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Modelling warehouse layouts based on Fuzzy Situational Maps

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Abstract: The main target of this research is to introduce a new way of thinking in a special field of logistic processes. This process is the inbounding process in a simple general type warehouse. The methodology chosen is the use of multicomponent fuzzy descriptors: signatures and situational maps, as they properly reflect the uncertain and sometimes non-deterministic nature of the conditions and constraints in this problem class. Our intention is to reach an optimal, or at least as close as possible to optimal warehouse layout for any given case.

Keywords: warehouse layout, fuzzy situational maps, warehouse inbounding process

1. Introduction

The main objective of this manuscript is to introduce a new way of thinking in a special field of logistic processes. A new approach will be shown for the design of warehouse layouts using the tools of fuzzy logic. This new approach will be able to support the decision making in relation to transportation of goods within a warehouse.

2. Fuzzy signatures

From the beginning of the 1950s, researches of AI mainly used deductive Boolean algebraic formulas. The limits of the Boole algebra's two valued mathematics had been soon realized by many scientists, therefore alternative structures were proposed, among others by Lukasiewicz, Bochwar, Kleene, etc. [1]). The real breakthrough happened in 1965, when Zadeh introduced the concept of fuzzy sets [2]. From a practical point of view, this approach opened the door to algorithms and approaches achieving a significant reduction of inference time.

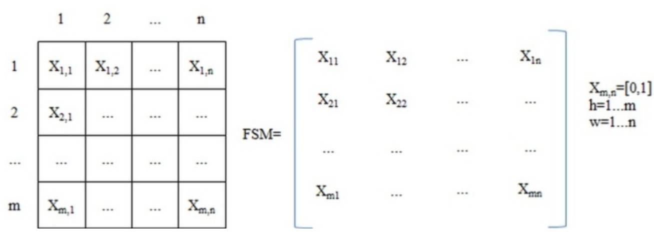
It must be mentioned that the original definition of fuzzy sets (A: X →[0,1]) was extended soon to L-fuzzy sets by Goguen [3] (A_L: X→L, where L is an arbitrary algebraic lattice). A special case of this is when L is simply a vector of fuzzy membership degrees and thus the set obtained this way may be called vector valued fuzzy set, which concept was introduced in [4], ($A_{v,k}$: $X \to [0,1]^k$, where the range of membership was a lattice of k dimensional vectors within the unit cube). An even further generalisation of the latter concept was the definition of fuzzy signatures, introduced in [5]. Some further advanced versions of the concept and description of complex data were later proposed in [6], [7], [8]. Here, every vector component can be a nested vector itself in a recursive way (1).

$$As: X \to [a_i]_{i=1}^{k}, a_i = \begin{cases} [0,1] \\ [a_{ij}]_{j=1}^{ki} \end{cases}, a_{ij} = \begin{cases} [0,1] \\ [a_{ijl}]_{l=1}^{kij} \end{cases} \quad (1)$$

Fuzzy signatures may be considered as special multidimensional fuzzy data. Some of the dimensions are inter-related in the sense that they from sub-groups of variables, which jointly determine some feature on higher level [9].

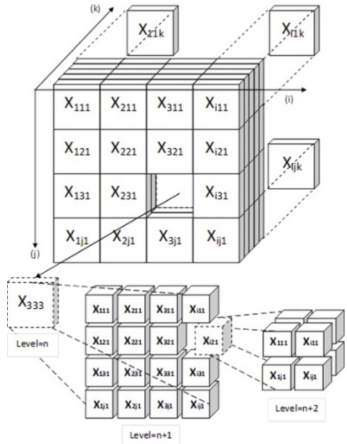
3. Fuzzy Situational Maps

The definition of FSM was introduced in [10]. In general, FSM may have an arbitrary multidimensional structure, in the next example however, for better understanding an only two dimensional case is presented (Fig. 1).



1. Figure: Two dimensional FSM represented in matrix or lattice

The two-dimensional FSM considered as a geometric lattice, where each node has a fuzzy value or a whole fuzzy set in extended case. The FSM can be represented as a lattice or in matrix as Fig. 1 shows. The values in the individual nodes can be interpreted as an element of a Fuzzy Signature, so the Fuzzy Situational Maps can be described as multidimensional structured Fuzzy Signatures. The multi-dimensional structure can be seen on Fig. 2.



2. Figure: Multi-dimensional FSM structure

Following this interpretation, it can be said that each node in an FSM can be itself a further nested FSM and, iteratively continued, down to depth n (for example, in case of a more complex warehouse hierarchy) can be lead a fine structured FSM in each node. The depths of nodes are independent from each other. This depth extension operation of FSM is a step to one level lower in the hierarchy, such as a zoom-in.

At the bottom level only fuzzy values or sets are in the nodes, this is the depth of the leaf level of the fuzzy signatures. The structure is fully expanded if each node is on the lowest level.

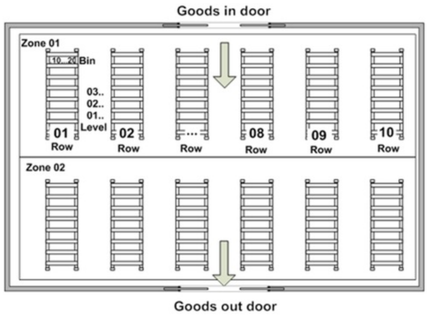
Starting from this base structure, the values of the next level parent structure are calculated by some fuzzy aggregation operation (n=max(n), n=min(n) or n=avg(n)), meanwhile the depth of the lattice is decreased by one in the actual node.

Follow from the definition of Fuzzy Situational Maps that the finer sub-structures determine the higher level parent node values, so each sub-structure has its own and independent aggregation operator. Of course the result of the reduction is highly influenced by the applied aggregation operator, so the choice and specification of the operator flag is a key role in the conclusion.

It is worth mentioning that fuzzy signatures and consequently also fuzzy situational maps may be embedded in „if-then” type rule based control and reasoning systems, whose original concept was proposed also by Zadeh in his key paper in 1973 [11]. This model was transformed to a lower computational complexity version soon by Mamdani [12]. The application of such a Mamdani-type fuzzy control system might be of interest and this Mamdani approach will be used later in the further study of the subjects discussed here.

4. Modelling warehouses layouts

The topic of this research focuses on a certain warehouse operation (inbounding) explaining also the reasons why optimised operation is rather important. The main question is how to be cost effective, how to eliminate every unnecessary or non-optimal operation and process, which represent unnecessary cost factors.



3. Figure: General sample of warehouse structure

4.1. Aspects of qualitative warehouse layout parameters

The method chosen is the use of fuzzy descriptors, namely signatures and situational maps, as they properly reflect the uncertain and sometimes non-deterministic nature of the conditions and constraints in this problem class. The intention is to reach an optimal, or at least as close as possible to optimal, warehouse layout for any given case. Thus, it is necessary that the properties of warehouses and stored goods are described in as general a manner as possible. The expected result will be an optimal warehouse layout that will certainly depend on the actual properties of the given warehouse, and on the type and properties of the goods that are to be stored in that warehouse

A general warehouse (and warehouse topology) has various physical properties. It is possible to split these properties into static and dynamic parts. It is also possible to determine priorities and strategies which should be taken into account during the inbounding process.

The warehouse contains several storage zones. Each storage zone contains several warehouse locations (racks or bulk storage places). The locations of these racks are known. Each rack has physical parameters such as length, depth, maximal load weight, etc. (See Fig. 3.)

4.2. A simplified quantitative model

In the model of a storage system the basic element is a “location”. Multiple locations make up racks, a multitude of racks makes up storage zones. A warehouse may have a number of storage zones. The physical set up of locations, racks and zones in a given warehouse is fixed and known.

Suppose that two basic crisp type decisions about a location are defined as the possible outcomes, based on a fuzzy rule base. They are the decisions “suitable” and “not suitable” for storing certain goods at certain location. These may be however true to a fuzzy membership degree, and these degrees can be described by fuzzy rules. In this approach the basic elements (the locations) can be represented in a somewhat flexible manner, thus by fuzzy sets and they can be arranged into fuzzy signatures.

In the above manner, the fullness of a warehouse may be characterized at the highest level. Going deeper down in the hierarchy, the „suitability” or „un suitability” of each of its part helps to decide how to proceed with the further locations. As soon as the desired location has been reached the fuzzy degree of matching of locations is changed (recalculated). The changes of values in the hierarchy have to be taken into consideration starting from the bottom up to highest level in accordance with the aggregation operation associated with the hierarchy. As a matter of course it is not necessary to recalculate the whole FSM structure, only the affected sub-signature of FSM.

5. Software implementation of the model

A simplified software environment is prepared which simulates an inventory management system. Of course it is not a standalone solution, only a suitable software environment to simulate the outlined model. The software demonstrates an inbounding process focusing on the proposal given for the destination of the receipt. The logic of the calculation of the proposed destination is based on the Fuzzy Situational Map model, combined with Mamdani typed inference systems

The aim of the software was to give a simulation of warehouse layout and to demonstrate inbound procedures with proposing target locations using fuzzy elements. The result of the simulation should be an optimised warehouse layout. The engine of FSS software implements the logic of FSM described in chapter 3.

It was very interesting to demonstrate a mathematical model in real life even if it is only a test environment. The first step in the implementation was to rebuild a real location controlled warehouse. Therefore, item master data, stock figures and the layout were collected form a real company’s ERP system.

At first the implemented fuzzy model focuses on the logistic process of inbounding. It is mandatory to build up an FSM structure as it was described in the logical model. The values of the FSM structure are dependent on both static and dynamic parameters of the warehouse current layout and on the item’s parameters.

The software calculates an advice (an optimal location based on the given parameters). As the complete FSM is recalculated after every inbound the advice will be always the optimal solution.

6. Optimisation and extending the model

It is our further intention to optimise the warehouse layout and the inbounding process by some heuristics. We arrange the population based on algorithms, such as evolutionary approaches might deliver optimal or quasi optimal results within attractable time.

As a matter of course this simplified model is not eventually realistic, but can be the starting point of a general and extended model. Of course a real implementation of a fuzzy aided warehouse module can be time and money consuming, but after a certain size of storage area or automatized warehouse processes, can be a recoverable solution

7. Summary

The target of this study was to show a simplified model using the tools of fuzzy on a special application. This part is a warehouse process (inbounding), which is not a common field of AI or CI. Of course this document is not detailed enough, but can be a starting point of new way of warehouse support module in the world wide used ERP systems such as SAP, Oracle or ERP Ln systems

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