

# SIMULATION IN THE WAREHOUSE DESIGN AND MANAGEMENT CONTEXT: A SURVEY

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## KEYWORDS

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## ABSTRACT

The dynamic character of today's competitive markets forces organizations to an incessant reassessment in an effort to respond to the continuous challenges. Warehouses as an important link in most supply chains should be an integral part of this effort. Hence, warehouses must continually be reevaluated to ensure that they are consistent with both the market's demands and the management's strategies.

The aim of this paper is to survey how simulation technique could represent one decision support system in the warehousing context.

## INTRODUCTION

Market competition requires continuous improvement in the design and operation of supply chains (SC). A supply chain can be considered as a network of entities (Figure 1). The efficiency and effectiveness of any SC is highly determined by the performance of the entities in the network. In this context, warehouses play an important role in companies' supply chains.

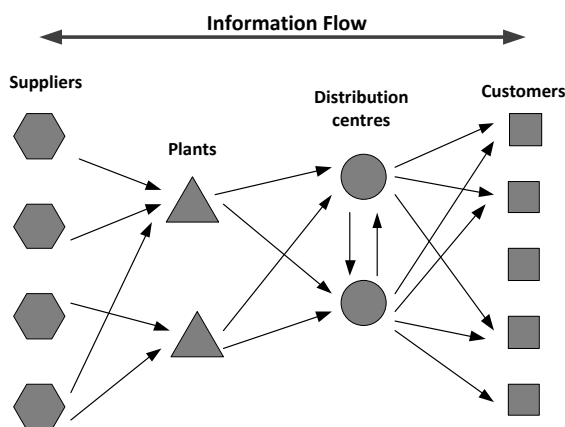


Figure 1: Typical supply chain network

On the other hand, modern supply chain principles compel companies to reduce or eliminate inventory levels. Additionally warehouses require labour, capital and information technologies, which are expensive resources. So, *why do we still need warehousing?*

According to Bartholdi and Hackman (2006) there are four main reasons why warehouses are useful:

- To consolidate products in order to reduce transportation costs and to provide customer service;
- To take advantage of economies of scale;
- To provide value-added processing and
- To reduce response time.

Rouwenhorst *et al.* (2000) classified warehouse decisions into strategic decisions, tactical decisions and operational decisions. Strategic decisions are the long term decisions and always mean high investments. The two main issues are concerned with the design of the process flow and with the selection of the types of warehousing systems. Tactical management decisions are medium term decisions based on the outcomes of the strategic decisions. The tactical decisions have a lower impact than the strategic decisions, but still require some investments and therefore should not be reconsidered too often. At the operational level, processes have to be carried out within the constraints set by the strategic and tactical decisions made at the higher levels. At this level, the concern includes the operational policies such as storage policies, picking and batching policies. In short, strategic decisions create limits to decisions taken at the tactical and operational levels and tactical decisions create limits to operational decisions.

Once warehouse decisions are strongly interrelated, design, planning and control of warehousing systems is a highly complex task where frequently conflicting objectives impose specific trade-offs.

Despite the various decision models available in scientific literature, the majority addressed isolated or simplified problems solved with analytic or heuristic methods in order to provide the best solution. However, most real problems are unfortunately not well-defined and often cannot be reduced to

multiple isolated sub-problems. Therefore, given the associate complexity and the stochastic nature of these systems simulation can be considered as a powerful technique to apply, as a decision support system, within a warehouse design and planning context.

Simulation modelling (in particular, discrete-event simulation) is a common paradigm for analysing complex systems. In fact, it is possible to reproduce and test different decision-making scenarios in order to determine, in advance, the level of optimality and robustness of a given strategy.

The aim of this paper is to explore how simulation technique has been used as a decision support tool to help practitioners and academic researchers in a warehouse design and planning context.

After an introduction to warehouse design and planning decisions, a review is proposed in order to analyse the scope of use and the main benefits reported from the adoption of the simulation technique. Finally some considerations are provided.

## WAREHOUSING

According to Van den Berg and Zijm (1999) and Rouwenhorst *et al.* (2000) warehousing processes concerns those material handling activities that take place within the warehouse functional areas, i.e. receiving, storage, order-picking, accumulation and sorting, and shipping of products.

Figure 2 shows the typical functional areas and flows within warehouses.

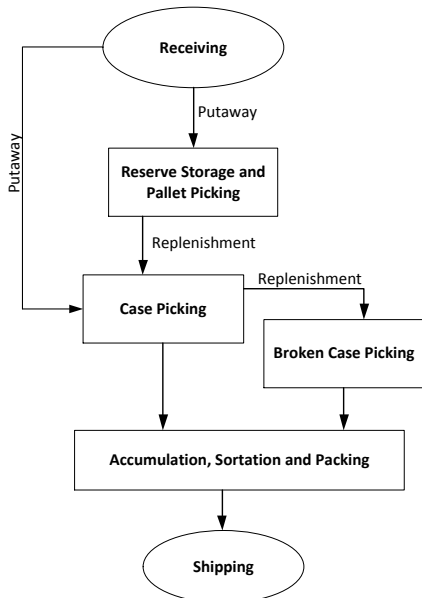


Figure 2: Typical warehouse functions and flows

At the receiving area products are unloaded and inspected to verify any quantity and quality inconsistency. Afterwards items are transferred to a storage zone or are placed directly to the shipping area (this is called a cross-docking operation). We

can distinguish two types of storage areas: reserve storage area and forward or picking area. The reserve area is the place for products to stay until they are required by costumers' orders. The picking area is a relatively small area typically used to store fast moving products. Most of the flows between areas are the result of replenishment processes. Order picking is one of the most important functions in most warehouses. Stock keeping units (SKU) are retrieved from their storage positions based on customers' orders and moved to the accumulation and sorting area or directly to the shipment area. The picked units are then grouped by customer order, packaged and stacked on the right unit load and transferred to the shipping area.

The design, planning and control of warehouse systems include a large number of decisions from a functional description, through a technical specification, to equipment selection and determination of the layout, and to the definition of operating policies. The overall structure decision determines the material flow patterns within the warehouse, the specification of functional areas and the flows between areas. Sizing and dimensioning decisions determine the total size of the warehouse as well as the space allocation among functional areas. Layout definition is the detailed configuration within a functional area and equipment decisions define an automation level for the warehouse and identify equipment types. Finally operating policies refer to storage, picking and routing decisions.

A brief description of problem category is given in Table 1.

Table 1: Description of warehouse design and operations problems (adapted from Gu *et al.*, 2007)

	Design and Operation Problems	Decisions
Warehouse Design	Overall Structure	Material flow Functional areas
	Sizing and Dimensioning	Warehouse size Size of the functional areas
	Equipment Selection	Level of automation Storage equipment selection Material handling equipment selection
	Layout	Aisle orientation Number, length and width of aisles
Warehouse Operations	Receiving & Shipping	Dock assignment Dispatch schedule
	Storage	Assignment and allocation of SKU to functional areas Storage location assignment
	Order picking	Batch size Picking policy Routing policy

The big challenge for both academic researchers and

warehouse practitioners is to get flexible structures capable to respond to changing conditions, to improve space utilization and to reduce congestion and movement.

## LITERATURE SURVEY

The presented survey has been conducted over the scientific literature in order to establish which general objectives simulation is called to solve within the warehousing context.

Reader may note that the survey considers references that involve decisions related with: (i) Warehouse Design; and (ii) Warehouse Operations.

### Warehouse design

Gray *et al.* (1992) developed an integrated approach to the design and operation of an order-consolidation warehouse. This approach included warehouse layout, equipment and technology selection, item location, zoning, picker routing, pick generation list and order batching. Due to the complexity of the overall problem, they developed a multi-stage hierarchical decision approach. The hierarchical approach used a sequence of coordinated mathematical models to evaluate the major economic trade-offs and to reduce the decision space to a few alternatives. Then, authors used simulation technique for validation and fine tuning of the resulting design and operating policies for a typical order-consolidation warehouse. A simulation model, written in SIMSCRIPT language, was validated using the analytical results, and in turn provided support for the approximations made in developing the mathematical models. Authors also compared the simulation results with the outcomes of the analytical models and concluded that the proposed approach was robust and accurate. The proposed approach was illustrated using a case study of an automotive spare-parts distribution centre.

Caron *et al.* (2000) presented a simulation approach to efficient layout design of the picking area in picker-to-part systems. The aim of this study was to compute the expected travel distance per tour considering both within aisle and cross aisle travel. The simulation model, written in Visual Basic, was essentially divided into five steps:

1. System definition;
2. Generation of samples to pick;
3. Definition of the picking tour for each sample;
4. Computation of the picking travel distance, and
5. Statistical analysis of the output data.

For the purpose of the study authors assumed that the storage capacity of the picking system was given and, consequently, the total length of the picking shelves was known. Experimental results showed that: (i) the expected picking travel distance may be significantly influenced by the number of aisles; (ii) layouts with a minimum number of aisles are preferred for a large number of picks; (iii) multi-aisle layouts are preferable for few picks per route and (iv) for intermediate number of picks the number of aisles is less crucial.

Ekren and Heragu (2009) presented a simulation based regression analysis for rack configuration of an autonomous vehicle storage and retrieval system (AVS/RS). The authors developed a mathematical function for rack configuration of an AVS/RS that reflects the relationship between the response and the factors of the system. The simulation model, developed using ARENA<sup>®</sup> 12.0, was used to determine the independent input variables (factors) levels of the regression model.

### Warehouse operations

Caron *et al.* (1998) evaluated and compared the expected travel distance for different routing strategies in low-level picker-to-part systems. The expected travel distance was first evaluated by means of analytic models taking into account the main systems parameters. Then, a simulation model of the picking system, written in Visual Basic, was used to test the accuracy of the analytic model. The simulation model was used to calculate the length of randomly generated routes according to the chosen routing policy.

With the purpose of maintaining the picker's regular workload Jane (2000) proposed two heuristic methods: one enlarged the order picking system by a new zone during the picking periods and the other reduced the system by one zone during the slack periods. The proposed methods were verified through empirical data and simulation experiments using Visual FoxPro 5.0 and Microsoft Excel 97.

Liu (1999) used a simulation study, using WITNESS simulator, in real word data to reveal the benefits of using clustering techniques for optimizing the storage policies and the picking process. The simulation studies revealed that the storage policy obtained by clustering techniques could significantly reduce the travel distance or time for picking operations within a warehouse.

Lin and Lu (1999) proposed a two-phase procedure to determine order picking strategies. An analytic method was first employed to classify all customers' orders into five different categories. Then, computer simulation was used to generate the appropriate picking strategy for each orders category. ProModel simulation software was used in this study.

Macro and Salmi (2002) developed a simulation model to quantify rack utilization and storage capacity of different configurations of pallet racks in a warehouse. Using ProModel simulation language, the authors developed a universal warehouse storage simulation model that can be used as a tool to analyse existing warehouse systems, and as a method to experiment with different storage and process options. In particular, the simulation model can be used to answer the following concerns:

- Warehouse capacity due to demand growth;
- Efficiency of the storage policy;
- Equipment and resources limitations;
- Performance of the order picking policy;

- Effect of the production run size.

The proposed model has successfully been used in two different cases: (i) medium volume, low SKU warehouse and (ii) medium volume, high SKU warehouse. For each model three significant output metrics were calculated, namely: rack utilization by rack type and the average and maximum number of pallets in storage.

Petersen and Aase (2004) examined storage, picking and routing policies simultaneously. Authors' aim was to evaluate several storing, picking and routing policies to determine which policy or combination of policies provided the greatest reduction in total picking time when compared to an existing baseline scenario. For that purpose a simulation model was used based on the operations of a given distribution centre.

Hwang and Cho (2006) developed a systematic approach for the performance evaluation of order picking warehouse system considering mathematical and simulation methods. A mathematical model was proposed to analyse the performance of the order picking system including the performance of the transport system. The developed performance evaluation model was based on the material handling cost for both cases of throughput and waiting due to congestion. Then, a simulation model using AutoMod simulator was used to validate the mathematical model.

Gagliardi *et al.* (2007) presented a discrete event simulation model that focus in the order picking and shelves replenishment processes and, as a first application, was used to discuss the impact of storage space allocation on the system performance. The simulation model has been coded in VB.net (Visual Basic 7.0) language and eight working weeks of a real high throughput warehouse which handles more than 12 million of case annually were simulated. The gathered results showed a large variability which did not allowed identifying a dominant rule.

Gopakumar *et al.* (2008) using ARENA® 10.0 developed a simulation model that was used as a tool to analyse an existing warehouse incoming receiving operations. Specifically, the model was proposed to evaluate methods to allocate docks to the incoming trucks in a systematic and efficient manner.

Kofjač *et al.* (2009) presented a real case study of inventory optimization in an automotive company. An anticipative approach was performed using simulation models supported by inventory control algorithms on selected samples of representative items. The simulation model, built using Matlab, yielded significant changes. The authors also considered that the simulator's transparency and visual presentation can play a significant role in the learning process of using methodologies that they are unfamiliar with.

Recently Chan and Chan (2011) presented a real case study regarding the storage assignment problem of a manual-pick and multi-level rack warehouse. Authors' aim was to determine which combination of factors improved the performance of the storage assignment policy of a manual-

pick warehouse in terms of travel distance and order retrieval time through a simulation approach. For that purpose three models of the same warehouse layout were built, using ARENA® language, with respect to three different routing policies, and twenty-seven combinations of factors (i.e. 3 storage assignment policies x 3 routing policies x 3 pick densities) were simulated. Experimental results were conducted on a multi-level rack warehouse. The gathered results showed that different combination of factors have different performance under different performance indicators. For example, for the order retrieval time and travel distance performance indicators, the performance of each combination of factors can be different. The one which performs better in terms of one performance indicator can result in the worst for the other indicator. For example, this study showed that horizontal ABC class-based storage has opposite performance under the two indicators.

## SURVEY ANALYSIS

From the presented literature survey, it is possible to say that simulation has mostly been used as a mean to validate the performance of warehouse design and operations policies. In particular, some of the operational research models and results reported in the scientific literature were validated upon simulation approaches. For example, a mixed optimization-simulation approach is found in Gray *et al.* (1992), Liu (1999) and Hwang and Cho (2006).

It is also important to notice that the number of references concerning warehouse operations is bigger than the number concerning warehouse design decisions. In particular, solutions aiming to evaluate the combination of storage policies and order picking policies are widely considered.

Given that decisions are strongly interrelated, for example product location is dependent on warehouse configuration, order picking strategy and technology in place, most of the research in the literature deals with specific practical cases. Thus, a general contribution seems to be scarce.

We believe that we are still missing many references on the application of simulation to warehousing problems. Nonetheless, our intention was not to provide a complete survey about the issue (we would like to do it in the near future), but to call the attention to the potential of the simulation technique in the field of the warehouse management.

## CONCLUSIONS

When designing a warehouse several decisions have to be made. For example, the size and layout of the warehouse, the selection of the appropriate storage and handling equipment and the adoption of the best storage, picking and routing policies. Thus, due to the tremendous amount of possible alternatives and the interdependency of several decisions warehouse design and planning became a very complex issue.

In such a complex context a decision support system (DSS) which combine simulation and analytical techniques can be of great help. Optimization methods will help to take decisions within certain assumptions and then simulation technique can be used to validate analytical solutions, evaluate sensitivity of those solutions and also to analyse the system behaviour in presence of uncertainty.

Simulation modelling technique allows the evaluation of operating performance prior to the implementation of a system. It enables:

- (i) powerful what-if analysis and;
- (ii) permits the comparison of several operational alternatives.

These features are a common background from the survey reported in this paper, which shows how simulation can be successfully adopted in different studies related with warehousing.

We also think that simulation is probably much more widely used in practice than is evident from this literature survey. This is due to the understandable reluctance to publish studies from a confidential nature.

**FUTURE WORK**

One important challenge in warehousing context is the integration and coordination of several activities in the warehouses. In particular, an important issue is to integrate design and operating decisions minimizing the system global cost.

In this context, a two-stage approach to solve warehousing problems and take advantages of the system dynamics can be taken:

1. Using optimization models to generate solutions taking into account some of the most important cost parameters;
2. Using simulation models to evaluate the solutions generated in the first phase.

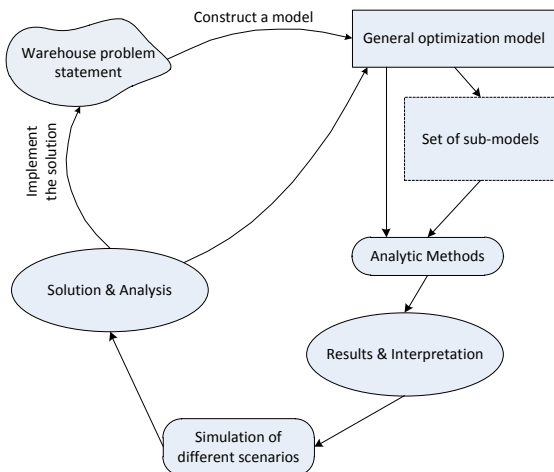


Figure 3: A DSS scheme for warehousing decisions

Future work can be carried out on the development of a DSS (Figure 3) that combines analytical and simulation techniques.

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