside the mixed locations. This task has a priority of 2 points. They could be combined with the low priority of the storage task.

This priority distribution allows the combining of different tasks, taking into account urgency and efficiency. When the priority level is low, it generates more opportunities to combine movements and to execute the secondary tasks.

4.3 Simulation Model

The first step in the design of the simulation model is the objective identification [23]. Our interest is to increase the efficiency in the intralogistics processes (handling resources) and to reduce the load time of shipping trucks.

The model contains the following elements: the warehouse dimensions (layout, aisles, docks), item properties (reference type, rotation, size, geometry), operators (speed, timetable, skills, activities time duration) and truck (capacity, destination, orders, timetable).

The objective of the simulation model we developed is to evaluate these integrated decision problems; the evolution in time (dynamics) of the system is very significant. Depending on the delays, the sequence, the resource availability the solution could be quite different. For testing the impact of these new algorithms with the dynamics of the process we developed a discrete event simulation model. The simulation software selected is Enterprise Dynamics 8 [25].

We have applied this system in a manufacturing process where the delays in the shipping process were critical. We defined four main indicators to evaluate the performance of the system: Loading time, waiting time, Vehicle filling rate, Time per task. In addition we obtained data from the operator status (loading, unloading, travelling full, travelling empty…).

The exchange of information between the algorithms and the simulation model is made by messages. At the beginning of the simulation run, the inbound and outbound orders are scheduled. During the simulation, tasks are generated according to the schedule and the details for the flow are received from task calculation server by messages. Each message has information about the client, order, timestamp… and the task calculation server returns the decision including the location and the operator assigned. The decision is made by taking into account the information about the status of model (position, priorities) and the database containing the details of the process (level of stock, order details, skills…).

Due to the high quantity of data for the implementation of the model a network configuration is needed. The simulation server and the algorithms servers and the database server are independent. Each server runs in different machines in parallel, to reduce the simulation time.

5 Case Studies

The integrated system has been tested with real conditions in two distribution centres. Some of the details of the processes are omitted due to confidentiality agreements.

5.1 Case I: Home Appliance Distribution Centre

The distribution centre belongs to a home appliance manufacturer. The centre has a floor of more than 50,000 m^2 and is about 10 m high. It is divided into two zones; one for large items, which are stored as a stack (refrigerators, washing machines, ovens). The second zone is for small items (irons, bread toaster, mixers). They are stored in conventional warehouse. The picking for the big items is done by article and for the small items is done by pallet and by box. The warehouse has more than 50 docks for loading and unloading.

In this DC there are two picking strategies. In the stacked area, big items are picked following a single-order picking strategy. Products of the same geometry can be picked together with clamps forklifts. In the pallet area there is a zone picking strategy. Picking is simultaneous, or synchronized, between the areas. The storage is class based. Most of the products are grouped by business family.

The task assignment in this DC is organized by process: unloading, verification, storage, picking and loading. Each process has a dedicated group of operators. Some of them are polyvalent and they can work in different processes, but not at the same time, among other aspects, due to some software limitations.

The main characteristics of the decision algorithms in the system are:

- **D1 Storage location assignment**: Initially, the storage assignment was class-based, using the business family as key characteristic to group the items. With the new algorithms properties like rotation are included to assign the best locations (golden zone) for the most popular references. The turnover of the products is periodically updated considering the last weeks demand.
- **D2 Order-truck-dock assignment**: In this case the load of each truck is transmitted by EDI systems. So the content of the load could be known in advance. In this case the number of docks is high (more than 50) and blocking is rarely a problem. Dock assignment is done considering the location of the load in the DC trying to minimize the travelled distance.
- **D3 Order picking**: Within the DC there are two types of picking strategies, one for big items (stacked) and one for the little items (conventional warehouse). One of the important points for the system is the capacity to combine different task. So our system has to generate this task to evaluate the physical distribution in space and time inside the model. The calculation processes are complex because there is a high diversity of products and the number of rules and restrictions is high. We have generated a data model to help in the

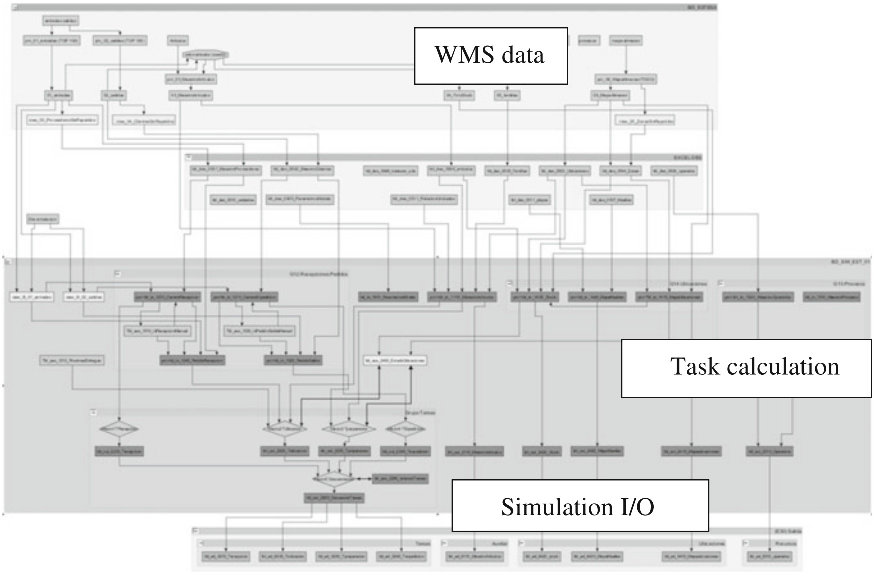

Fig. 4 Layout of one zone of the distribution center case II

transformation from master file data (order, stock, article master) to tasks considering the grouping criteria, pallet formation and replenishment. A detailed327 scheme for the data transformation process is shown in Fig. 6.

- **D4 Workforce assignment**: The task assignment strategy is the key algorithm to distribute the tasks considering the spatial location and time. Each operator has a skill matrix to determine its ability to perform the tasks. In the initial configuration the each warehouse (large items and small items) was divided into zones, grouping a set of families. The reason was to avoid long travels. In the new system this restriction was changed by the new algorithm shown in Fig. 3 where the assignment is based in the priority and the distance. With this strategy it is possible to combine movements in the near zones, obtaining high profits in the efficiency of the process.

5.2 Case II: Industrial Manufacturer

The second case study is an application for a manufacturer distribution centre. It belongs to a multinational manufacturing company. The company manufactures in Spain and distributes the products in Europe and the North of Africa. Products are voluminous and heavy. Each item is about one tone of weight and about one cubic meter of volume. The facility is about 300 m long and 60 m wide with a maximum capacity about 10.000 sku stored. The distribution centre is divided in three areas similar to Fig. 7. In the north side, each area has an input from the manufacturing

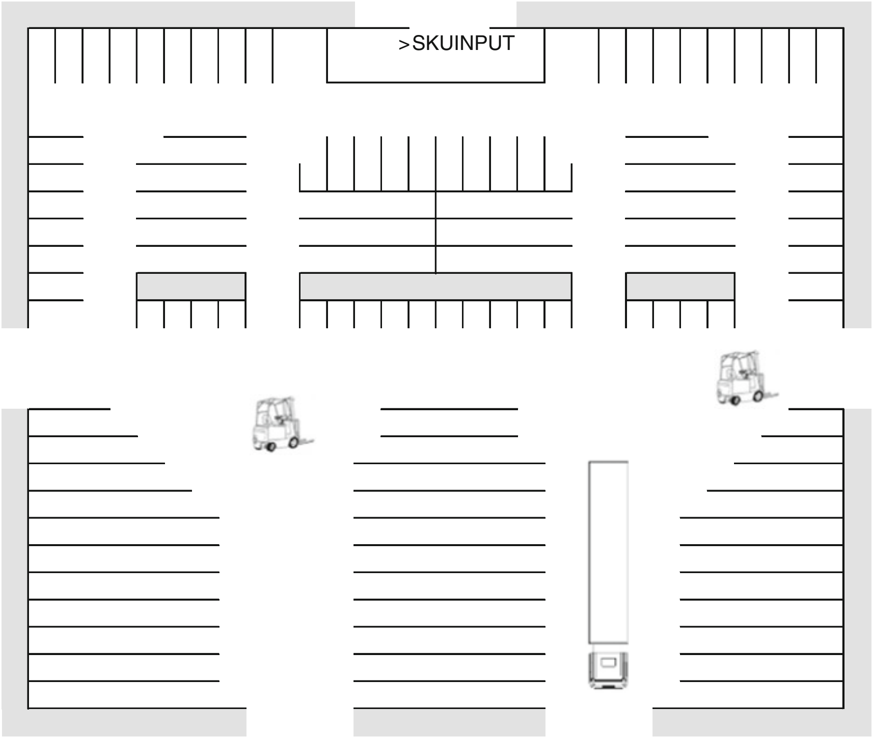

Fig. 5 Example of the storage location assignment schema applied in case I

process and some docks in the south side. The products can be stacked, depending on the reference, until five or six levels.

The handling process is made by forklifts which take the items one by one. The number of locations is less than the number of references. Some of the locations are dedicated to one reference and other locations have a mix of references inside. With the stacked storage, the mixed locations could lead to extra movements if the desired reference is not on the top of the stack. When the workload is not intense, some operators spend time classifying the mixed references.

It is organized by irregular aisles. Each aisle has different locations with different depths. The locations near the dock are assigned to the fast moving shipments, in those locations the storage is the same than the final freight. In the other locations, the locations are assigned to a single reference or multi reference.

The arrival of products in the distribution centre is continuous, 24 h per day and 7 days for week. The sequence is determined by the production plan. The warehouse operates three manufacturing machines. In the company the throughput of the manufacturing system is a high priority, the warehouse operations play a secondary objective. The process ends with the loading of the SKU, in trucks. This last process is the point where the problem is detected. The load time is long and it becomes critical especially in the central hours of the day when the workload is high. The initial configuration of the warehouse was in teams grouped by the process: one team for storage and one team for loading. In order to reduce long distances, each worker has a preferred zone to operate. The operator assigns the location of each item based on his experience, usually the nearest open location. The location is recorded in the WMS.

The main characteristics of the decision algorithms in the system for this case are:

- **D1 Storage location assignment**: The initial location assignment in this warehouse was dominated by the manufacturing rules. The production plan has higher priority than the rest of the activities. One team is dedicated to the storage of the materials arriving from the manufacturing process with the rule of the first-empty location. This strategy causes accumulation of items around the input, and the loading time increases due to high movements inside the DC. The new strategy is not the optimal but is a step in the improvement process. The storage is class-based, considering the main classes: Fast moving references, reference locations and mixed locations (with more than one location). The decision algorithm is represented in Fig 1. As an example the main variables evaluated in the algorithm are: Duration of stay of the item, volume of the item, future volume of the reference, distance to dock of the location, location filling rate or number of references of the location.
- **D2 Order-Truck-Dock assignment**: The order-Truck-dock assignment in this case consists of the selection of the best shipment for the truck regarding the net weight, and the best dock regarding the occupation of the loading platforms. When the truck arrives at the distribution centre, there is usually more than one piece of freight (set of SKU) available to dispatch. The assignment strategy is a balance between maximizing the truck filling rate and minimizing the waiting time.
- **D3 Order picking**: The picking process is made item by item, due to weight and volume restrictions. In this case the decision is to select the best item from different locations to configure the shipment. The picking location is selected depending on the distance to the dock assigned. Depending of the configuration of the freight, the distance and the loading time in the process could vary from 10 to 40 min.
- **D4 Workforce assignment**: With the integrated system, each operator has a skill matrix, with the preferred working zone and the abilities in the different task. The decision algorithm is similar to Case 1 and it is represented in Fig. 3. In the case the distances are large, additional restrictions are made to avoid long travels.

6 Results

After completing the validation process, the analysis is made with the data of seven production days. The model starts with the same layout as the real facility. Each day the model simulates the arrival of the items and the freight shipments with the same resource timetable.

Data collection plays a key role within simulation, as the data must truly emulate the realities of the system to the levels of accuracy and detail required. The data for this case study was filtered with a consistence analysis to avoid outliers in the simulation model. The model is validated by simulating a standard day in collaboration with the experts from the company.

To evaluate the integrated system we ran a simulation of seven consecutive days. To make comparisons with the real system, the initial layout of the model (sku assigned to location) is the same as the WMS in the real layout. The inbound flow and the outbound shipments are also the same.

For reasons of confidentiality the data results in this chapter have been scaled with a multiplier factor to avoid direct references. The relative effects between the initial solution and the new system have been maintained.

6.1 Results for Case I

In the Case I there are two main decisions to evaluate, the zone assignment and the combination of movements. In the initial configuration each warehouse (large items and small items) was divided into zones, grouping a set of families. The reason was to avoid long travels. After applying the new system we made an analysis reducing the number of resources with the impact of zoning. Results are shown in Fig. 6. This graph indicates the impact to the number of trucks that were delayed with the new strategy. Reducing the number of operators the delay was bigger using the initial zone strategy. With the new system using the operator teams the number of trucks that were delayed was between 2 and 5 %.

Another interesting result is shown in Fig. 7 where we compare the amount of tasks finished in the distribution centre during one day. Scenario A is the initial situation, scenario B is the system activated, without zoning restriction and combining movements. Figure 7a shows the picking tasks. They have high priority, so in both scenarios (initial and with the integrated system) all the tasks are finished on time, all the trucks are on time. On the second graph (Fig. 7b), the number of storage actions is represented. This task has minor priority, we observe that in scenario B, the number of tasks realized is higher with this strategy, and the number of resources is the same. The integrated system allows to increase the productivity by about 15 %.

In general the results obtained in case I show an overall increase in the efficiency at the operational level.

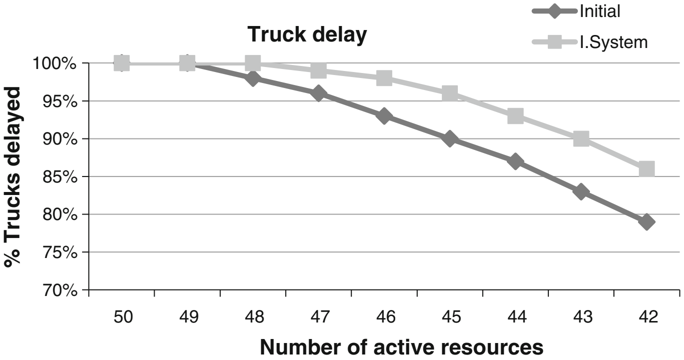

Fig. 6 Influence of the resources in the delay of trucks with the integrated system

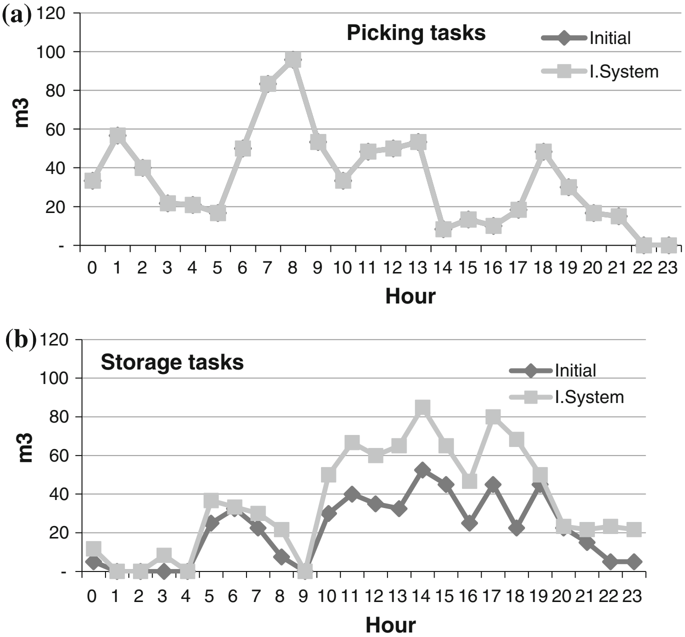

Fig. 7 Volume of the items moved in picking task (**a**) and in storage task (**b**) with the initial strategy and with the integrated system

6.2 Results Case II

The main objective in Case 2 is the reduction of the waiting time for the shipments. The detailed results are shown in the following table. The average improvement is a reduction of 24 % of the waiting time (Table 1).

Table 1 Result of comparison in the waiting time with the initial solution

Days	Initial	I. System
1	18	18
2	15	19
3	31	24
4	17	18
5	36	18
6	28	20
7	30	17
Average	**25**	**19**

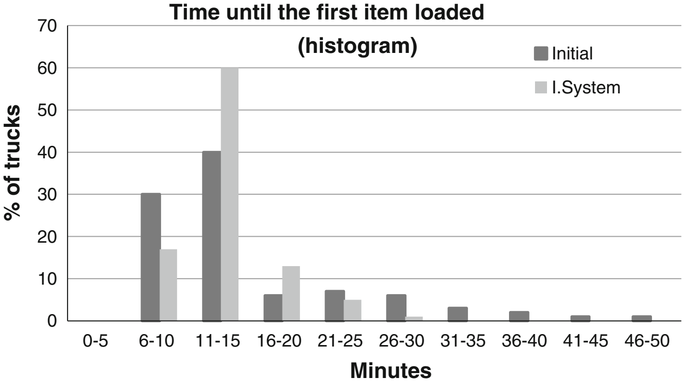

Fig. 8 Truck waiting time between entry time and the load of the first item

One of the main objectives is to minimize the time which we need for loading trucks in the distribution centre. In this case the objective function is the sum of the loading time and the waiting time. In addition there is a restriction to the minimum vehicle filling ratio. With the appropriate setup of the system we could obtain reductions of 24 % in the waiting time of outgoing trucks.

The time wasted until the first item is loaded is shown in Fig. 8. In the first group (between 6 and 10 min) the percentage of trucks is high in the initial strategy (30 %) and it is lower in the integrated system (17 %). The histogram “long tail” shows a high delay that arrives after 50 min in the worst case. With the integrated system the times are centred between 15 min with a maximum value of 30 min.

The Table 2 shows that the filling rate of the trucks stays in similar levels as in the original process, although the freights assigned are different. The range of the filling rate is the same, between 96 and 99 % and the average is the same, namely 97.6 %.

Table 2 Result of comparison in the filling rates

Days	Initial (%)	I. System (%)
1	97.23	96.72
2	98.26	98.26
3	97.23	99.28
4	97.23	97.75
5	96.41	98.16
6	100.00	97.03
7	96.82	95.80
Average	**97.60**	**97.57**

7 Conclusions

The decision-making in the logistics processes in distribution centres can be improved with the use of IT systems that integrate different problems. In the literature there are not many examples of combinations of decision problems. In the combination of decision problems dynamic effects are important. The system designed for the four coupled decisions has a positive impact in the overall efficiency of the operations in a distribution centre.

To obtain good decision, the information of the process is essential. All the calculations need high quality data with a high level of detail. Actual IT systems allow the integration from diverse data sources in the decision making process. To validate the effects of the dynamic effects the evaluation with a discrete event model helps to quantify the impact of all decisions simultaneously.

Two case studies are presented from two different sectors. Important efficiency enhancement is detected in the indicators: higher productivity rates, reduction of the waiting times, and better workload levelling.

The future work lines are related to the evolution of the system with the selection of the main significant variables, with the higher impact in the process. Another work line is focused on the improvement of the simulation model to identify the minimum level of detail and exploring multi-agent simulation to evaluate the decision making process.

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