



Significant Factors for Selecting the Right Warehouse Management System

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Abstract

Warehouses are essential components of logistics structure in companies and on one hand they play a crucial role in visibility, speed of whole supply chain system but on the other hand warehouses are cost factors of the company. In order to stay competitive in today's global marketplace all existing cost factors like logistics have to be examined and continuous improvements have to be realized. Today, customers' expectations are increasing rapidly, therefore warehouses need to raise their goals for inventory accuracy, visibility, better information flow, convenient service, personalized order fulfillment, flexible value-added service and responsiveness to special requests. Hence, choosing the right warehouse management system becomes one of major decisions to cover most of these requirements. The research methodology is multi-criteria decision-making (AHP) procedure, where both technical and managerial criteria on software and vendor selection were considered. The algorithm was collected with the preference of specialists' ratings for criteria, and the suitability of warehouse management system alternatives versus the selection criteria were compared to calculate appropriateness indices. Through these appropriateness indices the most suitable warehouse management system was researched. In conclusion, the results were evaluated and some recommendation points were mentioned.

Keywords: Warehouse Design, Warehouse Management System, AHP

Introduction

Warehouses have been part of the most of the production/non-production companies for hundreds years and they have an increasing importance with introduction of supply chain methods and Kaizen strategies. On one hand they are very important elements of the supply chain, but on the other hand they are one of biggest cost factors in the supply chain.

In the past when make-to-stock concept was common the warehouses were generally considered as storage locations to keep goods safely until the delivery is realized. Today, not only diversity and complexity of the goods are increased but also the customer requirements are also much more than what they were in the past decades. In order stay competitive, companies have to work with minimum stocks and realize the shortest delivery time from order taking to shipment. Hence, if usage of warehouses (without value added operations) is inevitable for a company, they have to be managed in a most efficient way to fulfill customer requirements without any schedule delays and with the minimum costs. New methods and tools like automation, layout studies, rack systems and WMS have been put into action for improvements.

WMSs which are similar to current ones have been introduced at the end of 1980's and they are for used executing and managing daily warehouse processes in many modern warehouse concepts. WMS can be described as a part of the supply chain system which is applied for increasing visibility, managing typical daily warehouse processes, resources and inventory in a most efficient and error free way. Typical warehouse processes can include put away/storage, picking, shipping, receiving and inventory adjustment. WMS capabilities can also be increased by integration to existing ERP, TMS systems or hardware like RFID, barcode or AGVs.

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The possible benefits from a WMS implementation can be explained as below:

1. Efficient space utilization
2. Increased labor productivity
3. Efficient vehicle/equipment utilization (Forklifts, pallet jack etc.)
4. Increased inventory accuracy
5. Reduced paperwork
6. Better customer service
7. Reporting (Order Monitoring, operator performance, stock information etc.)

Deciding on WMS implementation stand alone is a complex task which requires a detailed cost-benefit analysis. If a WMS implementation accepted then one of the next tasks will be deciding on the right software. Some companies may choose to write their own tailored software for their business requirements but for the others there are many vendors to get the software. Some of these companies are even among the well-known supply chain software suppliers as shown on figure 1.

This study was done to realize which main factors are taken into consideration when deciding on implementation of a WMS. In first step the main criteria are on WMS selection is listed. In the second step the criteria was reviewed by different academicians and specialists from the industry who are experienced in supply chain management and logistics. The criteria were updated based on these reviews. A comparison matrix was prepared for comparing each factor with others with a value scale between 1 and 6 (Figure 1). This matrix was send to responsible who will be taking part in deciding possible WMS software in their current company.

Top 20* supply chain management software suppliers							
No.	Supplier	2011 Revenue	URL	SCP	WMS	MES/MRP	TMS
1	SAP	\$1.018 billion	www.sap.com	x	x	x	x
2	Oracle	\$935.6 million	www.oracle.com	x	x	x	x
3	JDA Software	\$368.5 million	www.jda.com	x			x
4	Manhattan Associates	\$141.5 million	www.manh.com	x	x		x
5	RedPrairie	\$99.7 million	www.redprairie.com		x	x	x
6	Epicor	\$92.9 million	www.epicor.com	x	x		x
7	Descartes Systems Group	\$87.7 million	www.descartes.com				x
8	Servigistics	\$64 million	www.servigistics.com	x	x		x
9	Kewill Systems	\$63.7 million	www.kewill.com				x
10	IBS	\$58 million	www.ibsus.com	x	x	x	x
11	Totvs	\$57.8 million	www.totvs.com	x	x		x
12	Logility	\$52.3 million	www.logility.com	x	x		x
13	Lawson Software	\$51 million	www.lawson.com	x	x	x	x
14	Retalix	\$50.9 million	www.retalix.com	x	x		x
15	IBM	\$50.8 million	www.ibm.com	x			
16	Infor	\$50.5 million	www.infor.com	x	x	x	x
17	GTNexus	\$46.2 million	www.gtnexus.com	x			x
18	HighJump Software	\$45.8 million	www.highjumpsoftware.com		x		x
19	Quintiq	\$39.5 million	www.quintiq.com	x		x	x
20	Accellos	\$35 million	www.accellos.com		x		x
21	Kinaxis	\$34.6 million	www.kinaxis.com	x		x	

* Source: Revenue estimates provided by Gartner (www.gartner.com) with the exception of Retalix, which was provided by the company.

Figure 1. Top 20 Supply Chain Management Software



Literature Survey

Inventory control by different parties supply chain implies a significant financial investment to the enterprises. The main reason for inventory control is to foreseen and customer orders. It is known that the inventory may be lost over time. Many enterprises incorporate a safety inventory for work-in-progress. Gattorna and Walters [1] suggested that the inventory requires sophisticated methods of planning and control. Although many software are on the market for particular applications such as ERP and APS systems, they suffer from function restriction and are expensive to implement [4]. Kovacs and Paganelli [2] described that ERP systems mainly provide support for administration and operation of a conventional customer-supplier relationship. These systems are inadequate to cope with the advanced planning of modern manufacturing. Stadler [3] also showed that the transaction-based ERP systems is not in the area of planning.

Software selection is not a technical operation, a subjective and uncertain decision process selecting a suitable warehouse management system, depends on the assessment of objective, measurable criteria. Software selection decisions cover the simultaneous multiple criteria, including tangible and intangible factors; prioritizing these factors can be challenging. When evaluating and selecting data warehouse software, Kimball, Reeves, Ross, and Thornthwaite [5] suggested that the evaluation should encompass both business and technical requirements. The literature reviewed was limited to software selection applications used by different methodologies and frameworks.

Le Blanc and Jelassi [6] developed a multi-criteria decision methodology for decision support system (DSS) selection. Stylianou, Madey, and Smith [7] presented a socio-technical framework and the taxonomy of expert system shells evaluation criteria. Boloix and Robillard [8] proposed a comprehensive framework for software system evaluation. Hluic and Paul [9] presented a methodology for manufacturing simulation software selection. Beck and Lin [10] researched Automated office system decisions criteria. Seidmann and Arbel [11] presented Office Automation software and used AHP. Zahedi [12] researched Database Management System. Stylianou et al. [13] used Socio-technical framework to show expert system shells properties. Min [14] presented AHP methodology for Logistics Software selection. Sarkis ve Talluri [15] developed goal programming model and AHP model for Supply Chain Software and e-commerce communication systems. Wei et al. [16] presented ERP system criteria. Vlahavas, Stamelos, Refanidis, and Tsoukia's [17] developed an expert system based on various aspects of the multi-criteria decision aid approach for software evaluation. Kim and Moon [18] researched Workflow Management System. Ngai and Chan [19] developed a multi-criteria decision methodology for Knowledge management tool.

To quantify subjective and vague preferences of decision makers over multiple criteria with linguistic assessments, we calculate the prior weights of decision criteria with a fuzzy analytic hierarchy process (AHP) method. Analytic hierarchy process (AHP) first introduced by Saaty [20] has been a popular approach for supplier evaluation and selection, though it was extended with fuzzy theory to suitably address the ambiguities involved in the linguistic assessment of the data. Kar [21] applied group decision support theory with fuzzy AHP to the supplier selection problem, and extended AHP based on Dempster-Shafer theory to handle uncertainties due to the inability of human's subjective judgment.

Warehouse Processes and Warehouse Management Systems Capabilities

Typical warehouse processes and how they can be supported or managed by a WMS system are listed below:

1. Receiving: The goods receipt process is the movement of the products from the production area or from an external source like supplier. The warehouse inventory records and inventory tracking also start with goods receipt process. An EDI (Electronic Data Interchange) capable WMS system will lead to efficient resource planning like calculating required racks/area, manpower, forklifts etc. on the



- arrival time. WMS can also be used on receiving process monitoring by defining deliveries as open deliveries, already processed deliveries and so on.
2. Put away: Material movement from warehouse receivable point to the stock area can be defined as put away. WH staff can be informed through WMS to the pre-defined storage locations on goods receipt. The box/bin management can also be done by WMS.
 3. Quality Inspection: Inspection of the received goods can be mandatory in some companies. Here, WMS can support the business by allowing the WH staff to monitor which parts are being inspected, the inspection process time and inspection intervals, lot sizes required for each part number.
 4. Picking: Picking process can be defined as movement of the material from stock location as a part of the order fulfillment. Business strategies like FIFO, LIFO, partial quantity picking can be supported by WMS. Picking list can also be prepared through WMS.
 5. Shipment: Shipment process can be defined as movement of the goods to an external source which can be customer or another company location. Shipping process may include packing, goods issue and transportation. Delivery notes, freight documents can also be prepared to WMS. An EDI compatible WMS can also be used in sending ASNs to the customers as the goods leave the warehouse. Open and completed deliveries, wave picking/wave planning operations can also be managed through WMS.
 6. Cross Docking: Cross docking can be defined as delivering products from production to the loading dock and delivering them to the customer. Cross docking can be planned by WMS.
 7. Return Process: The stock receipt and stock management can be managed through WMS in case of return deliveries from the customer.
 8. Inventory Management: Inventory errors may lead to unplanned high costs to the company. WMS can contribute to inventory efficiency by supporting counting procedures like cycle counts and continuous counting. These procedures reduce the need of annual stock counts.

In addition to the mentioned points above WMS can be used in Kanban management, line feeding support, resource planning, reporting and RFID (Radio-frequency identification) device support to support business processes. The mentioned functionalities will be expending with the new technological improvements and changes in business requirements.

Research

We have developed AHP decision making procedure for the selection of a data warehouse system. The approach comprises a nine-step procedure as shown in Fig. 2. The details of the selection procedure are presented in the next section.

Group a committee of decision makers

The first step is to add a project decision makers, experts and senior representatives of user departments. The participation and support of top managers notably influences the success of WMS [22]. We connected academic personnel and experts/specialists from the well-known industrial companies.

Define warehouse management system project characteristics

Different enterprises or organizations may adopt a data warehouse system for completely different reasons. The size of company, internal needs and competitive pressure would also influence the adoption of WMS systems [22] The initial faith or aim for adopting a WMS system affects problem definition, identifying and structuring objectives, measuring the performance of objectives, and other subsequent decision-making activities. The decision makers need to analyze the WMS system selection problem by identifying decision factors such as stakeholders project aims, evaluation criteria, number of alternatives, and other concerns in order to provide the decision making process effectively.

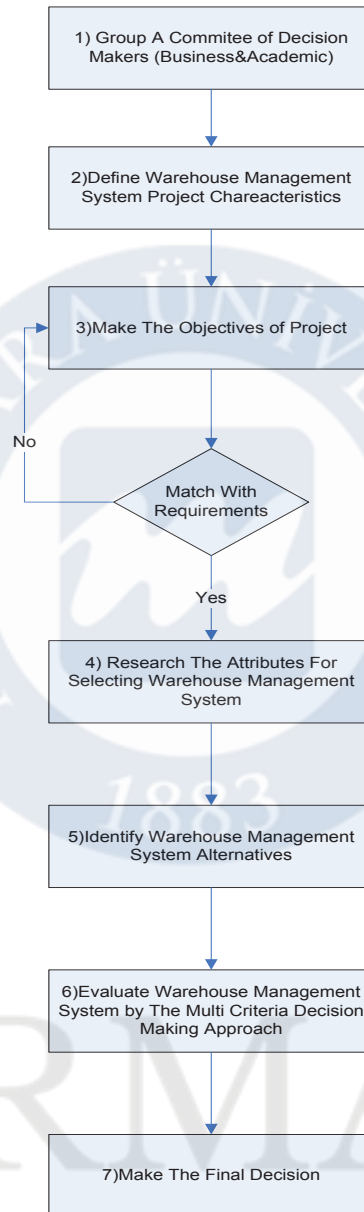


Figure 2. Research flow chart

Determining the Objectives of The Project

The main goal of defining and structuring objectives is to ensure insight for better decisions. The initial list of objectives for a decision problem includes both fundamental objectives and means objectives [23]. Designing the objectives involves organizing them so that the decision makers can describe in detail what an organization wants to achieve, and then incorporate these objectives into the decision model appropriately. For a given decision situation, the overall objective is the same for both the fundamental and means objectives structure. It characterizes the reason for interest and defines the breadth of concern. All relating objectives on different levels of a structure will be derived from the overall objective systematically.

It is important to separate between fundamental objectives and means objectives in the objectives structuring process. Fundamental objectives are those that are important simply because they reflect what the decision



makers are really want to accomplish. However, means objectives are those that help achieve other objectives [24]. Fundamental goals can be organized into hierarchies while means objectives can be organized into networks [24]. The upper levels in a hierarchy describe more general objectives, and the lower level objectives explain what is meant by the higher level objectives. A key difference between fundamental objectives hierarchy and means objectives network is that means objectives can be connected to several fundamental objectives, indicating that they help to accomplish these objectives. To separate means objectives from fundamental objectives and to establish their relationships, a guiding question “Why is that important?” can be used to complete these tasks for each identified objective, ask, “Why is that important?” Two types of answers seem possible. If the answer is that the objective is one of the essential causes for interest in the situation, such an objective is a fundamental objective. If the answer is that the objective is important only because of its implications for some other objective, it is a means objective. [24] provided four techniques to organize fundamental and means objectives further.

Research the attributes for selecting warehouse management system

The decision makers can derive the attributes or criteria to evaluate WMS systems from the created objectives structure. The attributes should involve both quantitative and qualitative measures that satisfy the aims of project and requirements of an organization. Then, these attributes were verified with external professional experts to ensure all attributes were well formulated and properly understood. The final selected attributes will be used to evaluate the WMS systems of the decision model. The decision makers selected two group criteria about WMS; namely software selection criteria and vendor selection criteria.

Software Selection Criteria

- a. Compatibility with existing ERP system
- b. Compatibility with existing Hardware (Barcode, RFID etc.)
- c. Inbound/outbound data transfer capability (EDI etc.)
- d. User friendly interface
- e. Database support
- f. Investment Costs/Indirect Costs
- g. Customization capabilities
- h. Reporting tools
- i. Lead Time Implementation
- j. Upgrade possibilities / Future Support
- k. Labor Productivity
- l. Routing Optimization
- m. Equipment Utilization
- n. Area Deployment Optimization
- o. Compatibility with possible new technologies (like wearable technologies)
- p. System stability
- q. Kanban, milk-run, line feeding support

Vendor Selection Criteria

- a. Vendor reputation
- b. Technical and training support
- c. Service Quality
- d. Number of companies running the Software
- e. Experience in WMS field
- f. Gartner Group Rating

The first decided above mentioned criteria was then reviewed and it is decided to reduce the points as a very long list might have resulted in complexities for the decision makers. Therefore some of the above criteria



were excluded from the list with the common agreement of the academicals and experts who took part in this study. The final criteria can be seen on the next section.

Evaluate the Warehouse Management Systems by Analytic Hierarchy Process

Analytic hierarchy process (AHP) is a multi criteria rank method developed by Saaty [25]. The AHP is a method based on the hierarchical analysis of a certain problem in elements of hierarchy that are structured in levels. The AHP method provides that problem is hierarchically decomposed and partially solved, and then those partial solutions are again combined in order to obtain a solution to the initial problem. According to the AHP method, elements of a problem under analysis are circulated in a hierarchical structure from the objective on top of a hierarchical structure, through criteria and sub-criteria on their respective levels, to alternatives on the lowest level. Final result of a problem analysis weight values in relation to the set objective. AHP help decision-makers to structure a complex problem in the form of a simple hierarchy and assess big number of quantitative and qualitative factors in a systematic manner. The application process of the AHP methods is based on the concept proposed by Vinod Kumar and Ganesh [26]:

- A hierarchical decomposition of the problem to be solved with the aim at the highest level, the criteria and sub-criteria at lower levels, and the alternatives at the lowest level.
- Comparison of pairs of elements in each level of the hierarchy in relation to the elements of the higher level, through application of the Saaty scale from 1 to 9. The decision-maker determines the value a_{ij} , of the elements i and j , where its $a_{ij}=1/a_{ji}$, $i, j=1, \dots, n$ and $a_{ii}=1$, $i = j$.
- Setting priorities for each element in relation to a higher authority – w_{ij} is a priority of the alternative i in relation to the criteria j , where it is $i=1, \dots, m$, $j=1, \dots, n$, m is the number of alternatives, and n is the number of criteria.
- Synthesis for all values of priorities so as to obtain the priority of each element in relation to the objective.

W_i is the alternative priority i and it is determined as:

where, c_j is the criteria priority j , and w_{ij} is the alternative priority i in relation to criteria j .

$$W_i = \sum_{j=1}^n c_j w_{ij}$$

Saaty's method is used at each level of hierarchical structure. Using the Saaty's method is assigned to each part of the quantitative characteristics reflecting their importance. The part with the highest priority is obtained by synthesis of these evaluations[27]. The decision maker focuses on them to obtain a solution of the decision problem. When solving the decision-making problem, it includes more experts. It has between the objective and criteria and the level of evaluators (experts), theirs evaluations (weights) indicate the degree of their soundness[28].

For the determination weights of criteria, Saaty's method has been chosen. This method takes into account the different preferences between the criteria and a wide point scale is determined for evaluation (Formula 1). It is therefore possible to detect even slight differences in preferences between the criteria, which are into account then in the process of setting the weights:

$$(S_{ij}) = \begin{cases} 1-i \text{ and } j \text{ are equivalent;} \\ 3-i \text{ is mildly preferred to } j; \\ 5-i \text{ is strongly preferred to } j; \\ 7-i \text{ is very strongly preferred to } j; \\ 9-i \text{ is absolutely preferred to } j \end{cases}$$

Values 2, 4, 6, 8 are intended to evaluate intermediate stages. This method compares each pair of criteria i and j . Their evaluation is written to the Saaty's matrix (Formula 2) according to the following rules:



$$S = \begin{pmatrix} 1 & s_{12} & \dots & s_{1k} \\ 1/s_{12} & 1 & \dots & s_{2k} \\ \dots & \dots & \dots & \dots \\ 1/s_{1k} & 1/s_{2k} & \dots & 1 \end{pmatrix}.$$

This method involves 5 steps (Saaty 1980), which includes calculation of the weights using normalized geometric average of lines in Saaty matrix:

1. First, Saaty's matrix was filled so that the diagonal values are equal to one ($s_{ij} = 1$). If the "ith" criterion is preferred to "jth" criterion, then the suitable value of Saaty's point scale has to be selected. If the "jth" criterion is preferred to "ith" criterion, inverse values has to be written: $s_{ij} = 1/s_{ji}$
2. For every i, the value

$$s_i = \prod_{j=1}^k s_{ij}$$

was calculated

3. For every i, the value

$$R_i = \sqrt[k]{s_i}$$

was calculated

4. In the next step, the value

$$\sum_{i=1}^k R_i$$

was calculated

5. In the last step of the method is determined weights of criteria according to the following formula:

$$v_i = \frac{R_i}{\sum_{i=1}^k R_i}.$$

Table 1. Software selection AHP Calculations

Category	Priority	Rank
Compatibility with existing ERP system	23,30%	1
User friendly interface	14,00%	2
Inbound/outbound data transfer capability (EDI etc.)	13,20%	3
System stability	10,60%	4
Investment Costs/Indirect Costs	9,90%	5
Compatibility with existing Hardware (Barcode, RFID, AGVs etc.)	9,10%	6
Lead Time Implementation	7,50%	7
Upgrade possibilities / Future Support	7,30%	8
Area Deployment Optimization	5,10%	9



	1	2	3	4	5	6	7	8	9
1	1	3.00	2.00	3.00	4.00	3.00	3.00	2.00	1.00
2	0.33	1	0.50	1.00	2.00	1.00	1.00	2.00	0.50
3	0.50	2.00	1	1.00	2.00	2.00	2.00	2.00	1.00
4	0.33	1.00	1.00	1	2.00	2.00	2.00	4.00	2.00
5	0.25	0.50	0.50	0.50	1	2.00	2.00	2.00	2.00
6	0.33	1.00	0.50	0.50	0.50	1	1.00	2.00	1.00
7	0.33	1.00	0.50	0.50	0.50	1.00	1	2.00	1.00
8	0.50	0.50	0.50	0.25	0.50	0.50	0.50	1	0.50
9	1.00	2.00	1.00	0.50	0.50	1.00	1.00	2.00	1

Figure 3. Decision Matrix of Software Selection

As it can be seen on the fig xx, "compatibility with existing ERP system" has far the highest priority in the software selection AHP calculations (Table 1). This is not very surprising as it was also expected in the beginning of this study. This criteria is followed by "user friendly interface" and "inbound/outbound data transfer capability", the priority difference between these two criteria is relatively small. Most surprising finding in this calculation is "investment costs/indirect costs" criteria are not within the top three rankings.

Table 2. Vendor Selection AHP Calculation

Category	Priority	Rank
Technical and training support	24,30%	1
Experience in WMS field	24%	2
Service Quality	22,80%	3
Number of companies running the Software	10,70%	4
Vendor reputation	9,20%	5
Gartner Group Rating	9%	6

	1	2	3	4	5	6
1	1	0.33	0.50	1.00	0.33	1.00
2	3.00	1	1.00	3.00	1.00	2.00
3	2.00	1.00	1	3.00	1.00	2.00
4	1.00	0.33	0.33	1	0.50	2.00
5	3.00	1.00	1.00	2.00	1	3.00
6	1.00	0.50	0.50	0.50	0.33	1

Figure 4. Decision Matrix of Vendor Selection

The results of the AHP calculation(table 2) on vendor selection criteria showed close results in top three rankings; "Technical and Training Support" (1st) , "Experience in WMS field" (2nd), "Service



Quality" (3rd). Gartner which is one of the world's leading information technology research and advisory company. Its rating is the lowest, which was not expected (figure 4).

Conclusion

This study was aimed at choosing the most important criteria on WMS selection. Although it was planned to apply only one AHP calculation, it is decided to make two different AHP calculations as there were many indispensable criteria which were classified in two main groups, namely "software selection" and "vendor selection". As mentioned in the introduction part, the evaluation criteria were decided by a group of academicals and experts from different industrial areas. These criteria were then evaluated by these academicals and experts individually, with these evaluations the AHP results calculated with below Consistency ratios: AHP Calculation on Vendor Selection: 2,0%, AHP Calculation on Software Selection: 5,3%

Normally it is not usual to apply two AHP calculations in such studies but we found it necessary to analyze the criteria in two main classification fields as "software selection" and "vendor selection". The most important criteria on software selection based on AHP calculation is "compatibility with existing ERP system". It is obvious that every company wants a seamless integration of a possible WMS system with the existing systems and applications. Therefore the candidate WMS system should be in capable of fitting to existing ERP system or being able to modified to fit to the existing ERP system. The second important ranked criteria is user friendly interface. In most of the companies the warehouse staff is generally not too qualified, so the WMS should be easy to learn and operate. The daily routine tasks should be easily completed through WMS menus, transactions and screens. Inbound and outbound data transfer capability is also very important as the data transfer in electronic form is the most fast and accurate way of the information flow. Either WMS or existing ERP system should be capable of inbound/outbound data transfer to help the company to keep competitive in the global environment.

The most important criteria on vendor selection based on AHP calculation is "technical/training support." Technical support is vital on integrating the new system to existing one(s), system modification and fulfilling possible future requirements due to system changes, internal/external customer requirements and future business adaptations. A good training is a must in order to use a system in an error free and efficient way. Experience in WMS field is the second important criteria. Experience in WMS field will carry the lessons learned from successful and not successful implementations.

Recommendation

The WMS supplier company can also bring the best practice in operations, processes, layouts etc. through the experience being worked with several companies. Service quality is ranked as third. The system breakdowns, error can result in operation stops and that lead to big costs due to stopping deliveries and not fulfilling customer demands on time. In addition to loss in terms of money, such problems may affect losing business partners in long term. So a fast and efficient service is a must, therefore online and remote connection possibilities for a fast solution can also be considered.

This study can be used after cost benefit study on deciding to use a WMS system is completed. In the next step the possible vendors and software can be evaluated based on importance criteria given on AHP calculations. This study can be regarded as a basic guide to compare the possible solutions, offers. Such studies will be useful on helping to decide the right system as number of vendors and number of WMS types in the market increase.



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