Simulation of an Order Picking System in a Pharmaceutical Warehouse

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Abstract - **The paper presents an agent-based simulation model of an order picking system. A pharmaceutical warehouse is used as case study with the purpose of improving the implemented picking processes. Warehousing activities affect the total logistic costs of a company or supply chain. The optimization of the required picking operations is one of the most important objectives when attempting to reduce the operative costs. This study intends to provide a proof-of-concept agent-based model for scheduling the number of human resources required for picking activities. The improvement in the service and the planning of the manpower used in the warehouse, thus achieved, leads to operation-cost reductions. The goal is accomplished by using the NetLogo agent-based simulation framework. The simulation outcomes suggest that dimensioning human resources is a means to satisfy the desirable level of customer's service.**

Keywords - Warehouse Simulation; Order Picking system; Agent-Based model; NetLogo.

I. INTRODUCTION

Recent trends in the warehouse planning have resulted in order picking design and management being more important and complex. Order picking operation is one of the logistic warehouse's processes. It comports the retrieval and collection of articles from a storage location in a specified quantity into a box to satisfy a customer's order.

Customers tend to order more frequently, in smaller quantities, and they require customized service. On the other hand, companies tend to accept late-arrival orders while they need to provide rapid and timely delivery within tight time windows [1]. In general, lead times are under pressure. This is particularly true for pharmaceutical distribution centres.

In this business, pharmacies can order at the click of a button and expect inexpensive, rapid and accurate delivery. Obviously, managing order picking operations effectively and efficiently is a challenging process for the warehouse function. A key objective is to shorten throughput times for order picking, and to guarantee the meeting of due times for shipment departures. In order to offer high customer service level and to achieve economies of scale in transportation to support the related costs, these small size, late-arrival orders need to meet the tight shipment time fence. Hence the time available for picking orders at warehouses becomes shorter, which imposes higher requirements on order processing time at warehouses [2].

Order picking operations often consume a large part of the total labour activities in the warehouse ([3], even claims up to 60%), and for a typical warehouse, order picking may account for 55% of all operating costs [4]. Most of the warehouses employ humans for order picking.

According to the movement of human and products, order picking is organized into picker-to-parts and parts-to-picker systems. In a picker-to-parts system the picker (the person that performs the order picking operation) walks along the aisles to pick items. In this system is used the pick by order. During a pick cycle, pick information is communicated by a handheld terminal or a voice picking system. No paper pick lists are needed. The parts-to-picker systems are usually implemented by the usage of "Automated Storage and Retrieval Systems" (AS/RS).

In the present case study we use a pharmaceutical warehouse that has four different storage areas depending on the type of product stored: products with low rotation rate, products with high rotation rate, big and fragile products and special products (inflammable). The maximum number of pickers is 15.

To simulate the order picking operations, an agent-based model of the warehouse is used. The agent-based model represents the real order picking entities and simulates the customer service indicators. For this work, we used the NetLogo modelling framework [5] to rapidly prototype simple, yet realistic, "what-if" order picking scenarios and analyse the system performance under different real set-ups. NetLogo is a free open-source programmable modelling and simulation platform, appropriate for modelling complex systems. One of its main advantages is the ease of programming. The language is very intuitive and specifically designed for agent-based modelling, thus the user needs only to program agent behaviour, not the agents themselves. Moreover, the researcher community extensively supports the modelling platform and regularly develop a number of tools useful to the modeller.

This paper has the following research objectives: (i) to assign the correct number of pickers for a certain average of served orders; (ii) to provide a tool based on a simulation model to analyse the performance of the order picking

 ISBN: 978-1-61208-234-9

process; (iii) to calculate the demand of each type of product based on real data; (iv) to calculate the orders rate that enter in the warehouse; (v) to create a framework with the capacity of generating orders randomly.

This paper is organized as follows. In Section II the existing literature is reviewed, the real system is presented in Section III. A modelling framework, the NetLogo implementation and the validation experiments are shown in Sections IV, V and VI. Conclusion and future work follow in Section VII.

II. Related Work

The two major types of order picking systems can be distinguished into parts-to-picker and picker-to-parts systems. De Koster et al. [1] have provided an extensive literature review of the order picking operations and their implementations. One of their conclusions was the lack of attention from the researcher community for the pickers-to-parts order picking systems despite them being the dominant implemented approach.

Picker-to-parts systems occur in two types: pick by order and pick by article (batch picking). It is also possible to distinguish picker-to-parts systems by the order arrival and release. This can be either deterministic or planned [6] or stochastic [7].

A polling model can describe the order arrivals and processing; a system of multiple queues accessed in a specified sequence by a multiple servers [8]. Hwang et al. [9] use clustering-based heuristic algorithms for the batching of orders for order picking in a single-aisle automated storage and retrieval system. Daniels et al. [10] consider the warehouse in which goods are stored at multiple locations and the pick location of a product can be selected dynamically.

There are also relevant applications in operation management. For instance, Koenigsberg and Mamer [11] consider an operator who serves a number of storage locations on a rotating carousel conveyor. Bozer and Park [12] presented a single-device polling-based material handling systems. Although these systems have been widely researched, they have not yet received systematic treatment and application in the picking process organized in a picker-to-parts system. The same situation occurs with the agent-based models. The literature mainly presents agent-based approaches to solve order picking problems where goods are stored at multiple locations or warehouse control solutions [13], [14]. The study described in this paper is applied to a real case, which the picking is organized in a picker-to-product system.

This work contributes to the literature by exploring the agent-based metaphor to simulate an order picking system in a realistic scenario using real data of a pharmaceutical warehouse.

III. Real System Description

Figure 1 shows the layout of the order picking workstation under study. This system can be classified as a picker-to-product system. Pickers work to fulfil orders. The number of order lines in an order is referred to as order size. Order sizes may vary significantly.

The pharmaceutical distribution center has four different storage areas depending on the type of product stored: products with low rotation rate, products with high rotation rate, big and fragile products and special products (inflammable) and a maximum number of 15 pickers.

The storage areas are arranged in a pre-defined layout and there is a common conveyor to transports the order boxes between them. A customer order may require products from one or more storage areas and the time to collect the products is different for each case.

At the order picking workstation, orders arrive sequentially using boxes on the conveyors. Once the picker and the required order product box are available, the picker moves to the product rack, then picks a number of required items and place it on the conveyor to be transported to the position where the order product box waits. The Figure 1 shows a scheme of this process. The picker works on one order at a time until all lines of the order have been picked and the order is said to be finished. When an order is finished, the system moves the finished order box to the dispatch area.

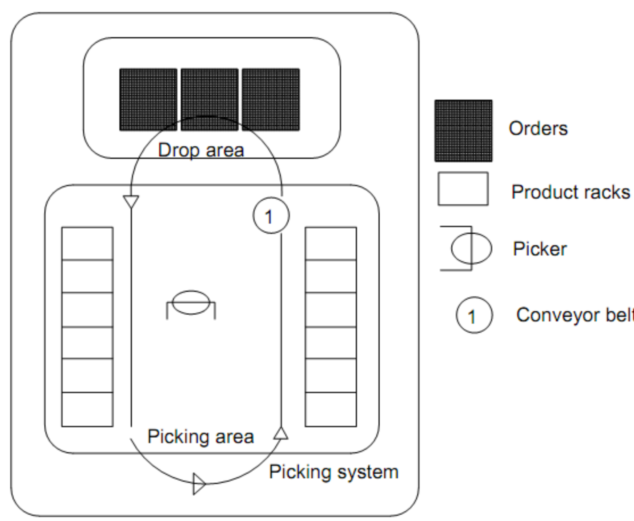

Figure 1. A scheme of order picking process

In this type of system, the picker can only pick items from the product racks that belong to the order currently being processed.

If for any reason the product is not available, the picking time is above a limit or some error occurs the order is deviated and need a special procedure is used to finish it.

IV. Simulation Model Description

In the following section we discuss the concepts of a pharmaceutical order picking system focusing on the picker-

 ISBN: 978-1-61208-234-9

to-parts system. We describe the processes taking place during the operation of the warehouse as well as the data used to model the system.

The workstation is modelled using an agent-based approach. Several pickers, products stored in racks, boxes with the products to complete the orders and a server-based management information system, compose such a system.

The user can adjust this model changing the number of pickers. The orders arrive randomly at the workstation with a rate of 7, 8 orders per minute and they have random lines of products based on the real data. This value is obtained by the analysis of the data of one entire month (65 000 records). The result is depicted in Figure 2 in a Poisson distribution. Orders are created based in this real rate.

Figure 2. Poisson distribution of the real data

In this model, customer orders can require one or more product lines from one or more storage areas. To describe this situation it was assumed four types of final product:

- if an order requires one or more products lines from one area, we call it a PROD1ZONE;
- if an order requires one or more products lines from two areas, we call it a PROD2ZONE;
- if an order requires one or more products lines from three areas, we call it a PROD3ZONE;
- if an order requires one or more products lines from four areas, we call it a PROD4ZONE.

The frequency and the average preparation time per each type of order are calculated using the real data from entire days. And the result is depicted in Table I.

Table I. Demand production and time preparation

Type of order	Frequency per Type of order (%)	Average Preparation Time (min)
PROD1ZONE	30.46%	5'
PROD2ZONE	27.89%	15'
PROD3ZONE	22.91%	25'
PROD4ZONE	18.74%	43'

This means that in 10 orders the amount of each type of final product is:

- PROD1ZONE: 3.1 orders
- PROD2ZONE: 2.7 orders
- PROD3ZONE: 2.3 orders
- PROD4ZONE: 1.9 orders

For this model it was assumed that products are always available in the warehouse, the pickers are equally skilled (homogeneous agents) for the order picking operations, the workspace is considered an open space and the time to pick a product from the shelf is standard and do not vary with the product.

The orders can have many different statuses: "arriving", "queuing", "placing", "preparation", "finishing" and "leaving" as it can be seen in Figure 3. The process time used in this paper represents an aggregation of all components that contribute to the processing time at the order picking workstation, the Effective Process Time (EPT). Initially orders move towards the warehouse entrance and stand in a sequential order until a place is chosen. If a free place exists, then the order must navigate to that place. Once the order has reached the place the status is changed to "waiting" and a counter is started. After the pre-defined finishing time has passed, the order changes its status to "leaving".

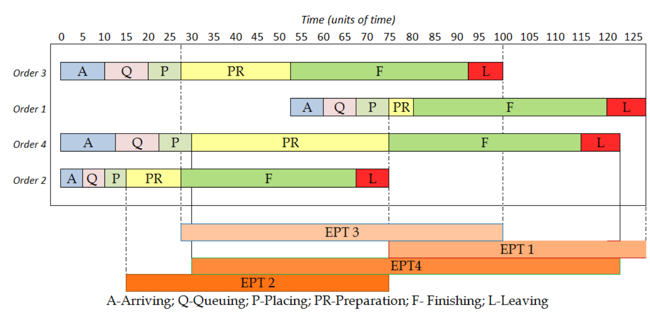

Figure 3. Orders status

Jacobs et al. [15] presented an algorithm to compute the EPT realizations directly from arrival and departure events.

An order picking workstation is characterized by several process time components (see Figure 3). At the core of the process is the time required for picking items (preparing and finish time), that is the raw pick time. Next to the raw pick time, pickers may require some setup between processing of orders. Conveyor systems may break down, causing unavoidable delays. Picker availability is also an issue since it is likely that a picker is sometimes not present at the workstation. These components are aggregated into a single EPT. The idea is then to reconstruct the EPT directly from order arrival and departure times registered at the operating order picking workstation under consideration with the obvious advantage that it´s not need to quantify each component that contribute to the process time.

Figure 3 shows an example of arrivals and departures of four orders at an order picking workstation. An arrival *Ai* occurs at the moment an order *i* is prepared at the order picking workstation. A departure *Di* occur when the picking has been finished and the respective order *i* is finished.

EPT realizations are calculated using the following equation:

$$EPT_i = D_i - A_i \quad (1)$$

where D_i denotes the time of i^{th} departing order and A_i denotes the arrival of the corresponding i^{th} order. The bottom part of Figure 3 illustrates how EPT realizations are obtained using Equation (1).

The picker agent has various statuses: “selecting the product”, “getting products from the rack”, “going to the workspace”, “preparing the product” and “sending the product”.

V. NETLOGO IMPLEMENTATION

In this paper, we describe the use of NetLogo as a rapid prototyping tool for an agent-based simulation framework to evaluate the setup of a pharmaceutical warehouse order picking system.

We present how our problem was modelled and which abstractions were used to achieve the outlined objectives. Furthermore, complexities and constraints inherent to this problem were identified. From that, a simplified model of an abstraction of the application domain was created without losing key aspects. Our purpose is to simulate the activities and operation taking place in an order picking system in way (i) to assign the correct number of pickers for a certain average of served orders; (ii) to simulate the orders behaviour: served and diverted; (iii) to calculate the orders rate that enter in the warehouse.

There are several concepts and agents involved in this model:

1. The Orders:

Orders are randomly generated to “arrive” in the warehouse following a probability distribution according to the historical data distribution. A preparation place is assigned (“placing”) to each order. Here, the order assumes the state “waiting” until the order picking operations are finished (“finishing”). Upon conclusion, the order assumes the state “leaving” and is forwarded to the dispatching area. The demand for each type of product is based on data from a pharmaceutical company.

If the waiting time is too long, (for any reason: product not found, place not available) the order is diverted.

2. The picker:

The user before setup can define the number of pickers and their initial location is randomly generated in the workspace. Simple reactive agents based on simple “if-Then” rules implement the pickers. The picker collects all the products to finish the order. There are four types of final products: PROD1ZONE, PROD2ZONE, PROD3ZONE and PROD4ZONE. Each final product has different picking time to be prepared (defined in the source code). Once the products have been collected, the picker moves to the sending area and places it on the conveyor. The picker restarts the cycle. In the proposed model, pickers are represented by agents.

3. The server:

The server is an agent responsible for the managing and dispatching of the orders.

If all positions for preparing the orders are full, the server does not allow orders to enter into the system to do the order picking operation; this causes a sequential order (“queuing” of orders).

The only interface variable that the user must set before the model runs is the number of pickers. All the other variables can be changed, allowing a dynamic observation.

The user can change also the following variables:

- The demand for each type of final product;
- The chance that orders are generated;
- The speed of the conveyor.

Various monitors and plots allow the user to display the result of these dynamics:

- The total number of orders;
- The number of free places;
- The number of instances of each type of product;
- A chart plotting the number of orders served every 100 ticks (NetLogo unit of time);
- A chart plotting the number of diverted orders every 100 ticks;
- An average number of orders served;
- An average number of diverted orders;

The user can experiment to change the values and seeing the result through the monitors and charts. It is possible to observe the visual phenomena that are developed such as bottlenecks, queues and the spatial distribution of diverted orders.

There are important aspects in this model:

- Queuing at the warehouse entrance;
- Bottlenecks at the exit;
- Congestion on the conveyor;
- The stochastic aspects are inherent in the model;
- Agents don't always move in exactly the same way;
- Demand of different final products may vary naturally.

Although NetLogo is a simple simulation framework, it proves to be a very useful tool for creating this type of agent-based model of real scenario. With respect to other simulation paradigms, the agent-based approach offers the users the possibility to observe not only the dynamic of the system but also the interaction of the situated entities in the system. One key point is also the agent movement. Specifically creating a realistic system where agents (e.g., pickers) can move having specific goals and destinations. The limitation in allowing agents to move dynamically in the NetLogo environment is that they are constrained moving discretely on a grid-based space patch-by-patch rather having smooth trajectories.

VI. VALIDATION EXPERIMENT

In this section the simulation experiments are discussed to validate the proposed model. First, a simulation scenario has been created to use as a test case representing the "real life" operating order picking workstation. Then, the model has been simulated at a real utilization level (using different number of picker-agents, the real demand and the real order picking times) to generate order arrival and departure events. Subsequently, these events are used as variables for the global model. Next, the model was simulated at various utilization levels (varying the number of pickers and conveyor belt speed) to measure the number of orders served versus the number of diverted orders.

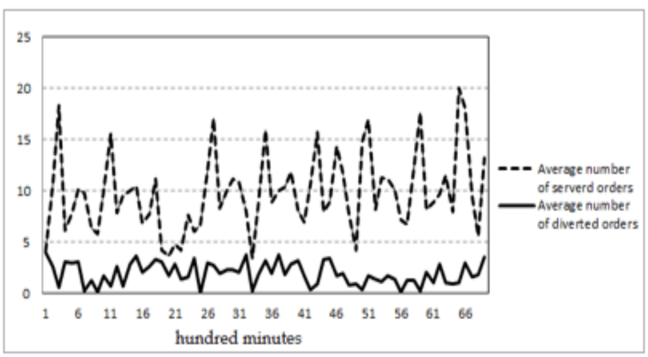

Figure 4. Orders behaviour in real system

For the aforementioned experimental set-up, a comparison has been made over the average number of served and diverted orders of this simulation model with those of the real system. In this way, it´s possible to assess the accuracy of the predictions of the average number of served orders. The real system's data are depicted in Figure 4 (in green the average number of served orders) while the simulation obtained results are depicted in Figure 5. The word "tick" in the graph of Figure 5 is a measure for the time that is used by NetLogo.

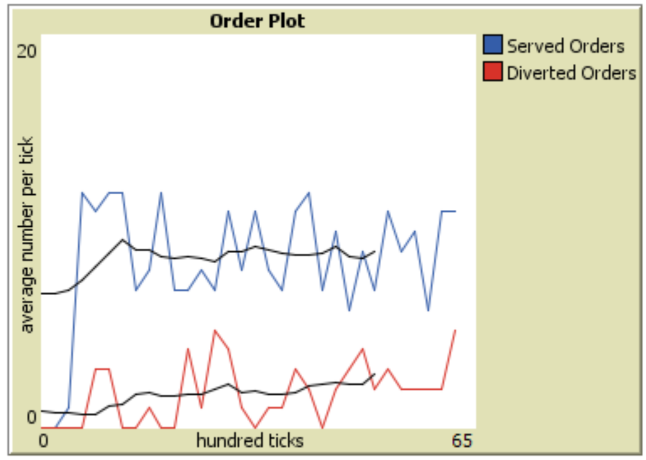

Figure 5. Order behaviour in simulated system

Analysing the order plot over a complete working day's operations, we get a good idea of the order average of served orders and diverted orders. By looking at the historical company's data, we can see that the diverted orders are in line with the current observations.

VII. CONCLUSION AND FUTURE WORK

This paper presented an order picking model implemented in the NetLogo agent-based platform. Although the model may appear to be simplistic, its conceptualisation encompasses many aspects of the observed system in the real world. The model manages to predict the average number of served orders using a certain amount of human resources by means of an agent-based simulation model with real data from a pharmaceutical distribution center. Arrival and departure time data are the only input required to calculate the time to complete the orders. The validation of the simulation study demonstrated that the data used are adequate to the required results. It was found that the proposed model accurately predicts the defined goal in a satisfactory degree.

In practice, the actual pick rate does not deviate from the expected rate. With this regard, the EPT represents the actual pick time of an order picking workstation. This will allow the identification of possible improvements for order picking activities.

The proposed model has practical use because collecting arrival and departure data of orders is relatively simple in warehouses and the output is easily perceived.

In future work, the model's layout will be improved and demonstrate how the presented approach in this paper can be applied to a more detailed order picking workstation (i.e., heterogeneous agents to represent differently skilled pickers, automation mechanism in the warehouse, etc.).

Besides that, the current advancements in order picking technology have allowed multiple orders to be processed simultaneously by a picker, which is often the case in large-scale warehouses. Thus, orders routings in large-scale

 ISBN: 978-1-61208-234-9

warehouses would not be processed in a FIFO sequence at the workstation. Performance analysis, in such a context, of order picking workstation will be also subject to future work. Therefore, it is important to improve and enhance the attributes of the agent-based model to tackle these issues.

ACKNOWLEDGMENT

This project has been supported by the FEUP project "Support system for availability and location of products for picking" and FCT (Fundação para a Ciência e a Tecnologia), the Portuguese Agency for R&D, under the grant, SFRH/BD/67202/2009

REFERENCES

1. R. de Koster, T. Le-Duc, and K. J. Roodbergen, "Design and control of warehouse order picking: A literature review," European Journal of Operational Research, vol. 182, issue 2, pp.68–73, October 2007.
2. M. Yu, "Enhancing warehouse performance by efficient order picking," Netherlands Research School for Transport, Infrastructure and Logistics, Doctoral Thesis, October 2008.
3. J. Drury, "Towards more efficient order picking," IMM Monograph No. 1. Report, The Institute of Materials Management Cranfield, U.K, 1988.
4. J. A. Tompkins, J. A. White, Y. A. Bozer, and J. M. A. Tanchoco, "Facilities planning," New York, John Wiley and Sons, 2003.
5. U. Wilensky, "NetLogo," Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL, http://ccl.northwestern.edu/netlogo/, (accessed September 2012).
6. N. Gademann and S. Van de Velde, "Order batching to minimize total travel time in a parallel-aisle warehouse," IIE Transactions vol. 37, issue 1, pp. 63-75, 2005.
7. T. Le-Duc, "Design and control of efficient order picking process," Rotterdam School of Management, Erasmus University Rotterdam, the Netherlands, Ph.D. dissertation, 2005.
8. M. M. Srinivasan, "Nondeterministic polling systems," Management Science, vol. 37 no. 6, pp. 667–681, June 1991.
9. H. Hwang, W. Baek, and M. Lee, "Clustering algorithms for order picking in an automated storage and retrieval system," International Journal of Production Research, vol. 26, issue 2, pp. 189–201, 1988.
10. R. L. Daniels, J. Rummel, and R. Schantz, "A model for warehouse order picking," European Journal of Operational Research, vol. 105, pp. 1–17, February 1998.
11. E. Koenigsberg and J. Mamer, "The analysis of production systems," International Journal of Production Research, vol. 20, issue 1, pp. 1-16, 1982
12. Y.A. Bozer and J.H. Park, "Expected move request waiting times in single-device, polling-based material handling systems," IIE Trans vol. 33, issue 1, pp. 55–63, 2001.
13. B. Kim, J. G. Robert, and S. H. Sunderesh, "Intelligent agent modeling of an industrial warehousing problem," IIE Transactions, vol. 34, issue 7, pp. 601-612, 2002.
14. B. Kim, S. H. Sunderesh, J. G. Robert, and A. St. Onge, "Intelligent agent based framework for warehouse control," Proceedings of the 37th Hawaii International Conference on System Sciences, January 2004.
15. J. H. Jacobs, L. F. P. Etman, E. J. J. van Campen, and J. E. Rooda, "Characterization of operational time variability using effective processing times," IEEE Transactions on Semiconductor Manufacturing, vol. 16, no. 3, pp. 511–520, 2003.

 ISBN: 978-1-61208-234-9