Holistic Agent-Oriented Supply Chain Modeling

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Abstract:

Evolution of economical and technological contexts pressure businesses toward transforming their demand and supply chains so they are more customer-centric, more collaborative, more innovation enabling, more agile and more personalized. Simulation models are needed that allow contrasting actual vs. proposed chains, analyzing the dynamic performance of these chains, and understanding their overall behavior in specific contexts. This paper proposes a holistic agent oriented approach for developing and simulating such models. On one hand the approach relies on the specification of a community of agents closely mimicking with fine granularity and comprehensiveness the various decision making actors in the modeled chain. On the other hand the approach exploits deep holistic visualization through multiple concurrent viewers hooked to the simulation agents, enabling decision makers to embed themselves into the simulation, getting global multi-perspective insights while the simulation is running.

Keywords:

Demand and supply chain design; Holistic modeling and simulation; agent-oriented modeling and simulation; client modeling

1 Introduction

The new economy is characterized by stiff competition as well as high market and technological turbulence, with an ever increasing emphasis on delighting customers. For a business to maintain a competitive position, it should strive to be demand driven and customer-centric, exploiting the dynamic and stochastic nature of the demand, stemming from rapidly evolving customer expectations. Supply chain agility and intelligence should be developed and exploited in order to delight customers while fostering profitability.

Businesses are thus challenged to transform their demand and supply chain so that it becomes more customer-centric, more collaborative, more innovation enabling, more agile and more personalized. Customer-centric demand and supply chains allow businesses to thrive through live and often web-enabled interactions with customers. The goal may, for example, be to profitably delight customers through product and service innovation and customization coupled with high delivery velocity and reliability. Such transformations of a demand and supply chain are a tremendous challenge, often shaking fundamental paradigms and forcing the business to move into uncharted territories.

Once businesses decide to address the challenge, they begin to analyze their current demand and supply chain and to identify the transformations that could be implemented in order to meet the new demands and expectations. However, these transformation projects often affect the core business processes and involve considerable investments with no guarantee of success. Decision makers are all too aware of the stories where firms went through with a transformation project only to face endless obstacles throughout the supply chain that either reduced or cancelled out the expected profit. Decision makers are therefore hesitant to endorse these major transformations without higher assurance of success.

Indeed, on the surface, proposed demand and supply chain transformations often appear ideal with their combination of customer centricity, agility, personalization and innovation capabilities as well as collaborative behavior. Yet the realization of the implied transformations raises a number of questions. Will the change be really worth the effort? What will be the impact on the key stakeholders? What are the repercussions and risks entailed by the change? What will be the dynamic behavior of the proposed demand and supply chain? How will the business manage and control this new network?

Simulation modeling has long been identified as having the potential to answer such questions and help better design and assess demand and supply chain transformations. Yet in reality, simulation models are generally either highly detailed and focused on specific facets, or much more aggregate when attempting to cover the overall chain spectrum. This has up to now drastically limited their applicability in industry.

This paper proposes and demonstrates a holistic multi-agent oriented approach to modeling and simulating demand and supply chains that has the potential to unlock the compromise between modeling breadth and depth, and thus makes it possible to achieve the envisioned potential of simulation in designing and assessing chain transformations. It aims at increasing the probability that transformative projects do indeed enable their business to become more competitive in the new economy. The paper blends conceptual, methodological and case-based applications content to deliver its contribution.

The paper is structured as follows. Section two positions and describes the essence of the research contribution. Section three presents the proposed holistic fine-granularity agent-oriented approach and platform for modeling and simulating demand and supply chains. Section four details the agent-oriented modeling approach through an in-depth case study. Then section five provides conclusive remarks.

2 Modeling and simulating demand and supply chain transformation

This section first presents a review of previous research on demand and supply chain simulation modeling, then positions more in depth the fundamentals of chain transformation using an illustrative case, and finally presents the essence of the proposed approach.

2.1 Supply chain modeling and simulation

Supply chain simulation research is constantly gaining in popularity since it is recognized as the most realistic way of investigating the impact of transformations without having to implement pilots or full blown transformations (Terzi and Cavalieri, 2004). Baggachi *et al.* (1998) use simulations to determine the site locations when designing supply chains. They present the modeling principles relating to this approach, as well as the architecture of IBM's Supply Chain Simulator that is based on the SimProcess software. Ingalls and Kasales (1999) show the benefit of using simulations to analyze performance in a dynamic context by comparing the results obtained by an optimization model with those given by Compaq's SCAT simulator, which is based on the ARENA software. Again based on ARENA, Jain *et al.* (2001) describe the abstraction process to consider when developing a model for supply chain simulation.

Strategic decisions on the design of supply chains can be evaluated with simulation. Chatfield *et al.* (2005) propose an object-oriented simulation architecture to create, save and execute a model via an information exchange language based on XML, termed the Supply Chain Modeling Language. Recently, research initiatives are trying to determine the generic elements that constitute these models (Rossetti and Chan, 2003). Biswas and Narahari (2004) propose a simulation tool containing an object library of elements in a supply chain, and an object model used for problem solving which supports optimization and simulation techniques.

The inherent difficulties in modeling and simulating demand and supply chains are mainly due to: (i) the heterogeneity of the entities that form the network, (ii) the complexity of the interactions, (iii) the influence of the environment, (iv) the importance of smart planning and decision making, and (v) the diversity of the organizational structures.

In past research works, the field of the study and the objectives of the simulation guide the model's design phase. These works do not explicitly integrate the interactions between the clients and the supply chain. In fact, in most reported supply chain simulation research, demand is considered through an inputted stochastic distribution and client behaviors are not modeled explicitly. However, in a customer-centric and demand-driven context, such approximation and aggregation become a major limitation. Demand stems from clients that have distinct profiles and, consequently, different requirements. Explicitly modeling the clients becomes a key in being able to assess the potential value of demand and supply chains capable of addressing the personalized needs of individual clients in a fast and reliable manner, succeeding in transforming these demands into actual sales. This is also a key in identifying the pitfalls of current demand and supply chains not having such capabilities. Overall, taking into account the dynamic interaction between actors of the chain as well as clients is a crucial step in creating a representative simulation model.

2.2 Demand and supply chain transformation

A complete survey of research on rethinking, transforming and designing demand and supply chains is beyond the scope of this paper. Indeed, each transformative element has been the subject of significant research. Consider personalization as an example. Research on mass customization has boomed since the early works of Pine (1993) which showed how mass customization shakes the fundamental paradigms upon which the then dominating mass production and distribution were built. Several research projects have proposed models for implementing mass customization strategies (Ahlstrom and Westbrook, 1999, Gilmour and Pine, 2000). It has been shown that postponing differentiation (Feitzinger and Lee, 1997) and using standardized methods and modular product structures help reduce the development stage of personalized products as well as the associated delivery delays. Christopher and Towill (2000) have shown that a key hurdle lies in designing products and processes adapted to and focused on accelerating material, financial and informational flows. Duray (2002) and Selladurai (2004) have both emphasized the importance of evolving management so as to be able to deal with innovative and personalized products. Montreuil and Poulin (2005) have introduced a novel framework for characterizing personalization offers and used it as a basis for studying design implications for demand and supply chains.

Montreuil (2005) has introduced an illustrative case in the recreational vehicle business which contrasts a current mass production and distribution oriented demand and supply chain, shown in figure 1, with a proposed transformation claimed to be personalized, customer-centric, collaborative and agile, shown in Figure 2. This case is to be used in the paper for illustrating the holistic agent-oriented modeling and simulation approach.

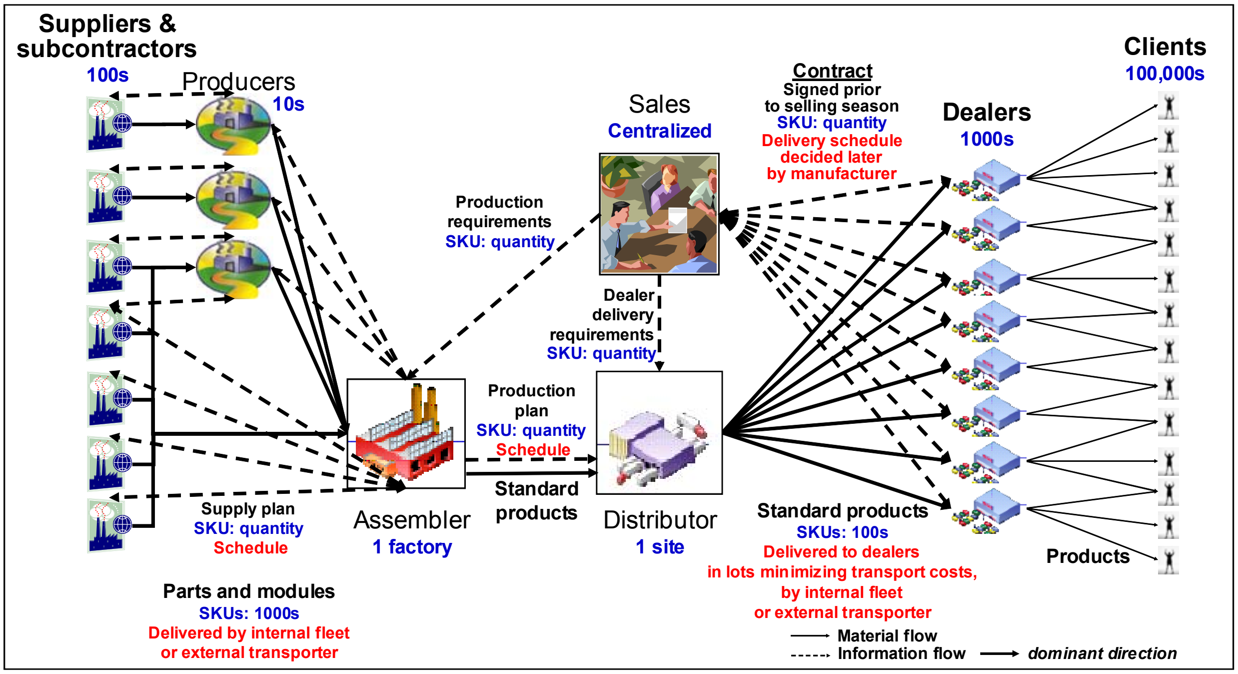

Figure 1: The current mass production and distribution oriented demand and supply chain

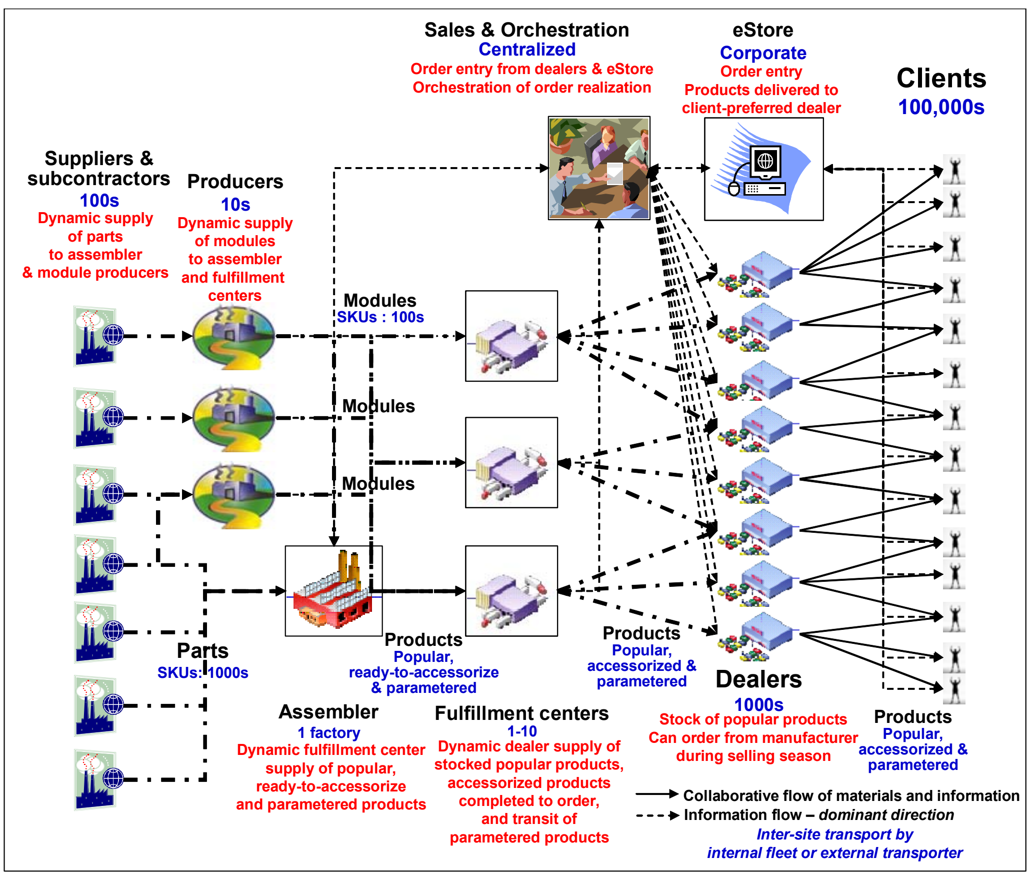

Figure 2: A personalized, customer-centric, collaborative and agile demand and supply chain

The proposed chain shifts away from strictly offering standard products, towards a much more personalized approach, offering a combination of popular products, accessorized products and parameterized products (as defined in Montreuil and Poulin 2005). Dealers are now allowed to order whenever they want instead of once several months prior to the main selling season. The business aims for one-day, three-day and ten-day delivery of popular, accessorized and parameterized products to dealers anytime during the selling season. In order to achieve such customer-centricity and agility, investments would have to be made into the product realization network. Setup times have to be reduced drastically, allowing mixed-model unitary flow through the main assembly plant. This plant has to feed a network of distributed fulfillment centers that can accessorize products from ready-to-accessorize products based on customer orders. Finally, collaborative practices have to be implemented within the supplier network to enable their required agility. The business also switches from mainly receiving parts from suppliers to receiving modules.

Figure 2 represents one of the many ways that the network in Figure 1 could be transformed with the aim of improving its competitive position. Before opting for this new network, the business would like to make sure that it will in fact be a profitable change.

2.3 Holistic agent-oriented modeling approach for demand and supply chain simulation

Simulation models are usually quite detailed when the simulation is focused on a specific part of the business. However, the larger the scope of the simulation, the more superficial becomes the model, using more and more aggregate data. Figure 3 illustrates this commonly accepted compromise between modeling depth and modeling breadth with a curve delimiting the perceived thoroughness of the current models and simulations.

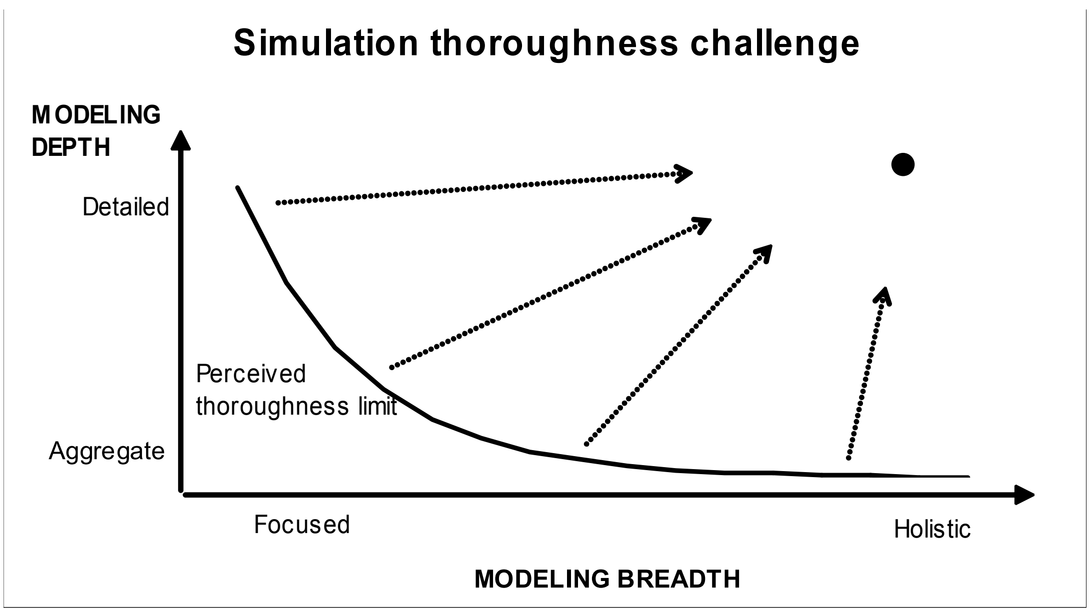

Figure 3: Simulation thoroughness challenge: increasing the capability for concurrent breadth and depth

As businesses are now trying to evaluate large scope projects that will affect every aspect of their own business (production, supply, logistics, finance, marketing, etc.) and most actors in the supply chain, they would highly benefit from a detailed model and simulator encompassing their multiple business facets as well their entire demand and supply chain. The high level of detail would also allow businesses to test any transformation project, whether very focused in a particular department or with considerable scope across the supply chain, and to easily see the effects on each aspect of the business. We therefore resolved to push the current thoroughness limits in figure 3. We aim toward increasing the modeling and simulation capability for concurrent breadth and depth, in order to enable the development of detailed simulation models that provide holistic as well as focused analysis capabilities.

The agent-oriented modeling and simulation approach we propose allows for the system to be represented by the identification and behavior specification of each individual and their interactions with other agents. These individuals evolve and act without any control or external intervention (autonomy), perceive their environment and respond to its changes (reactivity), initiate behaviors according to internal goals (pro-activity) and interact (sociability), (Wooldridge and Jennings, 1995). The properties characterizing the multi-agent system approach for modeling socio-technical systems make it a natural prospect for studying and representing the behavior of the different entities that constitute the demand and supply chain (Labarthe et al., 2006).

In this paper, the agent-oriented approach is extended significantly so as to allow fine-granularity holistic modeling and simulation of demand and supply chains. Indeed all the key actors in the chain are individually modeled through agents having specific behaviors. Such actors include the clients, the team for each dealer, as well as the logistics, production and supply planners and managers. Instead of emphasizing a theoretical presentation of the approach, the remainder of the paper focuses on an illustrative application as a means to introduce and demonstrate the proposed approach.

3 Agent-based modeling of demand and supply chains

The agent paradigm, which emerged from Distributed Artificial Intelligence, proposes a modeling approach allowing an explicit representation of individuals, their behavior and their interactions. This section describes how a demand and supply chain can be modeled using an agent-based approach so as to achieve a highly realistic representation that provides both a holistic perspective, encompassing the entire chain, and an in-depth perspective, allowing to investigate the impact of individual behaviors and interactions.

3.1 Architecture of the case study network

Figure 4 illustrates the demand and supply chain model for the recreational vehicle manufacturer used as the case study described in section 4. This snowmobile manufacturer deals with 250 suppliers in order to produce 126 different models. He receives one order from each of the 500 dealers in April from which he establishes his production schedule that will take place during the summer and fall. His logistics provider starts delivering finished products to dealers in mid-summer and continues to do so until December. Clients begin to visit dealers in the fall and make purchases until the end of winter, with a peak in December.

3.2 Agent-based model of the demand and supply chain

The agent-based approach analyses the supply chain in order to identify key decision makers and transpose them into agents in the simulation model. The first key decision maker in a customer-centric demand and supply chain is the client. Special emphasis is therefore put on faithfully representing the client’s personality, demand profile and behavioral capabilities when interacting with actors in the chain. The supply chain is then closely examined to identify all of the key actors in each of the businesses that will need to be modeled. For example, a supply chain could have suppliers, assemblers, manufacturers, wholesalers, distributors, dealers, logistics providers, etc. For each one, we identify and model all of the actors (purchaser, finance manager, marketing agent, production planner, dispatcher, salesperson, etc.) and their decision-making process.

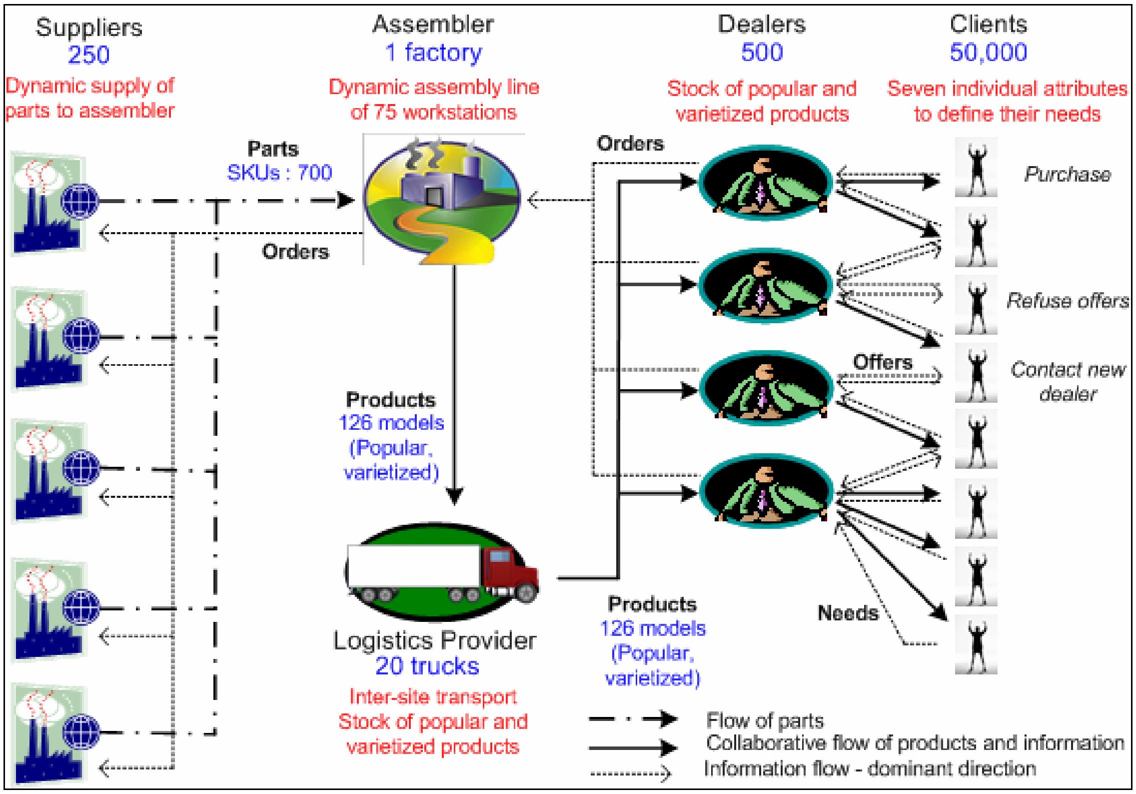

Figure 4: Modeled demand and supply chain

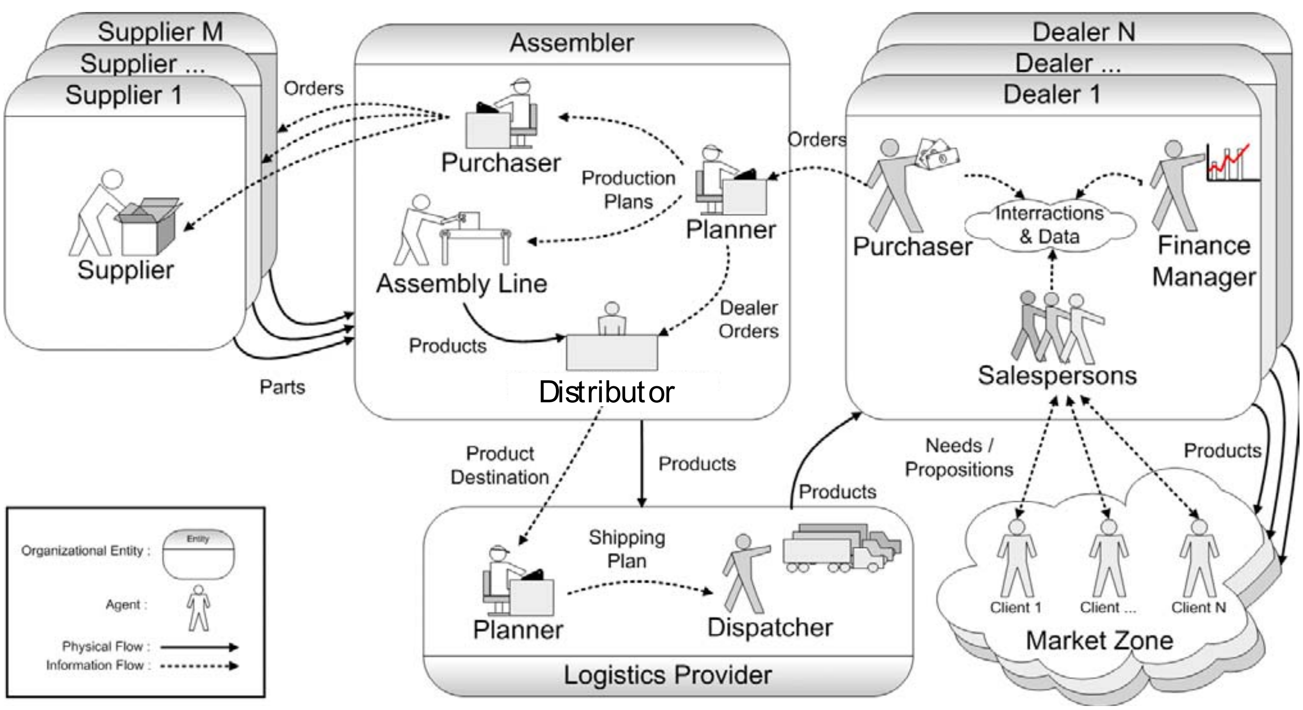

Figure 5: Case study model - agents and their interactions

Figure 5 shows, in a simplified manner, the relationships between the market zone and the four main types of organizational entities in the illustrative network: the dealers, the assembler, the logistics provider and the suppliers. To simulate the demand, each client is modeled as an individual agent. Dealers are each composed of a various number of sales agents, a financial agent and a purchasing agent. The assembler has four agents: a purchasing agent, a production planner agent, a production manager agent and a distributor agent. The logistics provider has two agents: a transportation planner agent and a dispatcher agent. The assembler has 250 suppliers, each represented by an agent. The implemented model involves an assembler, a logistics provider, 500 dealers and about 50 000 clients spread throughout the North American snow belt, as well as 250 suppliers from around the world, for a total of nearly 53 000 agents.

The model of the demand and supply chain thus obtained is then implemented into our simulation platform. The simulator exploits the information already available in most businesses and supplements with agent interactions. The simulation is highly detailed, recreating each of the key events and interactions in the chain by using decision-making processes as similar to those of actual clients and employees as possible.

3.3 The modeling and simulation platform

Although the focus of the paper is on the approach toward modeling and simulation of demand and supply chain, it is important to recognize that a modeling and simulation platform is necessary for enabling such an approach. Such a platform can contribute strongly to the feasibility and evolution of the approach. Mainly, the platform supports the modeling of the case, the management and analysis of informational input and output, the computational execution of the simulation, and the overall interaction with the users.

From a simulation perspective, the platform must become a multipurpose tool enabling the use of a simulation model for multiple objectives and experiences rather than a single focused experience. The platform may be used for recreating past activities and analyzing past performance. It may also be used to contrast how an altered chain would have performed under the same demand and external events. It can be used for creating alternate future demand and event scenarios for investigating the expected performance and robustness of the current chain and proposed alternatives. The platform thus becomes a virtual bench test exploiting persistent models.

The large scale nature of the models generated through the approach is such that it is impossible to contain their execution on a single computer. There currently exists two fundamental ways to generate the computational power to execute the models. The first is using a computational cluster composed of multiple processors which are exploited as a single entity by the software. The second is using a distributed network of processors, assigning organizational units and agents to specific processors in the network. The platform here implemented uses this second approach, exploiting a set of computers connected through the Internet, assigning specific agents and units to computers so as to balance the computational workload, and using a joint clock for synchronizing the multiple computers.

The scale, scope and complexity of the generated models require the platform to ease the understanding, analysis and evaluation of the models themselves as well as the experiments run using model-based scenarios. This is why the platform implementation has put strong emphasis on enabling the users to dynamically interact with the running simulation instead of limiting interaction before and after simulation runs. This permits decision-making users to observe the evolving dynamics across the demand and supply chain as it unfolds throughout the simulation. This is achieved through the dynamic concurrent display of significant views of the simulated demand and supply chain. As will be highlighted through the figures relating to section 4, the platform imbeds a number of ready-to-use, highly informative, visualization interfaces. These are dedicated to specific facets and actors of the demand and supply chain, allowing their examination from various perspectives such as sales, finance, production, inventory, transportation and supply. They track key performance indicators and status indicators. Overall they allow strategic decision makers a dynamic holistic view of the business. They also allow deep-focused examination of operational issues. Indeed, as the platform sustains chain-wide traceability of products, messages, decisions and events, the interfaces allow both synthetic observation and focused data mining. In the actual implementation in the Laval University laboratories, these viewers can be shown through multiple projectors displaying the dynamically evolving views concurrently on the laboratory walls, allowing decision makers to grasp the entire dynamics visually.

The platform allows the simulation speed to be adjusted by the users so that decision makers can dynamically follow what is happening over the entire demand and supply chain through multiple viewers plugged into the simulation. For example, a year of operation can be set to be simulated in an hour, then slowed significantly to examine in detail specific dynamics occurring at some time in the simulation, or speeded up when only the final results are desired for performance comparisons.

4 Deep holistic modeling and visualization of simulated demand and supply chains

The recreational vehicle manufacturer case introduced in sections two and three is used for illustrating the analysis capabilities of the proposed approach. In this section, the description focuses on modeling the supply chain and its agents, as shown in Figures 4 and 5, with a level of comprehensiveness making it comprehensible how one would then proceed to model the alternative customer-centric chain. The studied business designs, manufactures and sells snowmobiles on the North American market. The main agent types are described in the following subsections, with an emphasis on their fundamental nature, their behavior and their interactions in the overall agent community.

4.1 Client modeling

Each client is modeled as an individual agent. They are each provided with an identity, a personality, a demand profile and behavioral capabilities relative to their shopping process. As for their identity, each client has a name, address and personality characteristics. These are matched with overall statistical distributions about client population and demand. For example, the number of clients in a country, state or region is relative to the overall stochastic demand in these geographical zones.

Demand profiling of each client is achieved through three specific profiling facets: time, budget and product fit. The shopping process of each client is time delimited by a shopping start time, a target purchasing time and a latest shopping time. Each client is also provided with a budget: target spending on the product and maximal allowed spending. This budget is stochastically correlated with his product fit profile.

Each client is provided with personality characteristics influencing his decisions throughout the shopping process. First is his willingness to shop around, here expressed as a combination of the geographical perimeter around his address within which he is willing to shop for a product and the maximum number of dealer visits he is willing to do. Second is his tolerance to delivery delays, here expressed as the maximum time he is willing to wait for delivery of a product not available at a dealer at purchase time. Third is his tolerance to dissatisfaction due to product substitution, here expressed as a minimum satisfaction threshold below which he will not buy an alternate product instead of his unavailable favorite. Fourth is his immediate purchase impulsivity, here expressed as maximum satisfaction threshold above which he will immediately purchase the offered product.

Each model offered by the business in its product mix is here a specific combination among the following features: ten platforms, thirteen motors, three suspension types, two types of tracks, three types of seats and four offered colors. For example, the ten platforms are child, cruiser, deluxe cruiser, family, ice racing, jumping, labor, mountain, performance and super performance. Theoretically, 9 360 combinations could be offered by the enterprise. Among these, many are infeasible. For example, one cannot put the biggest engines on a child platform. Being a mass producer and distributor, the business has limited itself to offering to its clients only 126 standard combinations among the potential feasible combinations.

The client, when first entering his shopping process, does not think in terms of specific models. In fact, through its product fit profile, the client is modeled as focusing on the following attributes, weighted by relative importance: performance, maneuverability, durability, comfort, security, economy and appearance. Each feature, such as the platform and the engine, has fitting impact relative to each feature. For example, a small engine will contribute poorly to the performance attribute, yet will score high in terms of economy. The combination of features in a given model allows the computation of the relative fit of the model for each attribute. By using the specific client weights, the model fit for each client is calculated as a satisfaction level between 0 and 1. The theoretical ideal fit has a satisfaction index of one. The feasible ideal fit may have a satisfaction index lower than one and may not be offered by the business. The best fit corresponds to the model, offered by the business, which gives the highest satisfaction level.

From a behavioral perspective, each client visit to a dealership is explicitly modeled, including the client's interaction with a salesperson. During such a visit, the salesperson discusses with the client, assessing his needs as best as possible. Based on this assessment and product availability, the salesperson offers a product to the client, at a specific price and delivery time. Given this offer, the client evaluates his degree of satisfaction for the product by taking into account: i) the difference between his budget and the sales price, ii) the product fit, based on the match between the desired attributes and those of the model proposed, and iii) the dealer's proficiency (ex: welcome, showroom and suitability of the products). If the satisfaction towards the proposed offer is greater than the client's maximum satisfaction threshold, he buys the product immediately even if he had planned to visit more dealers before making a decision. If the satisfaction towards this offer is less than the maximum satisfaction threshold but greater than the client's minimum satisfaction threshold, he will put it in his potential buying list and continue visiting dealers. Once the client has reached his intended number of dealer visits or the limit of his intended shopping period, he will seek to purchase the offer with the highest satisfaction rate and then complete the shopping process, either ending up with a purchase or deciding not to purchase.

Thus, at the end of any period (an hour, a day, a week, etc.), the final state of any client active during this period belongs to one of the seven following categories:

Ideal fit *Blue* state:	he bought and received the model ideally fitting his needs;
Best fit *Green* state:	he bought and received the model in the product mix that best fit his needs;
Substitute *Yellow* state:	he bought and received a substitute model;
Delay *Orange* state:	he bought a best fitting model and accepted a significant delivery delay;
Lost *Red* state:	he decided not to buy even though he was offered models;
Shopping *White* state:	he is still undecided and pursues his shopping process;
No fit *Black* state:	he stopped shopping since there was no model even remotely satisfying his needs.

These states can be observed from a dealer perspective, the overall business perspective or the real client perspective, and can be focused on a dealer or the entire business. For example a client may be lost for a dealer, yet not for the business since he is going to another of its dealers. Depending on the communication openness between a dealer and a client, a dealer may think a potential client is still in a shopping state, yet for this dealer he may be actually lost.

Figures 6 to 8 depict sample screenshots for the simulation platform. They illustrate on one hand the nature of clients and their dynamic shopping process, and on the other hand the capability of the platform to help users visualize and analyze client-centric information stemming from the simulation. Figure 6 provides a client event matrix snapshot taken at simulated 11h06 on October 31st, 2006. It geographically depicts the dealer network. Each star on the map represents the location of a dealer. Although there seems to be fewer than 500 stars in this figure, it is because large cities have many dealers which are currently overlapped at this zoom level. The color of the dealer's star changes momentarily at the end of a client-dealer interaction to show its outcome in terms of the client state as perceived by the dealer. Furthermore, the essentials of each client-dealer interaction are messaged in the lower part of the map.

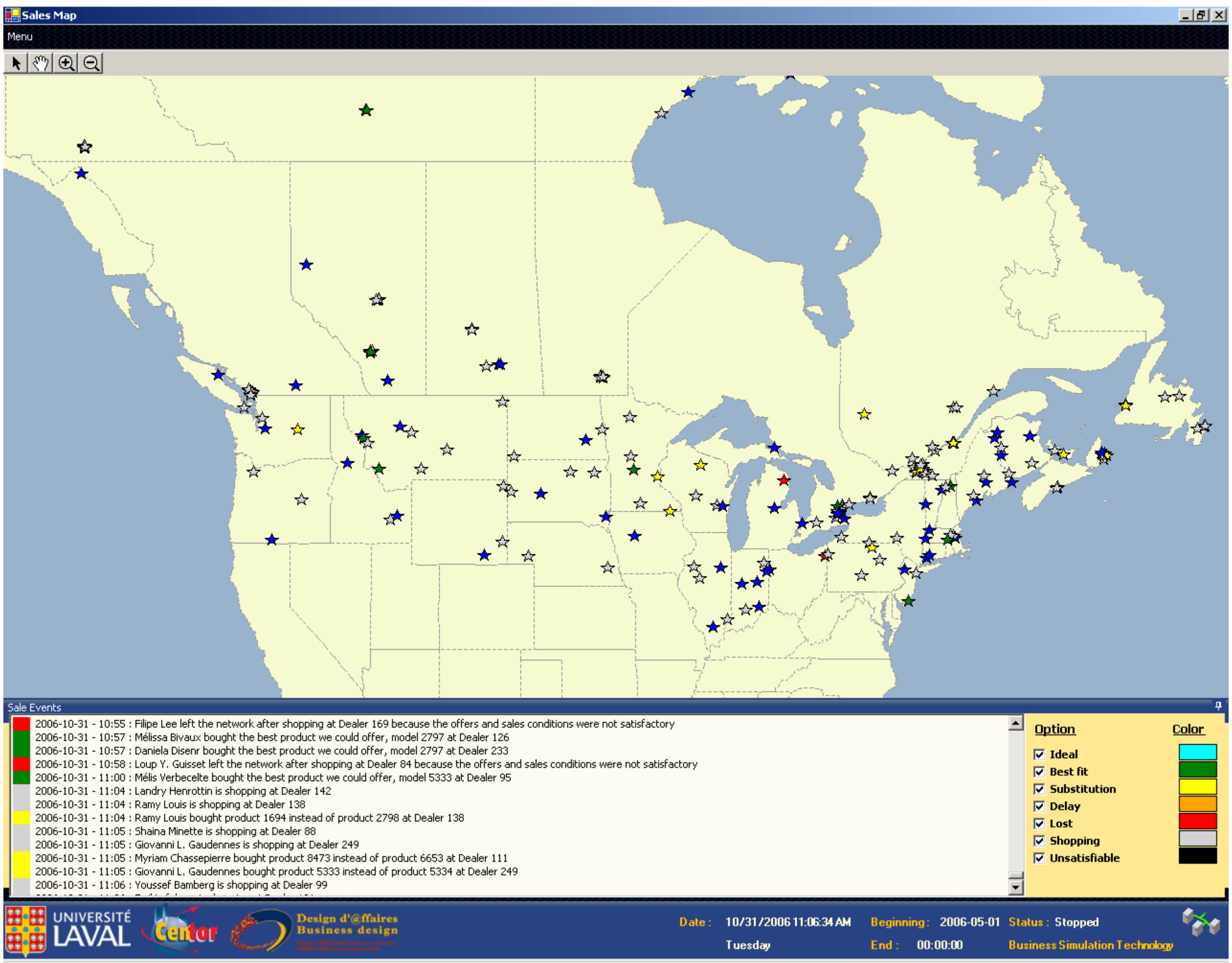

Figure 6: Client event map

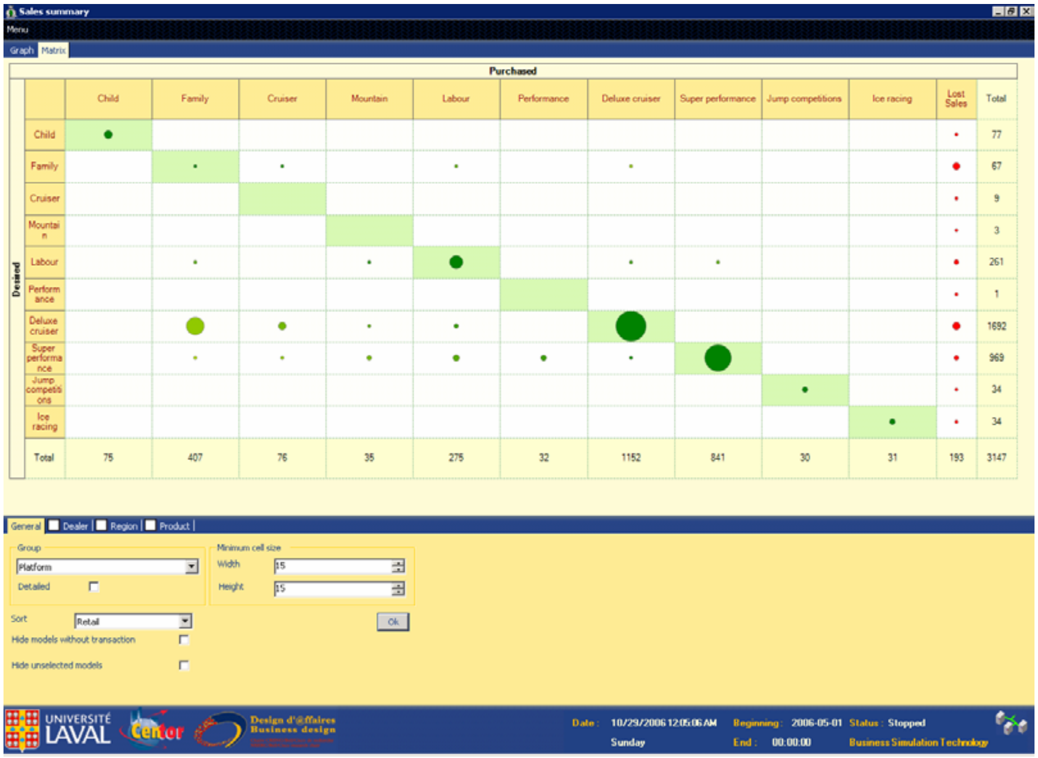

Figure 7: Client demand, purchase and substitution matrix for platforms

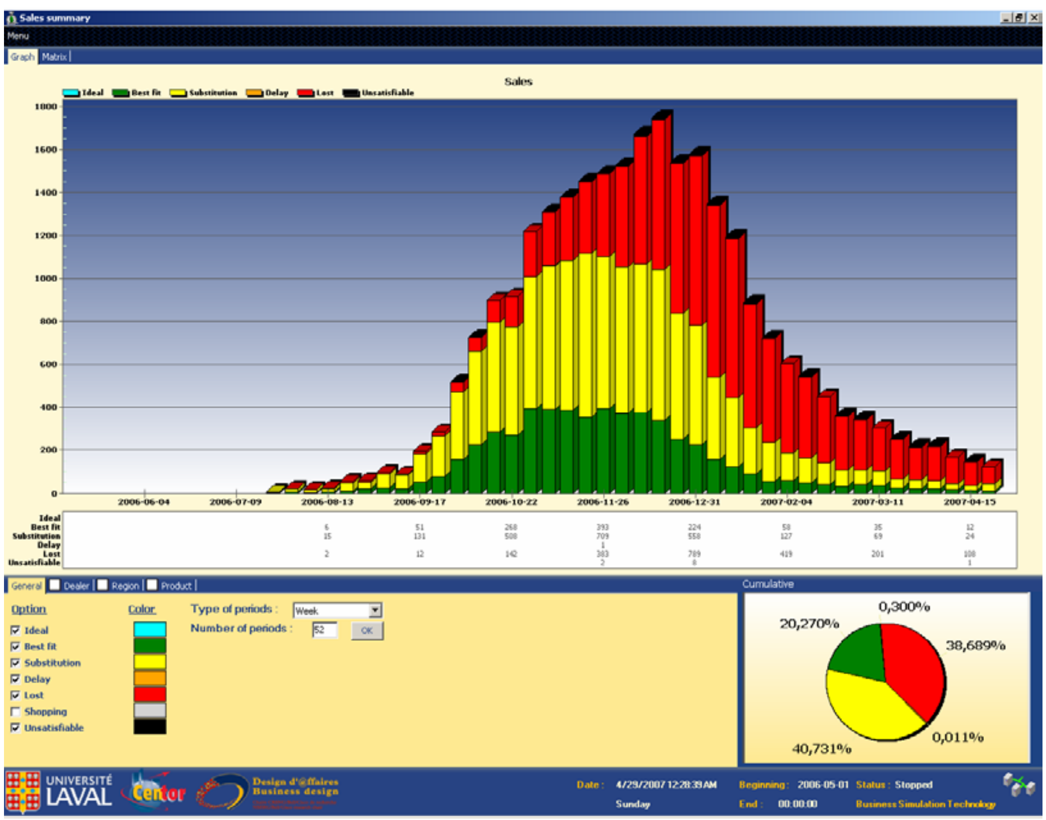

Figure 8: Active client state graph

Figure 7 provides a demand, sale and substitution matrix snapshot, taken at simulated 12h06 on October 29^{th}, 2006. This specific matrix focuses on the alternative platforms. Each line and column corresponds to a specific platform. The lines state what the client wanted, here it is the type of platform best fitting his needs. The columns state what the client purchased. The ideal situation would only show sales on the diagonal. Otherwise this confirms that clients had to make compromises and buy products based on platforms other than the most adequate platform. The summative lies and clients are highly revealing, enabling to contrast the actual sales and demand for each platform. For example, up to snapshot time, 969 clients wanted the super performance platform, yet only 841 clients purchased a product with this platform due to lack of availability. The lost sales column shows that lost sales have up to date been mostly associated with clients wanting Family and Deluxe Cruiser platforms.

Figure 8 depicts the active client state graph as of 12h28 on April 29^{th}, 2007. For each week, since the beginning of the simulation, the graph shows the number of clients in each state as perceived from the entire business perspective. Here the clients in the shopping state have been removed from the displayed graph to concentrate strictly on transactions concluded positively or negatively in each week. These shopping-state clients represent globally in average 82% of the active clients per week up to the snapshot date. The graph shows that 38,7% of the transactions have failed, resulting in lost sales, with a quite negligible 0,01% of no-fit states. Then respectively 20,3%, 40,7% and 0,3% have resulted in best-fit, substitute and delay clients. So, roughly one client out of five got what he wanted, two compromised yet bought while the last two were lost. The graph clearly shows that the percentage of lost sales increases as the selling season progresses, the dealers having less and less product availability for satisfying client demand. It also shows that even early in the season a large amount of substitutions are occurring, due to misfits in terms of dealer availability versus the actual demand. The platform allows dynamic data mining by displaying such graphs with various time granularities (day, week, month, quarter, year), various geographical zones (world, country, state, site), various organizational entities (business, specific dealer), and specific models or features.

4.2 Modeling the dealer network

As mentioned earlier, each dealer is modeled individually. It is here comprised of an executive agent, finance agent, a purchasing agent and sales agents. Each dealer has access to all client information depicted above that relates directly to its operation.

Each salesperson of a dealer has an individual profile specifying his perceptivity, his service inclination, and his client centricity. These three profiling parameters range from zero to one, from worst to best. His perceptivity affects his capability to listen and assess the real client needs and to find the best-fit product for the client and, if it not available, the best substitute products. His service inclination defines his willingness to walk the extra mile for the client. At worst he is so lazy that he considers only products in the showroom as potential offers to clients. At best he considers the entire available inventory and incoming products, as well as potential transfers from other dealers or the business (when allowed in the scenario). His client centricity indicates whether at best he focuses his offer selection process on optimizing client satisfaction or, at worst, he always aims toward offering the highest margin product he feels acceptable to the client.

The dealer's purchasing agent is responsible for proposing the overall number and cost of products to be purchased to the executive agent who then takes the final decision. Then the purchasing agent decides on the mix of models to be purchased, stating how many he purchases from each model and when he wants them delivered, first for filling the showroom, then to allow a steady flow of input in advance of expected demand to avoid in-season shortages. Both levels of decisions involve forecasting and heuristic decision making. There are myriads of ways of implementing these. For example, for the overall quantity to be purchased, currently the purchaser forecasts using a yearly moving average. Two types of dealer policies can be contrasted. The former does sales forecasts. The latter dynamically registers client demand and thus performs demand forecasts instead of sales forecasts. The business also provides a market trend analysis which affects the purchaser's overall forecast for next year, according to his belief in such analyses. Then the executive manager takes the forecast and translates it into a purchasing decision based on his risk orientation, thus multiplying the forecast by a risk orientation factor to get the purchasing quantity.

The dealer's finance agent sees to the accounting and is responsible for paying the received products to the manufacturer and for financing purchases whenever required. The platform depicts the financial cockpit of each dealer's finance agent. Figure 9 displays such a cockpit as updated at 11h06 on October 31st, 2006 for a specific dealer. It shows live financial graphs plotting monthly states of inventory, sales, cost of goods sold, gross margin and liquidities, as relates to dealing with the business. It also plots the dynamic evolution of cash flow, gross margin ratio and inventory. By providing three years of historical results, it allows the observation of repeating overall behaviors. For example, the dealer buys and receives products in advance during the season, resulting in inventory surges which are slowly depleted. The rightmost portion of the cash flow graph illustrates the risks of rapid negative cash flows if the currently purchased products are not sold to customers as expected.

Figure 9: Dealer financial cockpit viewer

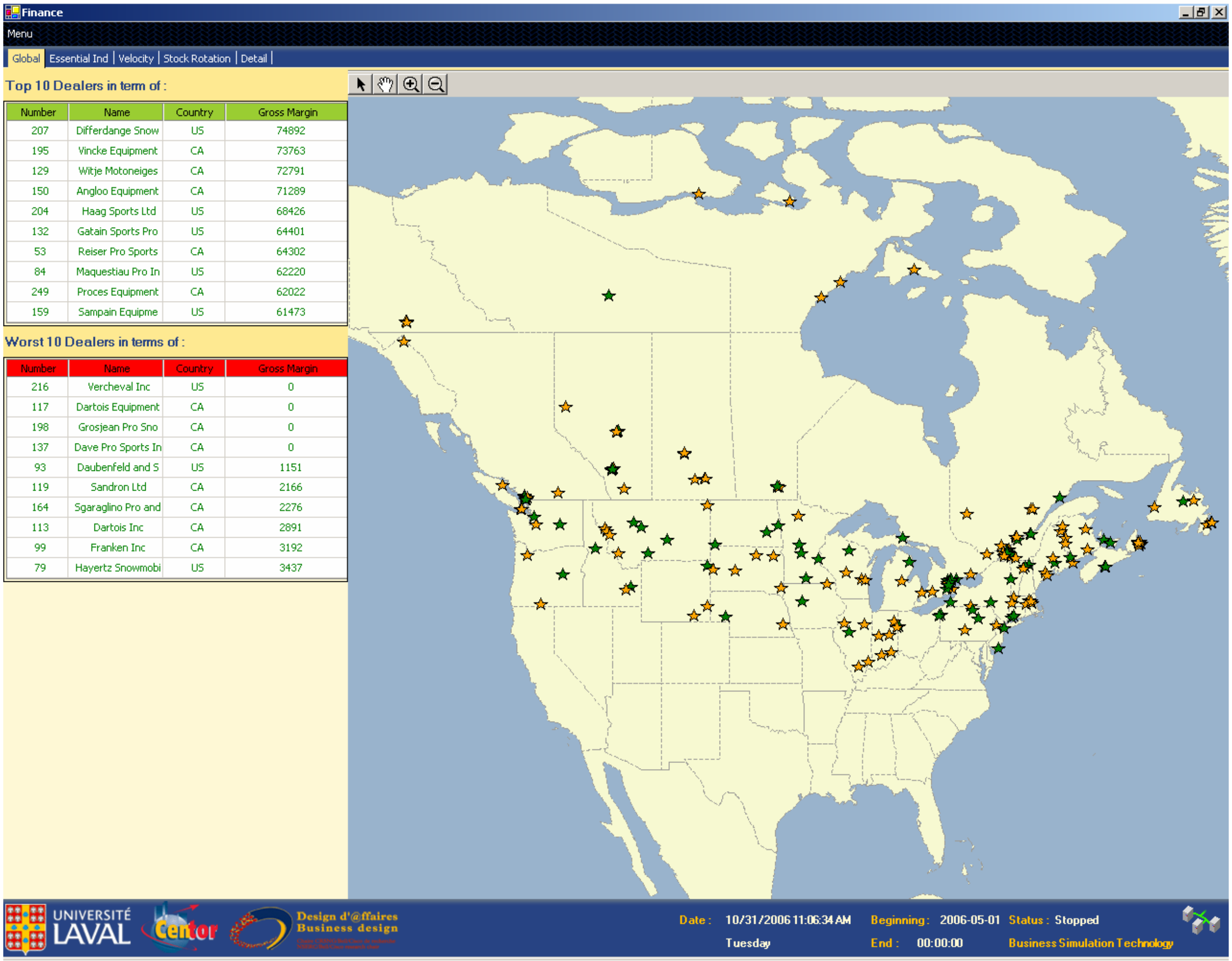

Figure 10: Financial dealer map

Beyond overall purchasing authority, the executive agent is responsible for setting the number of sales agents as well as the number of products in the showroom, based on the dealer's sales history and forecasts.

Taking an overall dealer network perspective, Figures 6 to 8 allow users to track client-oriented performance of dealers. Similarly, Figure 10 depicts a financial dealer map which tracks the financial performance of the dealer network. It resembles the client event map in Figure 6. Each star also represents a dealer. However, its color now indicates the dealer's dynamically updated financial situation. A summary of the top ten and worst ten dealer financial situations is provided based on a user specified financial indicator. The user can always mine the map by clicking on a dealer and visualize the financial state of each dealer relative to its business with the enterprise.

4.3 Modeling the assembler

The assembler's production facility is explicitly modeled with its assembly line composed of 75 workstations, each executing a set of operations depending on the product being assembled. The products move through the line at fixed intervals set by the takt time. When switching from producing one model to another, each workstation has a setup time. This setup requires at least one time slot to be left vacant in the line, allowing the station's resources, tools and equipment to be adjusted or replaced by those needed for the next model. Figure 11 provides a view of the assembly line which dynamically details for each workstation the tasks assigned to it and the model unit it is currently working on. For example, it shows that workstation 47 is currently responsible for an assembly process and assembles the first product model 6653. Such a view allows data mining, for example clicking on a product icon at a workstation shows the current product's serial number and all of its technical characteristics.

As summarized in Figure 5, the model of the assembler currently includes four agents: a planner, an assembly line supervisor, a distributor and a purchaser. The planner agent receives the dealers' orders which specify the quantity for each model as well as the requested delivery dates. He optimizes the assembly schedule, heuristically minimizing setup times and setup costs as well as manpower change costs that occur when changing from one model to another on the assembly line (Montreuil 2005). Figure 12 provides a view of the assembly plan, here depicting completed and planned production through a Gantt chart. For example, the next model scheduled to enter the assembly line is model 5334 with a lot of 650 units, from simulated October 29th to November 8th, 2006.

Figure 11: Assembly line dynamic state viewer

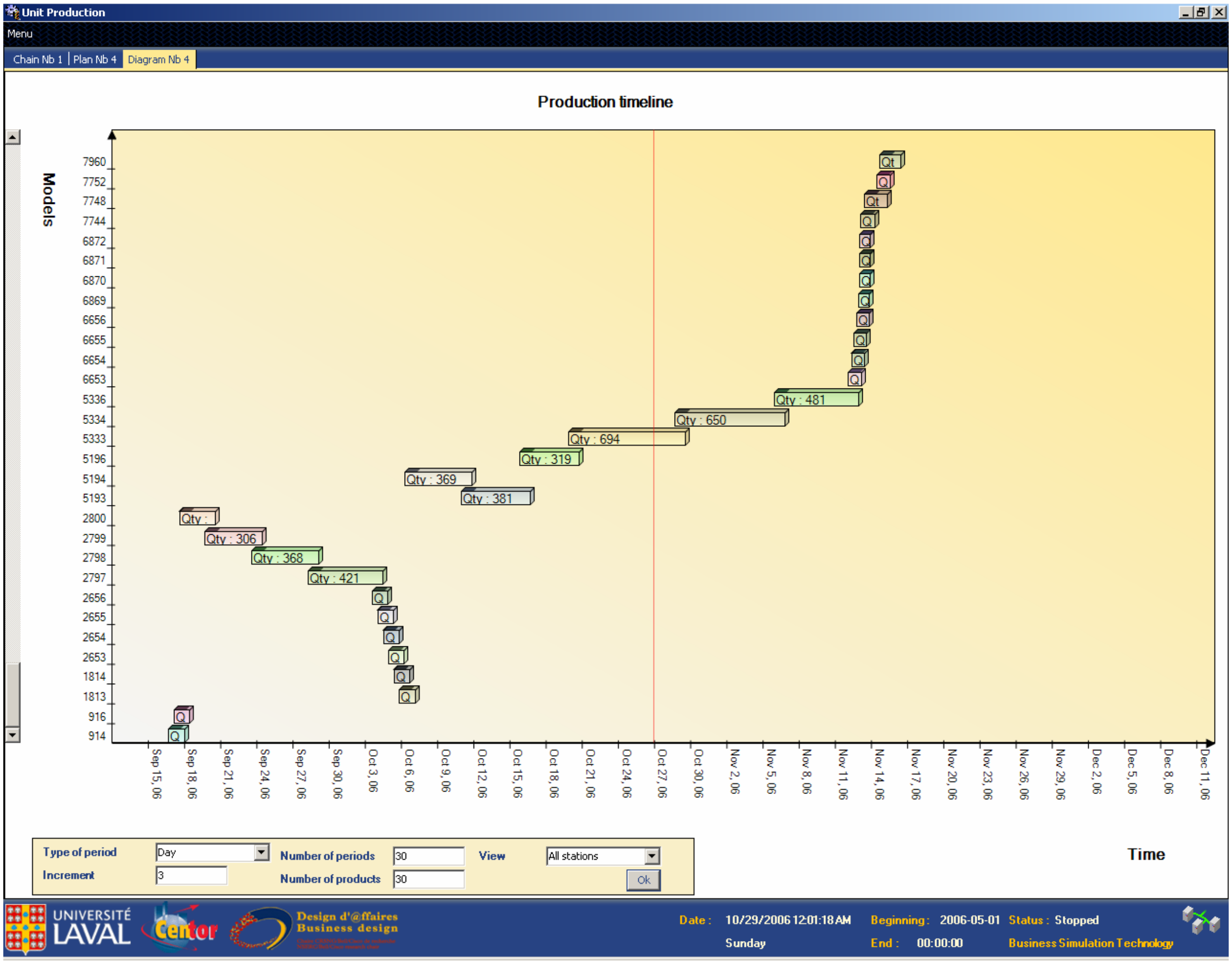

Figure 12: Dynamic assembly schedule viewer

The planner agent transmits his assembly schedule to the purchaser agent who validates the feasibility of having all the necessary parts available at the required time. Each model is here composed of about 400 parts and modules that are ordered from 250 suppliers. Figure 13 lists the bill of materials and the bill of suppliers for each model produced. For each part-supplier combination, the purchaser tracks the supply costs, constraints, delay speed and reliability, as well as quality. The purchaser agent informs the planner agent of the availability constraints, if any, and the latter adjusts the schedule accordingly. The planner agent sends the final schedule to the purchaser agent who then dynamically launches orders to suppliers so as to minimize the risks of being out-of-stock while keeping inventory levels as low as possible.

The supervisor agent receives the assembly plan from the planner and has access to parts inventory and delivery information. His responsibility is to make sure that the line actually follows the plan, enacting the setups, the resource moves and material delivery to workstations, reacting to breakdowns. He locally adjusts the plan if necessary to insure feasibility, otherwise he refers to the planner.

The distributor agent is responsible for the distribution of completed products to the dealer network. He monitors the inventory level of each dealer, their order list with the desired dates, and dynamically assigns products to specific dealers. This assignment is forwarded to the logistics provider who deals with the actual deliveries.

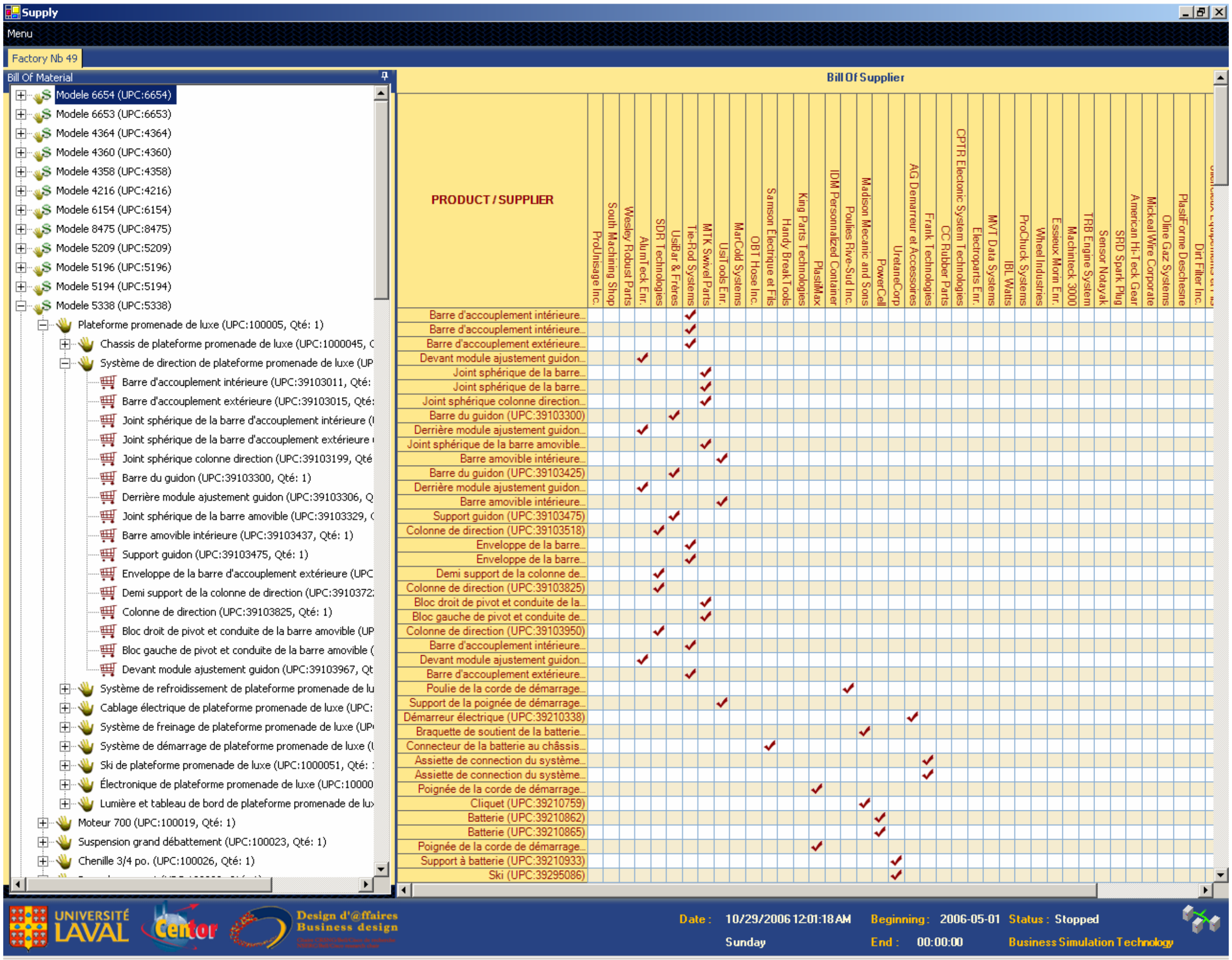

Figure 13: Bill of materials and suppliers

Figures 14 and 15 illustrate the depth of information available to the distributor agent. Figure 14 indicates how many products are currently present in each section of the supply chain: production, warehouse, dealers and clients. The image here clearly shows that the simulation is currently using a channel stuffing strategy since there are very few units in production and in the distribution center. In the early portion of the season, the dealers have to support the majority of the inventory and have just started selling. For example during the week of 2006-11-26, 177 products were in the distribution center, 7898 were in the dealer network and 8856 had been purchased and delivered to clients. No products were currently being assembled as production ended one week earlier.

Figure 15 shows the stock tracking viewer which situates each product in the supply chain. It can display detailed stock status in the production and distribution centers, the dealer network and each dealer, the client network and each individual client. In Figure 15, a stock tracking map is displayed for the dealer *Lespagnard Equipment Sports inc.*, where a block is assigned to each stocked product, the block size is proportional to the inventory level and its color is a function of the inventory status criticality. It clearly shows that at simulated 1h58 on October 31st, 2006, products 5334 and 5194 were the two products with the most stock, with respectively 14,9% and 13,4% of the dealer stock, while the available product with least stock is product 7744.

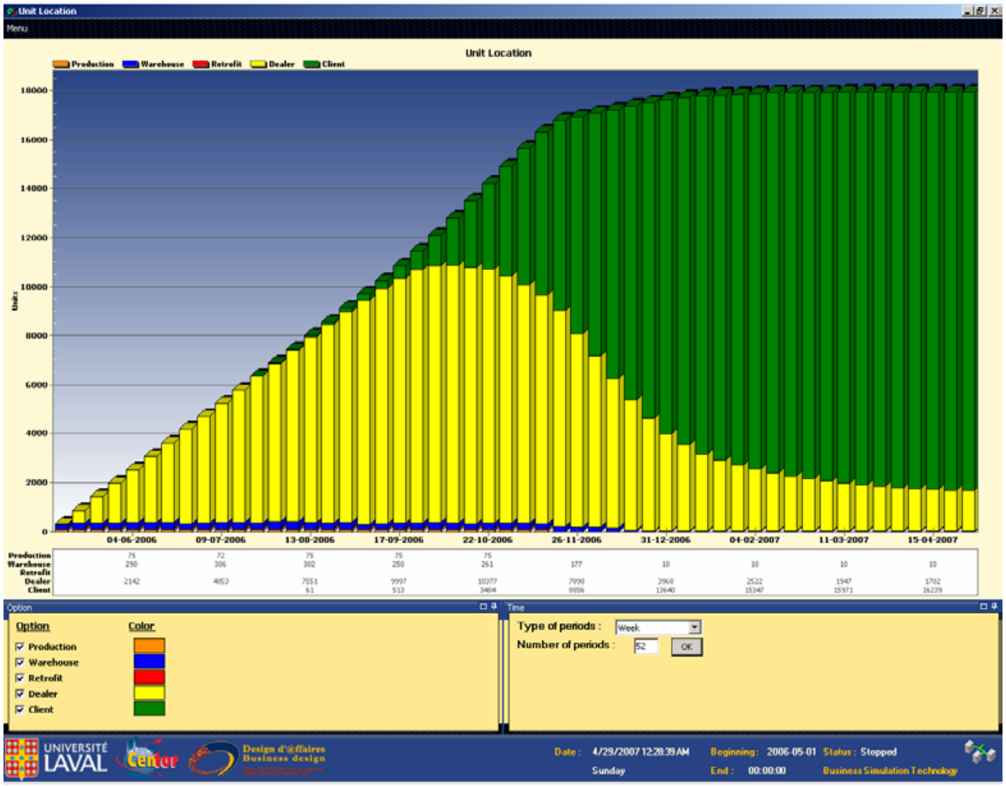

Figure 14: Supply chain product deployment graph

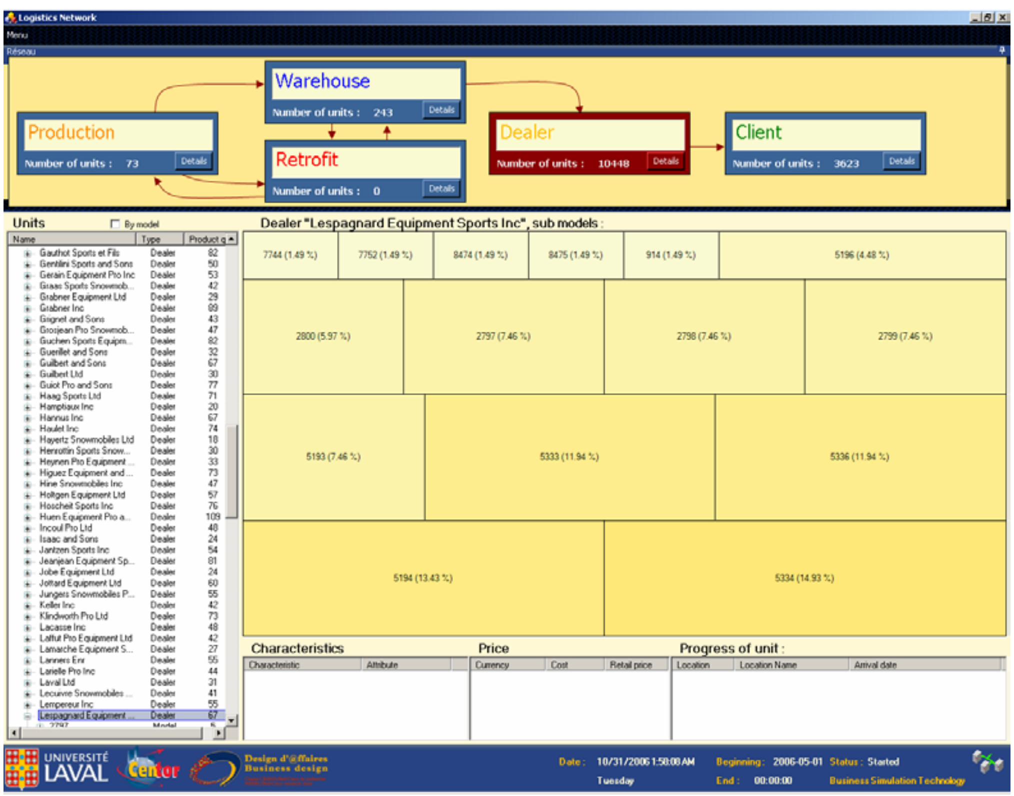

Figure 15: Supply chain stock tracking map

4.4 Modeling the supplier network

The supplier network here includes 250 suppliers. Geographically, some are in the same locality as the business, while others differ in terms of region, country or continent. Each supplier is currently modeled in an aggregate manner through its supplier profile. It is assigned a set of parts/modules to supply. For each of them, the profile sets whether production capacity is to be explicitly modeled or not, and if the item is stocked by the supplier or strictly made to order. If capacity is an issue, then the maximum production rate is specified, otherwise an availability lead time distribution is specified. When stocking is allowed, then the profile sets whether the inventory itself is to be modeled or if a stock availability distribution is to be used. Minimum order quantity, order bucket size, parts pricing structure and quality distribution are specified in the profile. Currently, transportation of parts to the assembler is under the responsibility of the supplier. In line with the supplier location, the profile sets transportation costs, delays and reliability. The supplier agent receives the orders from the business purchaser agent, informs him of delivery information and provides him with updates when significant deviations are known to be building up as contrasted with delivery promises.

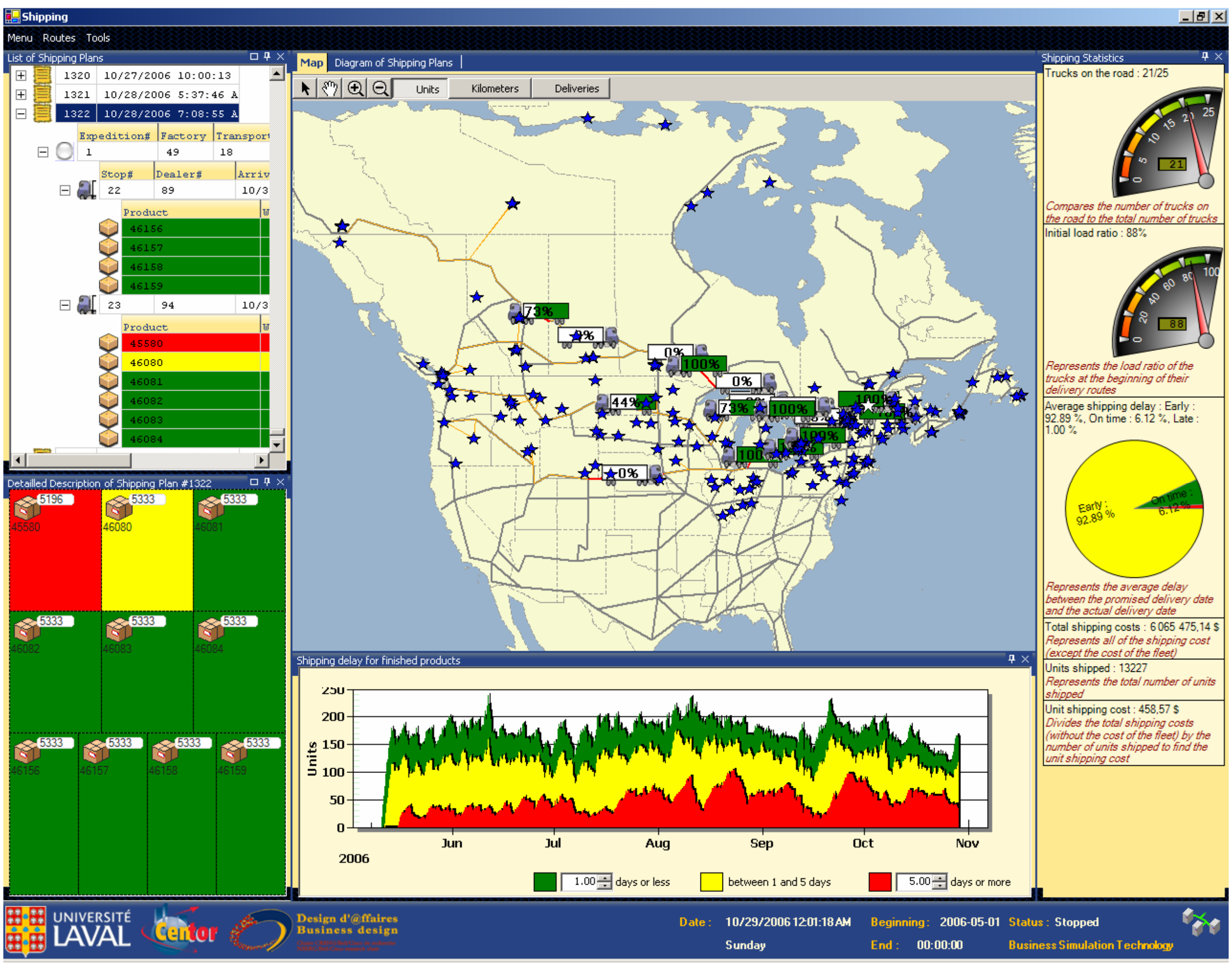

Figure 16: Product-to-dealers transportation cockpit

4.5 Modeling the logistics provider

The logistics provider is responsible for insuring the transportation of finished products to dealers. It is modeled as a combination of two main agents: the planner agent and the dispatcher agent. The actual transportation is currently performed by using a fleet of trucks and trailers leased from an independent fleet provider. The logistics planner agent dynamically receives lists of assigned products from the distributor agent. He is responsible for planning delivery routes, indicating when each truck is to leave, the set of dealers to be visited, and the products to be delivered to each dealer. He takes into consideration the delivery location, distance and preferred delivery date of every allocated product. The planner agent can use either heuristic algorithms or optimization models to design his transportation plans. Once his plan is achieved it is transmitted to the dispatcher agent who sees to its execution and monitors the progress of the delivery trucks through a simulated geographical positioning system (GPS).

The transportation cockpit shown in Figure 16 graphically depicts the monitoring of the delivery trucks, shows an activity log and details shipping routes. The map shows the state of each delivery currently in progress. Dynamically updated key performance indicators are designed to help monitor transportation efficiency. The average percentage of the truck capacity used versus delivery delays can be compared for both actual and historical shipments.

5 Conclusion

Evolution of economical and technological contexts pressure businesses toward transforming their demand and supply chains so they are more customer-centric, more collaborative, more innovation enabling, more agile and more personalized. Simulation models are needed that allow contrasting actual vs. proposed chains, analyzing the dynamic performance of these chains, and understanding their overall behavior in specific contexts. This paper has proposed a holistic agent-oriented approach for developing and simulating such models. On one hand the approach relies on the specification of a community of agents closely mimicking with fine granularity and comprehensiveness the various decision making actors in the modeled chain. On the other hand the approach exploits deep holistic visualization through multiple concurrent viewers hooked to the simulation agents, enabling decision makers to embed themselves into the simulation, getting global multi-perspective insights while the simulation is running.

The research demonstrates that it is currently possible to increase the capability for concurrent breadth and depth of simulation of demand and supply chains, pushing the actually perceived limitations in the compromise between breadth and depth. Technologically, the distributed simulation architecture underlying the platform reduces the computing speed bottleneck. Conceptually, the agent-oriented approach reduces the modeling complexity bottleneck. Methodologically, the reliance upon a structured three-tiered approach to develop the agent-oriented simulation model reduces the learning required prior to being able to generate such models, then structures and speeds up their development. Practically, the availability of a platform and a library of agents, viewers, etc., reduce the burden of creating new models. From an information requirements perspective, the approach exploits the huge availability of information stored in enterprise data bases, yet it still requires interaction with professionals for adequate modeling and parameter estimation.

The approach is in constant evolution from an instrumental and methodological perspective, as generations upon generations of prototypes enable testing of new capabilities and validating with industrial cases. It is a work in progress, in turbulent flux, as the limits and potentials are better understood. Furthermore, the approach and its supporting modeling and simulation technology now open a wealth of empirical research. For example, experiments can be designed to contrast chains with various capabilities in terms of agility, personalization, and so on, enabling to better understand the challenges involved and the impact on performance of specific transformational options and combinations of options. Finally an interesting avenue of research is to contrast the requirements in terms of agents to support the management of these demand and supply chains. Further research thus involves the development and testing of ever more intelligent agents, supported by metaheuristics and elaborate inference engines.

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