SYSTEM DYNAMICS AND DISCRETE SIMULATION IN A CONSTANT WORK IN PROCESS SYSTEM. A COMPARATIVE STUDY.

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ABSTRACT

In this paper we will study a production line operating under a Constant Work In Process (CONWIP) control System using System Dynamics and discrete simulation. The goal of our research is to determine whether various characteristics of a production line can be better understood using System Dynamics or discrete simulation. The software used in our investigation is VENSIM for System Dynamics and WITNESS for discrete simulation. In conclusion we have found that the best way to manage the production line is using both approaches in a complementary manner.

1. Introduction.

The pull control systems seem to be a major approach to managing and controlling a serial production line. A good number of research issues have been studied under a wide variety of assumptions: physical manufacturing layout (serial, assembly, splitting), balanced and unbalanced lines, service time and arrival pattern of products to the line, buffer sizing/allocation, solution procedures, cost structure, etc.

The question here is to analyze the CONWIP system introduced by Spearman, Woodruff and Hopp (1990) using two models in a complementary manner. The first is a System Dynamics model which studies those aspects more suitably and the second is a Discrete Simulation model which addresses those topics where the nature of the problem is typically discrete.

2. The Long Pull (CONWIP) Systems.

In a CONWIP system a card is attached to the order at the beginning of the production line and flows with the order through the whole process. When the order is processed at the final machine the card is dropped off and released back to the beginning to wait for another order. In such a way the card number is used to control the total number of jobs in the system because a job cannot enter the system if a card is not available. CONWIP seems to share most of the benefits of pull systems. However it is applicable to a wider range of environments (Lambrecht,Seagert,1990). One additional advantage has been found since a formula has been developed to determine main control parameter (number of cards to operate in the system) which does not depend on demand but on the capacity of the system. This formula obtains the number of cards as the quotient between the system mean cycle time (sum of cycle times for all the machines in the line) and the bottleneck mean cycle time. This ensures that the system achieves the maximum throughput while minimizing inventories. Although in some environments the cycle times can be deviated from mean cycle time, the number obtained from this formula provides a good estimation -a lower bound- of the number of cards to be used in the system. Every card added (to that number) will make the system more robust to fluctuations while accumulating higher inventories.

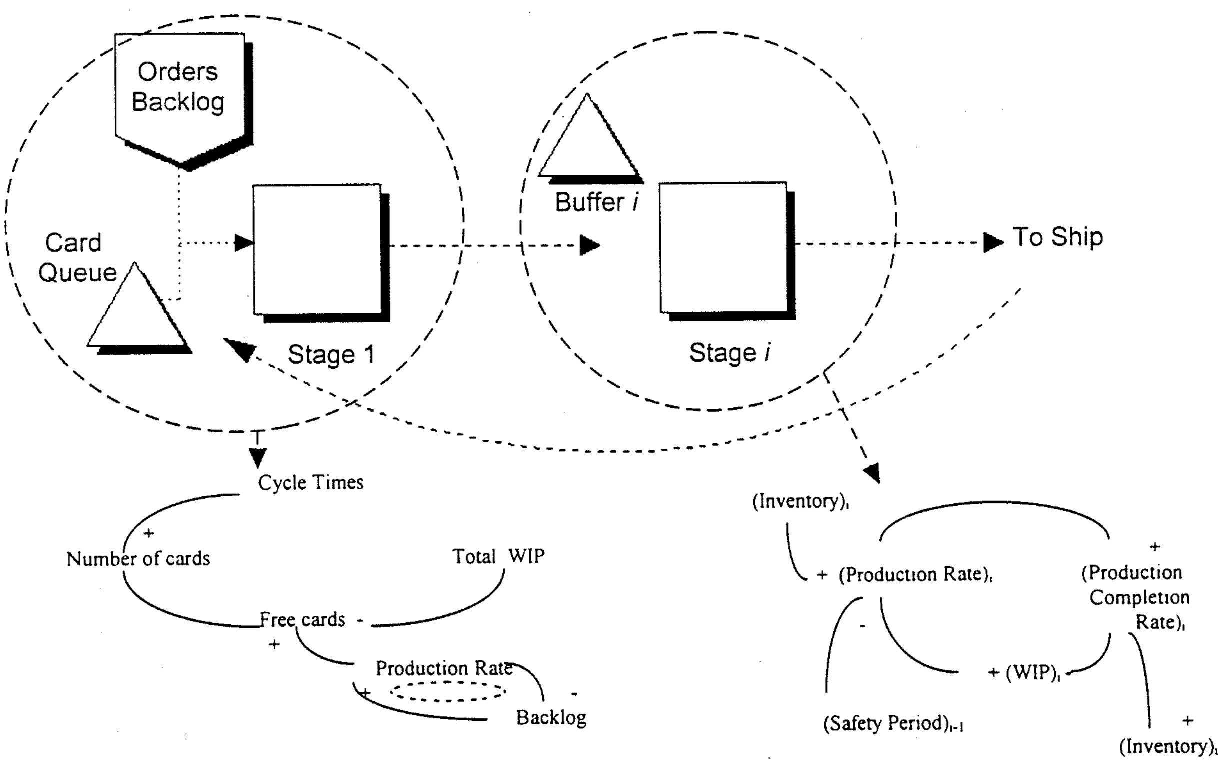
3. The Simulation Models.

Our research has two main purposes:

- To use the System Dynamics model to test the formula proposed above. This formula has been obtained theoretically and subsequently in different scenarios by extensive simulations. The purpose now is to use the optimization capabilities of the VENSIM software to compare its results with those obtained applying this formula.
- To explore the possibilities of combining the System Dynamics model with the Discrete Event Simulation model.

In order to study the continuous and discrete dynamics of the system two simulation models are constructed to offer some insight into the system behaviour. Thus, two production lines are modeled using VENSIM for the continuous case and Witness for the discrete one.

The System Dynamics model of CONWIP is shown in the following diagrams:



The software chosen for designing the discrete model has been WITNESS 6.0. WITNESS is a discrete event simulation software oriented to manufacturing models and provides as default the elements MACHINE and BUFFER. These elements have been used to implement the serial line. That backlog has also been modeled as a BUFFER element, and the CONWIP mechanism of releasing orders from backlog has been implemented by using a fictitious machine with a zero cycle time that continuously checks the backlog size and the number of cards in the queue -these have been modeled as an integer variable-.

4. Experiments.

Two sets of scenarios have been designed. The first one is a serial production line and the second one reproduces several manufacturing situations, such as demand fluctuations and breakdown. The serial line is composed by three machines (100 units capacity and cycle times of 1, 1 and 1.3) and its buffers. To simulate transportation times between machines, a one-period idle time has been implemented in every buffer. Two objective functions have been designed. First one, f_1, maximizes the difference between throughput and total inventory. A factor to weight inventory versus throughput has been introduced. The second function, f_2, maximizes throughput minus the total number of cards weighted with a factor. Both functions measures effectiveness of the system because they both try to maximize throughput while penalizing inventories or system´s Work In Process.

This scenario has been modeled with VENSIM with three different demands: a balanced demand of 77 units per period, a capacity excess of 50 units/period and a 100 units per period demand excess have been simulated and optimized with both objective functions. An initial value of 300 cards for all experiments is given and a fractional tolerance of 0.1 is permitted. A Discrete Event Simulation model using WITNESS has also been built and results obtained.

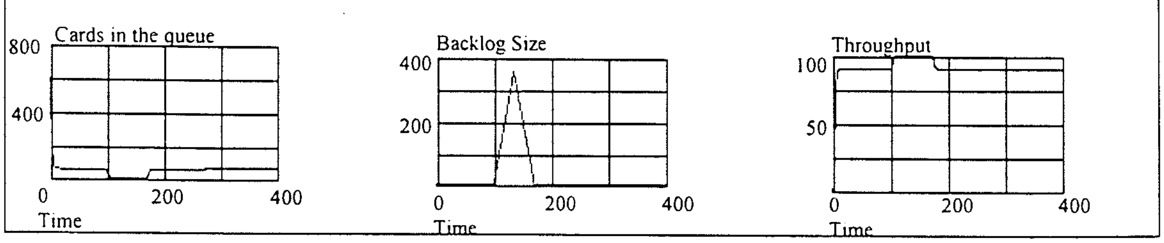
5. Results.

The results of the first set of simulations are shown in the following table:

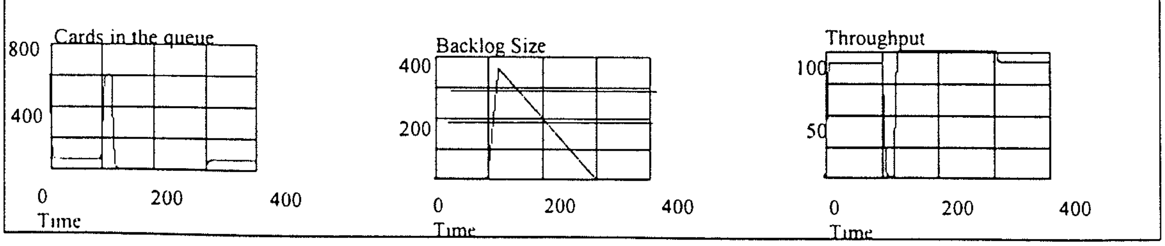
	Objective function	Optimum Cards Nº	Mean size of cards queue
Balanced Demand	f_1: $Max(T - \rho \times I)$	900	419
(77 units/period)	f_2: $Max(T - \rho \times NC)$	487	0
Capacity Excess	f_1: $Max(T - \rho \times I)$	900	415
(50 units/period)	f_2: $Max(T - \rho \times NC)$	316	0
Demand Excess	f_1: $Max(T - \rho \times I)$	486	0
(100 units/period)	f_2: $Max(T - \rho \times NC)$	487	0

The results for the second set of scenarios are summarized below:

DEMAND FLUCTUATION



BREAKDOWN



6. Conclusions.

For the proposed scenario, the optimum number of cards given by the formula is 485. The table indicates that when a demand excess exists there is no significant difference between the theoretical number and the simulation optimum. The results are also very similar for both objective functions. When a capacity excess occurs, none of the numbers of cards obtained in the simulation runs match the formula or match themselves, due to the fact that the cards in the queue does not increase inventory or decrease throughput. Cards remain waiting for orders, as it shows the mean size of the cards in the queue. The second function reaches the optimum at 317 cards -a smaller number of cards required to obtain maximum throughput-. Similar conclusions can be obtained for the balanced demand case.

The results of the second set of scenarios indicate the fitness of the System Dynamics to trace the evolution of the main parameters of the system.

From a more general outlook, our research points out some of the complementary aspects of using System Dynamics and Discrete Event Simulation. System Dynamics can be used for optimizing the system's parameters, and these results can be taken as initial values for a more thorough analysis using Discrete Event Simulation. A possible list of complementary aspects of a mixed System Dynamics-Discrete Simulation approach is summarized in the table below:

System Dynamics	Discrete Event Simulation
Qualitative Analysis. Long Term	Quantitative Analysis. Short Term.
Casual Loops/Feedback effects.	Layout/Topologies.
Optimization capabilities (VENSIM) Pre-design of Reference Values.	Linking an Optimization Module.
Non-easy Management.	Easy Management: Setup, Shutdown, Buffer Size/Allocation, Bottlenecks.

Some questions remain unsolved, like the scope of possible extensions of the System Dynamics model to other manufacturing layouts such as non-serial production lines. Another important question regarding CONWIP is the backlog sequencing and its optimization using quantitative methods as heuristics or simulated annealing, which are currently subjects of an ongoing research.

7. References.

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