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Optimizing the order picking process via simulation: a case study

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Abstract

A simulation-based approach is proposed to evaluate the performance of one of the most complex and expensive logistic functions taking place in distribution centers: the order picking process. The resulting case study is triggered by the need to switch from an order packing policy by item quantity to item volume in PAC 2000A, the largest cooperative of the CONAD consortium in Central-Southern Italy. The underlying discrete-event simulation model mimics warehouse organization, rules and behavior with the aim of pursuing optimality in terms of daily productivity and the corresponding savings on resources to be deployed. In particular, focus is on the number of supports and, thus, the space required to fulfil orders placed by retailers. Ad hoc scenarios are used to verify simulation credibility, while verification is carried out by using real data from the company's 2022 database. Numerical results show how, upon the non-deterministic arrival of customer orders in batch, the simulator allows to verify that the order packing policy by item volume, rather than quantity significantly outperforms the current company practice.

Keywords: Warehousing; order picking packing policies; simulation; performance analysis

1. Introduction

Distribution centers (DCs) represent the heart of the activities taking place in large-scale retail trading companies. Goods ordered from suppliers arrive in DCs to be stacked and stored and then leave according to the orders placed by the retail outlets. Therefore, planning and managing the logistic operations and activities carried out within DCs is essential to fulfill orders and meet the needs of the retailers in the shortest time and at the lowest cost possible.

In the literature, according to (Gong and de Koster, 2011), all the logistics processes taking place in a warehouse are fundamental in supply chains. However, the so-called order picking process, in which goods are picked from the warehouse to fulfil customer orders, is certainly the most expensive. At the same time, globalization, growing expectations and e-commerce have intensified the competition between warehouses, forcing them to manage a large number of small orders in a short time (Marchet et al., 2015). Therefore, it is necessary to improve the picking process by ensuring order fulfillment in a timely and precise manner, optimizing preparation times and remembering that unsatisfied customer demand can subsequently lead to additional costs.

The picking process consists of picking and grouping products that form an order that has been placed from a retailer. The process starts with the acquisition of orders based on the warehouse's delivery agenda. These orders are then divided into picking lists. A list contains all the instructions that the picking operator must follow to complete the preparation of an order: the details of the retailer, the type of support(s) to be used for the picking operations (i.e. rolls or pallets), the bay on which to place the prepared goods and the goods (from here on items) to be picked, along with their position in the DC, article code, item description and number of packages to be picked up. There are three (3) ways to pick up items in a warehouse:

- automatic picking in which items are picked up through the use of automated solutions;
- manual picking in which items are manually picked from the warehouse by operators called pickers;
- semi-automatic picking which is an intermediate solution that combines automatic storage, management and/or internal transportation activities with manual operations.

This stated, in the following we present a case study that focuses on the procedures related to the picking process currently used by PAC 2000A, the largest cooperative of the CONAD consortium in Italy with respect to size and turnover. PAC's sales network covers 5 regions in Central-Southern Italy: Umbria, Lazio, Campania, Calabria and Sicily. The aim of the study is to analyze the performance of manual order picking operations carried out by the picker who, through the use of an electric order picking vehicle, collects items from the warehouse shelves while moving along the aisles (or rows) according to an S heuristic. In literature, this picking system represents the most common picking technique used in DCs across Europe (de Koster et al., 2007; Marchet et al., 2015).

In PAC, picking lists are generated from orders according to a quantitative threshold usually equal to 110 packages per list. These lists are proposed to pickers through voice picking technology. Voice picking connects the pickers with the company warehouse management system through voice synthesizing systems featuring headphones and microphone devices. Practically, the picker's activities are guided by receiving and replying to voice commands.

An analysis on PAC's current system, which divides orders into picking lists, has highlighted some limitations in terms of optimally loading the delivery vehicles. Therefore, the company is evaluating an alternative system: dividing the orders into lists based on the final height of the supports containing the items to be delivered, rather than the number of packages. Although this is not exactly a "new" criterion used in warehouses, to our knowledge a formal study has not been carried out in academic literature.

The rest of the manuscript is organized as follows: the conceptual model describing the current order picking practice in PAC 2000A is proposed in section 2. The simulation model implemented in Rockwell's Arena is presented in section 3. The actual case study is carried out in section 4 with verification and validation activities and numerical experiments. Finally, conclusions and future research opportunities are drawn in the final section.

2. Conceptual Model

The order picking process currently implemented in PAC 2000A's distribution centers has been represented by using the flowchart in illustrated in Figure 1. For greater comprehension, a detailed description of the various activities that are part of the process has also been provided.

The picking process starts when a picker gets hold of a list via his/her voice picking device. The list contains the date and time of generation, the expected delivery date, the details of the retailer, the type of support(s) to be used for picking (i.e. roll or pallet), the truck bay on which the prepared goods are meant to be placed and the list of items to be picked along with an indication of their:

- location;
- description;
- number of packages to be picked;
- packaging;
- quantity of items to be picked;
- item ID code.

Once the list is acquired, the picker first selects the supports required for product handling and then begins the picking phase. Through the related voice picking device, the AS/400 system communicates the location of the first item to be picked. The picker confirms that he/she has reached the target position by responding with the pronunciation of the related check digit before actually picking the item.

For each item, one of the following three situations may occur:

1. All packages are present in the picking place. In this case, the picking time depends on the type of item, the quantity and the position of the picking place identified by the (aisle, slot, location). At the end of the picking task, the picker confirms completion via voice picking. Simultaneously, item availability is automatically updated by the AS/400 system.
2. Not all packages are present in the picking place and, therefore, the presence or absence of other packages is checked in the stocking position. If no other packages are in stock, the picker takes the packages that are present in the picking place and communicates via voice picking the number of packages that have been picked. The AS/400 system automatically updates the availability of the item withdrawn and generates a partial back order. On the other hand, if there are other packages in stock, a restocking activity starts: packages are either stored in the intensive

shuttle-type shelves or in free shelf space of the traditional warehouse stacks. In the former case, the picker sends a request to a forklift driver who is told to perform the physical restocking of the goods. In the latter case, the AS/400 system automatically notifies the forklift driver to do so. In particular, the AS/400 system provides the forklift driver with the location of the position to restore and, at the end of this operation, it updates the related availability.

3. None of the packages are present in the picking place and, therefore, the presence or absence of other packages in stock is verified. If there are no other packages in stock, the picker communicates the absence of packages via voice picking and the AS/400 system automatically generates a back order. If there are other packages in stock, the corresponding restock activity starts, according to the second option described at point 2.

The picker cycles through the picking process described until the list is completely empty. Upon list completion, the system prompts the picker to (re)pick the items that were previously unfulfilled, but now available. Subsequently, the picker packs the items and communicates the support(s) he/she used to the AS/400 system.

3. Simulation model

According to (van Guils et al., 2018), simulation is by far the most popular technique to analyze combinations of order picking planning problems (51%), followed by mathematical programming (28%) and analytical models (21%). The popularity of simulation basically lies in the fact that simulation models are able to provide a more detailed representation of order picking operations compared to other methods (op. cit.). This is a very common requirement in most fields of application (Legato et al., 2013; Furfaro et al., 2018; Legato and Mazza, 2018). Given the high level of detail and the narrow focus of the present case study, discrete-event simulation (Banks et al., 2000) has been chosen for testing two different order picking packing policies. The corresponding model has been developed using Arena simulation software by Rockwell Automation Technologies, Inc (Kelton and Sadowski, 2002).

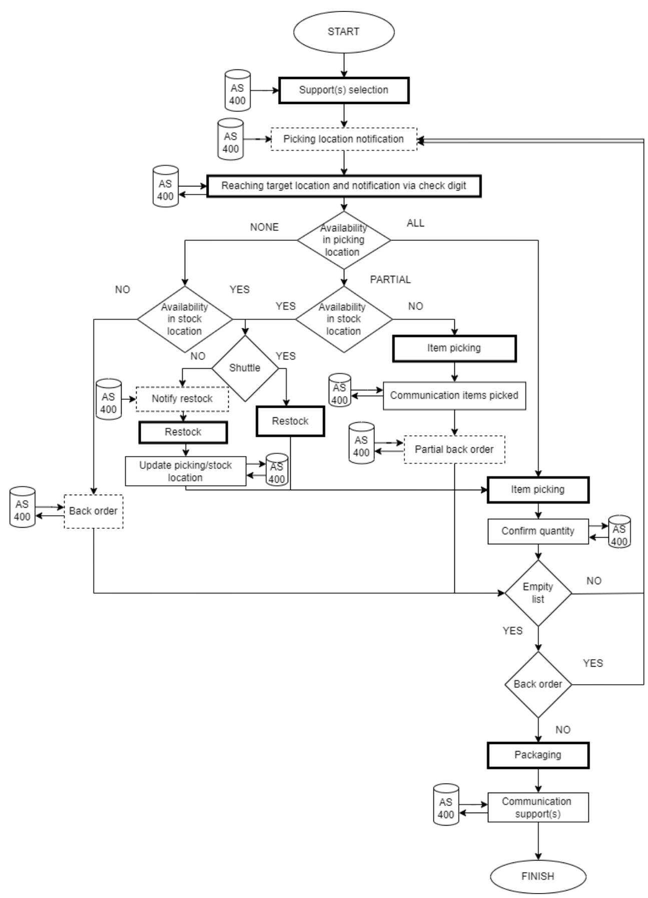

Figure 1. The model of the order picking process

The main assumptions of the simulation model are presented below:

- a working day starts at 5.00 a.m. and ends at 7.00 p.m. and it is divided into 14 one-hour time slots;
- the number of pickers working in the warehouse is scheduled per time slot;
- picking is carried out manually;
- a manually-driven order picking vehicle may carry multiple supports at a time (i.e. two pallets or three rolls);
- multiple pickers work simultaneously in the warehouse's picking area;
- an S-shaped policy is used to route picking vehicles through the warehouse aisles;
- warehouse aisles are wide enough to allow picking vehicles to pass each other within the same aisle (i.e. lane changing is allowed);
- items that are not stocked in the warehouse are left out of the picking lists;
- incompatibility constraints among items are not accounted for during the generation of picking lists;
- promotion and ordinary sales are processed in the same list;
- picking related to cross docking, full-palletized loads and vertical lift systems is not accounted for;
- truck bays host packed pallets/rolls and feature 45 single-space slots;
- a roll occupies 1 slot of a truck bay, whereas a pallet occupies 2 slots;
- no faults occur during operations.

As for the Arena representation of the order picking process, it has been conceived according to four sub-models, i.e. i) order creation per retailer; ii) list generation per retailer by number/volume of items; iii) item picking; iv) management of truck bays. The details are provided in the following.

3.1. Order creation

Order creation is illustrated in Figure 2: here daily orders placed by retailers and stored on the AS/400 system are modeled in batches.

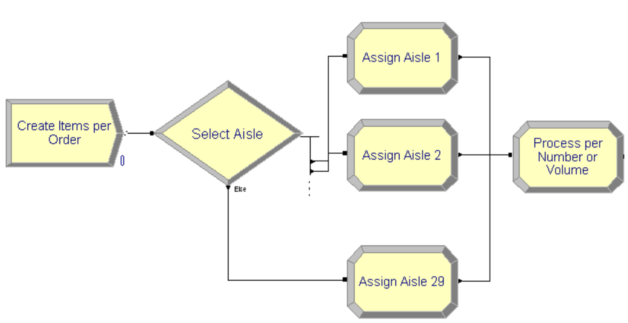

Figure 2. The order creation sub-model in Arena

An order contains a variable number of items and, for each item, the order specifies the number and volume of a single unit (package) to be delivered. All orders are processed on a first-in first-out basis and must be ready for delivery to the retailer in the shortest possible time.

3.2. List generation

By means of the sub-model depicted in Figure 3, orders are divided into picking lists. Each list consists of a certain number of lines: one for each item to be picked. Every item has a specific position within the warehouse and it is identified by the tuple (aisle, slot, location). Within a list, items are sorted according to the increasing aisle number in order to ensure compliance with the S-shaped heuristics during the picking activity. As requested by the retailer, both pallets and rolls can be used during picking activities.

Two different policies are implemented for list generation: by item number or by volume. In the former case, a maximum number of packages is set per list. According to company practice, this number is 110. So, an order with n packages to be picked will generate $\lceil n/110 \rceil$ picking lists. In the latter case, packing activities are constrained by the maximum height of the support. Due to security regulations, this height cannot exceed 160cm. For this reason, the maximum volume of a picking list (which includes the use of 2 pallets or 3 rolls) must be less than 2.5m^3.

Whatever be the packing policy, once completed, supports are transferred to the warehouse's exit area where they are placed in the assigned truck bay awaiting to be delivered to the retailer.

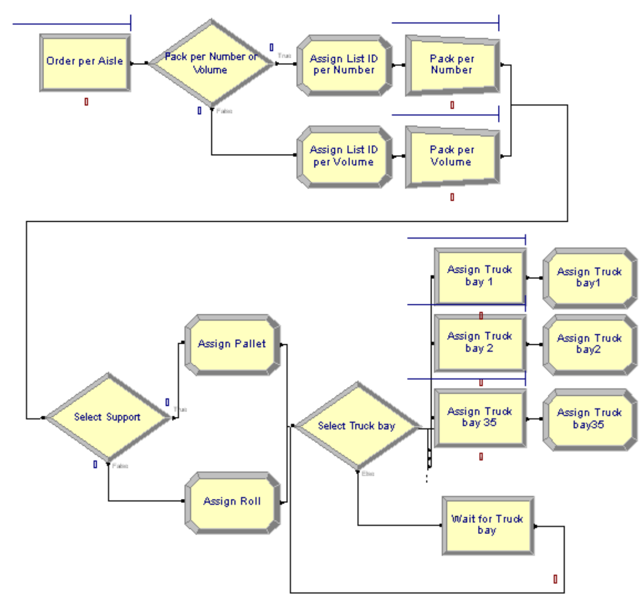

Figure 3. The list generation sub-model in Arena

3.3. Order picking

In the sub-model in Figure 4 a list is assigned to a free picker who receives the list via his/her voice picking device. The picker then retrieves the number and type of supports required and starts picking operations one-by-one. While doing so, one of the following situations may occur:

- item picking is successful: no further processing is required;
- item picking is not successful: the number of units required of a given item cannot be collected and, as a result, the picker will have to process the item again at the end of the list (note that an item can be processed at the most twice: at the second attempt the corresponding item row on the list is marked as successfully completed by default);
- a picker decides to skip an item and he/she will have to process it again at the end of the list.

If the height of the prepared items exceeds 1.60m and, therefore, the volume of the list exceeds 2.5m^3, the picker transfers the prepared supports to the assigned truck bay and picks up other supports in order to complete the list. This may occur ⌈(total volume of list [m^3])/(2.5[m^3])⌉ times.

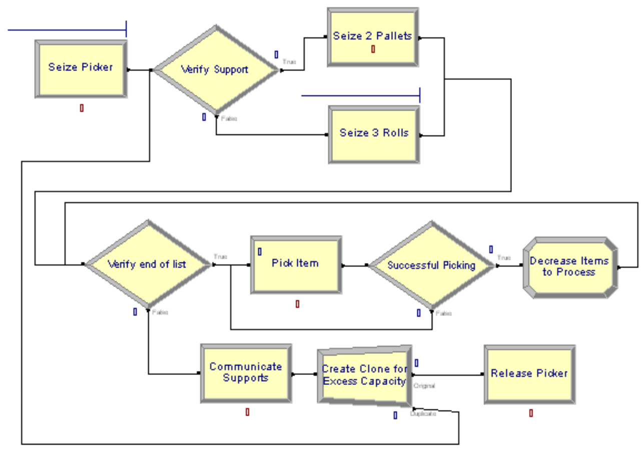

Figure 4. The order picking sub-model in Arena

After successfully processing the last item, the picker discloses the number of supports used during picking operations and places them in the assigned truck bay. List processing is now complete.

3.4. Management of truck bays

At the end of the support packing and wrapping, supports are ready for delivery and the picker places them in the assigned truck bay, as shown by the sub-model in Figure 5. Bays are usually filled to their maximum capacity or until their residual space capacity no longer fits the size of the supports belonging to the same picking list.

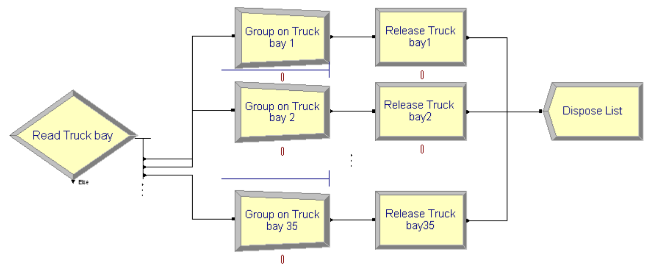

Figure 5. The management of truck bays sub-model in Arena.

4. Case study

The case study presented herein discloses how the introduction of a volume-based packing policy in PAC's company practices may effect productivity in the overall picking process. First verification and validation activities have been performed by means of *ad hoc* scenarios; then numerical experiments have been carried out on real company data, as reported in the following.

4.1. Verification and validation

A reasonable demonstration of the "correctness" of a simulation model is crucial for its credibility, especially when its meant to support upper-management decisions. This concern is addressed through model verification and validation.

As well stated in (Sargent, 2010), the aim of the verification stage in a simulation study is that of ensuring that the computer program of the computerized model and its implementation correctly represent the conceptual model. To this end, common-sense techniques and both numerical and animated traces have been applied on a set of *ad hoc* scenarios designed to verify the different impact of order packing by number of items, rather than order packing by volume. Among these, for illustrative purposes, let us consider a scenario featuring orders that in total contain 20580 items to be picked. Depending on the size of the items, one may expect significant differences in number of lists, number of supports (pallets and rolls), as well as utilization of the pickers assigned to carry out picking operations. In particular, if items are large in size, one may expect the "by number" policy to perform better since the roll/pallet will contain a fixed number of items (e.g. 110), no matter what the size. On the other hand, if items are small in size, the "by volume" policy should perform better since a roll/pallet will contain a number of items that is greater than the fixed threshold (e.g. 110).

Table 1. Verification of order picking policies.

Results/Policy	Small Size		Large Size	
	By Number	By Volume	By Number	By Volume
N° of lists	406	58	406	1,438
N° of pallets	442	62	1,710	1,594
N° of rolls	555	81	2,055	1,923

Picker utilization (%)	95	61	60	97

Table 1 shows the effects of the different policies when item size is set to 1,000cm^3 ("small size") and 100,000cm^3 ("large size"). Clearly, as expected, with small-sized items comes a smaller number of lists, supports (whether they be pallets or rolls) and utilization percentage of the pickers when using the "per volume" packing policy. For example, in a "small size" scenario to prepare 20,580 items the "by volume" policy outperforms the "by number" policy 62 pallets to 442. On the other hand, although the "by number" policy always generates the same number of lists whatever be the size of the items, in the "large size" scenario the "by number" policy unexpectedly requires a greater number of supports. The reason lies in the fact that list composition "by number" does not explicitly account for maximum height constraints. So, the picker must use a greater number of supports from those initially planned. Thus, even in this case, the "by volume" policy provides a better estimation.

As for model validation, it is usually defined to mean substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model (op. cit.). In this case study, validation activities have been carried out on the results recorded by the company in March 2022. Specifically, 95% confidence intervals (Nakayama, 2006) generated via independent replications over n = 10 runs by the simulator have been compared with the (real average) daily performance of the warehouse's order picking process in terms of number of lists and number of items. By way of illustration, Table 2 shows a two-way comparison of the results returned via simulation versus those of PAC 2000A (Sim vs PAC) for the "by number" picking policy.

Table 2. Validation of order picking policies.

Performance/Source	Sim	PAC
N° of lists	[650-840]	757
N° of items	[15,979-24,747]	23,351

As one may observe, the results reported from the related experiments show how faithfully the simulator mirrors the actual performance of PAC's current order picking policy. Therefore, the overall credibility of the simulator has been satisfactorily assessed.

4.2. Numerical experiments

The efficiency of the simulation model devised to support order picking operations has been tested in a real-life context. The numerical experiments have been carried out by first defining a set of input values based on historical company data from March 2022.

Table 3. Details of order creation.

Task	Distribution Function
Entities per arrivals	2+1250*BT(0.955,3.41)
Max n° arrivals	ANINT(NRM(94.1,12.4)

"BT" stands for a Beta distribution function, whereas "ANINT" represents ARENA's mathematical function to round to the nearest integer.

To begin with, in order to mimic the flow of morning arrivals, order placement has been defined in batches and by fixing the maximum number of daily arrivals, as shown in Table 3.

In Table 4 every order is organized per aisle (A) numbered 1 to 29, along with the percentage of items located in each aisle (%PA). The (integer value of) number of items to be picked as well as the volume of each item complete order definition. The latter information is necessary when testing the support packing policy per volume.

Table 4. Distribution functions for order contents.

A	% PA	Number of Items (Int f(·))	Item Volume (cm^3)
1	5.67	0.999+WB(7.87,0.582)	1.8e^3 + LGN(3.31e^4,6.7e^4)
2	1.99	0.5+LGN(0.982,0.869)	671+LGN(2.54e^4,3.98e^4)
3	2.81	0.999+WB(0.0189,0.287)	671+ERL(5.57e^3,3)
4	2.92	0.5+LGN(0.93,0.719)	194e^3+3.48^*BT(0.572,9.11)
5	3.28	0.999+EXP(1.03)	2.94e^3+WB(2.46e^4,0.864)
6	1.59	0.999+EXP(0.731)	1.59e^3+ERL(1.14^e4,2)
7	1.57	0.5+LGN(0.9, 0.725)	1.3e^3+ERL(7.45^e3,2)
8	2.11	0.5+ LGN(1.27, 1.44)	2.56e^3+GAM(1.7e^4,1.32)
9	3.21	0.5+LGN(0.949, 0.812)	960+LGN(2.18e^4,2.17e^4)
10	5.55	0.5+LGN(0.666, 0.34)	468+WB(9.44e^3,0.808)
11	6.26	0.999+EXP(0.997)	720+EXP(1.95e^4)
12	5.83	0.5+LGN(1.42, 1.74)	525+EXP(2.5e^4)
13	3.44	0.5+LGN(0.647, 0.312)	720+GAM(1.61e^4,1.99)
14	4.05	0.5+LGN(0.651, 0.325)	972+WB(2.19e^4,1.25)
15	2.69	0.999+EXP(0.844)	378+LGN(4.45e^4,7.67e^4)
16	4.27	0.5+LGN(0.691, 0.402)	1.05e^3+ERL(1.47e^4,2)
17	4.11	0.5+LGN(0.691, 0.437)	228+GAM(1.34e^4,1,61)
18	4.14	0.5+LGN(0.617, 0.279)	270+LGN(2.27e^4,3.43e^4)
19	3.59	0.5+LGN(0.827, 0.643)	635+LGN(2.53e^4,3.75e^4)
20	7.91	0.999+EXP(0.488)	1.26e^3+WB(2.1e^4,0.86)
21	2.50	0.5+LGN(0.805, 0.606)	635+LGN(2.85e^4,2.92e^4)
22	2.61	0.5+LGN(0.912, 0.84)	635+ERL(1.3e^4,2)
23	2.97	0.5+LGN(0.779, 0.574)	1.24e^3+1.02e^6*BT(0.3,10.6)
24	4.64	0.5+30*BT(0.293, 8.84	378+ERL(1.72e^4,2)
25	2.99	0.5+LGN(1.02, 0.931)	120+EXP(4.3e^4)
26	2.74	0.5+LGN(0.73, 0.502)	532+LGN(2.56e^4,5.33e^4)
27	2.28	0.5+LGN(0.6, 0.258)	506+LGN(1.89e^4,3.04e^4)
28	1.50	0.5+ERL(0.1, 6)	LGN(5.86e^4,1.79e^5)
29	0.79	0.5+15*BT(0.109, 0.545)	41+WB(1.5e^4,0.499)

The meaning of ARENA's abbreviations for the distribution functions provided above are: BT (Beta), ERL (Erlang), EXP (Exponential), GAM (Gamma), LGN (Lognormal) and WB (Weibull).

The service-related information is provided in Table 5. Service times are required for order picking, support retrieval, notifying support information and, finally, placing the packed supports in the assigned truck bay.

Table 5. Distribution functions for picking related tasks.

Task	Distribution Function (s)
Picking service time	LGN(46.3,64.5)
Support(s) retrieval	11+WB(83.7,0.751)

time	
Notifying support info	EXP(96.4)
Placing in truck bay	WB(69.5,0,587)

Two basic decisions made by the picker are modeled in the order picking process according to an n-way logic. In particular, the decision to retrieve pallets or rolls as the type of support to be used depends on the retailer placing the order, while skipping the picking task of a specific item is represented by a Bernoulli mechanism. Both options are in Table 6.

Table 6. Details of branching rules in *n*-way decisions.

Info	Branching Rule
send roll/pallet	2-way by condition *f(retailer)*
skip item	2-way by chance discrete(0.93,0.07)

Under the hypothesis of no kind of equipment failure, two types of resources are modeled: pickers and truck bays. The former are operative from 5:00 a.m. to 7:00 p.m. and are deployed according to the hourly schedule depicted in Figure 6. On the other hand, 35 truck bays are always available, each of which bears 45 space slots for pallet and roll placement.

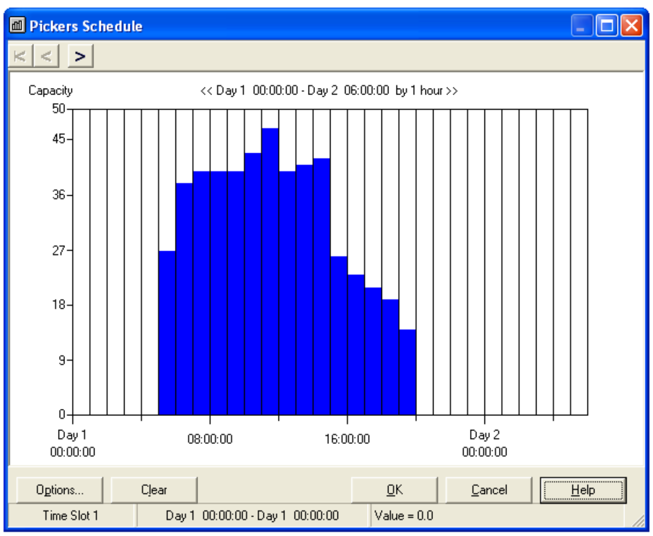

Figure 6. The working schedule of the order pickers

Given the above settings, the results returned by the simulator for the alternate packing policies in the order picking process are depicted in Table 7. They refer to productivity measures in terms of number of pallets and rolls handled per day and are expressed in terms of 95% confidence intervals.

Table 7. Results per alternative order packing policies.

Performance	By Number	By Volume	% Variation
N° of pallets	[504-590]	[431-507]	[13%-18%]
N° of rolls	[650-840]	[564-728]	[12%-17%]

As one may observe, the "by volume" policy outperforms the "by number" option. The difference in percentage is quantified in the "variation" column. The improvement ranges are [13%-18%] and [12%-17%] for pallets and rolls, respectively, while the average overall improvement is in the order of 15% for both types of supports. The goodness of this outcome finds evidentiary likelihood in the insight delivered by some members of PAC's management: according to their professional experience in other distribution centers, they believe that support savings can be achieved in the order of 17%.

5. Conclusions

A practical application of simulation has been proposed to support the order picking process at the operational level in PAC 2000A (the largest cooperative of the CONAD consortium for wholesale distribution of food products and general groceries in Central-Southern Italy). The simulator has allowed to optimize the picking process by assessing an alternative support packing practice "by volume", rather than "by number" of items. The predictive capability of the simulation tool has been validated thanks to both company data and experience. As for practical results, the case study has shown that by the end of a "typical" day beyond seasonal sales, pallet/roll packing by volume allows to achieve (average) savings in the order of 15%.

Opportunities for future research lie in the possibility of building a digital twin around the simulation model of the order picking process in connection with the logistic processes that drive its input and/or feed on its output.

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