Decision making in Supply Chains using Simulation: A Methodological Approach

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Abstract

The integrated analysis and optimization of today's complex supply chains that combine production and distribution are highly challenging both for the academic/research community and the supply chain partners. The traditional operational research models have been proven incapable to describe the complexity of global supply chains. The development and adoption of simulation based techniques seems to be the only reliable solution for modelling and testing the efficiency of a business system, as they support decision-making by studying simultaneously the effect of various critical factors.

This paper aims to develop a methodological framework that analyses, models and studies the operations of a supply chain using simulation. The proposed framework is based on Petri Nets theory; Petri Nets has been used successfully applied in the literature for a valid mathematical representation of systems with discrete time transitions. Moreover, the combination of Petri Nets with the Activity Cycle Diagrams provides a valid simulation modelling and a quite simple simulation program development.

The framework is presented through its implementation on the supply chain of a Ready Mixed Concrete Unit, located in Northern Greece. Specifically, the probability distributions of the stochastic variables are estimated using historical production data and the simulation model is built using Petri Nets, Activity Cycle Diagrams and the Simul8© software. Then, the validity and verification of the model is tested. Statistical analysis of experiments ('what-if' scenarios) is conducted and optimal decisions are proposed accordingly, regarding technological and resource investment. Finally, the paper provides future research directions.

Keywords: Simulation, Modelling, Decision Making, Petri Nets.

JEL Classification: M11

Introduction

The integrated analysis and optimization of today's complex supply chains that combine production and distribution are highly challenging both for the academic/research community and the supply chain partners. In addition, new management trends ask for the option to examine several alternatives before the selection and implementation of the best solution. The traditional analytical operational research models have been proven incapable to describe the complexity of today's global supply chains and the development and adoption of simulation based techniques seems to be the only reliable solution for modeling and testing the efficiency of a business system.

However, an effective supply chain simulation model should represent the business functions adequately, should determine and calculate critical performance factors and should lead decision-makers to obtain effective decisions that increase the profit of the supply chain [6]. The simulation software needs to be user-friendly and to analyze the business model in an appropriate depth. All the above, in conjunction with the need for quick and accurate decisions, motivated the development of a methodology, which proposes a reliable supply chain simulation model.

Therefore, this paper analyzes the way that real business problems were faced and decision making processes were supported, with the aid of simulation methods. In particular, the next chapter presents a literature review in relative research work, while in chapter 3 we introduce the methodological framework. The proposed framework is based on Petri Nets theory; Petri Nets has been successfully applied in the literature for a valid mathematical representation of systems with discrete time transitions. The combination of Petri Nets with the Activity Cycle Diagrams (ACDs), a technique that is widely used for the graphical representation of entities in discrete event systems, provides a valid simulation modelling and a quite simple simulation program development. The framework is presented through its implementation on the supply chain of a Ready Mixed Concrete Unit, located in Northern Greece in chapter 4, along with the main results of the simulation. The paper concludes with suggestions that arise from the results' analysis and provides future research directions.

Literature Review

The work of Calderon & Lario (2007) provides an extensive and general literature review on supply chain simulation, analyzing 70 relative papers for the period of 2000-2006, and presenting different simulation techniques that have been applied in various supply chains. A systematic methodological approach for supply chain simulation is described in the work of van der Zee & van der Vorst (2005). They suggest among other that future studies should focus on a particular sectors or supply chain types to develop tailored simulation tools. To this end, the methodology proposed in this paper is implemented on a ready mixed concrete supply chain. A variety of simulation techniques have been applied for the improvement of coordination and operation of the production and distribution of ready mixed concrete. Alkoc και Erbatur (1998) used Micro CYCLONE in order to simulate production functions of ready Mixed Concrete (RMC). Their objective was to improve productivity and optimize resource management, using sensitivity analysis. In 1998, the same research group studied thirteen RMC production models to find how resource allocation is affected in a cyclic procedure, again with the use of Micro CYCLONE. Sawhney et al. (1999) developed a Petri Net model in order to simulate RMC production, targeting at the synchronization of daily production with daily delivery at construction sites. Zayed & Halpin (2001) used also Micro CYCLONE to model and simulate an RMC industry. Their study analyzed alternatives for resource management. Wang, et al. (2001)

studied the delivery procedure of ready mixed concrete to sites and how it could be improved, with the aid of a simulation model based on @Risk software and historical enterprise data from a company in Singapore. Their results include the optimized time between truck arrivals, with optimization criteria the queue length and the productivity utilization factor. Tang et al. (2005) developed a concrete production simulation model, which serves multiple destinations and uses multiple transport trucks. A software called RMCSIM was developed in order to simulate one day of activities.

The contribution of this paper stem from its holistic study that takes into account all factors reported in the literature including production and delivery cost of ready mixed concrete as well as their interdependencies. This approach assures a comprehensive outlook of the supply chain, a direct confrontation of real problems and the substantial support of business decisions.

Methodological Framework

One of the basic prerequisites of a realistic simulation model that can represent adequately a system is the identification of the state variables that describe its behavior. In addition, the development of a valid simulation model is a difficult task due to the complexity of modern global supply chains. For this reason, the suggested framework first analyses the sub-models of the chain, and then combines them to build the global model. The scientific credibility of the modeling procedure was assured through the use of Petri Net theory.

Petri Nets is a fundamental procedures' modeling technique (van der Aalst, 1998). Classic Petri Net was discovered by Petri (Petri, 1962). Despite their simplicity, Petri Nets are not abstractive and they can describe complex business functions (Costa & da Cunha, 2006). Petri Nets have been used in system control, in business process re-engineering and in the development of Workflow Management software (Barber et al., 2006). Timed Petri Nets have been suggested as reference models into the design of simulation models (Barber et al., 2006).

The structure of a classic Petri network includes the main graphical elements of "Place", "Transition", "Arc" and "Token". The transition of the token from one place to another always occurs through a transition and an arc. Thus, for example, the procedure of ready mixed concrete production and delivery could be visualized as in Figure 1. This figure illustrates that the beginning of the workflow is an order input, meaning an input of a token (solid black circle) into the place "Order received". Afterwards, the token transfers through the transition "Prepare Concrete" and through the route suggested by the arc (arrow), to the place called "Concrete ready". All the sub-functions of product delivery process are included in the transitional element "Prepare Concrete". Once the token reaches the place "Order delivered", the order is considered complete into the supply chain.

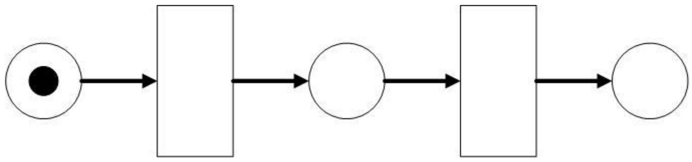

Figure 1: Petri Net representation of a simple procedure of production, transport and delivery of concrete

Petri Nets are combined with ACDs for transferring the model into the simulation software, a technique that has been proven effective by itself and in conjunction with Petri Nets (Tiwari et al., 2001).

Known probability distributions are selected to be the inputs of the simulation model, so as for the model testing to be possible. The validity of the model is made through various methods, as the widely known and reliable X^2, which is used both for discrete and continuous data. The simulation model is programmed with suitable simulation software, e.g. Simul8.

The stage of model validation and verification is critical. Regarding the verification, a usual technique is the model testing with known historical data, so that the deviation from the known result can be examined. As the validation is concerned, there are two tests that should take place. First, the "natural" validity test to assure that the model represents the system at least conceptually. This test is usually completed with the aid of experts and observations. The second test is the statistical validity test, which includes quantitative comparison of the simulation model and the real system. A relative "guide" for model validation and verification can be found in the work of Law & McComas (1990). Finally, the factors that are considered to be important for the study are identified and the appropriate number of experiments and "what-if" scenarios is designed. Suggestions and factors' correlation emerge from these experiments. Statistical analysis methods could then model the impact of a factor on one or more outputs.

It is obvious that the analysis, modeling, simulation, and study of an industrial unit supply chain operation comprises of a series of discrete stages that compose the methodological framework. These stages/steps are:

1 Real Problem Identification
2 Data Analysis
3 Model Development Using Petri Nets & ACDs
4 Historical Data/Distribution analysis
5 Simulation Model Programming
6 Model Verification and Validation
7 Model Simulation with Statistical Experiments
8 Scenario Assessment/What-if Analysis
9 Result Analysis/Suggestions

Implementation of the Methodological Framework

The proposed framework was implemented into a particular company located in North Greece. Following the steps of the methodology described before, the design of the simulation model begins from the real problem identification. The main objectives, as it was posed by the company’s management is the calculation of cost and volume of raw material needed per product type, the estimation of production and delivery cost and the estimation of optimum number of vehicles used for transport and deposition of the final products.

In order to confront the problem, a real data and process analysis was followed. The outcome was that the production starts with an order for a quantity of a particular concrete type. The company uses only sand, water, and cement as raw materials, which are mixed in different proportions to produce the three different concrete types. The volume of raw materials is assumed to be infinite, since the company has never faced a supply shortage. Also, it is assumed that the orders are served within the day using a FIFO rule. Afterwards, the ready mixed concrete is loaded on trucks, which transfer the product to the quality control process (checkpoint). This process is standardized and the product’s loss is not considered to have an effect on the supply chain. Also, the waiting time for a resource (truck) arrival to complete an operation is negligible. From the checkpoint, vehicles transfer the product to the delivery sites, which are divided into three distinct zones, according to the sites’ distance from the industry. The delivery of the product occurs at the final destination sites, with the aid of special vehicles (pumps), and so the order is complete. The stochastic variables are the order quantity for each concrete type while the mixing time, the number of vehicles and the order arrival frequency are systems parameters.

The design of the supply chain model is based on Petri net theory. At first, sub-models are developed. Such a sub-model for the Mixing Process is depicted in figure 2. This figure particularly represents the token “Order” positioned in the place “Order Ready” and the tokens “Aggregate”, “Sand” and “Cement” positioned in the respective places. These tokens are being transformed and transferred through their collection to the place “Raw Material Collection”, where they are ready for mixing process. The transition “Mixing” collects raw materials required for order production, so as to create the amount of cubic meters needed. As a result, the order reaches “Production in m^3” place in the form of order quantity token, ready to be loaded on suitable trucks.

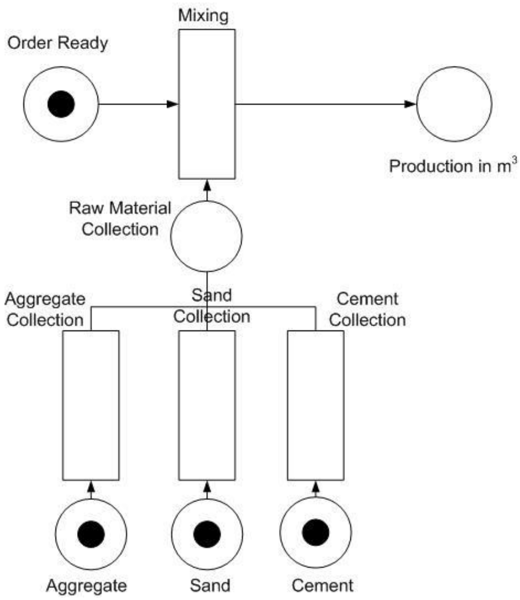

Figure 2: Perti Net representation of the Mixing Process Sub-model

This figure represents the production process for anyone of the three different concrete types that the company produces. The programming model for the entire supply chain was created through the synthesis of all the systems' sub-models using ACDs. The result, which is the supply chain's simulation model, is illustrated in figure 3.

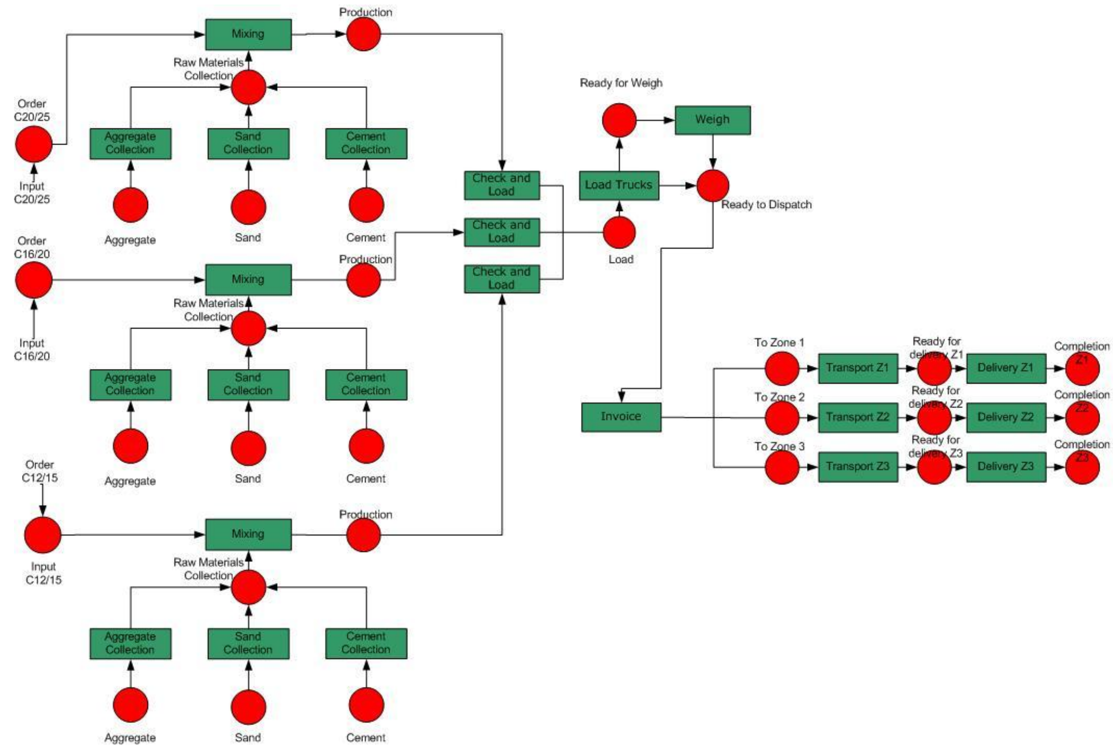

Figure 3: Supply Chain's Programming model, ACDs representation

Starting from left to right, this figure depicts the production, quality control and customer delivering processes of ready mixed concrete.

During the methodological step of historical data collection, orders for the year 2007 were collected. These data are analysed using statistical software (BestFit, ver. 4.5, Palisade) to select the best fitted input distributions for the stochastic variables. These distributions for concrete types C 20/25, C 16/20, C 12/15 are [Weibull(1,8535; 105,75) Shift=-9,1543], [Weibull(1,6512; 87,572) Shift=-3,7220], [Expon(23,863) Shift=-0,095837] respectively.
Then, combining all the steps of the proposed methodology described above, the simulation model was programmed employing the Simul8® software.

The verification and validation of the model was mainly based on the economical and technical data of the year 2007 and on the experience of the company's executives. As shown in table 1, the deviations of simulation results and real data are insignificant for all products.

Table 1: Simulation results and Historical data Comparison

A/A	Simulation results	Value (m^3)	Historical data (m^3)	Deflection
1	Annual C 20/25 Production	20977,83	21150,00	0,81%
2	Annual C 16/20 Production	18585,76	18608,50	0,12%
3	Annual C 12/15 Production	5926,65	5942,00	0,26%

The physical validation was based on observations made by the company that confirmed the correct response of the model. Statistical validation was checked and confirmed by executing goodness-of fit test of a hundred (100) random simulation runs in the normal distribution.
Afterwards, the execution of "what-if" scenarios was made; the effect of several modifications on production, load, quality control and delivery time was examined.

Statistical experiments were then designed and executed, in order to check the effect of five different factors (order quantity, order arrival, mixing time, number of trucks and number of pumps) in three different levels. More particularly, the number of "Trucks" was examined on the values of 10, 12 & 14, the number of "Pumps" on 2, 3 & 4, "Mixing Time" on 0.00236, 0.00295 & 0.00354 days, "Order Arrival" on 0.8, 1 & 1.2 days and "Order quantity" on C, 1.2C και 1.3C, where C is the quantity values of historical data, 1.2C and 1.3C the latter quantity's mean increased by 20% & 30% respectively. Since the number of executions for a full experiment was large and time consuming (3^5=243 experiments), an orthogonal vector of 27 experiments was chosen, with the aid of MiniTab statistical software, shown in table 2.

Table 2: Experimental Orthogonal Vector design

Experiment	Trucks	Pumps	Mixing time	Order arrival	Order quantity
1	10	2	0.00236	0.8	C
2	10	2	0.00236	0.8	1,2 x C
3	10	2	0.00236	0.8	1,3 x C
4	10	3	0.00295	1	C
5	10	3	0.00295	1	1,2 x C
6	10	3	0.00295	1	1,3 x C
7	10	4	0.00354	1.2	C
8	10	4	0.00354	1.2	1,2 x C
9	10	4	0.00354	1.2	1,3 x C
10	12	2	0.00295	1.2	C
11	12	2	0.00295	1.2	1,2 x C
12	12	2	0.00295	1.2	1,3 x C
13	12	3	0.00354	0.8	C
14	12	3	0.00354	0.8	1,2 x C
15	12	3	0.00354	0.8	1,3 x C
16	12	4	0.00236	1	C
17	12	4	0.00236	1	1,2 x C
18	12	4	0.00236	1	1,3 x C
19	14	2	0.00354	1	C
20	14	2	0.00354	1	1,2 x C
21	14	2	0.00354	1	1,3 x C
22	14	3	0.00236	1.2	C
23	14	3	0.00236	1.2	1,2 x C
24	14	3	0.00236	1.2	1,3 x C
25	14	4	0.00295	0.8	C
26	14	4	0.00295	0.8	1,2 x C
27	14	4	0.00295	0.8	1,3 x C

The variance diagrams (figure 4) illustrate that there is no strong correlation for the values that were tested. The increase of quantity and arrival of orders results to a small increase of the order completion time, while small changes of mixing time, number of trucks and number of pumps do not have a statistically significant impact. The fact that in experiment No 15 there is a significant increase of order completion time (346% for delivery zone 2) was important, since this means that if the company retains truck and pump resources (12 trucks and 3 pumps) and at the same time an increase of order arrival (0.8 days), order quantity (+30%) and mixing time (+20%) occurs, then a significant customer service problem might emerge.

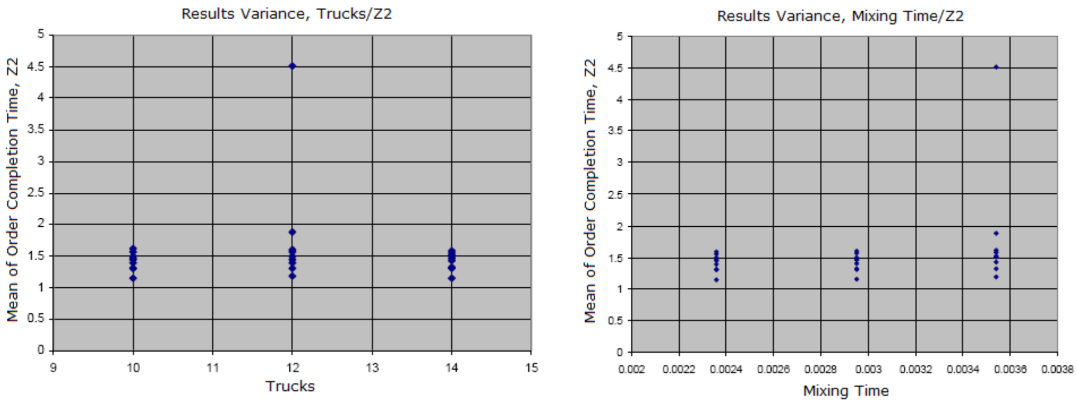

Figure 4: Variance Diagrams of Mean Order Completion Time for various levels of number of Trucks and Mixing Time (Zone 2)

Following this, it was decided that an additional experimental set of values should be examined. Changes that "Trucks", "Pumps" and "Mixing time" would have on the order completion time in delivery Zone 2 were examined, since this zone includes the largest proportion of order delivery. From the new variance diagrams (figure 5), a strong correlation does not appear between vehicle number and order completion time, but between mixing time and the later. In particular, the order completion time increases exponentially with the mixing time.

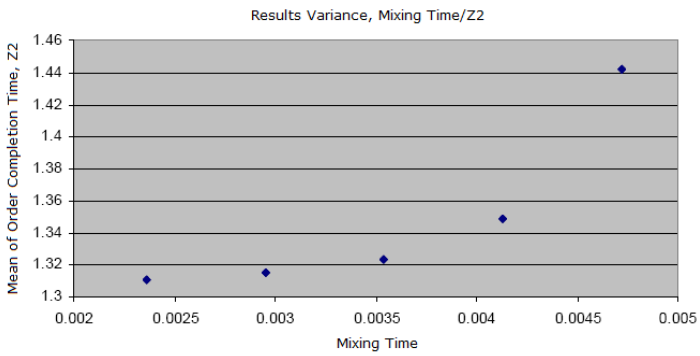

Figure 5: Variance Diagramn of Mean Order Completion Time with Mixing Time (Zone 2)

Regarding small values of mixing time, the new experiments agree with the results of the previous experiments, that there is not a significant increase in order completion time. This means that the company will not have obvious advantages by investing in technology that would decrease the mixing time by 20%. Nevertheless, if the mixing equipment fails and this result to a mixing time increase of over 50%, then the company faces considerable delays of product delivery.

By implementing the proposed methodological framework for the simulation modelling of the particular company, several conclusions emerged. They are described in the following chapter.

Conclusions – Future Work

The proposed methodological framework forms a flexible tool for simulation model development, not only for a ready mixed concrete industry, but also for a production unit’s supply chain. The discrete stages/steps approach of the real problem confronts simulation model development in a way that it can be implemented in various supply chains, independently form the production, quality control and delivery process, and no matter what the final product is. The use of Petri Net and ACD techniques are a significant contribution to this direction and can ease the model design and assure its mathematical validity. Also, the framework is not restricted to the use of a particular simulation program and provides the possibility for the user to use its own scientific methods for model verification and validation. The steps of statistical experiments and scenarios’ assessment integrade the framework, providing significant support to the decision-making processes. The result is the design of an effective supply chain simulation model, which can simultaneously calculate the efficiency of the network, illustrate the real-world process, increase the chain’s profit and forms a valuable strategic tool for contemporary decision-makers.

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