A 'Lean' Fuzzy Rule to Speed-Up a Taylor-Made Warehouse Management Process

Lapo Chirici, Kesheng Wang

A 'lean' Fuzzy Rule to Speed-up a Taylor-made Warehouse Management Process

Lapo Chirici[1] and Kesheng Wang[2]

[1]Department of Business Informatics – University of Pisa (Italy)
lapochirici@gmail.com

[2]Department of Production and Quality Engineering – Norwegian University of Science and Technology (Norway)
kesheng.wang@ntnu.no

Abstract. The minimization of the inventory storage cost and - as a consequence - optimize the storage capacity based on the Stock Keeping Unit (SKU) features is a challenging problem in operations management. In order to accomplish this objective, experienced managers make usually effective decisions based on the common sense and practical reasoning models. An approach based on fuzzy logic can be considered as a good alternative to the classical inventory control models. The purpose of this paper is to present a methodology which assigns incoming products to storage locations in storage departments/zones in order to reduce material handling cost and improve space utilization. The iterative Process Mining algorithm based on the concept of Fuzzy Logic systems set and association rules is proposed, which extracts interesting patterns in terms of fuzzy rules, from the centralized process datasets stored as quantitative values.

Keywords: Logistics, Warehouse management, Putaway process, Fuzzy rules, Data Mining

1 INTRODUCTION

In this era of such drastic and extemporaneous changes, manufacturers with global view pay strong efforts in striving to achieve a lean production, outsource their components, and manage the complexity of supply chain [2].

Warehouse management plays a vital role to be a central actor in any kinds of industry which put-away process is a key activity that brings significant influence and challenges to warehouse performance.

In this dynamic operating environment, reducing the operation mistakes and providing accurate real time inventory information to stakeholder become the basic requirements to be an order qualifier. Here, an OLAP based intelligent system called Fuzzy Storage Assignment System (FSAS) is proposed to easy manipulate the decision support data and rationalize the production in terms of storage location assignment problem (SLAP).

adfa, p. 1, 2011.

In condition of information's uncertainty, fuzzy logic systems can provide methodologies for carrying out approximate reasoning processes when available. Identifying an approach that can bring out the peculiarities of the key operations of warehouse is focal to track the priorities for the storage in terms of Stock Keeping Units (SKUs) [3]. Hence the need to develop a Put-away Decision Tree in order to automates the analysis of possible hidden rules useful to discover the most appropriate storage location assignment decisions. Some examples of SKU features are their dimensions, weights, loading values and popularity. All these are important in order to find out the relationship between the SKU properties and the relative assigned storage location. The aim of the paper is to create an algorithm that would be able to provide the best allocation position for SKUs in a just-in-time manner and with a lean and intelligent stock rotation. This approach provides strategic decisions to optimize the functionality and minimize the costs in a full automated warehouse.

2 THE "PUTAWAY'S DILEMMA"

2.1 Manage the SLAP

Warehouse storage decisions influence the main key performance indicators of a warehouse, such as order picking time and cost, productivity, shipping (and inventory) accuracy and storage density (Frazelle, 2002). The customers are looking always to obtain more comprehensive services and shorter response time. The storage location assignment problem (SLAP) results essential to assign incoming products to storage locations in well-defined departments/zones in order to reduce material handling cost and improve space utilization (Gu et al. 2007).

Handling the storage location process is an activity that requires the supervision of several relevant factors. Up to now, some warehouse management systems (WMS) have been developed to acquire "simple data" by the warehouse operators and let recorded to computer support in intelligent slotting (storage location selection) in such way to ensure a constant quality of information available [1].

Besides that, both the lack of relevant data and WMS low customization capability for supporting the put-away process, highlight a common problem the warehouse manager has to deal with. Thus, the put-away decisions are often based on human knowledge, sprinkled unavoidably by a high gradient of inaccuracy (and consequently long order time), which can bring to a negative impacts on customer satisfaction [9].

2.2 Previous theories on SLAP

Warehouse is used to store inventories during all phases of the logistics process (James et al., 2001). The five key operations in warehouse are receiving, put-away, storage, order picking as well as utilizing and shipping (Frazelle, 2002). Hausman in 1976 suggested that warehouse storage planning involves decisions on storage policy and specific location assignment. In general, there are a wide variety of storage policies such as random storage, zoning, shortest/closest driveway, open location, etc

(Michael et al., 2006). As each of the storage strategy with its own characteristics, there are different ways to solve the storage location assignment problem (SLAP). Brynzer and Johansson (1996) treated SLAP improving a strategy for pre-aggregate components and information for the picking work in storehouses. And this latter leveraging on the product's structure/shape in order to reduce order picking times. Pan and Wu (2009) developed an analytical model for the pick-and-pass system [5], [6]. His theory was founded on three algorithms that optimally allocated items in the storage, analyzing apriori the cases of a single picking zone, a picking line with unequal-sized zones, and a picking line with equal-sized zones in a pick-and-pass system. A nonlinear integer programming model built on a branch-and-bound algorithm was developed to enlighten class-based storage implementation decisions, considering the storage space, handling costs and area reduction (Muppani and Adil, 2008).

2.3 Introducing Fuzzy Logic

Fuzzy logic has already proven its worth to be used as tool to deal with real life problems that are full of ambiguity, imprecision and vagueness [3]. Fuzzy logic is a derivative from classical Boolean logic and implements soft linguistic variables on a continuous range of truth values to be defined between conventional binary. It can often be considered a suspect of conventional set theory. Since fuzzy logic handles approximate information in a systematic way, it is ideal for controlling non-linear systems and for modeling complex systems where an inexact model exists or systems where ambiguity or vagueness is common. A typical fuzzy system consists of a rule base, membership functions and an inference procedure. Fuzzy logic is a super set of conventional Boolean logic that has been extended to handle the concept of partial truth-truth-values between "completely true" and "completely false". In classical set theory, a subset U of asset S can be defined as a mapping from the elements of S to the elements the subset [0, 1], U: S -> {0, 1} [8].

The mapping may be represented as a set of ordered pairs, with exactly one ordered pair present for each element of S. The first element of the ordered pair is an element of the set S, and the second element is an element of the set (0, l). Value zero is used to represent non-membership, and the value one is used to represent complete membership. The truth or falsity of the statement. The 'X is in U' is determined by finding the ordered pair whose first element is X. The statement is true if the second element of the ordered pair is 1, and the statement is false if it is 0.

3 FROM FUZZIFICATION TO SLAM

3.1 Online Analytical Process

In order to collect and provide quality data for business intelligence analysis, the use of decision support system (DSS) becomes crucial to assist managers within problem solving critical area (Dunham, 2002). Online analytical process (OLAP) is a decision support system (DSS) tool which allows accessing and parsing data in a flexible and timely basis. Moreover, OLAP enables analysts to explore, create and manage enterprise data in multidimensional ways (Peterson, 2000). The decision maker, therefore, is able to measure the business data in different deeper levels and aggregate them depending on his specific needs. According to Dayal and Chaudhuri (1997), the typical operations performed by OLAP software can be divided into four aspects: (i) roll up, (ii) drill down, (iii) slice and dice and (iv) pivot. With the use of OLAP, the data can be viewed and processed in a real time and efficient way. Artificial Intelligence (AI) is one of the techniques that support comprehensive knowledge representations and practical manipulation strategy (Robert, 1990). By the use of AI, the system is able to learn from the past experiences and handle uncertain and imprecise environment (Pham et al., 1996). According to Chen and Pham (2006), fuzzy logic controller system comprises three main processes: fuzzification, rule base reasoning and defuzzification. Petrovic et al. (2006) argued that fuzzy logic is capable to manage decision making problems with the aim of optimizing more than one objective. This latter proved that fuzzy logic could be adopted to meet the multi-put-away objective operation in the warehouse industry. Lau et al. (2008) proposed a stochastic search technique called fuzzy logic guided genetic algorithms (FLGA) to assign items to suitable locations such that the required sum of the total travelling time of the workers to complete all orders is minimized. With the advantages of OLAP and AI techniques in supporting decision making, an intelligent put-away system - namely Fuzzy Storage Assignment System (FSAS) - for the novel real world warehouse operation is proposed to enhance the performance of WMS system. Two key elements would be embraced: (1) Online Analytical Processing (OLAP) in the Data Capture and Analysis Module (DCAM); (2), a fuzzy logic system in the Storage Location Assignment Module (SLAM), with objective to achieve the optimal put-away decision minimizing the order cycle time, material handling cost and damage of items.

3.1.1 Fuzzy Storage Assignment System.

The Fuzzy Storage Assignment System (FSAS) is designed to capture the distributed item's data (warehouse status included) from different organizations along the supply chain. The crucial passage concerns the conversion of data into information to hone the correct put-away decision for SLAP [10]. The tangible influence on the warehouse performance is immediately recognizable. In fact, it also allows warehouse worker to visualize a report regarding the status of SKUs in real time, both in arriving both already stocked in the warehouse. The architecture of the FSAS is illustrated in Figure 1. Generally, FSAS consists of two modules: (1) Data capture and analysis Module (DCAM) and (2) Storage location assignment module (SLAM). These are used to achieve the research objectives through a fully automated recommendation storage system.

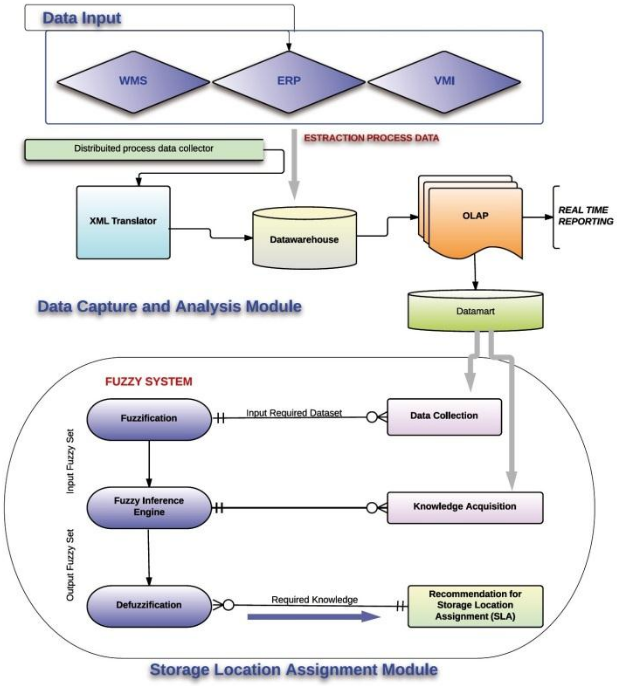


Fig. 1. - Fuzzy Storage Assignment System Algorithm

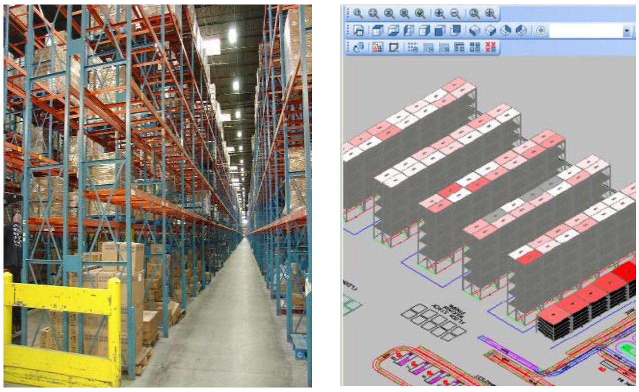
4 LEVERAGE THE MODEL

4.1 Data capture and analysis Module (DCAM)

Three major components of Data capture and analysis Module (DCAM) are central data warehouse, OLAP and data mart. The first one is used for connecting various systems with different data sources, including the WMS, ERP and VMI, which are independent systems but may hold valuable data of the storage SKUs to a central data warehouse in order to fulfill SLAP. It ensures the availability of required data for further analysis. DCAM plays the role of decision support system that offers warehouse engineer or manager relevant specific information, including the item's activities information, demand correlation and warehouse information.

The second component, OLAP, provides calculation and multi-dimension structure of data. Warehouse management bases on these information in SKUs and the warehouse to make strategic decision formulating the Fuzzy rules for SLAP. Through holistic manipulation of quality information, the warehouse engineers are able to develop a set of specific rules or algorithms to fit their unique daily operations, warehouse configuration and their operational objective. DCAM offers the refined parameter of SKUs and warehouse that act as the input of the next module-SLAM for generating the automatic recommendation for SLAP.

The last but not least component, the data mart, is developed to store the refined parameter and fuzzy rules (as a fuzzy rule repository), directly and specifically support the SLAP.



(a) (b)

(a): Portion of a six-tiers warehouse
(b): Software to design customized warehouse in 3D

4.2 Storage Location Assignment Module (SLAM)

The storage location assignment module is used to decide the correct storage location for arrival SKUs, based on the analyzed information and the fuzzy rules set from DCAM. Its major component is the fuzzy logic system that consists of a fuzzy set, a fuzzy rule and fuzzy inference.

The fuzzy rules is a set of rules that integrate the elements of the selected storage strategies, experience and knowledge of expert, and regulations. It is characterized by an IF (condition) THEN (action) structure.

The set of rules determines each item storage location; the system will match the characteristics of the SKU and current warehouse (conditions) with the fuzzy rule and then find out the action (where it should be shored). Finally the automatic put-away solution is generated. The SLAM start from the data mart in the former DCAM, it provides the parameters that are format compatible to the fuzzy system, than the parameters will be the input into the fuzzy system that is specifically developed to support the SLAP. The output of fuzzy system will be explained as the recommendation of final storage location for the inbound cargo, than the warehouse workers will store the inbound cargo as the recommendation, finally the storage information will be updated to the WMS system.

4.2.1 The "Golden zone" partition.

There are golden zone (the most accessible), silver zone (middle accessible) and bronze zone (the least accessible). Therefore there are 3 subzones inside each of storage zone, A, B and C in the sequence of the accessibility in which zone A with the highest accessibility.

5 THE REAL CASE

5.1 Problem identification

Generally, the Espresso Siena & Co. is characterized by a handle large amount of requests in warehouse operation. Efficient storage location assignment may result in minimizing the cost as well as the damage rate in order to increase the customer satisfaction. However, the current practice of SLAP in deciding storage department, location and the suitable tier relies on the warehouse manager is based on his knowledge. Problems may be raised as the wrong storage environment offers the storage item (resulting in deterioration of item quality) and the long storage location process (resulted in longer inbound shipment processing cycle). This is caused by the insufficient data availability and the lack of systematic decision support system in the decision process. According to the past experience, cargo storing in high tier of a pallet rack or the item with higher loading weigh have more probabilities of getting damage or higher loading height, because of the difficulty to control the pallet truck well. The more expensive cargo, the higher loss the warehouse suffers from the damage.

To ensure the accurate and real-time data can be used, the proposed FSAS for integrating data, extracting quality data from different data source and assigning appropriate storage location for the inbound items, in the way to minimize the risk of getting damage and the loss from it during the put-away and storage process.

5.1.1 Deployment of Online Analytical Process in DCAM.

SKU data and warehouse data are captured and transferred into the centralized data warehouse from the data source systems. Through the OLAP application it's possible to build up a multidimensional data model called a star schema. This is composed of a central fact table and a set of surrounding dimension tables and each table has its own attributes in variety of data type. The users are able to view the data in different levels of detail, so the warehouse engineer can generate real-time report for decision-making. In fact the OLAP function allows finding out the statistics of SKUs activities for a specific period of time, representing the SKUs dimension, storage environment and information of warehouse etc [11]. This gives the possibility to master the critical decision support data by the warehouse operator. To ensure the OLAP approach functions properly, the OLAP data cube needs to be built in advanced in the OLAP sever. The cube is developed in a star schema (Figure 2) consisting of dimensions, measures and calculated members.

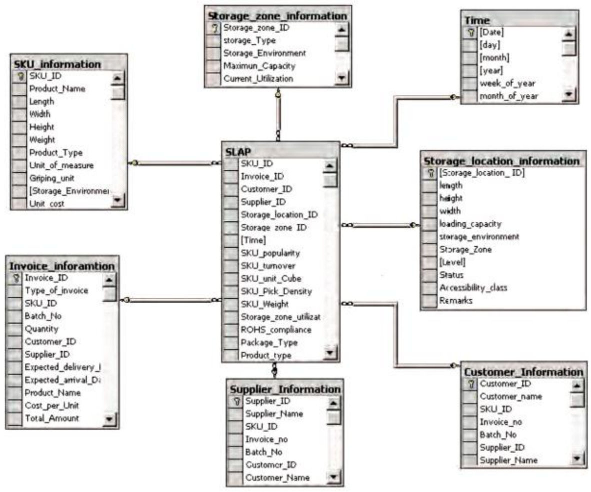


Fig. 2. The relational database structure of DCAM

5.1.2 Relevant properties considered.

Dimensions.

In SKU dimension, the “SKU_ID”, and “Product Type” fields are used to find out the dimensions of the SKU and the other characteristics for the storage department selection. In the “Invoice” dimension, the “Invoice ID”, and “SKU_ID” and “Invoice _Type” fields are used to find the activity patterns of SKU’s for deciding the location inside the department for the SKU.

In “Time” dimension, the “Delivery Date” and “Arrival Date” field are used to find the expected storage time for the SKU and the number of transaction during the specific period.

Measures.

“Loading Item Height”, “Loading Item Width”, “Unit Cost” and “Unit_Cube” etc. are all used to provide critical information for the warehouse manager, in order to realize fuzzy rule composition and perform as a fuzzy input for implication process.

Calculated Member.

The calculated member calculates the mean of “Popularity”, “Turnover”, “Cube_Movement” and “Pick_density” etc., needed for fuzzy rule composition and implication process.

5.2 Deployment of fuzzy system in SLAM

The fuzzy rules and membership function of the company have to be first formulated in the fuzzy system for each parameter. The parameters (Table 1) and the fuzzy rules of others rule sets are specifically set by the warehouse manager, in order to truly reflect the operational conditions of such product families. The formulation is worked out by the knowledge of experts with the revision on the past experience on the warehouse daily operation; the historical revision could be achieved by the help of the OLAP report, in the former module-DCAM. Different sets of fuzzy rule, with particular parameters, make the decision to determine the storage zone/department, storage location and tier level for the item storage. The fuzzy rules are stored in the knowledge database and defined as a conditional statement in IF-THEN form [10], [12].

Some examples of fuzzy rules are shown in Table 2. The warehouse manager ranged from 0-1 determines the membership function of each parameter. There is more than one type of membership functions existing, some with Gaussian distribution function, others with sigmoid curve, or quadratic and cubic polynomial curves. For this case study, since it's possible to demonstrate the manager's knowledge through the trapezoid and triangular membership functions, the graphic formats of the membership functions of the example parameters are demonstrated as the Figure 3.

The MATLAB-Fuzzy Logic Toolbox needs to create and execute fuzzy inference systems. With the above fuzzy rules and required data, the final storage location for the incoming item would be automatically generated from the Fuzzy Toolbox for SLAP.

In order to demonstrate the feasibility of the system, one supplier delivery input is selected into the FSAS system. When the market-operating department fulfill the relevant data into the ERP, these will be extracted by central data warehouse and then go to the OLAP module. At the same time, the warehouse department is informed and starts to go through their slotting decision tree.

SYMBOL	PARAMETER	RANGE
C	Cube Movement (m3/Month)	0 – 1830
D	Expected Storage Days (Days)	1 / 365
IH	Loading Item Height (m)	0.3 / 3
IW	Loading Item Width (m)	0.2 / 2.5
IL	Loading Item Length (m)	0.5 / 6
IWt	Loading Item Weight (kg)	20 / 5000
IVol	Loading Item Volume (m3)	0.03 – 26
IV	Loading Item Value (€)	750 / 12000
PWt	Pallet Department Loading Item Weight (kg)	75 / 1000
PH	Pallet Department Loading Item Height (m)	0.5 / 2.5
Pρ	Pick Density (Request/ m3)	0 / 60
P	Popularity of Storage (Times/Month)	0 / 60
T	Turnover Rate (Units/Month)	0 / 450
SC	Storage Department Capability (m3)	0 / 46
SA	Storage Location Accessibility (m)	20 – 140
ST	Storage Tier	1 – 6

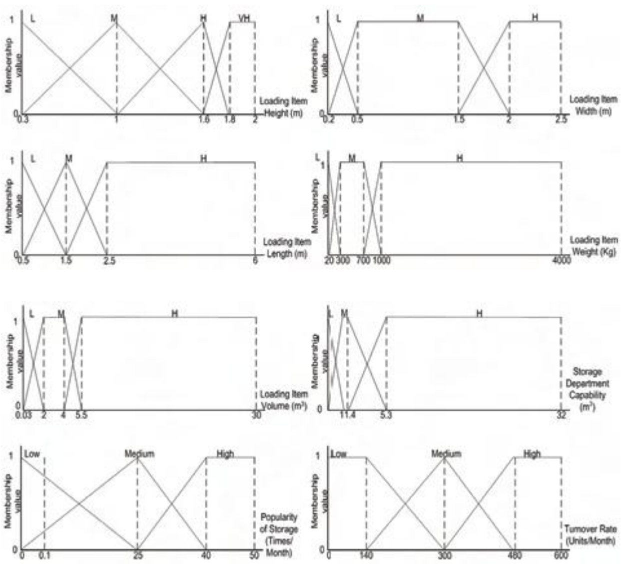
Table 1. The parameters taken into account to optimize the put-away decision process

RULE 1:		
IF	Loading Item Height ➔ Low	AND
	Loading Item Width ➔ Short	AND
	Loading Item Length ➔ Short	AND
	Loading ItemWeight ➔ Small	AND
	Loading Item Cube ➔ Small	
THEN	**Capability of Storage Depart-ment is LOW**	

RULE 2:		
IF	Popularity ➔ High	AND
	Turnover Rate ➔ High	AND
	Cube Movement ➔ Hight	AND
	Pick Density ➔ not Hight	AND
	Expected Storage Days ➔ Short	
THEN	**Accessibility of Storage Zone is Good**	

RULE 3:		
IF	Loading Item Value ➔High	AND
	Loading Item Height ➔ High	AND
	Loading Item Weight ➔ High	
THEN	**Tier Selection is Medium**	

Table 2. Fuzzy Association Decision Rule



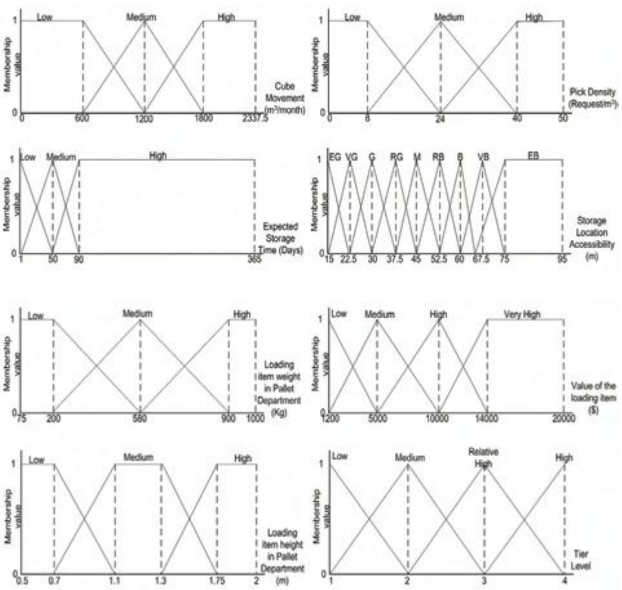


Fig. 3. The MATLAB graphic function model

6 CONCLUSIONS

This research tries to introduce the design and the implementation of a FSAS, which embraces the fuzzy theory to achieve warehouse capacity improvement and optimize the put-away process. The implementation of the proposed methodology, in the aspect of warehouse management through simulation, has been succeeded. Incorporating the error measurement and the complexity of the process into the fitness evaluation, the generalized fuzzy rule sets can be less complex and more accurate. In the matter of generation of new fuzzy rules, the membership functions are assumed to be static and known. Other fuzzy learning methods should be considered to dynamically adjust the various parameters of the membership functions, to enhance the model accuracy. Future contribution of this endeavor goes to validate the decision model in a way to be launched in case companies. Despite increasingly manufacturers and retailers emphasize the just-in-time inventory strategy, the delivery orders will become more frequent with smaller lot size. This creates considerable demand for put-away processes in warehouses, since put-away process is able to match the characteristics of the storage item and the storage location. In order to achieve this standard, the warehouse operators first need to master the characteristics of the incoming items and storage location and then correctly match the storage location, minimizing the material handling cost, product damage and order cycle.

An OLAP based intelligent Fuzzy Storage Assignment System (FSAS) becomes suitable to integrate day-by-day operational knowledge from human's mind, supporting a key operation in warehouse-put-away process, minimizing product damage and material handling cost. FSAS enables the warehouse operators to perform put-way decision: (i) real-time decision support data with different query dimensions (ii) mimicking the warehouse manager to provide recommendation for SLAP. Further research on enhancing the fuzzy rules generation is considered to improve the accuracy in the suitable storage location assignment. As the database has been well developed for the put away process in the DCAM, this is eligible to provide overview on the past performance of the warehouse.

7 REFERENCES

1. Chede, B., Jain, C.K., Jain, S.K., Chede, A. (2012). Fuzzy Logic Analysis Based on Inventory Considering Demand and Stock Quantity on Hand. Department of Mechanical Engineering, Mahakal Institute of Technology and Management (Ujjain).
2. Blecker, T. and Huang, G. Q., (2008). RFID in Operation and Supply Chain Management – Research and Application, Erich Schmidt Verlag Gmbh & Co. (Berlin).
3. Chirici, Lapo; Wang, Yi; Wang, Kesheng, (2012). A Tailor Made RFID-fuzzy Based Model to Optimize the Warehouse Managment. I: Proceedings of IWAMA 2012 - The Second International Workshop of Advanced Manufacturing and Automation. Tapir Akademisk Forlag 2012 ISBN 9788232101108. pp. 491-498
4. Castro, L. and Wamba, S. F., (2007). An inside look at RFID Technology, Journal of Technology Management & Innovation - Jotmi Research Group (Santiago Chile). Vol. 2, No.1, pp. 128-141.
5. Convery, T., (2004). RFID Technology for Supply Chain Optimization: Inventory Management Applications and Privacy Issues, Northwest Pump & Equipment Co. University of Oregon (USA).
6. Ho, G. T. S., Choy, K. L. and Poon, T. C., (2010). Providing decision support functionality in warehouse management using the RFID-based fuzzy association rule mining approach, Hong Kong Polytechnic University.
7. Wang, K. and Zhang, Z., (2012). Application of Radio Frequency Identification (RFID) to Manufacturing, SINTEF Report, Norway.
8. Zadeh, L. A. (1965). Fuzzy sets, Information and Control, Vol. 8 No.3, pp. 338–353.
9. Zou, C. and Jiang, C., (2006). The Applications of RFID Technology in Logistics Management and Constraints, Northwestern Polytechnical University (China) and Trans Tech Publications (Switzerland).
10. Lam, C.H.Y., Chung, S.H., Lee, C.K.M., Ho, G.T.S. and Yip, T.K.T. (2009). Development of an OLAP Based Fuzzy Logic System for Supporting Put Away Decision, International Journal of Engineering Business Management, Vol. 1, No. 2, pp. 7-12.
11. Laurent, A., Lesot, MJ., (2009) Scalable Fuzzy Algorithms for Data Management and Analysis: Methods and Design. IGI Publishing.
12. Li, D., Laurent, A. and Poncelet, P., (2009) Mining Belief-Driven Unexpected Sequential Patterns and Implication Rules in Rare Association Rule Mining and Knowledge Discovery: Technologies for Infrequent and Critical Event Detection. IGI Publishing.