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Examining the Dynamic Behaviour of an Aeronautical Specialized Supply Chain with Multiple Order Priorities

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Abstract: Most aeronautical specialized supply chains accept orders with a variety of priorities, with high-priority orders being less common than low-priority orders. Ideally, they need to complete processing these orders before their process time runs out, since completing it after the deadline might result in fines for the company. In this study, we use the concept of cellular automaton to analyze the dynamic behaviour of ultimate critical time orders with multiple priorities. The simulator provides the possibility to investigate the influence of different process parameters on the system load, based on a cellular automaton concept for transport in networks. The simulation results help us to understand the dynamic behaviour of orders with multiple priorities.

Key words: Cellular automaton-style algorithm, time based supply chains, dynamic analysis

INTRODUCTION

Since twenty years the global competition puts pressure on many aeronautical oriented supply chains to improve their internal business process lead time. These companies succeed in the global aeronautical market, when they can process their customer orders fast, reliably and on time[1]. Supply chains that can achieve the named goals more efficiently can gain more trust as well as a better customer relationship[2].

Since shorter lead times are demanded constantly, companies are challenged to optimize their supply chains and to find new concepts to satisfy customer orders as they appear. To clarify the basic understanding about it we investigated the following realistic scenario. A company is recognized around the world as an approved supplier of materials for aerospace airlines. It handles about 2000 orders weekly (punctual delivery according to the International Air Transport Association (IATA) shipping norms) and coordinates seventeen stations worldwide and one central warehouse in Spain.

The dynamics of the company can be explained by the following scenario. If a plane in Sweden stays on the ground as a result of a lacking part, the company must deliver the component within 48 h, even if the part is currently only available in a company warehouse in Japan. Any supply company (if they have a contract with an airline) which is not able to send the spare parts within the allotted time despite contractually agreeing to do so will have to pay large fines for not fulfilling its contractual obligations.

In this study we use the concept of Cellular Automata (CA) based on a concept for transport in networks[3] to develop a method for investigating these complex processes. The simulation results help us to understand the dynamical behaviour of such order processes.

The integrated possibilities of the cellular automaton approach in transport field is reflected by the richness of research areas, methods and software. For example, concepts in theoretical computer science, applied mathematics and statistical physics have been very successful in explaining dynamical phenomena in urban growth and traffic flow[4-8]. For this reason, researchers[9-13] have argued that concepts used for the investigation of traffic dynamics can also be applied to the study of economic phenomena and supply networks.

MICROPROCESS ARCHITECTURE

Each Order O_n at a company passes through a chain of processes, with each work process being represented by an individual section s_j.

For the purposes of this study, a company with five sections (j= 1....5) will be used. Present modeling approach consists of a number of single actions, which can be

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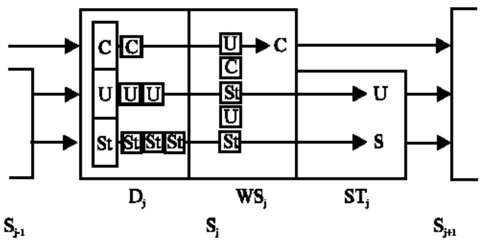

Fig. 1: Microscopical section

complex in themselves again. These components interact with each other, performing the basic actions of an order passing through during its life in a company.

Figure 1 shows one formal component of the dynamic flow of individual orders passed through the different Sections S_j (rectangles) of the work process. Section S_j represents the possible location of an order O_n. Each subunit of S_j passes an order O_n that has gone through the local work process on to the next subunit in the same S_j, or to S_{j+1}. Each section S_j is further subdivided into a distributor D_j, a workspace WS_j and a storage unit ST_j.

Definition: Distributor D_j : This is the waiting room for all O_n that have not been assigned to a specific employee $E_{i,j}$ in the workspace yet. It has a data list for all unassigned O_n.

Definition: Workspace WS_j : This is where the actual employees can be found. Since the individual employees can only have a limited number of discrete states, they can be represented as individual cells in a cellular automaton in the way they interact with the rest of the section.

Definition: Storage ST_j : This is the waiting room of orders with Priority P_2 and P_3 (Eq. 1) that have gone through the work process required by the local section, but have not been moved yet to S_j. Each ST unit has a numerical value ST_{Fin} that determines how much time is left until the storage sub-unit is emptied.

CELLULAR AUTOMATON-STYLE ALGORITHM

For a better understanding and visualization of the basic processes, a cellular automaton-style algorithm was developed. A cellular automaton is a discrete dynamical system, which is used as mathematical model to investigate self-organization in statistical mechanics and is especially suitable to model the dynamics of complex systems[9,14-16].

A cellular automaton is defined by a set of discrete cells R in a finite number of states S, a finite neighbourhood N and a local transfer function: $\delta : S^N \to S$. Each order represents a cell, which can be in the state S: {1,2,3,4,5,6,7} according to the definition of T_{Fin} below. As fulfilling orders is a linear problem, the automaton is one-dimensional and the considered neighbors reduce to one. A finite number of new orders is generated in each time step which is taken to be one day in real life. Orders which are fulfilled will be deleted at the end of each time step. Therefore, the automaton's size can vary at every time step, because the number of orders M which can be fulfilled in one time step is fixed. For present simulation we give each order the following information. The value of a cell represents T_{Fin} which is defined as:

$$P(T_{Fin}(O_n)) = \begin{cases} C: \ T_{Fin} \le 2d & (P_1) \\ U: \ 2d < T_{Fin} \le 3d & (P_2) \\ Std: \ 3d < T_{Fin} \le 7d & (P_3) \end{cases} \quad (1)$$

Where, T_{Fin} is the time left until the deadline, expressed in days (d). Orders are created setting a cell's value to the number of remaining days until the order must be fulfilled. If an order is not fulfilled at the end of one time step, its value will be decreased by one. If the order reaches a value of zero, it will be set back to one and a counter representing the amount of failed orders is increased. This corresponds to the fact that the owner of the supply chain has to pay for every order he fails to fulfill. A cell i can only be considered if its state s(i) is lower than its successors state s(i+1). But there is always the possibility that an order cannot be fulfilled in a time step depending on the value of barrier parameters like the certification error E_c (implying that the material cannot be proccessed further) or the storage error E_s (the product connected to this order is not on stock) and the human error E_h. Each parameter inhibits with a stochastic probability that the order can be fulfilled. Thus, the transfer function δ resolves to:

$$\delta : s(i) \to s^*(i, s(i+1), M, E_c, E_s, E_h) \quad (2)$$

The user can define the distribution of order types and the values of the barrier parameters as an input for the simulation.

Finally, define the following three states of the supply chain:

Operating Supply Chain (SC_{Opera}): misses of execution of an order occur only on very few days.

Metastable Supply Chain (SC_{Meta}): misses of execution occur fairly often, but there is no overall increase of their number.

Fig. 2: Possible transitions of states of the supply chain

Collapsed Supply Chain (SC_{Collap}): misses of execution occur every day and their number increases steadily leading to a system consisting mostly of failed orders.

Figure 2 shows the possible transitions of states. Note that there is no return to a metastable state possible once the supply chain is collapsed.

RESULTS

Dynamics of the supply chain with multiple order priority: Time critical orders are passed on and worked on in preference of all others, leaving out parts of individual phases (Fig. 1). While this assures that these orders are completed in time in most cases, it eventually generates a large bottleneck of standard orders (P_3) who are eventually upgraded to urgent ones (P_2) or even time critical ones (P_1) while they wait for being assigned to employees. Reducing this bottleneck is an important task for all companies with similar process chains. Figure 3 shows the simulation results for the current situation. The order flow is in an excellent state, misses of execution of an order occur only on very few days. The supply chain is in a SC_{Opera} (operating state).

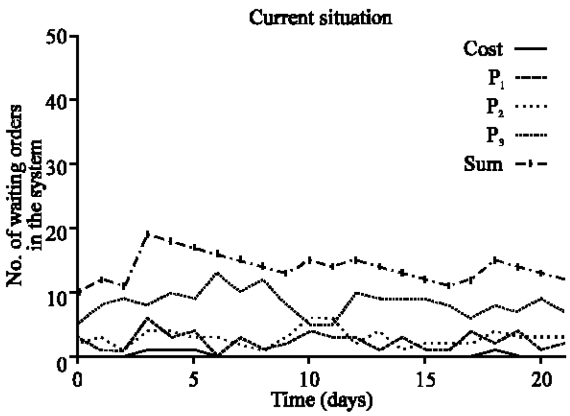

Fig. 3: Parameters: 20% P_1, 25% P_2, 55% and P_3, 11% certificate error

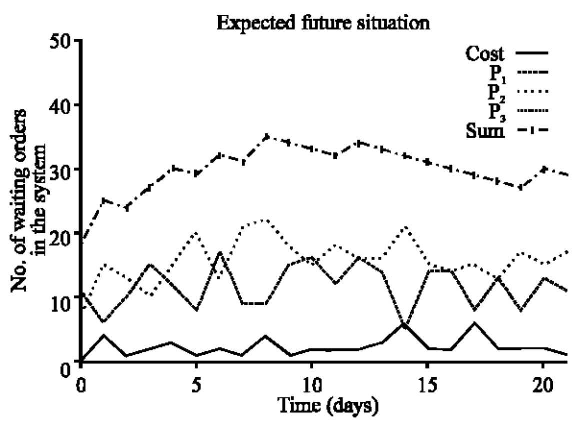

Fig. 4: Parameters: 40% P_1, 60% P_2, 0% and P_3, 20% certificate error

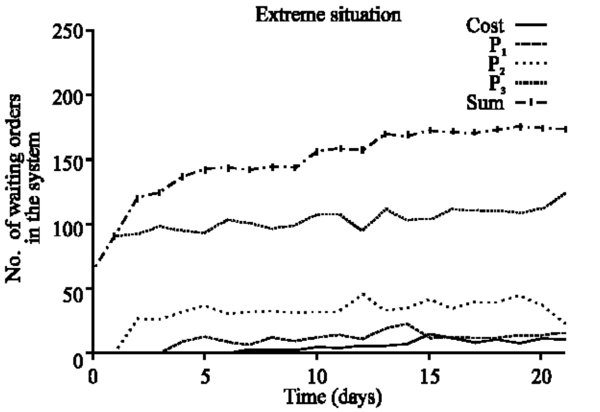

Fig. 5: Parameters with high failure rate (certificate error)

Figure 4 shows the simulation results for higher values of time critical orders. The number of orders in the system sums up to a higher level, but does not increase significantly in time. This supply chain is in a SC_{Meta} (metastable state), because small increments of time critical orders can cause its collapse.

Misses of execution occur every day and will increase the overall costs and therefore reduce the profit. In the future, increased demand from airlines thanks to increased air traffic means that suppliers might no longer be able to accept orders with P_3, leaving a mixture of orders with P_1 and P_2. To keep up with the increased demand, supply companies will have to reexamine their process chain and optimize it to provide the same high-quality service their customers are used to while at the same time keeping up with the larger number of high-priority orders.

Figure 5 shows the supply chain in a SC_{Collap} (collapsed state). The probability of the occurrence of certification errors is very high. The distribution used here was 100% for P_3 and 60% for the certificate error. The number of orders in the system stabilizes at a very high level and the number of misses of execution rises from day to day.

CONCLUSIONS

It is possible to describe a real complex time oriented supply chain process by means of a cellular automaton based discrete automaton. The simulator describes clearly the behaviour of the real order processes in the supply chain. The straight influence of the barrier parameters is as well visible as the influence of the distribution of order types. In future releases the model will be expanded to more complex processes, e.g. that an order can be kept back for some days due to communication with the customer. Furthermore, the model will also be expanded to deal with the interaction of supply chains all over the world.

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