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Teaching Supply Chain Dynamics Beyond the Beer Game

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Abstract

Supply Chain Management (SCM) is continuing to gain importance, both in industry and academia. Most SCM courses offered by universities and business schools are text-based. Approaches to illustrate the dynamic behaviour of supply chains are the well-known Beer Game and simulations. Even though the Beer Game allows students to see consequences of individual decisions for the entities of a linear supply chain, learning effects are limited because of the rather special setting. The paper discusses how we used discrete event simulation models described in the literature as requirements definitions for replicated model development. This teaching approach, whilst very ambitious, was highly successful. The students were familiarized with a graphical simulation language. Detailed engagement showed the students the importance of verifying and validating simulation models. Remarkably the degree of reproducibility of some published simulation results is rather low. Furthermore, we obtained hints as to why similar SCM models differ in their results.

1 Introduction

Supply Chain Management (SCM) is continuing to gain importance, both in industry and academia. Although SCM courses are now widely offered by universities and business schools, the curricula are often based on texts, focusing on alleged benefits of the concept, prerequisites for realizing SCM, analytical SCM models and case studies. However, text-based learning is limited to gathering concepts and does not familiarise with dynamic effects of decisions in a supply network.

Simulation methods have been applied to study dynamic effects in very different types of systems almost since the appearance of computers. Well-known applications are system dynamics models, originally developed by Forrester [1,2], for studying feedback loops. The Bullwhip Effect [3,4], an intensely discussed demand amplification phenomenon, is sometimes also named as Forrester effect [5].

In this paper we consider discrete event simulation models that analyse the effects of information sharing, which is a main concept of SCM. The results of the simulation studies show considerable differences and the reasons for these divergences are not adequately discussed in the literature. We decided to replicate some of the simulation models in a seminar on SCM to get a better understanding of why the results may differ. The students were taught how to use the Extend simulation environment and requested to reconstruct the model of the supply chain which the authors of selected papers may have been used. Goals of this approach were

- to allow the students to familiarise themselves with a powerful, graphically-oriented simulation package,
- to show them the potential of simulation models for studying dynamic effects in supply chains,
- to evaluate whether the description of the simulation models is clear enough to serve as a requirements definition for a replicated implementation, and
- to improve our understanding of why the results of simulating the behaviour of supply chains differ remarkably.

2 Approaches for Teaching Supply Chain Dynamics

An overview of the evolution in teaching SCM is presented in [6]; trends in SCM curricula are, among others, the integration of Information Technology (IT) throughout the supply chain, the emerging emphasis on globalization in supply chains, and the growing importance of sustainability and reverse logistics [6]. SCM curricula often include experiential approaches such as the use of SCM software packages or project-based company visits [7,8]. In the remainder of this paper we focus on Supply Chain Dynamics, considering the effects of decisions on the temporal behaviour of supply chains.

2.1. Analytical SCM Models

If we assume simple relationships in an SCM model, analytical methods may be used to obtain exact results on questions of interest. Representative papers following this approach are [9,10,11,12,13,14,15,16,17]. Analytical models allow deducing stringently some properties of the systems studied. The mathematics applied to allow these derivations may be quite advanced and may exceed the mathematical capabilities of most business students. Even worse, the model of the real system has typically to be oversimplified to allow the application of exact algorithms. Real supply chains are often too complex to be studied analytically. For instance, if several customers of a manufacturer have to be considered, the scheduling rules and decisions of the manufacturer become a highly relevant part of the supply network. However, considering the results of complexity theory (e.g., [18]), it is, for instance, not possible to solve detailed analytical scheduling models of a job shop.

2.2. The Beer Game

Over the years, the Beer Game has become a popular tool in teaching Supply Chain Dynamics and its results confirm the widely discussed Bullwhip Effect. Originally developed at the MIT by Sterman [19,20,21] as a board-game, it became a component of almost every executive program in SCM. Computerized versions of the Beer Game are offered via the Web by the

- Massachusetts Institute of Technology, MIT Forum for Supply Chain Innovation
  http://beergame.mit.edu/
- Swiss Federal Institute of Technology, ETH Center for Enterprise Science
  http://www.beergame.lim.ethz.ch/
- TU Darmstadt, Produktion & Supply Chain Management Group
  http://130.83.11.91:8080/
- MA-system, Lund
  http://www.masystem.com/beergame

The Beer Game distinguishes four entities: A factory, distributor, wholesaler and a retailer. In the computerized games four people may play together (typically from remote workstations) or they may also opt for role-playing any given manager; the computer is substituting the missing human decision makers. In artificial intelligence research [22] it is discussed whether computers may play the game without human intervention and even whether computers may qualify as supply chain managers at least in this restricted environment.

It is assumed that no information except order quantities is shared between the decision makers of these entities and that the demand at the Point-Of-Sale (POS) remains unknown to the upstream companies. In each round of the game, the managers have to decide how much they order; the order size is communicated only to the supplier and not to other entities. Furthermore, ordering information is transferred with delays and the lead-time in operations also results in delays. The game shows effects of missing information exchange and of delays in transferring materials and information. Even with almost stable consumer demand, inventories, backlogs and the associated costs incurred by the four companies vary considerably. Students, playing the Beer Game for the first time, are typically enthusiastic about feeling the effects of insufficient coordination so drastically. Therefore the game is quite successful in teaching the impact of local decisions, made without sufficient information, on all members of the supply chains, and in visualizing the bullwhip effect.

However, several weaknesses exist in the Beer Game:

- Inflexibility in the structure of the supply chain
- The supply chain is introduced as a linear system, neglecting effects of decisions by companies that are not members of the supply chain
- Neglect of capacity constraints
- Unrealistic assumptions, such as the delay in transferring information, which do not reflect the potential of today's powerful communication systems
- Inflexibility in changing underlying parameters which hampers students' natural desire to play around with the model.

Several modifications of the original Beer Game exist (e.g., [23,24]). For instance, in the stationary Beer Game [24], the customer demand values in different periods are independent and identically distributed, and all players know a priori the demand distribution. However, the original version of the game leads to more surprising results because the bullwhip effect also results for almost stationary POS demand values.

Business games are sometimes classified as one type of simulation models (e.g., [25]). In [26] a hands-on approach for teaching SCM is described, providing a Spreadsheet-based and a simulation-based model of a Just in Time game and of the Beer Game. The students preferred the simulation model to the spreadsheet, since it is easier to handle and the visualization of flows allows better understanding of the underlying causes. A more general and more expressive model than the Beer Game should be developed to analyse different impacts of sharing information on Supply Chain Dynamics and the associated performance effects.

2.3. Simulation Models

Considering the limitations of the two approaches described above, discrete-event simulation seems to be the most appropriate method to analyse practical problems and show dependencies in the SCM context, and thus has also gained importance in teaching SCM [26,27,28,29].

2.3.1. Preconfigured Simulation Models

In discrete-event simulation models as well as in business games the students are typically expected to run, slightly modify and analyse an already implemented model. The basic properties of the model, as defined by its developer, limit students in their natural desire to experiment with the settings beyond changing some parameter values. In the OPESS project (http://opess.ie.iwi.unibe.ch/), supported by the Swiss Virtual Campus program to develop learning objects for Operations Management, ERP and SCM systems, we also followed such an approach and developed simulation models focusing on information sharing strategies, Vendor Managed Inventory, and scheduling decisions. However, the students were only able to modify a few parameters of the preconfigured models.

2.3.2. Replicated Simulation Models

To foster a better understanding of the underlying mechanisms, we wanted to allow master students in business administration to gain broader experiences by developing SCM simulation models from scratch. This requires prior knowledge of SCM concepts as well as understanding basic modelling approaches and simulation procedures. Designing, building, testing and analysing the results of simulation models is rather demanding for students without previous experiences in this area. Challenging tasks in developing simulation models are to determine whether the computer program performs as intended (verification) and whether or not a simulation model represents the system under investigation accurately (validation) [30,31]. Verification and validation should be understood not as single steps in the modelling process but as a continuous activity throughout the entire life cycle of the simulation model [32].

A clear definition of the requirements, including a description of the real system and the acceptable simplifications for developing the system, is regarded as a prerequisite for an efficient and effective development process by many software engineering methodologies. As in the development of other types of software, it may be difficult to define all relevant requirements of a simulation model a priori. Prototyping and evolutionary system development are concepts to ease the strict requirements definition suggested by waterfall models (cf. [33]).

A major problem in developing simulation models with students is to define a realistic, motivating and manageable business scenario. On the one hand, it is typically not possible to develop a model which closely resembles a complex real-life situation. On the other hand, textbook descriptions are mostly oversimplified and do not provide much insight into Supply Chain Dynamics. Since requirements definitions of simulation models can be regarded as simplified views of real systems, one can use them if the intended object of investigation is not directly accessible to the students, e.g., if business partners are not willing to let students gain detailed insight into their supply chain planning and execution. Thus it is surprising that only few efforts exist to replicate the results of simulations models described in the literature; an interesting replication study is described in [34].

3 Teaching Supply Chain Dynamics by Replicating Simulation Models

3.1. Goals

Based on these considerations we decided to use simulation models described in research papers on the SCM as requirements definitions.

Students often lack the background knowledge to critically scrutinize the assumptions of published simulation models. The implementation of these models requires their extensive inspection and leads to discussions about the accuracy of the model descriptions and the adequacy of the assumptions. This also conveys the importance of verification and validation tasks. The focal points in our course were set on verifying simulation models as well as checking the validity of conceptual models of the selected publications. Our goal was to transform the conceptual models sketched in the research papers into computer programs in order to replicate the sometimes contradictory results of the simulation studies.

3.2. Selection of Papers and of the Simulation Environment

Based on a prior literature review on simulation studies about information sharing strategies in the field of SCM [35], eight papers were selected for detailed examination and replication (see Table 1). We selected papers that describe the models as well as the underlying assumptions in much detail to provide a good chance for replication.

As the course was designed for master students with a major in business administration, specific knowledge in programming languages could not be presumed. Therefore simulation software packages supporting graphical modelling were considered to develop the simulation models. Due to the variety of packages offered, the evaluation of software suitable for an SCM teaching environment is a challenging task. Although surveys on commercial simulation packages exist (e.g., [36]), hands on experience, e.g., with a demo-version, is highly recommended for selecting a suitable package. After a detailed evaluation we decided to use the Extend simulation package, developed by Imagine That Inc. (http://www.imaginethatinc.com/). Several reasons led to this decision:

- Support of modular system development
- Predefined blocks
- Drag and drop functionalities
- Real time animation

- Relational database for data management included
- Data import and export to Microsoft Excel
- Batch runs supported for time-intense analyses
- Support of sensitivity analyses
- Inclusion of an open source evolutionary algorithm
- Inexpensive lab licences for students
- Free downloadable player for viewing Extend models
- Our previous experience with Extend in the OPESS project.

Source	Focus
Closs et al. [37]	Closs et al. analyse the effects of POS information sharing on inventory and service levels based on a divergent four stage supply chain.
Waller et al. [38]	Based on a real-life supply chain in the electronic industry, Waller et al. analyse the impact of high demand variability and multiple distribution channels on supply chain performance.
Merkuyev et al. [39]	Merkuryev et al. analyse the influence of POS information sharing on the bullwhip effect in a linear four stage supply chain.
Zhao et al. [40]	Based on a two stage divergent supply chain, Zhao et al. discuss the effects of shared demand or order information in combination with variable customer demand structures on supply chain costs.
Smaros et al. [41]	Smaros et al. analyse the impact of information sharing by changing numbers of VMI adopters in a multi-product case on the production efficiency of a manufacturer.
Tu et al. [42]	Tu et al. discuss the effects of shared POS data and planned orders (upstream) and inventory data (downstream) in a three stage supply chain.
Angulo et al. [43]	Based on a four stage supply chain, Angulo et al. analyse the impact of information sharing in an existing VMI cooperation on inventory and service levels as well as on supply chain costs.
Chatfield et al. [44]	Chatfield et al. extend the Beer Game by implementing stochastic lead times and analyse the influence of information sharing on the bullwhip effect.

Table 1: Description of papers selected for the replication study

Figure 1 gives an impression on simulation modelling in the Extend environment at the most detailed level by using predefined blocks. The example visualizes the management of product deliveries, emphasizing the data manipulation in associated databases DB. Material flows and information flows are distinguished by displaying them in different ways: Material flows are displayed by twofold lines, information flows by thin lines. Constructs consisting of considerable details can be aggregated into user-defined and user friendly modules, which may be combined to develop extensive models.

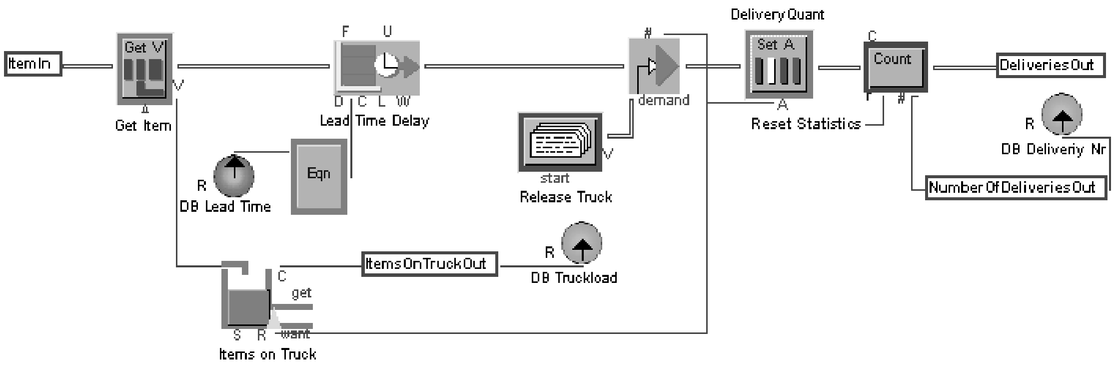

Figure 1: Predefined Extend blocks at the most detailed level

To become familiar with the simulation environment, students had to go through Extend's comprehensive tutorials. In addition, we offered a full-day introductory training session in which we focused on the use of Extend in the area of SCM, in order to support students in their early modelling activities.

3.3. Reproducibility of Simulation Results

From a rigid viewpoint, traceability and reproducibility of derived results is a main criterion of scientific work. For simulation studies, all information necessary to replicate the results should be available. However, this ideal is typically not achieved by the papers. Reasons for irreproducibility may be:

- The most precise requirements definitions would be in a formal or at least semiformal notation. However, most simulation models are described in natural language, offering sometimes (too) much room for interpretation.
- We cannot be sure whether the design of different simulation packages influences the results: Theoretically it should not; in practice, we do not know.
- Simulation models react to detailed features of simulation runs, e.g., the starting value of random numbers.
- Due to page constraints, authors often cannot describe all details of their models and the analysis of their results in the papers. However, with Web pages as complementary tools, far more information could be provided for those interested in details of the simulation studies. The models themselves could be made downloadable or even accessible via the Web.

In some cases the students managed to obtain results quite close to the published figures, typically after guessing a lot of implicit assumptions by trial and error. This led to multiple iterations until the students and their supervisors were satisfied with the models and their results. The fuzziness in describing main properties of the models in the chosen papers is impeding the replication and the verification of results. For instance, the reorder point calculations under stochastic demand are often described only rudimentarily and the usage of shared information in computing reorder points is often not well defined. Since the reorder point level affects the mean inventory significantly, the replication of SCM simulation models is considerably hampered if this detail is not described.

Even with graphically oriented simulation tools, modelling complex situations is not a trivial task. Simulation tools provide many ways to model well-defined properties of a system. The complex interdependencies between material and information flows may result in inconsistent models where reasons for unexplainable model behaviour and results are hard to identify. In discrete event models the sequence of events occurring at different entities of the supply chain has to be handled with care. For instance, if demand information is shared with the supplier to improve his forecast accuracy, the temporal relationship between the data has to be modelled very carefully. Thus, even in the replication of existing simulation models the validity should be confirmed by conducting sensitivity analyses through a variation of parameter values, such as lead time or order quantities.

The detailed work with the simulation models also provided conjectures as to why some rather similarly formulated research questions concerning the behaviour of Supply Chain Dynamics are answered differently in the literature. Order quantities determine the order frequency; the number of incoming orders per period will typically differ, even if the consumer demand is constant. For instance, an order inter-arrival time of 4 days leads to 1 or 2 orders per week and therefore to a high variability in weekly demand values. Thus, the mean and the standard deviation of demand for an upstream company are influenced by the order policies of its customer. Computations (like forecasting and determining reorder points) that consider demand variability are strongly influenced by this phenomenon [45].

3.4. Evaluation of the Teaching Approach and Future Activities

There were significant differences in modelling approaches taken by the students with respect to model logic, design and modularisation. The design decisions made by the students were not always fully comprehensible. While some models were easily understandable and concise, the mechanisms applied in other models appeared as rather obscure.

The seminar was seen as a success both by students and teachers. The progress achieved by the students during the course as well in simulation model design as in understanding supply chain behaviour was very encouraging. We observed more intense learning processes and far more motivated students than with a pure text-based approach or the use of preconfigured simulation models.

The course was evaluated by using the standardized course evaluation form of our university as well as with interviews of the students. The overall rating of the course by the students was 5.5 out of 6, interestingness and relevance of the course were rated 3.69 out of 4. The students evaluated the course very positively despite its difficulty, which was considered as "too high" and "much too high" by 67 and 17 percent of the students, respectively. The learning effect was also high, with a third of the students rating their learning experiences as "good" and two thirds as "very good".

For the tutors the seminar also proved to be successful, since the students were highly motivated and pointed out interesting questions for further research. The team spirit experienced during the entire course extended from students to tutors and professors. The success of the approach, namely the extension of the traditional use of already implemented simulation models to teach Supply Chain Dynamics, confirms the value of hands-on experience and experiential learning for students.

Despite of the high amount of effort particularly in the development phase of the simulation models, the reusability of the student-developed models is rather low. The design of the models was, as to be expected from students without prior simulation design knowledge, not very comprehensible. Reusing the student-developed models in subsequent courses could result in teaching improper design methods.

Building on last year's experience we are planning to let students modify and enhance an existing simulation model, which represents a linear supply chain, into a model of higher complexity. Compared to the approach presented in this paper, the use of pre-developed and verified modules with well defined interfaces should result in higher validity and reusability of the enhanced SCM model. The modules will be extended by students to whom exact requirements definitions will be given; the details of the implementation and the assembly to a comprehensive model will be left to the students. The informal student collaboration, which was very important last year, will become more formalised by this modification of the course. Whilst the students will have stricter guidelines with regards to interfaces, the freedom in design decisions will remain and hopefully ensure a valuable learning experience.

4 Conclusions

Whilst the Beer Game is a valid and proven tool for teaching some basics of Supply Chain Dynamics, the replication of discrete-event simulation studies provides far more opportunities for a deeper understanding of the complex interdependencies between the entities in the supply chain and the respective decisions. These learning processes can only be successful if they are fostered by intense guidance from knowledgeable tutors.

Advantages of active involvement of students in understanding Supply Chain Dynamics are undoubtedly the high level of motivation, commitment and the high degree of knowledge gains. The heavy workload for students and teachers alike unfortunately makes the approach unsuitable for large groups of students without providing a significant numbers of well-trained tutors. Furthermore, reusability of the student-developed models for later use is rather limited and most models have to be considered as a throw-away prototype, as suggested in one approach of software engineering [33].

It is remarkable that the degree of reproducibility of some published results of simulation models is rather low. Some problems that occurred in the development of the simulation models provide hints as to why quite similar models developed to study Supply Chain Dynamics differ in their results and their recommendations for designing efficient and effective supply chains.

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