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Dynamic Control Card in a Production System Controlled by Conwip Approach

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Abstract

In this paper, the focus is on the dynamic control card in a conwip system. An approach to set the number of cards in order to adapt to the change of the production systems both in terms of external change as the demand and internal change as the work time of the machine, failures and so on. A Multi Agent Architecture is proposed to implement a flexible and extensible approach that can be implemented in a supply chain and not only in a single manufacturing system. Then, a set of rules is proposed to change the number of cards in the system. A dynamic simulation environment has been developed to test the control approach under different dynamic states. The performance measures evaluated are the average utilization of the manufacturing system, the throughput time, throughput, work in process and average available cards. The proposed approach is compared with a kanban control.

Keywords: Conwip; kanban; Multi Agent Systems; Dynamic Environment; Simulation.

1. Introduction

The pull production control approach leads to reduce inventory and hence the associated cost of inventory reduction, where the manufacturing scenarios allow applying this control approach. The implementation of a pull production control systems can be achieved by kanban or conwip.

In kanban systems [1], a production authorization cards, called Kanban, are used to control and limit the releases of parts into each production stage. Conwip system [2] uses a single card type to control the total amount of Work In Process (WIP) permitted in the entire production system. When a job order arrives to a CONWIP system, a card is attached to the job, provided cards are available at the beginning of the production system. Otherwise, the job must wait in a backlog. When a job is processed at the final station, the card is removed and sent back to the beginning of the production system, where it might be attached to the next job waiting in the backlog. In these control approaches, the number of cards involves significantly the performance of the production systems. In case of kanban systems, it has to design the number of cards for each production stage and there are *n-variables*; in case of conwip systems only one parameter has been designed: the number of cards of the entire production systems.

The design of the number of cards in pull systems can be obtained by two approaches [3]:

- Card setting; it sets the number of cards given a manufacturing condition in order to obtain an adequate level of performance. In this case the number of card is fixed and can be re-designed when the manufacturing conditions change significantly.
- Card control; it identifies a set of rules that change or maintain the number of cards in the production systems. Then, the number of cards is variable in order to optimize the performance of the production system.

In this paper, the focus is the formulation of a set of rules to card control in a conwip system where the manufacturing conditions are changing dynamically. The approach is tested by developing a dynamic simulation environment and it is compared with a kanban system. In section 2 is discussed the literature on card controlling approaches. In section 3 is explained the proposed approach and in section 4 the simulation environment developed has been illustrated. In section 5 the simulation results are discussed. Finally, the conclusions and future development are showed in section 6.

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2. Literature Review

There are few researches in developing approaches of dynamic card controlling and for specific purposes. Gupta and Alturki [4] developed an approach in a kanban system with two types of cards. The variables to set are: the initial number of kanban, the instant to re-planning the number of cards and an acceptable probability of backlog. The objective is to reduce the backordered demand and the WIP by the knowledge of the demand on the next period.

Hoop and Roof [5] proposed a procedure that dynamically increase or decrease the number of cards by a statistical throughput control in a make to order environment. Then, a throughput rate level is set and the throughput of the system is monitored; if the throughput is over or under the limits, then cards are added or subtracted to the system.

Takahashi and Nakamura [6] explained an approach for make to stock environments. In the proposed approach by the simulation it is analyzed the average waiting time of the customers for different demand rates and for different number of cards. Then, it is defined a target value for the average customers waiting time and if a change of the demand rate is detected, the number of cards is changed by the results of the simulation runs.

Christelle et al. [7] analyzed a CONWIP system which consists of three stations in series. They proposed an analytical method to evaluate performance of conwip systems with inspection for the two following cases: satured systems and system with external demands.

Yang [8] investigated the performance of Single-kanban, Dual-kanban, and Conwip for the production of different parts on a single flow line.

Tardif and Maaseidvaag [9] proposed an approach in a make to stock environments controlled by a conwip system. The objective of the approach is the trade off between the inventory level of finished goods and the backordered demand. The procedure is the following: if the inventory level is under a defined lower control limit an extra card is added, if the inventory level is over a defined upper control limit the card is subtracted. In this approach, a maxim number of extra card is available.

Framinan et al. [10] described an approach on card controlling in a conwip system. The objective of the procedure is to obtain a given throughput rate for make to order environments. It is fixed a time interval of monitoring the throughput rate level; if the throughput is over a defined upper control limit the card is subtracted. In this approach, a maxim number of extra card is available.

Kumar and Panneeerselvam [11] discussed the literature concerning the kanban system. The authors point out the importance of the dynamic set of the minimum number of kanbans.

From the analysis of the literature the following issue can be drawn:

- In some approaches proposed, the number of parameters to set is numerous; then a proper procedure to set these parameters to adapt at changing of the manufacturing environments is needed.
- Many approaches assume that some data are known, like demand, or can be estimated by simulation.
- Some approaches proposed concerning make to order environments, while other are developed for make to stock environments.

The proposed approach is based on a set of rules in order to increment or decrease the number of cards available in manufacturing system. The approach concerns both make to order and make to stock environment and it works on few parameters to set; no data about demand or lead time are known in this approach. A proper simulation environment has been developed to test the proposed approach in a conwip system and the variability of the performance changing the parameters to set. Moreover, the performance is estimated in a very dynamic environment in order to study the adaptability of the proposed approach.

Finally, the proposed approach is developed by a Multi Agent System paradigm in order to obtain a distributed control system.

3. The proposed approach

The proposed approach concerns the decision to increase or decrease the number of cards by observing the manufacturing conditions. The changing of the manufacturing conditions can be classified in:

- external; in this case, the changing is caused by external events such as the demand (volume or distributions).
- internal; in this case the changing is caused by elements of the production system, such as the manufacturing times, failures of the resources, and so on.

The objective of the approach is to adapt the number of the cards to the manufacturing conditions in order to obtain an opportune level of performance in terms of: throughput, lead time, WIP and utilization of the production system.

The control approach is based on monitoring the average utilization of the manufacturing resources and the average utilization of the cards. From the point of view of the cards utilization:

- a low utilization of the cards can be caused by high number of cards or the reduction of the demand;
- low number of cards or increase of demand lead to a high utilization of the cards.

From the point of view of the average manufacturing resources utilization:

- a low system utilization can be caused by the decrease of the demand or a low number of cards that limits the number of parts in the production systems;
- a high system utilization can be caused by the increase of the demand or a high number of cards that leads to increment the number of parts in the production system.

In order to obtain a decision control approach by limited computational time four rules has been proposed as showed in table 1.

Table 1. Card number control rules

Rule no.	
1	if average system utilization is high and average cards utilization is high then increment number of cards
2	if average system utilization is high and average cards utilization is low then reduce number of cards
3	if average system utilization is low and average cards utilization is high then increment number of cards
4	if average system utilization is low and average cards utilization is low then reduce number of cards

The rules in Table 1 are computed in a periodic review approach; the disadvantage is the introducing of a new parameter to set like the interval between the reviews.

A Multi Agent Systems (MAS) paradigm [12, 13] can be adopted to implement the control approach. In particular, two agents have been proposed: a control agent and manufacturing agent.

The development of a distributed architecture leads to obtain the following advantage:

- distributed and open, lacking central control and standardized communication;
- heterogeneous: compatibility and interfacing problems;
- rapid change: new subsystems appear, existing ones disappear
- rapid growth: huge amount of unstructured information;

The Manufacturing agent provides the information about the manufacturing conditions to the control agent in order to implement the policy control.

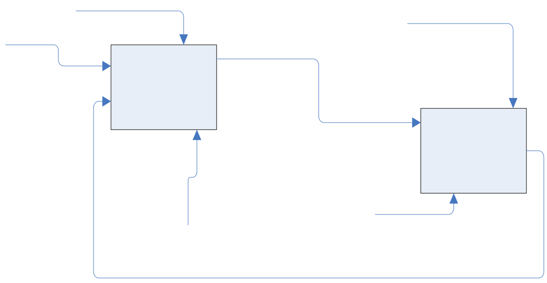

Figure 1. IDEF0 Diagram.

Figure 1 shows the basic representation of the agent's interaction during the control process. As the reader can notice in the IDEF0 diagram of Figure 1, it is possible to locate two independent processes: the control process that is performed by the control agent and the manufacturing system process, which is performed by the manufacturing agent. The control process is triggered by the periodic review time and it is constrained by the Strategy constraints of the control approach. The output of this process is the request of information about the manufacturing systems. In order to process such outputs the control process uses a proper control strategy.

The manufacturing system process is triggered by the control agent request information and it is constrained by objectives of the manufacturing system. The manufacturing system process elaborates the information about the manufacturing conditions to submit to the control process. Such process is undertaken by using proper manufacturing system information.

The control agent implements the above rule on the manufacturing conditions information provided by the manufacturing agent and decides about the number of cards. The processes showed in Figure 1 are a general framework that can be specialized to particular enterprise architecture.

Figure 2 shows the activity diagram of the control approach proposed in this paper, in particular the following action can be located:

- The Manufacturing System Agent sets initial cards number like the number of the kanban control approach and waits for the periodic review date;
- After the review time, the Manufacturing System Agent collects the performance about the average utilization of the manufacturing system and the cards and sends it to the Control Agent;
- The Control Agent applies the four rules (see table 1) and sends to the Manufacturing System Agent whether the number of cards has to be increased, decreased or nothing action is to be performed.
- The manufacturing System Agent applies the policy of the Control Agent and waits for the subsequent period of review.

The initial number of cards is the same as in the kanban approach. As benchmark is developed a kanban control system with fixed number of cards computed by the following expression:

$$n \geq \frac{DL(1+\alpha)}{Cap} \quad (1)$$

where,
n is the number of kanban;
D is the average demand;
L is the lead time;
Cap is the capacity of the containers.

4. Simulation Environment

In order to test the proposed control approach the Arena® discrete event simulation platform by Rockwell Software, Inc. is selected for building up the simulation model.

Discrete event simulation

- in many commercial tools and simulation packages, nowadays the simulation model is automatically created from high level modeling languages and notations
- allows to validate and optimize dynamic and discrete systems such as production systems. These models facilitate evaluating different scenarios and maximizing their potential output and benefits. Arena®
- based on the known SIMAN simulation language - is well suited for modeling shop floors of production systems in which each entity (part) follows a manufacturing route through production resources (servers, material handling systems, buffers, and so forth) [14]. The production system simulated consists

of three manufacturing cells, in order to test the control policy, the manufacturing times are equal for each manufacturing cell and in particular 5 unit of time. The production system manufactures a single type of product that visits the three manufacturing cells. The initial number of cards is the same of the kanban policy control in the same conditions (equation 1). The length of the simulation is 1500 unit of unit time. Table 2 reports the simulation experiments conducted (scenarios).

Table 2. Simulation Experiments.

Scenario	Interarrival	Manufacturing times
1	Constant – negexpo(0.1)	constant – equal for each manufacturing cell: 5 unit time
2	Constant – negexpo (0.2)	constant – equal for each manufacturing cell: 5 unit time
3	Impulsive interarrival: negexpo(0.1) for 500 unit time negoexpo(0.3) for 500 unit time negexpo(0.1) for 500 unit time	constant – equal for each manufacturing cell: 5 unit time
4	Impulsive interarrival negexpo(0.1) for 650 unit time negexpo(0.5) for 200 unit time negexpo(0.1) for 650 unit time	constant – equal for each manufacturing cell: 5 unit time
5	constant – negexpo (0.2)	constant – equal for each manufacturing cell: 5 unit time cell 2: 10 unit time for a 500 unit time
6	constant – negexpo (0.2)	constant – equal for each manufacturing cell: 5 unit time cell 2: 15 unit time for a 500 unit time

The scenarios concern the inter-arrival of the parts:

- constant during the simulation experiment with two levels of congestion of the manufacturing system (scenarios 1 and 2);
- constant with impulse that simulate an exception of the customer demand (scenarios 3 and 4);

From the point of view of the manufacturing system:

- working time constant end equal for each manufacturing cell (scenarios from 1 to 4);
- working time constant end equal for each manufacturing cell and for a single manufacturing cell, a temporal variation of the working time (scenarios 5 and 6).

The performance measures computed for each simulation scenario are: throughput, manufacturing lead time, utilization of the manufacturing resources, WIP, number of cards and the utilization of the cards.

Furthermore, because of the random input and in order to guarantee a statistical validity of the results, for each run, the number of executed replications guarantees, for the output performance measures, that the length of confidence intervals (95% level) of the mean among replications is lower than 10 % of the mean itself.

Several scenarios have been considered to test the control policy as showed in table 2.

The simulations have been conducted for a kanban system used as a benchmark and in a manufacturing system with the proposed dynamic control card.

5. Simulation Results

The results of the simulation are showed in table 3. Table 3 shows the percentage difference of the proposed approach compared with the fixed number of cards (benchmark – kanban).

The results of scenarios 1 and 2 with constant demand lead to the following issues:

- the average utilization of the manufacturing systems decrease when the demand is increased;
- the throughput time is reduced when the congestion of the manufacturing system is low;
- the throughput is affected by low variation;
- The dynamic control leads to better performance about the work in process and reduce the number of available cards when the congestion is high.

The dynamic conwip approach proposed adapts the number of cards to the dynamic conditions of the manufacturing system obtaining better performance than kanban approach. The improvements are better when the congestion level is low.

The results of scenarios 3 and 4 with impulsive variation of the demand lead to the following issues:

- the average utilization of the manufacturing systems and the throughput are affected by low variation;
- a low reduction of the throughput time;
- the average available cards increasing, while the work in process decrease; the cards is available only in the periods when is necessary to increment it.

These results show how the performance of the proposed approach improve when external exceptions as demand changes occur.

The results of scenarios 5 and 6 with one working time different form the others machines in a limited period:

- the significantly variations are both the reduction of working in process and the available cards.

When the working times are very different among the manufacturing cells, the improvements of the proposed approach is reduced.

In summary, the main benefits of the proposed approach, compared with a kanban system are: the reduction of the Work In Progress and the reduction of the lead time. The benefits are evaluated in the last column of table 3 that reports the average value of the performance over the all scenarios.

Finally, several simulations are conducted compared the time of the periodic review. The results reported in figure 3 are match up with the periodic review of 500 unit times.

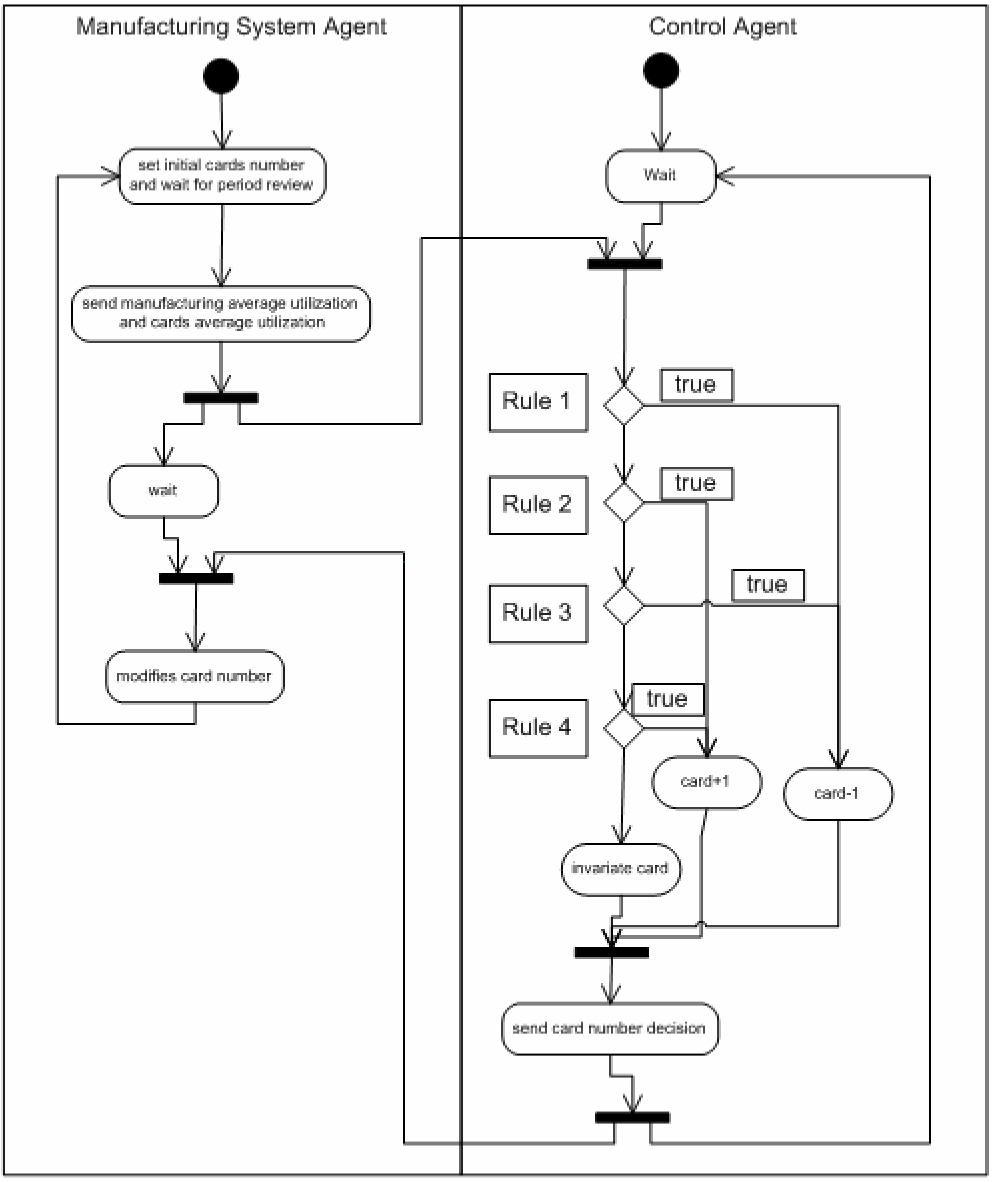

Figure 2. UML activity diagram.

Table 3. Simulation Results.

	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5	Scen. 6	Average
Average system utilization	-0.37%	-2.78%	-0.46 %	-0.33%	-0.88%	-0.95%	-0.96%
Throughput time	-33%	3.75%	-7.90%	-6.13%	-1.83%	-1.50%	-7.77%
Throughput	0%	-1.64%	0.41%	0.33%	-0.10%	-0.11%	-0.19%
Wip	-3%	-37.38%	-23.73%	-19.44%	-11.79%	-10.74%	-17.68%
Available card	29.67%	-37.33%	10%	14.33%	-30.50%	-30.33%	-7.36%

The values reported in the graphs of figure 3 are the following:

- 1 -> 400 unit times;
- 2 -> 300 unit times;
- 3 -> 200 unit times;
- 4 - > 100 unit times;
- 5 - > 50 unit times;
- 6 - > 15 unit times.

As the reader can notice, the approach is robust against the different values of periodic review. In particular, only for very low period (about 15 unit times) the performance is more variable because the control approach is instable and it leads to modify the number of cards more times.

6. Conclusions and Future Development

In this paper an approach to dynamic control the number of cards in a conwip system has been developed. A Multi Agent System is proposed to implement a set of rules to control the number of card. The MAS leads to develop a distributed approach that can be integrate in a wide manufacturing system with different control systems. Moreover, the MAS architecture can be integrated in the upper level of production planning and control of the enterprise. The proposed approach is compared with a kanban system and a dynamic simulation environment has been developed for validation. The simulation results show that the proposed approach leads to reduce significantly the WIP in a dynamic environment both for the demand and for working time. The others performance are more close between the proposed approach and kanban system. Another issue is that the approach proposed is robust to the interval time of periodic review; the dynamic control approach is unstable when the periodic review time is comparable to working time of the manufacturing resources.

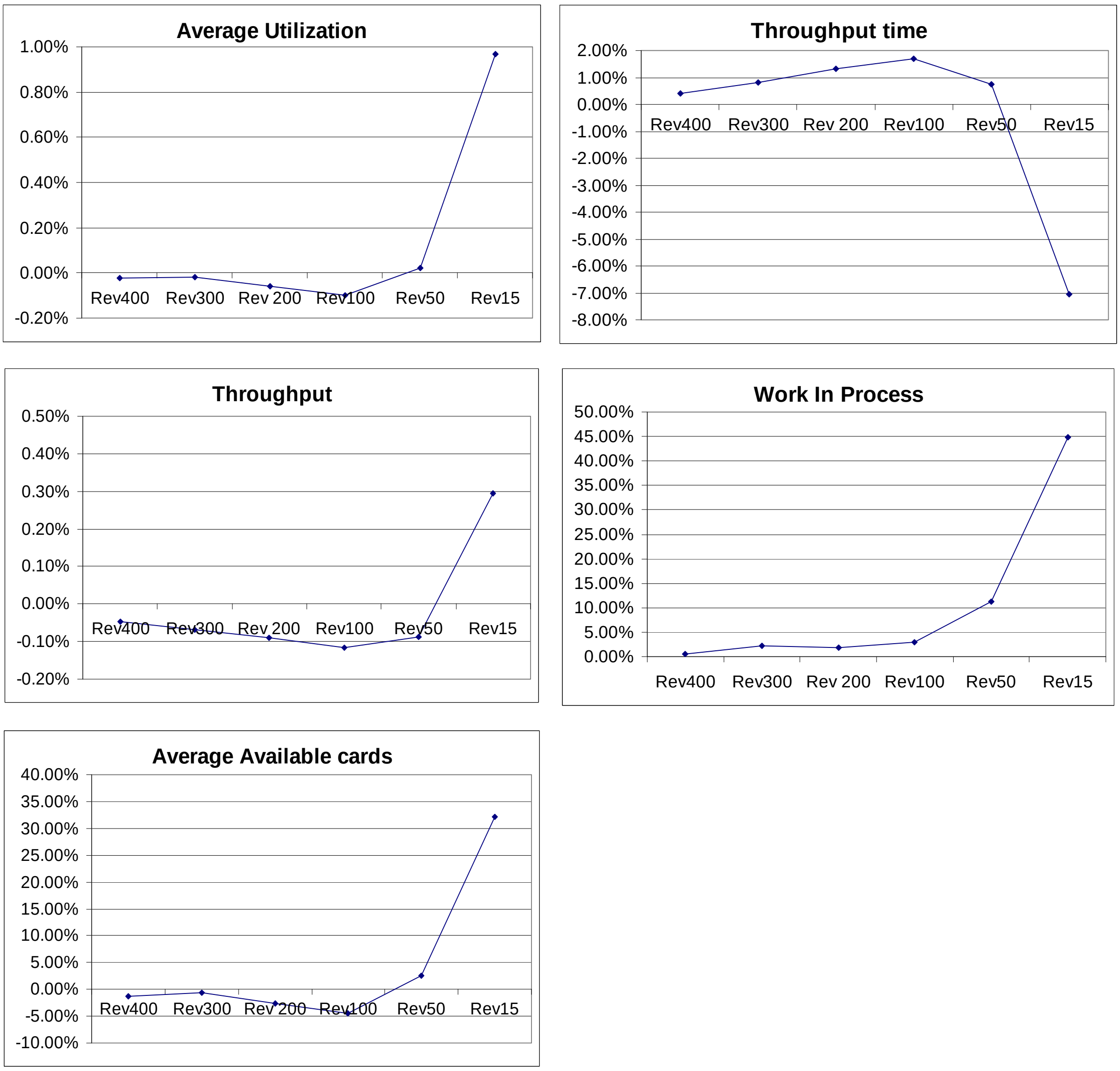

Figure 3. Simulation performance comparison average scenarios.

The main results achieved by the research are:

The dynamic control is implemented by Multi Agent Architecture. This allows to obtain the advantages of: computational efficiency, reliability, extensibility, robustness, maintainability, responsiveness, flexibility, and reuse.

- The dynamic control card proposed allows to reduce Work In Process and lead time of the parts. The improvements are tested in several dynamic conditions by a simulation environment. The different scenarios tested allow to quantify the benefits for each scenario characteristics.
- The proposed approach leads to significantly improvements where external exceptions occur as the demand variability.

Future researches concern the extending the approach to multi-product environment and the implementation of a fuzzy inference engine in order top reduce the number of adding or subtracting of cards.

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