Supply Web Agent-Based Simulation Platform

D. Hakimi, B. Montreuil, O. Labarthe

Abstract:
A Supply Web is a network of interrelated supply networks, each embedding interlaced supply chains, involving multiple organizations with collaborative or competitive supply relationships. The Supply Web concept involves both high complexity and large scale modelling. It requires to deal with soft, behavioural and systemic perspectives to address issues facing managers in these large complex supply systems. In this article, we introduce a Supply Web Simulation Platform to support the decision making in the complex environment of Supply Webs. The platform is a multi-agent tool that creates virtual worlds featuring complex organization behaviours and relationships while considering a granulated level of detail. The platform is connected through a Database to a set of Supply Web Business applications that allow users to visualize, monitor, mine and assess the dynamic states and performances of the virtual supply webs studied enacted by the Simulator.

Keywords: Supply Web, Large and Complex System Modeling, Agent-Based Simulation, Multi-Agent Systems

1 Introduction

The Supply Chain Management (SCM) field has experienced multiple evolutions since the early 1980s (Miri-Lavassani, et al., 2009). In the beginning, the focus was on internal operations of a firm. Then the decisional boundaries were extended to consider dyadic relationships between the firm and its adjacent suppliers or customers and, later on, to consider members of a linear supply chain. Finally, the SCM started to focus on networks of supply chains (Harland, 1996).

The notion of overlapping supply chain networks has recently lead to the introduction of the Supply Web (SW) concept (Montreuil, et al., 2009), which is formally defined in Hakimi et al. (2009) as: “... a network of interrelated supply networks, each embedding interlaced supply chains, involving multiple organizations with collaborative or competitive supply relationships.” This definition emphasizes the fact that supply operations in a certain supply network influence companies that are not belonging to this supply network but have direct or indirect supply relations with one or more members of this supply network.

One main objective behind the SW introduction is to highlight the complexity inherent in these new organisational environments. Such complex environments re-shape the associated business rules and managing modes. The notion of SW brings out the importance of the direct and indirect relationships occurring in a wide supply context and evolving in extended decisional boundaries. Therefore, new generations of Decisions Support Systems have to consider the networks of supply networks. Montreuil et al. (2009) introduced the supply web mapper as a visualisation, mining, and assessment application allowing analysts and decision-makers to explore efficiently SWs. This application is one of the elements of the SW Decision Support Systems defined in Hakimi et al. (2009).

To empower these systems with more flexibility and decision support features, this paper introduces a multi-agent, distributed and modular SW Simulation Platform. The huge size of data and the number of events and operations in complex SWs impose many challenges for developing a generic, yet easily customized, simulation platform. The modeling approach focuses on conserving the complexity of SWs, while providing users with the right capabilities to tackle this complexity and make better decisions.
The article is structured as follows. The second section presents the motivations underlying the SW Simulation Platform. The third section is dedicated to the literature review on the simulation of complex adaptive systems such as SWs. Section four briefly overviews SW Decisions Support Systems. The fifth section introduces the SW Simulation Platform. Section six describes the architecture of the SW Simulator. The seventh section discusses some applications of the SW Simulation. Finally, section eight concludes with a summary of the key contributions and future research avenues.

## 2 Supply Web Simulation Motivations

The objective of this section is not to discuss the virtues of simulation. They are discussed extensively in the literature (Shannon, 1998; Law, et al., 2000; Stefanovic, et al., 2004). The objective is rather to emphasize the reasons that motivated the decision to create a SW agent-based simulation platform.

The importance of recognizing the impact of SW was first observed in a collaborative research project between Proctor & Gamble (P&G) Canada and the University Research Center on Enterprise Networks, Logistics and Transportation (CIRRELT). P&G Canada can be seen as a complex manufacturing organization operating many distribution centers and many factories. The organization and some of its major clients, complex retailer organizations with many distribution centers and stores, had intentions of extending their collaboration through joined initiatives. Simulation has been identified as one of the most effective and less expensive options for supporting the assessment of major joint initiatives, especially in the case of multi-sited partners, each with its own supply network. It is well known that changes in a part of a complex supply system can create waves of changes through the entire system (Stefanovic, et al., 2009). A SW Simulation was perceived as a key enabler for decision-makers to capture the impact of the introduced changes.

Such a simulation application can be used for exposing to partners in a SW the potentials of adopting a collaborative vision or strategy through the result of live simulations. Partner behaviours can be modelled very realistically while those of non-contributing members of the SW can be approximated as best as possible. Each partner can decide to expose some or all the internals of its model to other partners, as well as some or all the outcome of simulated runs, depending on its confidence level with the other partners.

A SW simulation application can be used to support the development and the enhancement of the SW business applications. It can provide various contexts and flows of events, allowing the developers to cover the largest possible number of cases. It can also provide extreme scenarios to test the behaviour of these applications, make sure they can work properly in critical situations, and to determine their limits and the new required features.

Since the simulator is conceived to produce virtual, parallel worlds and since it is an interactive application, users can follow the evolution of a simulation, interact with it by introducing or changing a strategic, a tactic or an operational decision and they can see the impact on the entire virtual SW in an accelerated mode. Thus, it can be used by managers for testing different decisions and performing what-if analyses, as well as to teach new managers and to introduce them into the complex supply environment of a specific company.

## 3 Literature review

Many authors argue that soft, behavioural and systemic approaches are required in order to tackle the real and daily challenges facing supply chain managers (Harland, 1996; Beamon, 1998; Choi, et al., 2001; Lazzarini, et al., 2001; Vonderembse, et al., 2006; Pathak, et al., 2007; Stefanovic, et al., 2009). In this section two research fields are examined to grasp the complexity of SW Simulation: Supply Networks and Supply Simulation.

### 3.1 Supply Networks

Research investigations in the field of supply chains and networks have begun considering the perspectives of Complexity Theory and Complex Adaptive System (CAS) (Pathak, et al., 2007). To be considered a CAS, a system should meet two conditions: adaptivity and existence in a complex environment with many relationships and interactions (Choi, et al., 2001). Therefore, supply networks should be considered as Complex Adaptive System Networks (CASNs) (Surana, et al., 2005; Pathak, et al., 2007). Since a SW is a network of supply networks, it will exhibit even more adaptivity and will exist in an even more complex environment.

One of the important implications of CASNs is the recognition that the changes in the internal states of a network can be initiated by elements residing both inside and outside the CASN (Pathak, et al., 2007). In addition, the CASN offers managers a new perspective to view, analyse and handle their business. It allows managers to be aware of the adaptivity of other firms, the complexity of the overall system and the dynamics of the surrounding environment. According to Pathak et al., 2007, the concept will also drive the research to study the complex decision making processes in the context of dynamic, complex and wide supply networks. Another implication is the ability of the CAS perspective to approach real world management issues by integrating more realism and empirical data in research models (Anderson, 1999).
3.2 Supply Simulation

Simulation can be used to model intricate supply contexts close to real systems, execute those models, and observe system behaviours (Stefanovic et al., 2009). Simulating entities belonging to CASs involve modeling these entities as adaptive elements that can adjust their decisions in response to their environments and to the actions of other entities. These simulations generate results about larger-scale systemic behaviour in ways that are analytically intractable and can provide methods for examining the dynamic behaviour of systems. While most existing supply chain research focuses on studies using surveys, standard discrete-event simulation, case studies of dyads, or analytical models, the CAS applied to Supply Chain Management research requires agent-based and computational models, process models that are dynamic and generative, and case studies of larger sets of firms (Pathak et al., 2007).

Several recent researches have recently identified that Supply Chain Management issues are not addressed from a CAS perspective and suggest that the Supply Chain Management discipline has to embrace the CAS approach (Surana et al., 2005; Braha et al., 2007; Pathak et al., 2007). Almost all the contributions regarding the Complexity Theory occurred outside the operations management and Supply Chain Management disciplines (Pathak et al., 2007). For example, the special issue of Management Science on Complexity Theory did not carry any article dealing with supply chain issues (Amaral et al., 2007).

This article intends to fill some of this gap by introducing a multi-disciplinary, multi-agent SW Simulation Platform. An architecture related to the simulation platform is proposed in order to generate complex SW environments where multiple organizations are interacting within multiple supply networks impacting each other through direct and indirect supply relationships.

4 Supply Web Decision Support Systems

As it was mentioned earlier, and will be made explicit in the next section, the SW simulation platform completes and connects to the SW decision support systems introduced in Hakimi et al. (2009). To provide the reader with a clear view of the simulation platform environment, this section summarizes sub-section 2.3 and sections 3 and 4 of Hakimi et al. (2009).

The SW concept involves two major challenges for Decision Support Systems (DSS). First, DSS must enable capturing a SW context and making explicit its elements, their behaviour and their relationships. Second, DSS must help delimiting the desired piece of the global SW and linking it to its context through multi-dimensional relationships to offer the users the possibility to zoom in and out of specific sub-sections of the SW. To deal with these two challenges, a database and a set of applications are used.

4.1 Supply Web Solution Deployment

The design of DSSs in a SW context is based on a set of solutions deployed over multiple organizations. An organization is modelled as a combination of a Decision System, an Information System (IS) and an Operating System (Figure 1).

A SW solution is integrated into the IS of the considered organization and interacts with other components of the IS, such as databases and software packages. A SW solution is fed by two kinds of supply data: data about the internal supply operations of the member itself and data about the supply operations of other actors. In such a collaborative context, SW members have to sign bilateral agreements to exchange data. It is not a prerequisite that the members exchanging SW data be trading partners, as for example the retailers in Figure 1 are exchanging data without exchanging any physical flow.

4.2 Supply Web Solution Structure

To provide the same representation to multiple organizations, each SW solution consists of a database, a set of business applications and a gateway, as illustrated in Figure 2. Regardless of the owner of the solution, the SW database has the same data structure and the same tables. This point is important in order to obtain a general representation of any supply context as sets of sites belonging to organizations and exchanging physical, informational and monetary flows. Since the SW database merges data from multiple ISs belonging to different organizations, it is necessary to standardize the received data before transferring it to the database. This role is ensured by the gateway application which makes sure that elements are uniquely identified and that the pieces of information are stored in the right SW database tables.
The SW business applications are composed of a set of three applications enabling profound understanding and decision support about a selected SW context. These applications exploit the content of the SW database to which they are connected. The SW Mapper is designed to help statically visualize, mine and assess a SW context and its performance. The SW Playback is conceived to dynamically visualize, mine and assess the past of a SW context and its performance. The SW Monitor aims at monitoring, mining and assessing in real-time a SW context and its performance.

Figure 2: A Supply Web Solution Structure, source: Hakimi et al. (2009).

5 The Supply Web Simulation Platform

The SW Simulation Platform, of which an instance is referred to as a SW Simulation Solution, is a combination of the SW Simulator and the SW Simulation Database as shown in Figure 3. The SW Simulator is a multi-agent application that allows simulating SW environments. It aims at substituting a real SW environment by a virtual SW world. The SW simulation database plays for the SW Simulation Solution the same role that the SW Database plays for the SW solution. It also contains the SW Functional Data required for agent behaviour.

Figure 3: Integrating a Supply Web Simulation Solution into a Supply Web Solution

To model a supply context, two types of data are necessary: the structural data and the functional data (Swaminathan et al., 1999). In our research, the structural or configuration data is used to configure the SW context and it consists of the structure of the SW data such as the attributes of organizations, sites, products, and product families and categories. This type of data is found in both the SW database and in the SW simulation database. The SW functional data corresponds to the pieces of data composing the profiles of different actors of the SW. It is this data that determines the behaviour and the decision-making process of the actors. Each one of the simulator agents is associated to an actor and uses his profile parameters to mimic his behaviour.

The generation of simulated SW events is among the important functions of the Simulator. SW events are rapid changing data reflecting the dynamics of the SW. Examples of events include a sale, an order, a shipment, an order handling, and an inventory update (Hakimi et al., 2009). The simulator takes as an input the SW structural data and functional data, and creates a virtual SW environment where agent applications mimic the real world organizations’ behaviour. The generated events of this simulated world are sent by the simulator to the SW simulation database.

The SW business tools such as SW Mapper, Playback and Monitor can be connected to the SW simulation database as they are normally connected to regular SW database. The switch between the two databases is made by a simple address change. There is no difference for these tools to be connected on a real world or on a simulated world. They offer the same main capabilities in both cases.

Whereas the functional data is a must for the SW simulation solution, since it is used to generate the agents’ behaviour, it is not required for the other current constituents of a SW solution because they deal with the behaviours’ results, which are the SW events, rather than with the behaviours themselves. Since the SW structural data and the SW events have the same table structures, and since the SW business tools do not require SW functional data, mapping these tools on either database does not affect their normal functions.

Building a generic SW Simulator is a very challenging mission. While it is relatively easy to standardize the SW structural data and the events, it is very difficult to do so for the SW functional data because it is related to the internal behaviours of members and systems of each organization. Even if it is sometimes possible to determine certain dominating behaviours patterns, there are many exceptions that make it tough to create common data structures, especially when the objective is a very granulated level of detail. Since the standardization of the SW functional data is trickier than the standardization of the SW structural data and the SW event, and since the SW business tools do not require the SW functional data, it is much easier to build generic SW applications than to build a generic SW simulator. The next section explains how we addressed this challenge.

6 The SW Simulation Architecture

6.1 General Overview

The SW Simulator is a multi-agent platform. It consists of a set of multi-agent applications distributed on many computers inter-connected through the Web by using
TCP/IP protocols. Each multi-agent application can run on a single computer, share the same computer with other multi-agent applications, or be distributed on many computers depending on its needs in terms of processor and memory capacities required for its proper execution. As shown in Figure 4, inspired from Ahn et al. (2004), the multi-agent application consists of four modules: the interaction module, the communication module, the behaviour module, and the Graphical User Interface (GUI) module.

The communication module is responsible for standardizing, sending and receiving messages, and for communicating with the database. The interaction module packs the messages to send to the other agent applications and passes them to the communication module which forwards them to the synchronizer application which then transfers them to the right destination. The interaction module also receives external messages through the communication module, unpacks them and transfers their contents to the right internal agent. As depicted in Figure 5, the behaviour module is the core of the application and contains the agents that determine the role of the application in the simulation.

The launching of a simulation engages the following steps:

- The synchronizer connects to the Database and gets the list of available SW scenarios to simulate;
- Through the synchronizer GUI, the user selects the desired scenario. The synchronizer is now in the listening state waiting for the organization applications to request connections;
- Through the GUIs of the organization applications, the user associates each application to a company in the SW to simulate;
- Each organization application sends a connection request to the synchronizer;
- Upon receiving a connection request, the synchronizer establishes a TCP/IP connection with the requesting application. Then, it sends the information about the scenario to simulate;
- After receiving the information about the scenario to simulate, the organization application loads its profile associated with the selected scenario. The organization profile consists of structural data and functional data about the corresponding organization.
- The organization application builds the virtual organization by creating the necessary environment, objects and agents and setting them in their initial states.
- The organization application notifies the synchronizer that it is in the "ready" state;
- After the synchronizer is notified that all participating organizations are ready, it sets its clock to the initial time and notifies the user that the simulation is ready for execution;
- After the user launches the simulation, the synchronizer starts the organization applications.

6.2 The Synchronizer

The synchronizer ensures the coordination of the organization applications and the communication between these applications. It makes sure that different events are handled according to the right order of occurrence and that all the organization applications operate at the right speed according to the common master clock.

The Synchronizer’s GUI serves as interface with users. It provides the possibility to select and parameterize the scenario to simulate, to launch the simulation, pose and play it, slow it or speed it, and stop it. It provides also general information about the simulation such as the current simulation time and the connection status of the organization applications.
The connection manager establishes the connection with the database and the initial TCP/IP connections with the organization applications. It also reconnects the organization applications in case the established connections were lost.

The synchronization manager ensures the synchronization among all the participating applications by continuously validating that the time of the local clocks of these applications matches the time of the synchronizer’s master clock and by closely following the execution sequence of events involving more than one organization. The synchronizer’s communication manager plays the role of a SW message dispatcher. The organization applications are not connected directly to each other. Each has only one bilateral TCP/IP connection and this unique connection is with the synchronizer. When an organization sends a message to another organization, the message is sent from the sending organization’s communication manager to the synchronizer’s communication manager which transfers it to the destination organization’s communication manager. When the synchronizer’s communication manager receives a message, it checks the destination address and forwards the message to the corresponding organization.

6.3 The Organization applications

The organization applications represent different members of the SW to be simulated. An organization can be seen as a combination of a Head Office, an IS and a set of sites representing the physical nodes belonging to the organization. An organization can for example represent a retailer, a distributor or a manufacturer. Depending on the role played by the organization, it may encapsulate stores, distributions centers and/or factories, as shown in Figure 6.

![Figure 6: A Simplified Class Diagram Section Showing the Organization Structure](image)

Figure 6 illustrates the basic and most generic organization and site structures to be found in a SW simulation. For example, a site can have basic attributes such as an address and a unique identifier, can belong to an organization, send and receive orders and shipments, and manage a list of products. The store, which inherits the site’s proprieties, has also generic store behavior and structure. It has a store room and a front-store, handles market demand and its agents manage the operations between the store room and the front-store.

Depending on the desired modeling level of detail, children classes can be added to refine the behaviour of different entities. For example, other classes such “Grocery Store” class and “Electronic Store” class can inherit from the “Store” class to reflect more specifications and advanced behaviours of the simulated entities.

In the same simulation environment, instances of different abstraction levels can be found. Some stores can be modeled as sites, others as stores, others as grocery stores, and some others as stores of a specific retailer. This modeling approach is very important, especially in a SW context where the number of simulated entities can increase rapidly and where the focus is on detailed dynamics of the supply context. This strategy has many advantages:

- Obtaining a fast and representative generic model: Since generic classes are already developed and their generic behaviour is representative of most supply contexts, obtaining a first generic simulation featuring basic physical, information and financial flow exchange is a matter of adapting and putting the profiles of the organizations and their sites into the SW simulation database. A generic simulation is not designed to take in consideration the specific particularities of different industries but can provide a representative level of detail of a SW environment.

- Fast modeling of a complex environment: The more finely an entity is modeled, the more effort and time the modeling takes. Therefore, the combination of different levels of abstraction for different entities can accelerate the modeling process. The entities requiring more attention can be modeled finely and the others can be represented at different abstraction levels depending on their importance.

- Continuous development of customized behaviours: Creating customized behaviours for different entities can be done gradually by adding subsequent classes that inherit the proprieties of their preceding parents and by exploiting the potentials provided by agent-based modeling. The simulation can reach very granulated levels by modeling the important entities as close to reality as possible. For instance, a retail store floor can be modeled as a virtual world with the equivalent of real products, shelves and store equipments, and various management system agents and with customers shopping and employees working. Each customer and each employee can be modeled as a distinct person with a distinct profile.

- Testing while developing: When the first generic level is obtained, development of customized behaviour can be done by progressively adding new features. The evolution of the simulation development can be done smoothly by integrating the new features in an already working environment. Users can beneficiate from these new features as soon as
they are integrated since it is not necessary to wait to make major changes in order to produce new versions of the simulation.

- Taking all the elements of a SW in consideration: Modeling the less important elements as generic entities with representative behaviours results in not sacrificing them by excluding them from the model or aggregating their behaviour in a simplistic black box. This way, their impact, their existence and their behaviour can be assessed, then refined when deemed pertinent.

- Efficient processor and memory capacity management: Optimizing the use of the computing processor and memory capacity is a key in succeeding in simulating a large SW context. Generic behaviours require much less memory and processor capacity than do sophisticated and complex behaviours. Using generic instances for some entities of the model helps lower the burden on the network of computers and increase the smoothness of the simulation execution.

6.4 The Simulator Agent-Based Modeling

Conceptually, the modeling approach used for the organizations modeling is a hybrid of the recursive modular protomodel based approach (Montreuil, 2006) and a multi-agent approach (Labarthe et al., 2007). The organizations are multi-agent applications. The behaviour of their agents is mapped on the behaviour of real actors or systems in the modeled organization. Each site has a set of products to manage. It encapsulates an IS and other components depending on its nature. sketches an example of a retailer agent model. A generic store has a backroom a floor shop and a set of agents representing different store management systems.

The Simulator Agent-Based Modeling

The SW simulator can serve multiple purposes. Its link to the multi-dimensional, multi-user and multi-interface SW business applications of the SW Decision System offers many features that can help provide different users with a practical and powerful managerial instrument which can serve multiple decision levels. This section presents a few applications of the simulator to illustrate how it can be used and how it supports managers and researchers in different contexts, each according to its interest and focus.

7 Some applications of the SW Simulation Platform

As was mentioned earlier, the SW Decisions Systems allow statically, dynamically and in real time to visualise, monitor, assess and mine SW contexts and their performance. On the one hand, these applications provide the same capabilities when connected on virtual worlds created by the simulator as when connected on the real world (Figure 3). On the other hand, integrating the simulator with the SW Decision Systems leverages its capabilities considerably.

The SW Monitor acquires a special and important role when it is connected to a simulation. It is considered as the visualization module of the simulator. The monitor handles the SW events as soon as they are recorded into the database, by adjusting and visualising the states of the SW and updating the associated Key Performance Indicators (KPIs). When it is connected on a running simulation, it translates the event data to a visual output showing the evolution of the simulation. As long as the difference in time between the occurrence of an event in the simulation and the corresponding update on the monitor is very small, users can follow the evolution of the simulation on the monitor’s visualizers. The monitors can provide screens focusing on different aspects of the SW such as transportation, inventory, sales and demand, or yet finance, allowing users to investigate different aspects concurrently.

Moreover, users can exploit different capabilities and features provided by the SW Monitor, the SW Mapper and the SW Playback. They can investigate different
KPIs by digging in and out through product, organization, time and/or supply depth dimensions. They can trace the evolution of customized KPIs over time through dynamic graphics and charts. They can focus on specific elements of the SW such as a product, a set of products, a site or an organization. They can have a panoramic view on large contexts of the SW, or they can travel between focused and extended views (Montreuil, et al., 2009, Hakimi, et al. 2009).

7.2 Creating and Comparing Different Scenarios

The SW simulator agents represent the decision entities within a simulation. They encapsulate behaviours that shape their decision-making process. Simulating the organization’s as-is behaviour involves developing agents corresponding to the key decisional actors and implementing the decision processes of these actors as behaviours of corresponding agents. The obtained simulation model aims to exhibit the closest possible behaviour to the real behaviour, given the development time and resource availability constraints. Organizations are interested in accessing the impact of infrastructure changes before implementation. The adopted Multi-agent modeling approach offers the possibility of testing the impact of these changes as it involves only switching the parameters of the concerned agents to use a behavioural setting reflecting the new way of doing.

Since agents are used in the SW simulator for strategic, tactic and operational decision levels, different changes at any combination of these decision levels can be implemented and studied. It is possible to simulate management strategy changes over a supply network, from the highest level to the smallest level. The simulator can be used for simulating any supply chain concept or strategy; from a lean, to an agile, or a leagile supply chain. The impact of these changes can be simulated and studied. The Simulator except mapping the profiles of new or - existing entities, the Simulator instead mapping the profiles of new or - existing entities. The Simulator here introduced is rather designed as a powerful tool to provide comparisons of the impacts of different actions in the extended complex SW environment and on the relationships between actors.

7.3 Focus on Visualization and the Dynamics of Simulated Environments

The goal of the SW simulator is not to provide optimal solutions for local problems. The conceptual approach adapted for developing the SW simulator is a soft systemic approach where the level of detail is important, and complex behaviours and relationships between different elements are considered in a complex environment. Applying this approach to a large environment such as a SW context involves a large quantity of data, enormous number of computing operations and a complex set of variables interacting together. Comparing scenarios through a quantitative approach by creating experience plans and running many replications (Law, et al., 2000) is not currently achievable, because the normal variability and the level of uncertainty inherited in the real world SW systems are already highly complex to control. According to Pathak et al. (2007), the impact of uncertainties within a many-entity environment may overwhelm the limited robustness of small-scale globally optimal solutions. This means that even if the variability of the simulations is kept to its minimum level, leaving only the variability of the real system, the number of replications required for any comparison will be very important, as each replication takes significant execution time. Also, a key purpose of the SW simulating is to allow the users to follow closely the evolution of the simulation through visual interfaces.

The SW simulator is designed to allow users to grasp the complexity of SW contexts and to support them in making decisions in these contexts. The focus is on the dynamics, the interactions and the mutual impacts occurring in SWs. The SW simulator helps the users understand the impact of various SW elements on their operations and businesses and assess the real impacts of these decisions on the internal operations, on the external partners and on the rest of the SW.

The SW visualization aspect acquires an important role in order to support the purpose for which the SW simulator was designed. Users need to visually follow the progress of the simulation through comprehensive and dynamic sets of interfaces. They also need to track the evolution of different metrics and KPIs to complete their understanding. The SW simulator core itself is not equipped with tools that provide these capabilities but its features are enhanced through the integration of the SW tools as mentioned earlier.
The multi-screen and multi-focus characteristics provided by the Monitor allow different levels of analysis. They allow managers to follow the states of specific elements such as the inventory level of a product in certain sites or to monitor complex elements such as the product supply process from plants to stores. It can allow cross-department collaboration by bringing together managers from different perspectives, such as marketing, supply chain management and finance, to work jointly in a board room to unify their visions and develop common strategies. In the case of cross-organization collaboration, actors from different organizations can create scenarios involving a global strategic vision and jointly follow and study the simulation and its results. Users have the possibility to increase and decrease the simulation speed or temporarily stop it. They can zoom in and out dynamically through different sections of the SW and assess closely multiple KPIs.

While the Monitor provides the possibility to observe the simulation in real time, the Mapper and Playback allow studying the simulation from its beginning until its current time. The Mapper provides static multi-dimension visualization, mining and assessment of any selected supply context and its performance at any desired depth through product, organization, time and supply dimensions. For example, a user can focus on the supply chain of a product by finding the produced quantity, the sold quantity globally or in a specific site, the quantities exchanged among organizations or among sites at any desired time span. The Playback lets users replay back the simulated past as many times as they need while the simulation is still running, is stopped or after it ended. Users can dynamically visualize, assess and mine the simulated past of a SW context and its performance by replaying the past evolution of the simulation and dynamically following various KPIs.

7.4 Local Optimizations and SW simulations

While the SW simulator is not designed for optimization, it is a powerful tool to test the impact of local optimizations of different components of the SW. Some SW sections can be optimized, outside the simulator, by using optimization procedures such as mathematical programming, metaheuristics or meta-models. The obtained result is then used to parameterize the configuration, as well as the functioning and/or the behaviour of certain SW elements. The resulting configuration and/or behaviour are implemented into the profile of the corresponding elements in a SW simulation. The SW simulation, in this case, provides two advantages. First, instead of testing these sub-systems in isolated environments by injecting random input data, the simulator provides a realistic testing environment that takes in consideration the interactions of different elements in a virtual SW context. Second, since local optimizations do not necessary guarantee a global optimization (Eschenbacher, et al., 2003; Capar, et al., 2004), the SW Simulator allows studying the impact of a local optimization on the entire business context, on the external partners and on the extended SW in a dynamic monitored environment.

It is also important to emphasize that each agent in a simulation can be modeled with a very complex behaviour involving local optimization through decision rules, heuristics, and even mathematical programming, when deemed appropriate by the users to represent reality adequately. For example, a shop scheduler may exploit scheduling algorithms and heuristics. This requires more processing and memory storage for these agents so as not excessively slowing down the overall simulation. Ultimately, the agents may use the exact same software tools as the real actors in the Supply Web.

8 Conclusion

Supply Webs are complex environments in which complex relationships between supply networks, organizations, sites and humans occur. Changes in a part of a SW can create waves of changes that reach distant actors. Managers need to evaluate the impact of their decisions on their internal operations, on relationships with their partners and on their environment. They need also to understand the impact of external actions on the internal operations and on their businesses. Since the SWs are complex systems that exist in dynamic environment, they can be considered as complex adaptive systems as suggested by the complexity theory. Approaching the SW concept from a systemic soft perspective requires tools which consider the complexity inherited in SW systems, focus on the behavioural and relational aspects and represent finely these systems. In this article we introduced the SW Simulation Platform as a tool in a series of SW Decision Systems that support decision making in the context of SWs.

The platform consists of a SW simulation Database and a multi-agent SW simulator. Two types of multi-agent applications are found in the Simulator. The synchronization application ensures the chronological logic within the virtual world created by the simulator. The organization applications represent the companies interacting in the virtual SW environment. The Simulator offers advanced agent behaviour to reproduce environments as close to the reality as possible. Different abstraction levels of organizations, sites and agents are provided to allow full understanding of managerial implications, to focus on important sections of the SW and to consider all elements of the SW context without gross aggregations and simplifications. The SW Simulation Platform features are enhanced by connecting the platform to SW Decision Systems through the database. These systems allow dynamically visualizing, monitoring, mining and assessing the virtual SW context and their performance.

Future research is needed on rendering the Platform more generic, easily customizable and applicable for various industrial contexts. Agent behaviour modeling is a rich area for further research, allowing on one side
to accelerate the creation and edition of original and variant models, and on another side to represent more realistically the behaviour of various types of agents regularly encountered in Supply Webs. Supply Web visualization is yet another rich avenue for further research, designing new viewing capabilities and assessing their value added. Further research should involve extensive win-win collaboration with industry, to further advance and validate the Supply Web concepts, methodologies and technologies.

Acknowledgments

The authors thank software analyst Alexandre Morneau for his help. The project was supported by Canada Research Chair in Enterprise Engineering and the Discovery Grant Program of the Canadian Natural Science and Engineering Research Council.

References


