Second Asia International Conference on Modelling & Simulation

Supply Chain Simulation in the ECLIPS Project

Yuri Merkuryev
Galina Merkuryeva
Riga Technical University
Kalku Street 1
LV-1658 Riga, Latvia
merkur@itl.rtu.lv
gm@itl.rtu.lv

Jonas Hatem
Bram Desmet
MÖBIUS Ltd.
Kortrijksesteenweg 152
9830 St.-Martens-Latem, Belgium
Jonas.Hatem@mobius.be
Bram.Desmet@mobius.be

Abstract

ECLIPS is a European research project addressing the state-of-the-art in supply chain management. It is aimed at minimization of total inventories through the whole supply chain, taking into account a product life-cycle, from its introduction into market, through a maturity phase, and finally to an end-of-life phase. In order to achieve this goal, simulation is used intensively in the ECLIPS project. From one hand, it supports supply chain management processes (e.g., optimization and decision making), thus providing conditions for minimization of inventories. From another hand, simulation provides a platform for testing algorithms and tools, being developed within the project. The paper discusses different aspects of using simulation in the ECLIPS project.

1. Introduction

ECLIPS is a European research project addressing the state-of-the-art in supply chain management [1]. Its abbreviation stands for 'Extended Collaborative Integrated Life Cycle Supply Chain Planning System'. Six partners from the industrial, academic and consultancy sectors have teamed up to work together on this project. These are a Belgian consulting company MÖBIUS, specialized in business process management and supply chain management, a French services company EURODECISION that specializes in supply chain optimisation, a young Belgian IT services company LoQutus with key expertise in integration of data, applications and processes, a Latvian academic partner Riga Technical University that is responsible for bringing and further development of the academic state-of-the-art in demand forecasting and simulation-based supply chain multi-level planning, as well as 2 industrial partners that are providing possibilities for checking developed algorithms and tools in a real-life environment: a German company Huntsman Advanced Materials that is part of the Huntsman group, world's largest privately held chemical company, and a Czech company PLIVA-Lachema Diagnostika of a pharmaceutical manufacturer PLIVA.

By combining their individual strengths in the project covered area, the partners are committing to answer today's supply chain challenges such as globalization, increased product diversification and shortening product life-cycles.

The ECLIPS project is aimed at minimization of total inventories through a supply chain, taking into account a product life-cycle, from its introduction into market, through a maturity phase, and finally to an end-of-life phase (see Fig. 1).

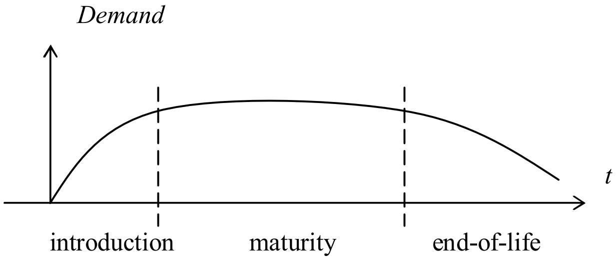

Figure 1. Product life-cycle

Simulation is intensively used in ECLIPS. Firstly, it serves for simulation-based optimization of supply chain management parameters during the maturity phase, providing possibilities for realistic modelling of supply chain operation [2]. Secondly, it supports analysis of switching conditions to/from the maturity phase that is necessary for making decisions on choosing appropriate supply chain management algorithms. Finally, simulation provides a platform for testing algorithms and tools, being developed within

978-0-7695-3136-6/08 $25.00 © 2008 IEEE
DOI 10.1109/AMS.2008.39

the project. These aspects of using simulation in the ECLIPS project will be discussed in the following parts of the paper.

2. Simulation-based multi-echelon cyclic planning and optimization

Multi-echelon cyclic planning and optimisation at the product maturity phase [3] is based on integration of analytical and simulation techniques. Analytical techniques are used to obtain initial planning decisions under conditions of stochastic demand and constant or stochastic lead time. Simulation techniques extend these conditions to backlogging and capacity constraints. In this case, the multi-echelon cyclic planning problem is formulated as a simulation-based optimisation problem that is aimed to determine optimal parameters of cyclic schedules at different supply chain echelons. Within simulation-optimisation scheme a simulation model is used in traditional way with a simulation optimiser in negative feedback.

The following are main assumptions that define the scope of a network simulation model: (1) Demand is considered to be uncertain, while predicting the demand mean value, its variations are estimated by a standard deviation of the demand per period; (2) Lead times of the processes are considered to be variable and/or stochastic; (3) Capacities are limited, or finite; (4) Demand is considered to be independent only for customised products; (4) Full backlogging is allowed; (5) Planning is performed for a finite planning horizon.

A network simulation model itself is built as process oriented model with a one-directional flow of goods. It is presented by two types of atomic elements: stockpoints and processes. Any process with a stockpoint connected with a directed arc defines a stage. A set of stages that belong to the same network level creates an echelon. The supply chain generic network is constructed from basic sub-networks, such as linear, convergent and divergent. The replenishment and delivery logic for sub-networks is defined.

Average total cost of a cyclic schedule that includes a sum of set-up, ordering and inventory costs is defined as the main network model performance indicator. However, in order to avoid unconstrained minimization of the total cost, a service performance measure such as order fill rate is introduced as an additional performance measure to be analysed in simulation optimisation experiments. As controllable variables, lengths of replenishment cycles and order-up-to-levels for stock points are defined in the model.

The simulation environment for cyclic planning and optimisation is built in the ProModel simulation software. It provides automatic generation of the simulation model of a generic network described in the Excel format by using the ProModel ActiveX technology; as well as definition of an initial point for simulation optimization using analytical calculus, and realization of the simulation-based optimization algorithm to find optimal parameters of a multi-echelon cyclic schedule and optimise network simulation model performance measures.

The main idea of a cyclic schedule is to use fixed order intervals at each stage or echelon while synchronizing these cycles in a multi-echelon supply chain to keep cycle inventory and order costs low. For that, additional cyclical replenishment constraints that define cyclic policy, e.g. power-of-two policy, are introduced. The main blocks of the environment, its architecture and examples of network simulation models are given in [3].

3. Simulation-based analysis of the optimality gap between planning policies

In practice, periodic order review policies are preferable for a multi-product and a multi-location stock case, as they are easier to control, and reducing administrative costs could reduce higher inventory costs. However, when product demands are dynamic, e.g., in the product life phase-in and phase-out stages, flexibility in spacing of planning periods could result in lower total costs for the non-cyclic planning policy. Evaluation of the difference between the performance measures of cyclic and non-cyclic planning policies in supply chains gives possibilities to determine efficiency of a specific planning policy at the different stages of the product life, and provides a control mechanism that will allow smooth switching from cyclic planning to non-cyclic one. Simulation is defined [4] as the most suitable technique to investigate the optimality gap between performances of cyclic and non-cyclic planning policies in conditions of demand variability and uncertainty for switching to cyclic planning.

Simulation scheme for optimality gap evaluation is introduced in [4] and presented in Fig. 2. Here, for a cyclic policy its optimal parameters received from the above optimisation problem are used. Simulation experiments are also applied to reveal significant parameters affecting the difference between costs of cyclic and non-cyclic schedules.

Cost comparison requires careful analysis to ensure that the differences being observed are attributable to actual differences in performances and not to statistical variations. This is done by performing multiple simulation replications for each planning policy and comparing average results received from replications. Confidence level is defined at least at 95%. Statistical hypothesis for making these comparisons are introduced and tested. An additional cost of a cyclic schedule (ACSS) is estimated by the mean value and its confidence interval. The width of the ACSS confidence interval will be used to indicate accuracy of the ACCS estimate.

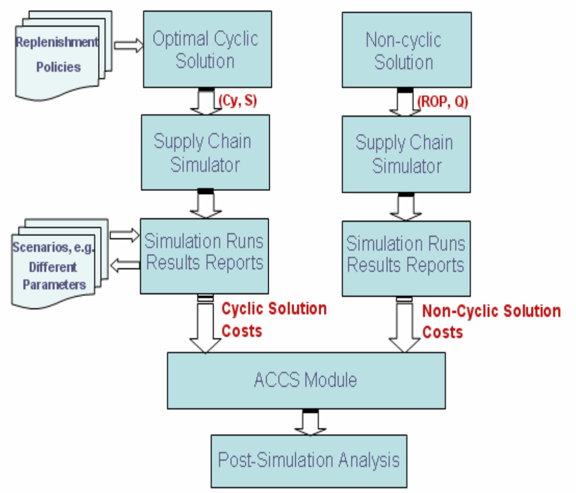

Figure 2. Optimality gap evaluation through simulation experiments

4. Validation through simulation

Another goal of using simulation is the validation of algorithms and tools, being developed within the project. To attain this goal, a simulation software has been built and business cases have been simulated. This chapter will subsequently discuss the simulator requirements and assumptions, the concepts behind the simulation, the simulation process, a theoretical case and an anonymous business case.

4.1. Building simulator

4.1.1. Requirements and assumptions. Before the simulator was built, an exercise was performed to set the goals and requirements it has to meet. The results of this reflection can be easily summarized as follow: build a multi-echelon inventory simulator which can be used to validate research results and which is adaptable and flexible. This last criterion aims at simulating new cases without a lot of effort and being able to easily incorporate new/different concepts.

The simulator has initially been built around the following assumptions:

1. Independent customer demand can enter at any echelon in the modelled supply network and is given as either a deterministic variable or constant time-series.
2. Lead times of processes are considered to be known and either constant or uncertain.
3. Inventory can be managed with a reorder point policy (ROP) or periodic order review policy (POR).
4. Finite capacity per product (*a stockpoint*) and a collection of stockpoints (*a stockpoint container*).
5. Capacity can be limited at a process level.
6. Multiple products can be handled at the same physical location. Each product has its own inventory policy and parameters.
7. Undelivered orders are backlogged.

The first assumption about the use of time-series for demand has two mayor advantages over pulling values out of a distribution. At first, a simulation run can be re-performed with exactly the same demand data for process tracing. This is only possible with the random number generator which can be seeded with the same values (*seeds*). Often the seed is based on the current time, and thus changes continuously. At second, using a pre-defined demand variation permits to easily separate the impact of lead-time variability on the network from the impact of demand variability. This could be a huge advantage in some research-situations. The mayor drawback of this approach is that the creation of demand time-series creates some (manual) overhead. This eventual problem has been overcome with a separate demand generator.

The second assumption implies that lead times are constant or normally distributed with a certain average and deviation. Of course, negative lead times are not allowed.

The third assumption offers the possibility for using either a cyclic or a non-cyclic policy. These policies have been modelled with fixed parameters. For the cyclic (POR) policy, the most important ones are cycle length and order-up level, and for the non-cyclic (ROP) policy these are the reorder point and the order lot size. The detailed discussion of those parameters are not the subject of this paper, but good references can be found, e.g., in [5].

The finite capacity assumptions (fourth and fifth) are at stockpoint and process levels. The concept of stockpoints and processes is explained in more details in the *Simulation concepts* part of this chapter.

The sixth assumption about multiple products is related to the third, fourth and fifth assumptions. This assumption is self-explanatory.

The last assumption is about backlogging. Different policies for dealing with this subject exist. For instance, one possibility is that orders which cannot be delivered could be partially delivered and the remaining quantities would be in the backorder (*a partial delivery policy*) Another possibility is that the full quantity should be delivered (*a full delivery policy*). The discussed simulator currently supports both of these policies.

4.1.2. Choice of a simulation tool. On the market, there are different tools to support simulation of supply chains. Of the most known are WITNESS (by Lanner Group), ARENA (by Rockwell automation) and Enterprise Dynamics (by Incontrol). Some smaller (or more niche) players exist, such as ProModel (by ProModel Corporation).

For developing of the considered simulator, Enterprise Dynamics was judged as the most appropriate tool, mostly because of the relative ease of use and the flexibility it offers to the programmer.

4.1.3. Simulation concepts. Enterprise Dynamics uses so called "atoms" as the smallest component available in a model. The tool provides a huge library of them to create all sorts of simulations. If a certain function is unavailable as an atom within the tool, users can create those themselves and add them to the library. Unfortunately, no standard atoms were available/useful for the discussed simulation. Atoms have therefore been created especially for the ECLIPS project, inspired by already existing atoms made by MÖBIUS in the past.

The network has been modelled according to the process-stockpoint methodology. Hereby, for each node, a process (which captures the use of time and the eventual function of "assembly") is linked to a stockpoint (which stores a certain product). Graphically, a process is represented with a rectangle, and a stockpoint - with an inverted triangle. The connection between them is represented with a line. A simple example can be seen in Fig. 3.

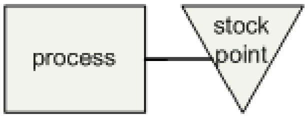

Figure 3. Process and stockpoint symbols

For each stockpoint, a stock keeping policy can be defined, according to the assumptions given above. The same goes for processes, which are based on a bill of resources, which is lined to the bill of materials for the products running over the resources.

Different process-stockpoint combinations are linked to form a network. The network starts with stockpoints which contain only inventory of the start products or materials. At the end of the network, "demand" pulls inventory from the network and represents customers. Different echelons are possible within the network. Sometimes, assembly or distribution is possible. An example of this concept is given by a graph in Fig. 4.

If multiple products are taken into account, such visualisation gets very complicated. For this reason, stockpoints at the same site can be grouped together in a container (the same goes for processes). In Figure 5, the different stockpoints are given letters for each product. In the process, different assembly formulas are given according to the bill of materials of the relevant products.

A finite warehousing capacity can be taken care of by implementing constraining rules on the stockpoints or containers. Finite process capacities can be handled by limiting the number of items that can be started each day and/or not being able to produce more than a certain number of items simultaneously.

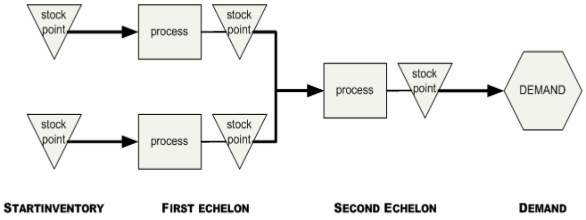

Figure 4. Sample network

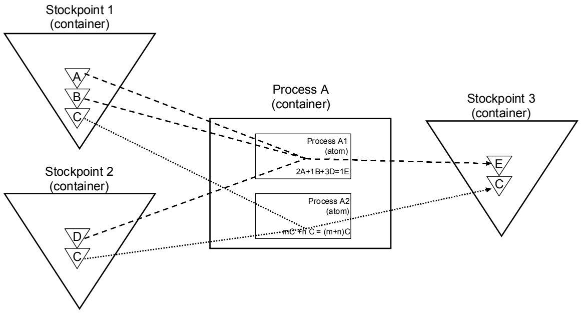

Figure 5. Multi-product concept

3.1.4. Simulation process. The simulation process consists of six tasks. They are graphically represented in Fig. 6. Each of those tasks has been implemented in the environment most suitable for its purpose. Where flexibility was needed, a commonly used spreadsheet was used. Where simulation efficiency was primordial, the dedicated package was used. Let us discuss briefly implementation of each task.

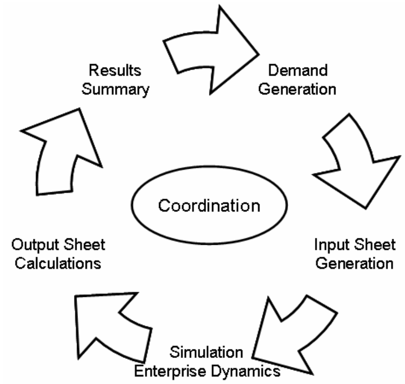

Figure 6. Simulation process

Demand Generation. The process of a simulation replication starts with demand generation. Each endpoint gets a generated demand with its requested parameters (averages, CODVAR (*a coefficient of demand variation* that is calculated by dividing the standard deviation of the demand by the average demand), etc.).

Input Sheet Generation. At the next step, the generated demand is inserted into an input sheet ("network dynamics"). This input sheet contains description of the network ("network statics") and necessary formulas to adapt values of requested inventory policies.

Simulation in Enterprise Dynamics. The simulation consists of the following 3 parts:

1. building a simulation model according to specifications in the input sheet;
2. the simulation itself;
3. generation of output flat files.

An example of the visual representation of a process and stockpoint is given in Fig. 7.

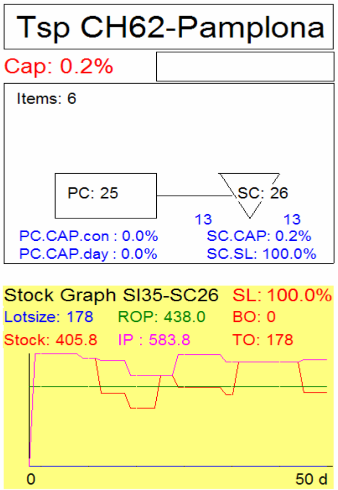

Figure 7. Visual representation in the Simulator

Output Sheet Calculations. The output calculation sheet picks up different flat files generated by the simulator software. The sheet calculates KPI's *(key point indicators)* such as costs, average inventory levels, etc.

Summary Results. The KPI's are pulled from the output sheet and saved in a summary table with simulation results.

Coordination. The whole process is coordinated to assure a seamless and controllable environment. The coordination task takes care of starting the process again for the requested number of replications, CODVARs, etc.

4.2. Theoretical case

The first simulation tests have been performed on a five echelon linear case (Fig. 8) where all echelons had the same parameters (lead time = constant = 2 days; demand = constant = 100 items each period; cycle = 7 days or order lot size = 7 days worth of demand).

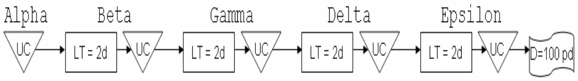

Figure 8. Linear case

The order-up levels were set at 900 units and reorder point levels were put at 200 units for replications without variation.

Three different policies have been simulated:

- non-cyclic (ROP) policy;
- cyclic policy without synchronisation;
- cyclic policy with synchronisation.

Target service levels were set at 95%. Synchronisation in cyclic policies has to deal with the timing of the starts of the cycles. Unsynchronized cyclic policies have cycles that start at the same time. Synchronized cyclic policies have cycles that start at different moments depending on lead times. Under this last policy, products are "handed over" from one process/stockpoint to the next one.

In the simulation, effects of the different replenishment policies were clearly visible. In the non-cyclic policy, the ordering started each time a predefined replenishment level was reached. In the cyclic policies, orders started at the same time, or with a (predefined) lag. The screenshot in Fig. 9 gives an overview of the final simulation model.

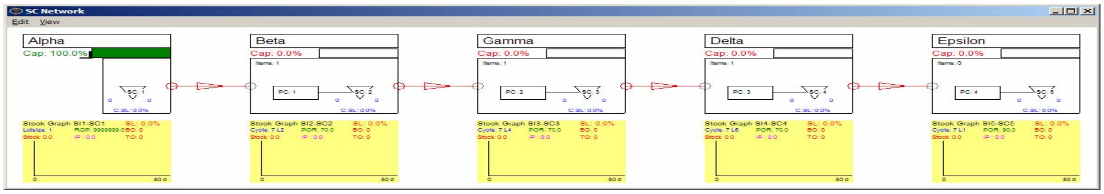

Figure 9. Screenshot of linear case simulation

The three different policies were simulated different times for different CODVARs and with and without lead-time variability.

Simulation results in Fig. 10 reflect a situation with zero lead time variability. Similar curves were received when lead-time variability has been set on 25%.

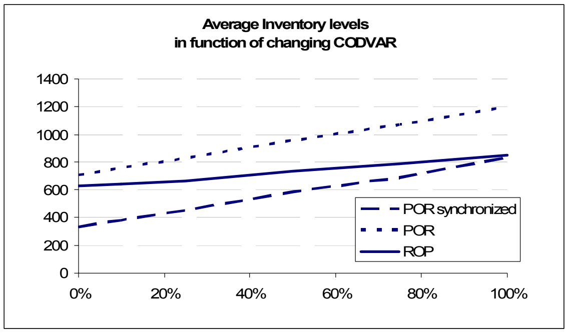

Figure 10. Average Inventory levels in function of changing CODVAR

The following conclusions can be made for the considered case:

1. The formulas used to calculate the inventory marginally put more inventories if variation augments in the cyclic case compared to the non-cyclic case.
2. Synchronising the network when using a cyclic policy yields remarkable benefits.
3. The break-even point between the synchronized cyclic policy and the non-cyclic policy lies somewhere near a CODVAR of 100%.

Other theoretical cases (assembly, distribution, etc.) are currently under investigation.

Once the discussed case was "cracked", confidence in the simulator was high enough to test a real life business case.

4.3. Business case

A large chemical company was interested in knowing what the impact would have were it is switching from a non-cyclic policy to a cyclic replenishment regime. A small part of their supply network was selected for this analysis.

The network in the case was divergent and produced 26 end-products from one base chemical. The network had 15 nodes in 6 echelons and had, besides the start product and the end products, 14 intermediary products. The static simulation parameters (lead times, product bill of materials and routing, costs, etc.) were set to the company's real parameters. The network dynamics (demand) has been generated based on the known average demand for a certain time period.

For comparison, actual inventory levels were provided. A screenshot of the simulation model is given in Fig.11.

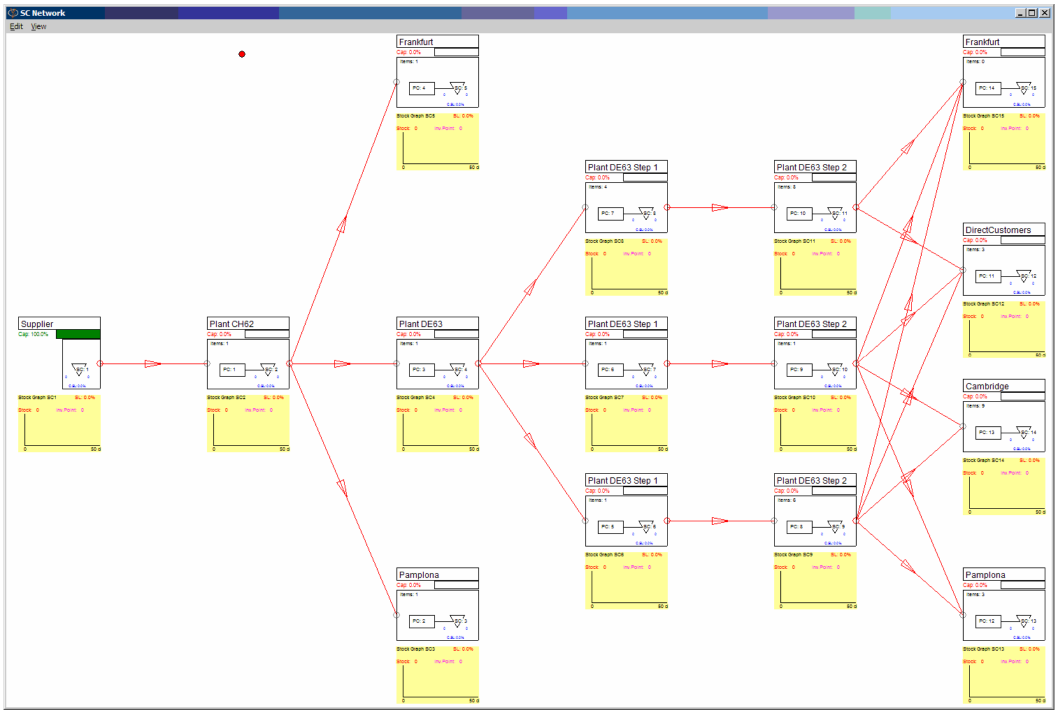

Figure 11. Screenshot of business case simulation

Two different policies were tested:

- A non-cyclic policy with optimal parameters calculated using analytical formulas, with a target service level of 95%.
- A cyclic policy with optimal cycle lengths calculated with the ECLIPS MECP tool (that had been developed within the ECLIPS project for calculating cycle lengths under certain simplifying assumptions) with a target service level of 95%.

Table 1. Summary business case

Description	Inventory, in kg	Realized Service Level
Real life situation	40.000	n.a.
Non cyclic	27.500	96%
Cyclic	36.560	99%

Simulation results are summarized in Table 1. It could be recognized that the considered inventory management policies yielded decreasing of inventory levels in comparison with the actual situation. Their further reducing could be expected by simulation-based tuning of the cyclic policy (e.g.., by optimization of cycle lengths under more realistic assumptions).

The considered real life case refers to the inventory data provided by a chemical company, for a selection of products in the supply network. Unfortunately, information on the real life service level was not available.

In the considered case, the non-cyclic policy offered the lower inventory levels then the cyclic one. On the other hand, the cyclic policy provided a higher service level. Its additional advantages are “soft benefits”, such as implementation simplicity and convenience.

5. Conclusions

Different aspects of using simulation in the ECLIPS project were discussed. The project is aimed at minimization of total inventories through the whole supply chain, taking into account specifics of different phases of a product life-cycle.

In the ECLIPS project, simulation is used, from one hand, in order to develop optimization and decision making algorithms, aiming to achieve minimal levels of inventories. From another hand, simulation provides a platform for testing algorithms and tools, being developed within the project.

Simulation-based multi-echelon cyclic planning and optimisation and analysis of the optimality gap between cyclic and non-cyclic network planning policies are two tasks that are defined in the ECLIPS project maximum programme and are used to refine the results received with the only analytical techniques in the ECLIPS minimum program.

In order to use simulation for testing developed algorithms and tools, a dedicated simulator has been designed. Through its application to considered theoretical and real life cases, the simulator proved its suitability for the project aims. Future developments around application of the simulator will incorporate consideration of additional theoretical cases (e.g., for assembly and distribution configurations), refinement of the business case for more products and actual service levels, as well as development of a fully detailed business case.

6. Acknowledgment

The presented research is funded by the ECLIPS Specific Targeted Research Project of the European Commission "Extended Collaborative Integrated Life Cycle Supply Chain Planning System".

References

[1] www.eclipsproject.com/portal/ ECLIPS web site.

[2] Yuri Merkuryev, Galina Merkuryeva, Bram Desmet, and Eric Jacquet-Lagreze, “Integrating Analytical and Simulation Techniques in Multi-Echelon Cycle Planning”, *Proceedings of the First Asia international Conference on Modelling & Simulation, AMS 2007. 27-30 March 2007, Prince of Songkla University, Phuket, Thailand. Edited by David Al-Dabass, Richard Zobel, Ajith Abraham, and Steve Turner.* IEEE, 2007, pp. 460-464.

[3] Galina Merkuryeva, Yuri Merkuryev, and Liana Napalkova, “Simulation-Based Environment for Cyclic Planning and Optimisation”, *Proceedings of the International Mediterranean Modelling Multiconference I3M 2007, October 4-6 2007, Bergeggi, Italy. Edited by Agostino G. Bruzzone, Francesco Longo, Yuri Merkuryev, and Miquel Angel Piera.* University of Genoa, 2007, pp. 318-325.

[4] Galina Merkuryeva and Olesja Vecherinska, “Simulation-Based Analysis of Optimality Gap between Replenishment Policies in Supply Chains”, *Scientific Proceedings of Riga Technical University,* RTU, 2007, pp. 41-45.

[5] Sven Axsäter, *Inventory Control*, Springer, 2nd ed. Edition, 2006.