The Supply Net Game

Bernd Scholz-Reiter

Department of Planning and Control of Production Systems
University of Bremen, BIBA-IPS, Hochschulring 20, 28359 Bremen, Germany
Tel.: 49 421 218 5576, Fax: 49 421 218 5640, email: bsr@biba.uni-bremen.de

Salima Delhoum

Department of Planning and Control of Production Systems
University of Bremen, BIBA-IPS, Hochschulring 20, 28359 Bremen, Germany
Tel.: 49 421 218 5549, Fax: 49 421 218 5640, email: del@biba.uni-bremen.de

Abstract

The paper describes a game called, the supply net game, built around the structure of a production supply network based on the "anchoring and adjustment heuristic" which is known as the one people use to make inferences about uncertain events. The game involves four players where everyone manages his manufacturing unit that consists of four production lines which proceed to the joint development of products with the other units. While planning production and controlling inventories, every person should try to minimize the costs caused by both holding items on stock and being in an out-of stock situation. The paper stresses the valuable impact and contribution of management games for management and engineering education in general and particularly the significance of learning implicit skills as well as gaining insight in inventory control and management of complex distributed production systems such as the system dynamics production network model introduced and analyzed in the paper. The game will be used later in a controlled experiment which is not under the scope of this paper.

Key Words

Management game, production network, system dynamics

Introduction

In the system dynamics literature, the value of management flight simulators, also known as microworlds, was repeatedly demonstrated (Senge 1990; Bakken et al. 1992; Sterman 1994; Sterman 2000). Management flight simulators are learning processes / tools or environments that help activate double loop learning (Bakken et al. 1992) because when the user "flies" a simulator, time and space are compressed, and hence, he can deduct interactively the feedback structures that exist within the system (Senge 1990, 312-338; Graham et al. 1992; Senge and Sterman 1992). The advantage of these learning environments, therefore, is that they make cause and effect relationships more visible to the user. Simulators enable accelerated learning, what Probst and Büchel (1994, 95) call "learning by doing", and Senge (1990, 313) "learning through doing". The simulator is a learning laboratory that stimulates risk-free try outs of strategies, illustrates the relationship of system structure to behavior, and portrays learning according to the scientific method where the objective is to understand the problem genesis and dynamic behavior of complex systems in order to provide sustainable policies. These mediums are necessary because people are bounded rationally (Simon 1982) and have "misperceptions of feedback" (Sterman 1989a, Sterman 1989b; Sterman 1994) which steadily affect their reasoning and interpretation capabilities in complex systems in presence of feedbacks, time delays and nonlinearities (Sterman 1989a; Sterman 1989b; Bakken 1993; Paich and Sterman 1993; Diehl and Sterman 1995; Larsen et al. 1999; Langley and Morecroft 2004). Sterman (1989a) indicated that the mental models people use to decide are deficient because of their open-loop structure (see Senge et al. 1994, for a definition of mental models); furthermore, the misperceptions of feedback generate the underestimation of the supply line in the beer distribution game that induce the wild oscillations of inventories. Moreover Miller (1956) proved through several experiments that human capacity to process information, the so-called channel capacity, for one dimensional stimuli, is limited to the number seven (bits). Miller (1956) gave the range seven plus or minus two as the interval that includes the capacities observed in laboratories.

Because all of the shortcomings of mental models, information processing, memory, etc. the importance of management flight simulators is corroborated although the performance of subjects who used them in experiments did not notably improve (Sterman 1989b; Bakken 1993; Paich and Sterman 1993; Langley and Morecroft 2004). Some work point to their limitations when it comes to learning transfer issues to real world settings (Bakken et al. 1992), the increase of organizational performance (Vennix 1999), and the issues of simulators as teaching and research instruments (Größler 2004). From a methodological point of view the question is more how to embed management games successfully in learning laboratories (Graham and Senge 1990; Graham et al. 1992; Warren and Langley 1999) as part of a systems thinking intervention with problem conceptualization, model formulation, and hypothesis test phases that help develop systems thinking skills and learning transfer frameworks (see Maier and Größler 2000, for a classification of games, management flight simulators, etc.).

It is not clear from the literature if a mental model elicitation method (ladder of inference, left-hand column method, etc.) embedded together with a gaming environment in a controlled experiment could have an effect on the quality of the decisions generated by the subjects especially for the deterministic task of inventory management – bullwhip effect related situations - in production networks. The paper introduces and analyzes the supply net game that is built for its future use in such an experiment. The results of the experiment will be released in a prospective publication.

Management Games of Production Systems

Management games are widely employed to train managers and workers and are also a fundamental trend in management and engineering education. Warren and Langley (1999) underscore that managers should have access to gaming simulation tools in order for them to cope with the business systems in which they evolve and to reap strategic management skills. Scholz-Reiter et al. (2002b) emphasize the need to introduce management games to workers and engineering students to learn the task of inventory management and aptitudes like communication and cooperation in complex distributed production systems such as production networks. Maier and Größler (2000) distinguish between single-user and multi-user games whereby the former is labeled as "simulator" and the latter as "planning game". This separation is explained by the implications of group size dynamics on learning.

The literature on management games is replete with applications such as people express management flight simulator (Sterman 1988); multiplier accelerator (Sterman 1989b); boom and bust (Paich and Sterman 1993); web-based beer game (Oliva and Gonçalves 2005) complement to the board game (Sterman 1989a), etc. (see also Maier and Größler 2000, for a list of games). Since the paper captures the instance of a production system, the attention is focused on this kind of systems for which there are some board implementations like the beer game that illustrates the four sectors linear supply chain (Sterman 1989a) and the dice game (Lange and Ziegenbein 2005) that portrays Goldratt´s theory of constraints for capacity management problems. System dynamics models include the simple inventory management task (Diehl and Sterman 1995, Aybat et al. 2004). Games contingent on methodologies other than system dynamics exist for distributed production systems; Cosiga, Glotrain, and Share game to name a few. Cosiga is an internet-based game sponsored by the European Commission that aims to train European engineers on the principles of concurrent engineering as well as product development and makes the case of a truck manufacturer. Five players coordinate their efforts for the specification, design and manufacture of a product around the game's platform that uses communication means intensively (chat, email, and video conference) because cooperation is prominent (Scholz-Reiter et al. 2002a; Cosiga 2003). The project was the essence of a joint course at the University of Bremen, Nottingham and Trondheim in Germany, United Kingdom and Norway respectively. Glotrain, developed at the BIBA institute of the University of Bremen, was devised to let users learn implicit skills in distributed production systems with the help of modern telecommunication technologies (Glotrain 1997; Windhoff 2001). Analog to Glotrain, Share game was born in BIBA; the difference between the two games lies, in that; the latter encourages several processes of inter-organizational learning, product development and collaboration simultaneously. Share game prevails on a production network model, as well as Cosiga, and it is dedicated to the product development of a jet-ski and cell phone and based on concurrent engineering concepts. Both scenarios (one for every product) entail nine persons – three per organization with different hierarchical levels from employee to department head. The game is meant to reinforce trust, collaboration and teamwork in and across teams whereby communication is primordial and is achieved via telephone and message boards that go down sometimes during the game to simulate remote participants in disparate regions (for a detailed description of the game see Baalsrud Hauge et al. 2005).

The *Supply Net game* is built upon a pull production and logistic supply network and has, as a replenishment procedure, the “anchoring and adjustment heuristic” described by Tversky and Kahneman (1974) as one of the heuristics people utilize to make inferences about uncertain events. Each of the four players manages the stock levels encompassed in his manufacturing unit by ordering for the four production lines consecutively in the same sequence from line one to four. At the same time, he tries to minimize the costs incurred. The minimization of costs corresponds to bringing the bullwhip effect to its smallest expression since the effect, defined as demand variability over a supply chain generates stacked backlogs when demand booms and huge inventories when orders fall; the two situations for which costs are high. It is hypothesized that the two types of costs, (a) € 0.5 per product on hand per minute and (b) € 1.0 for out-of-stock cost, are the same for all manufacturers. The game includes four organizations; nevertheless it is limited to four participants, which is better than the nine (five) participants, for the three companies, that the Share game (Cosiga) calls for. Indeed Share game’s greediness on personnel and subsequent infrastructure (computers, phones and rooms) make it almost impracticable in small and medium enterprises (Baalsrud Hauge et al. 2005), which are assumed to be the major beneficiaries of such tools. From another side when it is about the choice of a modeling methodology for the supply net game, system dynamics is adopted because it possesses a long tradition of contribution to the refinement of individual and organizational learning (see Morecroft and Sterman 1994, for case studies). Finally, the application is more than a mere gaming environment because it is designed to be part of a systems thinking intervention under the framework of a controlled experiment with performance measurements of learning.

Modeling of Production Supply Networks: A Summary Review of the Literature

In a production and logistic supply net many manufacturing units integrate their activities and processes to satisfy customer demand which may be a supply chain / network or an individual company (retailer). The factory takes advantage in partnering on the network because it can then respond to external fluctuations either of customer demand or supply variations as a network which helps amortize the shocks. However, when the internal complex dynamics of the network, such as production specifications and logistic channels, favor the external noise signal – from one or both end-positions - the amplification will gain in intensity, which will hit back the individual unit even stronger. Although a shared definition of the production network or production in networks does not exist yet, it is accepted that such a network entails the distributed joint development of the product and is regarded as a new form of cooperation between manufacturers over a long period of time (Wiendahl and Lutz 2002). This contrasts with the variable production network (VPN) whose structure lasts for the duration of a project (Wiendahl et al. 1998). The VPN is not under the scope of the paper.

Production planning and control in a production net is so that there is a general integrated planning for the whole network and an individual planning carried out by every manufacturer separately in regard to his production and assembly processes. Wiendahl and Lutz (2002) proposed the application of (a) load-oriented or order release control methods and (b) decentralized control loops. Both approaches suggest decentralization, but whereas the former consists of the placement of an order only when the production system can handle it, and therefore, try to eliminate unwanted behaviors occasioned by the bullwhip effect; the latter will process a job only if the next workstation is able to complete its operation. Other methodologies for modeling production nets employ open queuing network methods where a node represents a processing machine and the arc the logistic channel to the next processing station and the objective is to minimize the production lead time which is given by the length of the longest path in the network. Azaron et al. (2005) develop an open queuing net of a dynamic multi-stage assembly system for which the lead time and operating costs are minimized through a variant of multi-objective programming; the goal attainment method. In this open network the arc lengths and processing times are stochastic and the model is discretized. Hieber (1998) illustrated a general diagnosis technique for the optimization of production nets. In addition to optimization, algorithms based on the simulated annealing heuristic are applied to determine an “optimal” path through the manufacturing net for an incoming order (Azevedo and Sousa 2000). Software agent technologies also consider the harmonization of the production agenda of the single manufacturing unit with the supply requests within the network (Dangelmeier et al. 2001; Neubert et al. 2004).

Supply Net Game: the Case Study

The supply production network (Figure 1) is made up of four factories Fi, i = 1..4 where each one is constituted of four parallel production lines Lij, j = 1..4, and every line has a work-in-process (WIP) that stores the products before production and a stock of manufactured lots. Every WIP has a minimum (null) and no designated maximum value. The supply of raw materials for the WIP is assumed to be unlimited in capacity and it is done from outside the network to the production line Lii (i = 1..4) that manufactures the finished items Pii which are then delivered outside the network to the customer (in this case, the distributor). Lij ($i \neq j$) takes the quantity it needs from Lii to produce Pij, in that; Lii is considered as the link, of the lines Lij, to the outside network(s) through which the supply is fueled.

The procedure in the net is so that the customer makes his orders of products Pij (j = 1..4) – product j manufactured by Fi - to line Lii of factory Fi (i = 1..4). The manufacturing line Lii passes the ordering information to the other lines Lij ($i \neq j$) which start the production of Pij. The semi-finished parts Pij, j = 1..4 ($j \neq i$) are circulated between the two factories: Fi (Fj) ships the part Pij (Pji) to Fj (Fi). Furthermore, the line Lii keeps track of the parameter-production matrix and, hence, governs the *internal* coupling (in the same factory) of the production lines. The more couplings in the system, more dynamic and complex the behavior is. In this instance, only lines L12 and L14 are coupled; in other words, the processing of one product P12 necessitates one product P14 – in addition to one item P21 since all lines are externally (with other factories) coupled. The minimum lead time on Lij is denoted Tij which includes the cycle time and the transport time from Lij (Fi) to Lji (Fj). Tij is constant and the machine capacity is supposed unrestricted.

The case explores a simplified theoretical instance of a production net, yet it exhibits complex non linear dynamics. The choice is on four factories because that renders the behavior of the net more challenging, than with two factories, in terms of the feedbacks and nonlinearities created by the production processes, and logistic channels. Although the model is theoretical, it exists in practice networks of production where the product starts from a processing machine a1, visits another machine a2 and then returns to a1. Some real-life settings are the semiconductor industry for example. The supply chain industries that could benefit from the game are those where the oscillations of orders and inventories are strong such as the semiconductor & high-tech, commodities (beer, pampers…), automobile, aviation, chemicals or shipping & distribution.

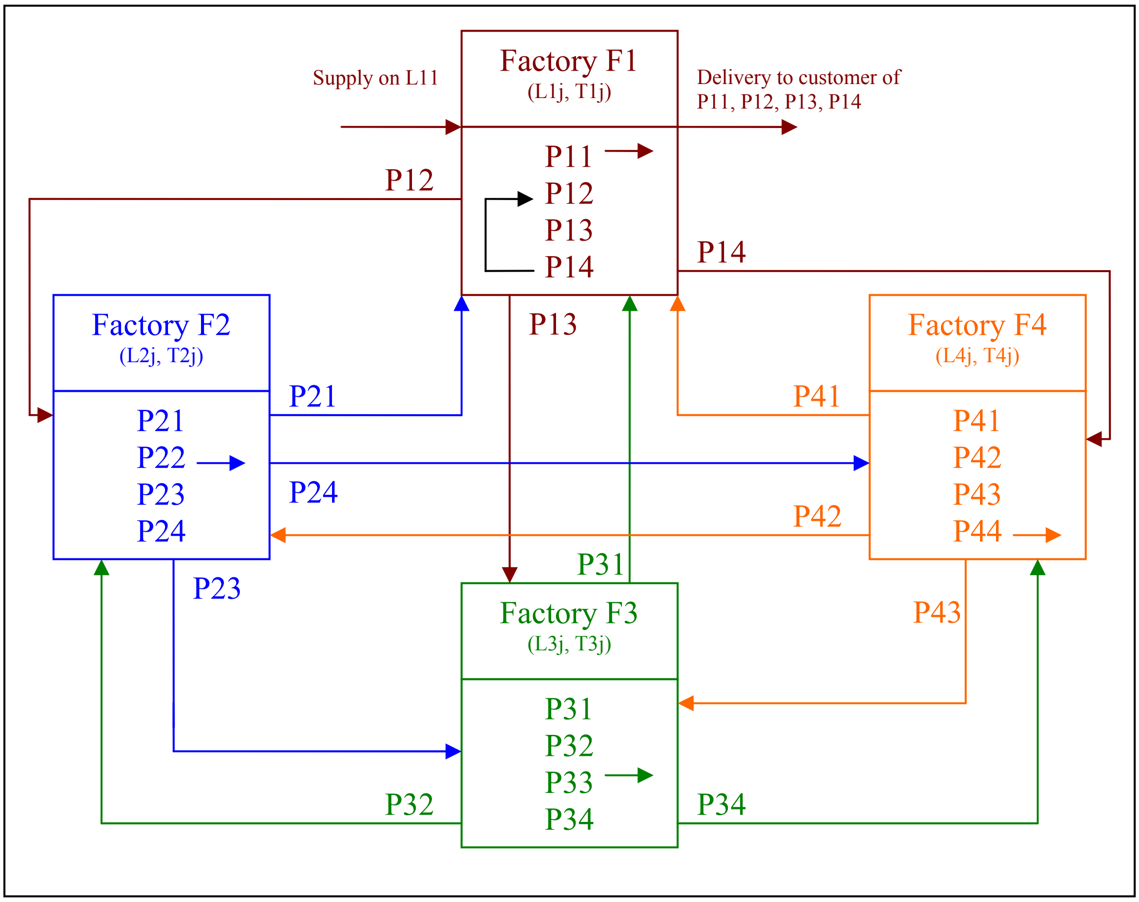


Figure 1: General Structure of the Production Network

Pij is the product j (j=1..4) manufactured by factory Fi (i=1..4). Pij and Pji (i ≠ j) are exchanged between factories Fi and Fj and then delivered outside the net whereas Pii is delivered outside the network only. In F1 the lines L12 and L14 are coupled. The same supply and delivery structure is true for all Fi. Lij is the production line for Pij and Tij the min lead time on Lij.

Structure of the Supply Net Model

The model proposes a continuous modeling approach for the supply production network contingent on the continuous flow and time of the system dynamics methodology because despite the different existing products, the focus is not on the individual item type which is regarded as an aggregate product, but rather on the dynamics created by such systems. Sterman (2000, 208) indicated that the error generated by the approximation of a discrete event into a continuous flow is negligible in comparison to the error in model constant measurements and hence, promoted the use of the continuous approach as long as the purpose of the model could be met. Scholz-Reiter et al. (2005b) suggested the use of both continuous and discrete modeling approaches because the latter allows a real description of the manufacturing system, but it is demanding in programming whereas system dynamics continuous simulation facilitates the implementation of the control strategy, however, at a higher level of aggregation (see also Scholz-Reiter et al. 2005a).

The model employs the “anchoring and adjustment heuristic” as the replenishment procedure because the approach follows the descriptive research on the bullwhip effect in supply chains, for which the decision maker is considered as “bounded rationally”. Tversky and Kahneman (1974) described the heuristic as being among those people utilize to make inferences about uncertain events. Sterman (1989a) used it to model the decision making processes in the beer game supply chain model, and found that the heuristic imitated correctly the decisions of the actual players of the board game according to the statistical results of the regression models.

Figure 2 illustrates the production line L11 of factory F1 which processes product P11 and then ships it to the customer. The line L11 also orders and receives the required supplies in raw materials, for the production of P11, P12, P13 and P14, from outside the network according to the demand expressed by the respective lines. Figure 3 shows how line L13 is linked to L31 based on the principle of the joint development of products between the factories of the net so that items P13 and P31 can then be delivered to the customer.

The other two lines of factory F1, L12 and L14, have the same structure as that of Figure 3 with one additional characteristic of coupling. Besides the models in Figure 2 and Figure 3 are representative of the procedure applied to the other factories.

The idea behind the model for line L11 is that there is a customer who sees how much of products P11, P12, P13 and P14 he has on stock so that he can place his orders to L11. The order function for P11 (*order rate distributor for P11*) is supposed to follow a random normal distribution. From last period demand, a smoothed expectation is derived; in addition, the adjustments of the stock and WIP are computed based on their desired levels. The summation of these three values gives the order rate for P11 *(order rate P11)* in accordance with the anchoring and adjustment heuristic. The order is transmitted to an external supplier with assumingly unrestricted capacity, and therefore, P11 is produced and shipped to the customer. Backlogs of unsatisfied demand are taken into consideration and answered first when stocks permit it.

The order rate for article P13 *(order rate P13*) is calculated with the expectation of the customer's demand for P13 – demand for P13 equals the order for P11 - *(order rate distributor for P11*), and the adjustments of the stock and WIP of P13 with one variant; the expectation of last period order rate of items P31 is also considered (Appendix A). Indeed the stock of P13 should be ample enough to satisfy not only the customer request, but also the demand of the line with which it jointly produces, in this case, L31. The order rate of products P13 is placed to the line P31 which sends them when available; otherwise they go to the backlog. Next to the acquisition, the processing line L13 manufactures the lot and ships (a) the order of articles P31 to L31 *(shipping rate P13)* and (b) the quantity of products required by the customer *(ship dist P1311).* The latter is delivered out of the net, so in order to avoid that its stock falls to zero; L13 places an order for raw materials *(supply P13 from L11)* to the external supplier via line L11.

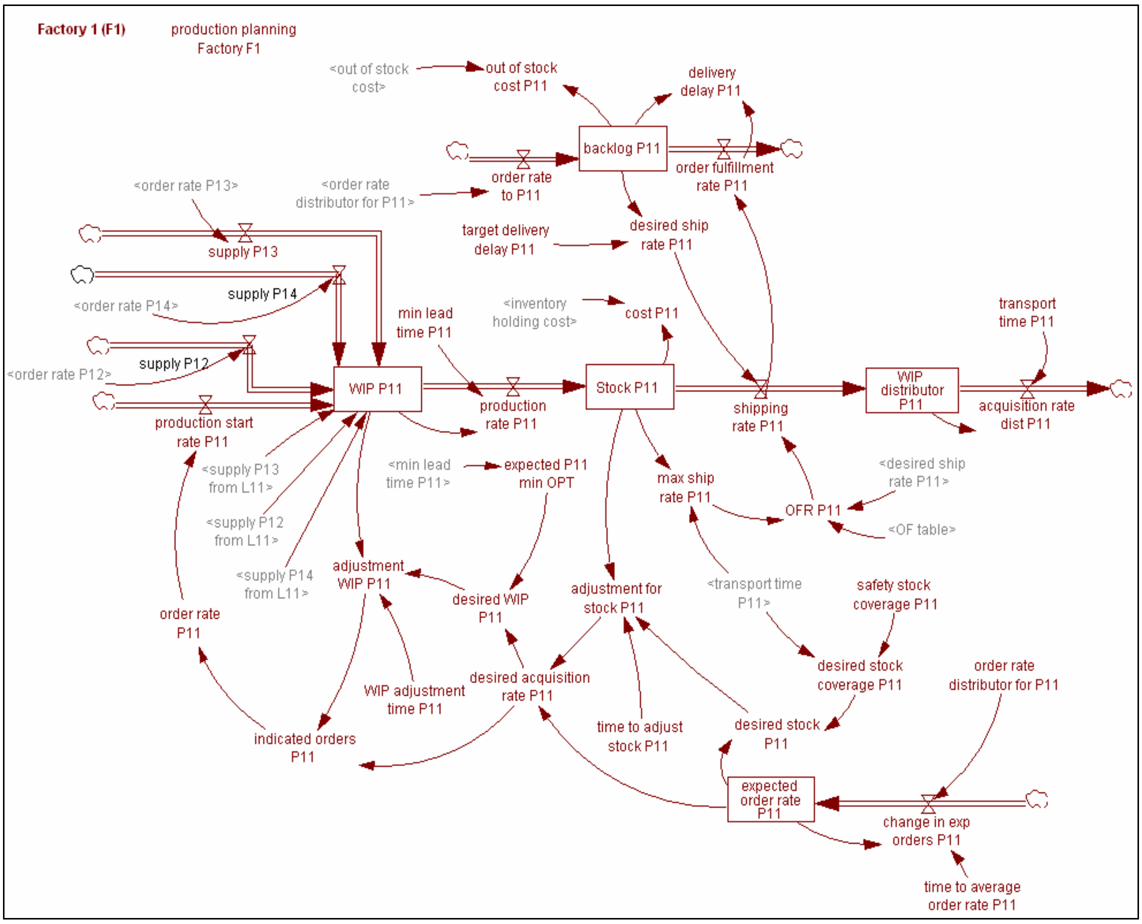


Figure 2: System Dynamics Model of the Supply Production Line P11

On the other side the order rate for items P31 *(order rate P31)* is set without the recourse to the order rate for P13 (*order rate P13*), i.e. only customer demand and the adjustments for both stock and WIP suffice, since the structure does not have a linear topology, but rather a backflow (Appendix B). Otherwise there would be a redundancy of computations.

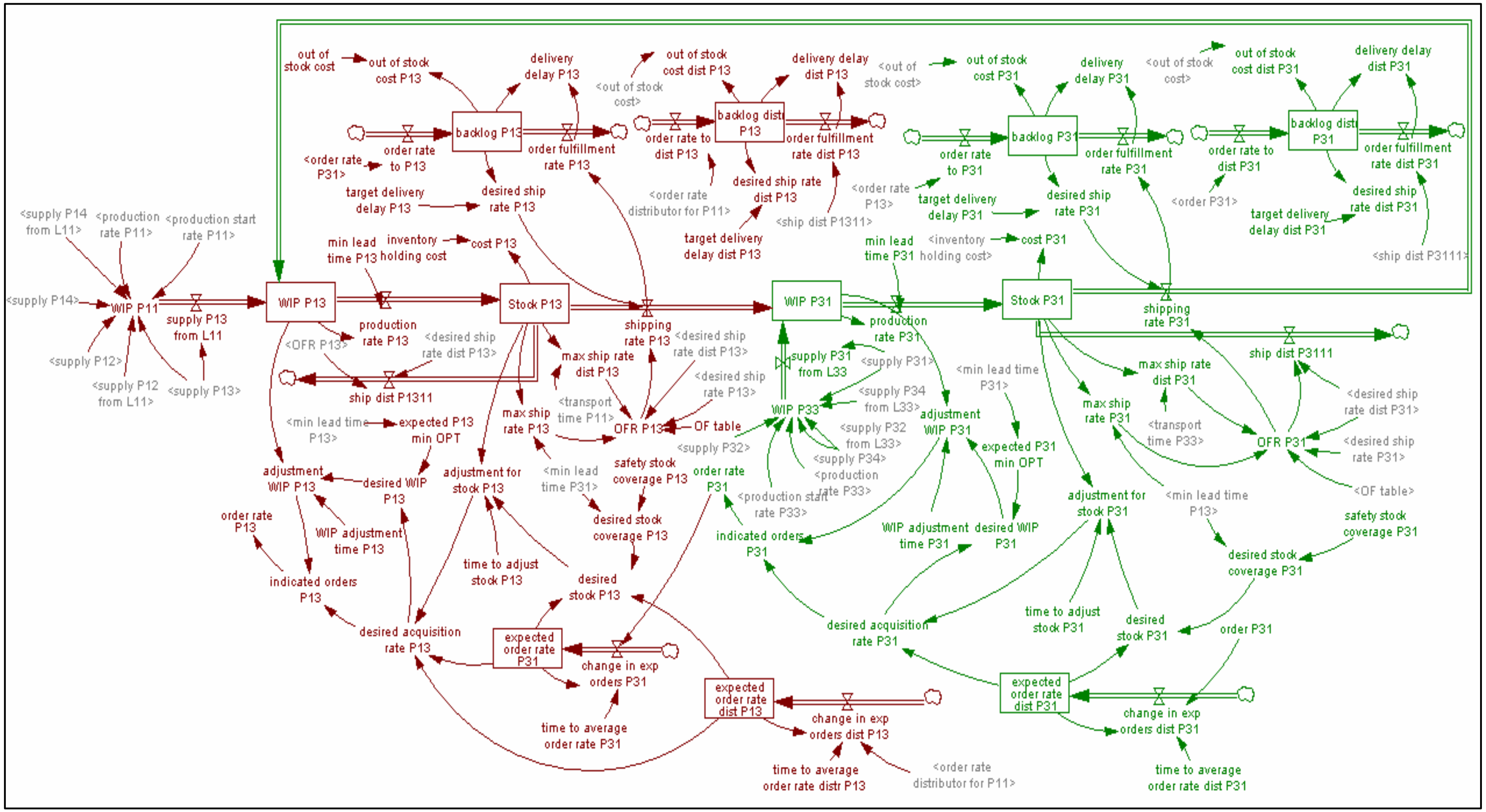


Figure 3: System Dynamics Model of the Production Lines L13 and L31

The order fulfillment ratio function *OFR P13* makes sure that the stock of products P13 will not turn negative because of the two outflows. It is expressed as follows:

OFR P13 = OF table (MIN (max ship rate dist P13, max ship rate P13) / (desired ship rate dist P13+desired ship rate P13))

Where *OF table* is the same function for the whole production model and it is designed to reach quickly unity due to the topology of the system.

Model Analysis

The data used in this section come from the simulation of the production net and not from the experiment. Since the model is theoretical, a reference mode does not exist to be checked for behavior reproduction which occurs sometimes in system dynamics. Figure 5 shows the response of both stocks and WIP of lines L13 and L31 to an unanticipated 100% step increase in the exogenous customer order function for items P31 (denoted as *order P31* in Figure 3). The original customer order is 12 products per minute and augments to 24 products / minute at time 300 (Figure 4).

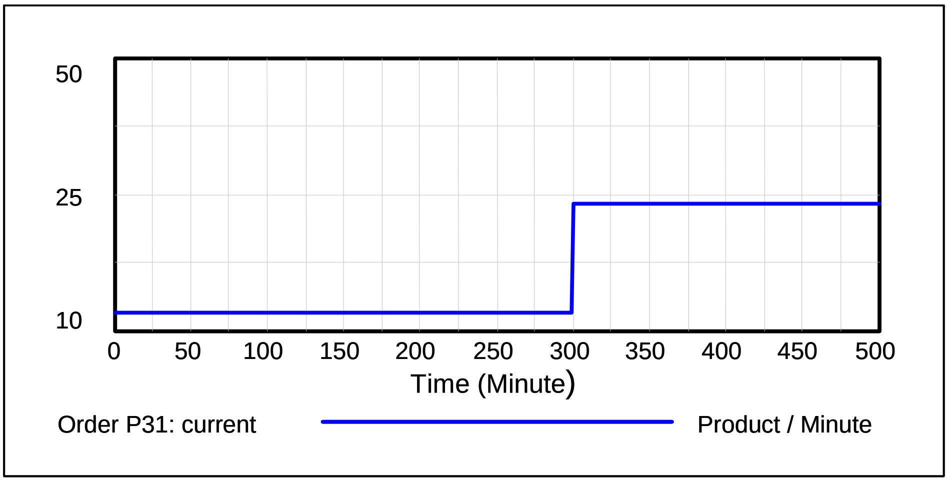


Figure 4: Step Increase in Customer Demand for Product P31

The stocks and WIP for both items P13 and P31 rise immediately after the step increase in demand at time 300 minutes (Figure 5). After the step increase the desired stock for product P31 almost doubles to reach 192 products / minute from the initial value of 96 products per minute (Figure 6). On the other hand, the stock P13 overshoots the desired stock P13 and the former is ahead of the latter by a distinct phase lag of ten minutes which is the value of the coverage time for stock P13 (*desired stock coverage P13*). The stock P13 and desired stock P13 exhibit wilder oscillations than the stock P31 and desired stock P31. Figure 6 also manifests the amplifications of stock P13 to stock P31 which amount to 350%. It is important to remember that the customer demand of P13 (*order rate distributor for P11*) is a random normal distribution (Figure 7) at the contrary of customer demand for P31 which is the linear step input in Figure 4.

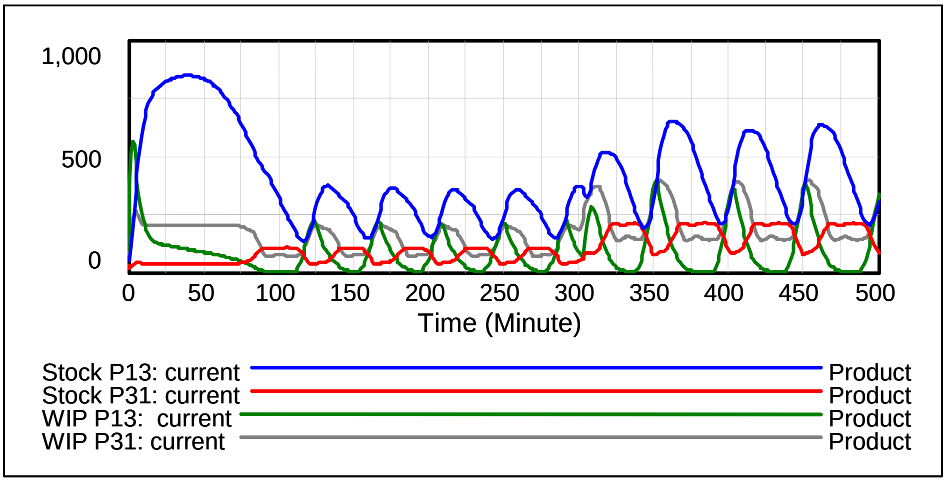


Figure 5: Response of the Stocks and WIP of Lines L13 and L31 to the Step Increase

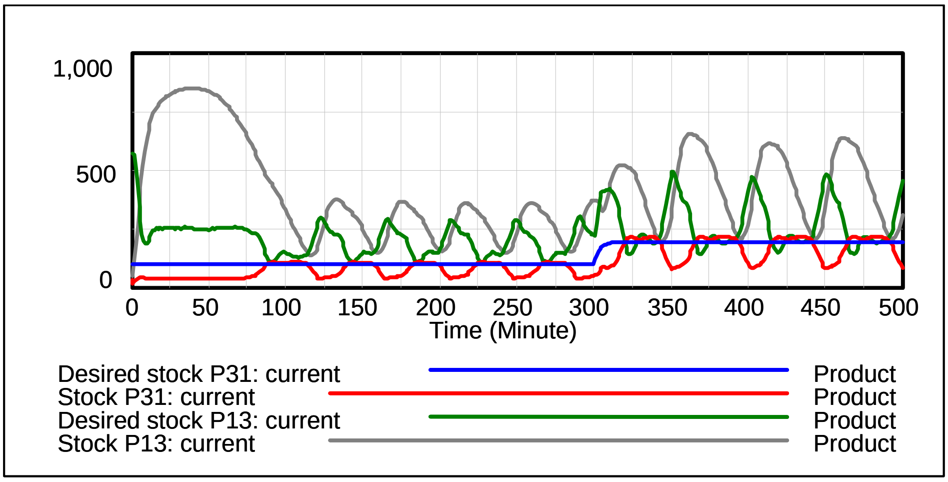


Figure 6: Response of the Stocks and Desired Stocks of Lines L13 and L31 to the Step Increase

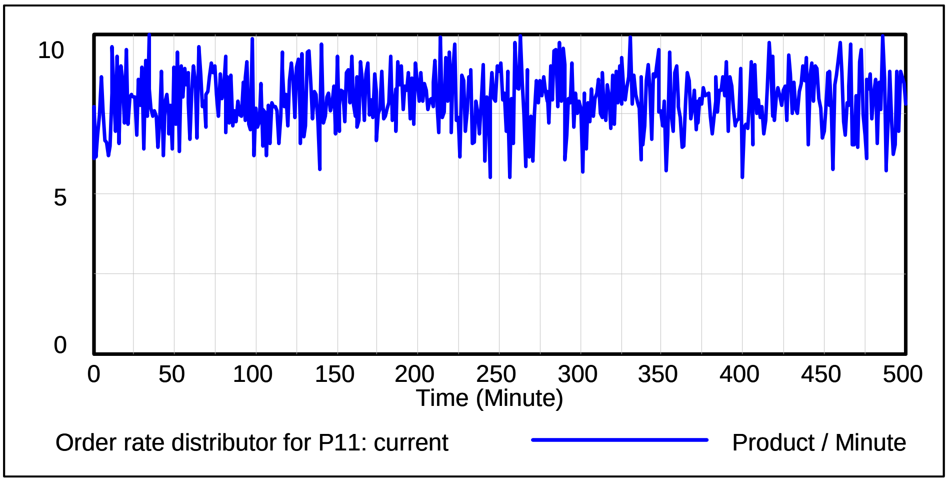


Figure 7: Customer Order for product P13

The customer order rate for product P13 is assumed to be the same as that for product P11, which is a random normal variable: order rate distributor for P11 = RANDOM NORMAL (5, 10, 8, 1, 1). Random Normal is a normal distribution in Vensim with the parameters: min, max, mean, standard deviation, seed.

Therefore, the order rate for items P13 and P31 look like Figure 8 and Figure 9 respectively.

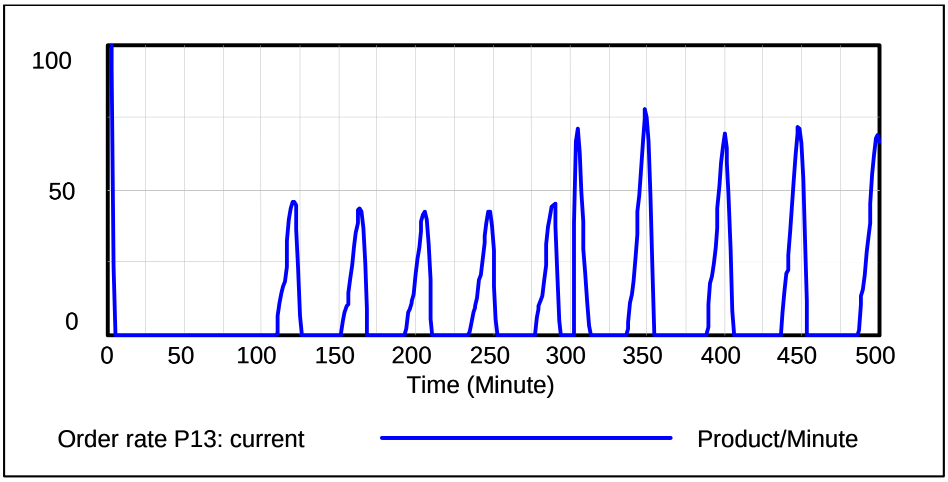


Figure 8: Order Rate P13

When the coupling in the production system is more complex, which means that the production processes (production matrix specifications) and subsequently the logistic channels more intricate, then inventory oscillations will increase. Further simulations demonstrate that when the supply is continuous in time and the supply time increases then the amplitude of oscillations will decrease because the stock is adjusted more smoothly. It is important to note that when the supply and order are both discrete in time and the supply time increases, which means that the reacquisition time (time between the order is placed and the supply is made) will also increase, and lead to larger inventory oscillations because the manufacturer will have to build up a larger safety stock which is one of the triggers of the bullwhip effect.

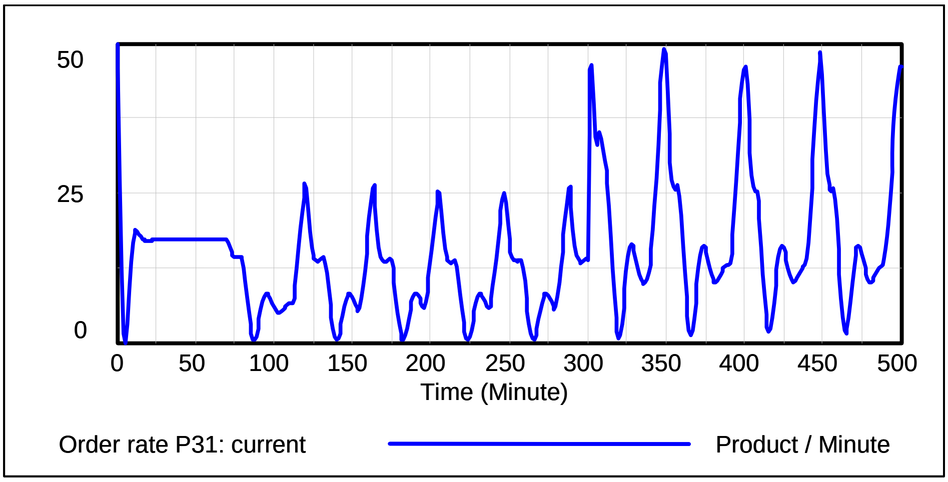
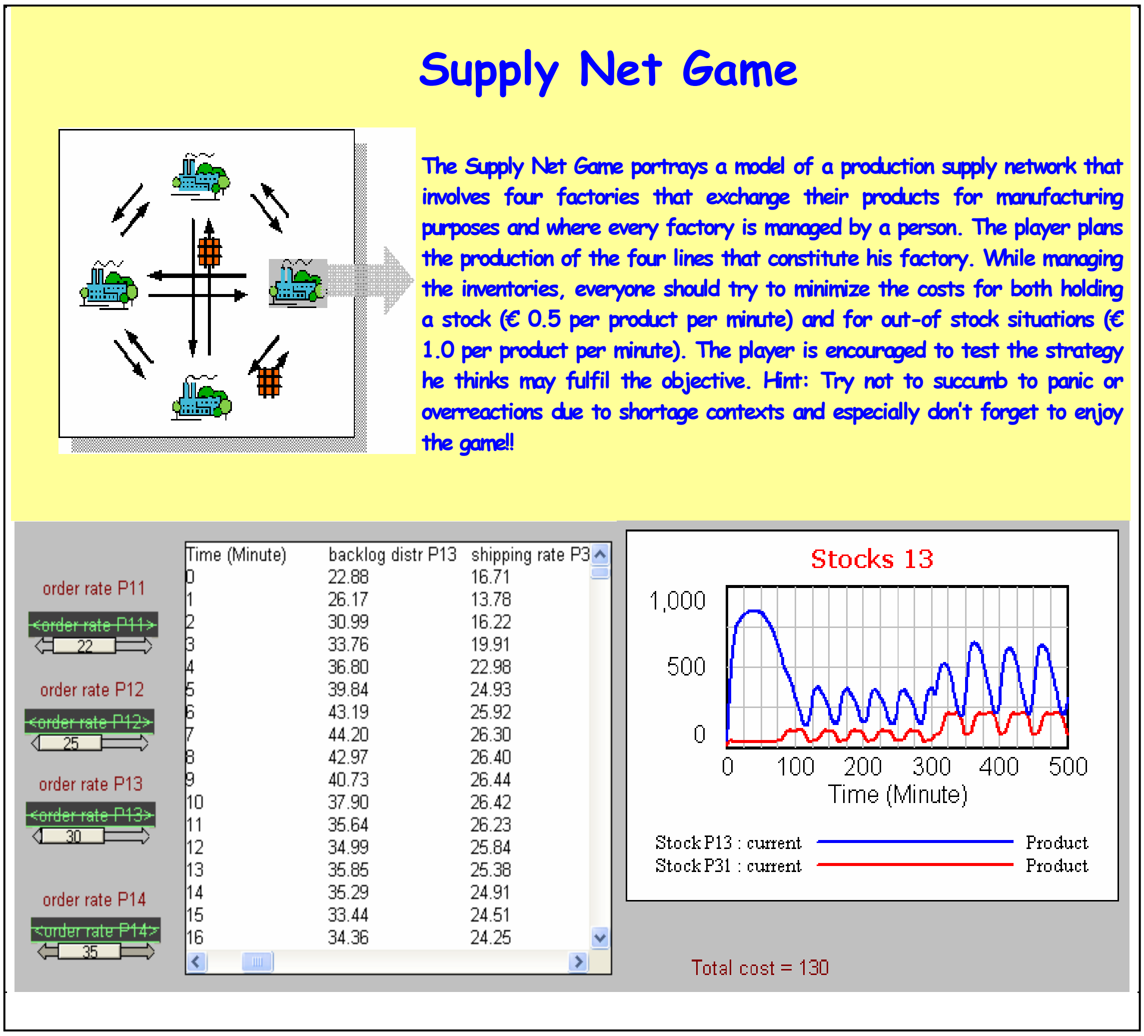


Figure 9: Order Rate P31

Supply Net Game

On the basis of the production network case modeled and simulated with Vensim DSS 32 version 5.4a, the supply net game is designed and played in teams of four persons. Every player is assigned to the inventory management of one factory, which means that he orders, in every simulation period, for the replenishment of the stocks by making four decisions on the amounts of products he needs for the four production lines under his control. For example in factory F1, the person fixes the values of *order rate P11*, *order rate P12*, *order rate P13*, and *order rate P14* in this sequence. Then the next player, who can - like the others - readily see the levels of stocks and WIP of the rest of the team, decides on the quantities of items to request for every one of the products that his factory manufactures. Likewise the two remaining players repeat the procedure. While regulating his inventories, the player should care about not letting them drop too much because there is an out-of-stock penalty of € 1.0 per item per minute and at the same time, impeding the build up of stocks because of the € 0.5 cost for each product on hold. Indeed the objective of the game is for the team to perform the task of inventory management and to pursue the minimization of the total cost. In the fulfillment of the task the players are not allowed to communicate although production nets encourage cooperation and collaboration in teams.



Supply Net Game

The Supply Net Game portrays a model of a production supply network that involves four factories that exchange their products for manufacturing purposes and where every factory is managed by a person. The player plans the production of the four lines that constitute his factory. While managing the inventories, everyone should try to minimize the costs for both holding a stock (€ 0.5 per product per minute) and for out-of stock situations (€ 1.0 per product per minute). The player is encouraged to test the strategy he thinks may fulfil the objective. Hint: Try not to succumb to panic or overreactions due to shortage contexts and especially don't forget to enjoy the game!!

order rate P11
<order rate P11> 22

order rate P12
<order rate P12> 25

order rate P13
<order rate P13> 30

order rate P14
<order rate P14> 35

Time (Minute)	backlog distr P13	shipping rate P3
0	22.88	16.71
1	26.17	13.78
2	30.99	16.22
3	33.76	19.91
4	36.80	22.98
5	39.84	24.93
6	43.19	25.92
7	44.20	26.30
8	42.97	26.40
9	40.73	26.44
10	37.90	26.42
11	35.64	26.23
12	34.99	25.84
13	35.85	25.38
14	35.29	24.91
15	33.44	24.51
16	34.36	24.25

Total cost = 130

Figure 10: Interface of the Supply Net Game for the Player Responsible for F1

Figure 10 displays the interface for the player in charge of the replenishment of the stocks that pertain to factory F1, namely those for articles P11, P12, P13 and P14. The subject sets the levels of the four order rates and has complete information about the values of his stocks, WIP and backlogs as well as those of the entire network. In addition he has knowledge of the incoming orders to F1 (from the customer and the factories) and the shipments sent to F1 from the external supplier and the factories within the net. In order to enable the multi-player interactive simulation game, an appropriate graphical user interface will be utilized. In addition there are thirty simulation periods and the player faces no time pressure.

Discussion and Directions for Future Work

Management games are fun, attractive and entertaining. They provide a diverting atmosphere that tends to break the daily routine of rigorous work for students and professionals alike. However, reports about their effectiveness are mixed (Graham et al. 1992). Some games are so intricate that they are played only once, others bore their users after they have played sometime. Gaming environments generally lack appropriate measurement methods in regard to learning purposes. In spite of these limitations they are being more and more present in the formal curriculum of engineering and management education as innovative forms of teaching that promote accelerated learning.

The paper introduces the supply net game that describes a potential distributed production environment since the game is characterized by the joint-production development between manufacturers analogue to distributed production systems. The supply net game could be utilized to learn the integration and coordination of the general net planning function to the individual member manufacturing plans and processes in the production net; and therefore, the game promotes the acquisition of implicit skills by managers and students. This is thought to represent a source of interest for schedulers in particular and decision makers in general as well as students to “fly” the supply net game. Although it is based on a theoretical model, there are some real-life settings for such production nets especially in the semiconductor industry. Some industries that could potentially benefit from the use of the game, in respect to those where order and inventory oscillations occur are semiconductor & high-tech, commodities (beer, pampers…), automobile, aviation, chemicals or shipping & distribution.

The supply net game is thought and developed in order to be part of a systems thinking intervention in a controlled experiment with subjects randomly assigned to one of two groups. The control group will play the game only whereas the treatment group will have the opportunity to experiment with the elicitation of the mental models of his members with the resort to elicitation methods in order to confirm / reject the hypothesis that stem from the literature. Furthermore, the protocol stresses the performance measurement of learning both within the game, in terms of the cost minimization function, and for learning transfer skills from the "virtual" world to the work place. To do this the subjects will be asked to play a different game with the same issue of inventory management. The supply net game in its actual format does not support any form of communication or cooperation between the players whereas most supply production nets emphasize collaboration. This shortcoming may be relaxed in future work that will include the results of playing the game in teams.

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Appendix A: Determination of *order rate P13*:

Order rate P13 = MAX (indicated orders P13, 0)
Indicated orders P13 = adjustment WIP P13 + desired acquisition rate P13
Desired acquisition rate P13 = MAX (expected order rate P31 + expected order rate dist P13 + adjustment for stock P13, 0)
Adjustment for stock P13 = (desired stock P13 - Stock P13)/time to adjust stock P13
Adjustment WIP P13 = (desired WIP P13 - WIP P13)/WIP adjustment time P13
Desired WIP P13 = desired acquisition rate P13 * expected P13 min OPT
Desired stock P13 = desired stock coverage P13 * (expected order rate P31 + expected order rate dist P13)
Expected order rate P31 = Integral (change in exp orders P31, order rate $P31_{to}$)
Expected order rate dist P13 = Integral (change in exp orders dist P13, order rate distributor for $P11_{to}$)
Order rate distributor for P11 = RANDOM NORMAL (5, 10, 8, 1, 1)

Appendix B: Determination of *order rate P31*:

Order rate P31 = MAX (indicated orders P31, 0)
Indicated orders P31 = adjustment WIP P31 + desired acquisition rate P31
Desired acquisition rate P31 = MAX (adjustment for stock P31 + expected order rate dist P31, 0)
Adjustment WIP P31 = (desired WIP P31 - WIP P31)/WIP adjustment time P31
Adjustment for stock P31 = (desired stock P31 - Stock P31)/time to adjust stock P31
Desired WIP P31 = desired acquisition rate P31 * expected P31 min OPT
Desired stock P31 = desired stock coverage P31 * expected order rate dist P31
Expected order rate dist P31 = Integral (change in exp orders dist P31, order $P31_{to}$)
Order P31 = 12 + STEP (12, 300)