TOWARDS AN INTEGRATED IS FRAMEWORK FOR THE DESIGN AND MANAGEMENT OF LEAN SUPPLY CHAINS

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Abstract: In this paper we present Co-LEAN, an integrated suite of software tools suitable for the design and management of lean supply chains. In addition to providing full operational support in the planning and execution of the lean supply chain, Co-LEAN supports internet-based collaboration in the innovation and product design, manufacturing strategy, and supply-chain improvement tasks. The paper discusses the information system support requirements of a lean supply chain, describes the main components and the integration mechanisms of Co-LEAN and concludes with a brief description of its pilot use in a major supermarket chain.

1 INTRODUCTION

The notion of lean supply chain has been a natural extension of the concept of lean manufacturing. Since mid-1990s, the philosophy and the toolset of the lean approach were extended to cover the full spectrum from the end customer to the raw material suppliers (Hines and Rich, 1997; Rother and Shook, 1998; Hines *et al.*, 2004). The holistic nature of lean ideas calls for an equally holistic approach to the supply, which deviates from limited in time, place and scope activities, such as (optimised) supplier selection, supply chain sourcing and supplier development (Jones *et al.*, 1997). Lean supply chain management is contingent to the formation of proactive relationships with all-tier suppliers, and includes activities that extend beyond sourcing and logistics. Consequently, in broad terms, lean supply chain management can be defined as the collaborative improvement of the entire product lifecycle (from early design through planning, production, maintenance and disposal) across both functional and organisational boundaries. It involves planning, executing and designing across multiple partners in the supply chain to deliver products of the right design, in the right quantity, at the right place, at the right time.

In practical terms, a lean supply chain uses lean manufacturing principles, such as 5S, visual factory, *takt* time, pull, flow, etc. (Womack and Jones, 2003) and Rate Based Planning and Execution (RBPE), a way to smooth production and deliveries along the supply chain (or network) through capacity planning on the basis of the end-products bills of materials (Reeve, 2002). Employing these lean techniques along the chain, the objective is to reduce redundancy in materials, information and knowledge by providing them dynamically where they are wanted, when they are wanted. To achieve this, a number of challenges arise which include the difficulty to see and manage cause-effect relationships that occur across company boundaries and are responsible for waste, the requirement to break walls between normally insulated parties, and the need to practice collaborative decision making by developing a win/win philosophy of thinking supported by agreements and trust between partners (Sako, 1992, Cox, 2004; Hines *et al*., 2004; Evans and Wolf, 2005). And, as the lines between innovation/product development and manufacturing and the supply chain are blurring, the lean supply chain moves away from arm’s length contractual relationships towards obligational contractual relations (Sako, 1992; Kerrin, 2002) that both support and are supported by collaboration in product and process development, common vision and shared goals, supply chain design, planning and execution, as well as supply chain improvement (keizen).

In practice, however, lean supply chain implementations are rare, and collaboration in the supply chain is still at an embryonic stage, mainly concentrated on efforts for information exchange among participants at the purely operational level, in

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the form of collaborative planning, forecasting and replenishment (CPFR), vendor managed replenishment (VMR) and synchronised supply (Barratt, 2004; Holweg *et al*., 2005). This comes as a consequence to the fact that organisations can integrate their processes at the operational level with relatively low difficulty, since this integration is accomplished through codified information exchanges. Other processes, such as innovation, improvement and strategy, which are crucial to the implementation of the lean supply chain, require the capturing of tacit knowledge and the management of complex interactions among the agents that hold it. Collaboration in such issues requires either face-to-face meetings, or the employment of advanced information and communication technologies to "virtualise" social interaction and support tacit knowledge exchanges. In fast-changing industries with world-wide supply chains, where challenges and opportunities can arise at any instance, the holding of meetings is quite difficult and may be unproductive. Nevertheless, Internet can act as the base enabling technology not only for information exchange but also for more advanced collaboration modes.

Towards this end, in this paper, we present an integrated suite of software tools that can effectively support the design and the management of a lean supply chain. The suite consists of specially developed tools to support collaboration among supply chain partners in the innovation and product development process, to assist in the development of transparent and participative manufacturing strategy, to enable the lean supply chain design and planning, to facilitate its robust (adaptable) RBPE, as well as supporting problem-solving and improvement forums. Following, in Section 2, we review the ICT requirements for an internet-enabled lean supply chain. In Section 3 we present our suite of tools explaining briefly each one's functionalities. Finally, before drawing our conclusions, Section 4 outlines the operational environment of the suite's pilot application.

2 REQUIREMENTS FOR AN INTERNET-ENABLED LEAN SUPPLY CHAIN

Lean management concentrates on four areas which are linked to different activities, at different levels. The *identification of value* and the determination of the appropriate structure for delivering it (*manufacturing strategy*) are strategic decisions/activities, whereas the *specification and the improvement of the value stream* are activities between the strategic level and the purely operational one, to which the techniques such as *"flow" and "pull"* belong. At the strategic level, the identification and management of the *value stream* starts with the definition of value from the customer point of view. In the supply chain value is defined not only by the end customers, but also by the internal ones. Value has to do with products, services and associated information, and is created by innovative offerings that best meet the needs of customers. This implies that, in addition to other suppliers which fill organisational knowledge gaps, customers should have an active role in the innovation and product development process whose final outcome is a collaborative effort.

Organisational knowledge gaps are the result of the discrepancy between the knowledge an organisation has and the knowledge it needs for the solution of specific problems, including innovation and product development. In filling these gaps, the role of information technology is not only to organise data into useful information, but also to support the transformation of information into organisational knowledge. Even more, since innovation is a social process involving diverse actors, there is a demanding necessity for information and communications technologies to support the knowledge flows among the relevant actors and artefacts, in a way that enhances the creation of new knowledge. As knowledge and information flows are the key determinants of successful innovation and new product development processes (Tidd *et al*., 1997), their technological support can augment their efficiency, effectiveness and, consequently, their role as sources of competitive advantage.

Once value has been defined in the form of product (or service, or both), the means of producing and delivering this value to the customer have to be decided. This is the subject of operations/ manufacturing strategy which links the external environment to the specific internal capabilities of the firm(s) and its/their corporate strategy. Manufacturing strategy is at a higher level from the decision to implement a lean supply chain. Supply-chain decisions belong to one of the four interrelated decision areas of manufacturing/operations strategy (capacity, supply chain/network, technology, and development and organisation) (Slack and Lewis, 2002). The manufacturing strategy development is an iterative process that involves participants from different functions (marketing, product development) and, sometimes, different organisations. ICT can assist and leverage this collaborative effort by not only helping strategists to reach an agreed action plan effectively, but also to augment learning the manufacturing strategy process *per se* (Karacapilidis *et al.*, 2006).

The definition of value and the alignment of the operations with it act as inputs for the specification of the value stream which extends along the whole supply chain. Mapping, or better modelling and simulating, the value stream facilitates the definition of the supply chain and the identification of initiatives for its improvement (reducing or eliminating waste) (Rother and Shook, 1998; Duggan, 2002). For these multiple participants/stakeholders settings, collaborative modelling and simulation technology (Miller *et al*., 2001; Taylor, 2001) can enhance both the design and redesign tasks by acting as the *transitional object* (Morecroft, 2004) for improvement ideas, mind frames and argumentations. Collaboration technology can also be employed for general problem solving and improvement along the supply chain, thus fully supporting actions towards the "continuous search for *perfection*" imperative of lean.

Although the "flow" and "pull" imperatives are associated with the design phase of supply chain (the definition of structural and operational characteristics of the system), they also entail purely operational challenges which are concentrated at the information layer and not with the knowledge one, on which the value stream definition and perfection components rest on. For supply chain planning and execution, internet technology has been proposed as a better alternative to attempts of legacy system (ERP) integration along the supply chain (Kehoe and Boughton, 2001). Since lean is contingent to stable demand and operating conditions, at this level, it is necessary to implement intelligent technologies to assist in the efficient reconfiguration of the supply chain when demand or internal operating conditions change significantly. This can be done by exploiting, automatically or semi-automatically, the collaborative relations that exist among the partners of the supply chain.

The lean supply chain characteristics can be summarized in the requirements for synergy, as well as knowledge and information integration across activities in the entire product(s) life-cycle. Information and communication technologies can provide the basis for achieving these objectives.

3 THE CO-LEAN INTEGRATED SUITE

The Co-LEAN suite consists of five interconnected tools that operate on the internet for enabling the implementation of the lean supply chain:

- Co-INOV supports the collaborative innovation and product development process (value specification),
- Co-MASS assists in the collaborative development of transparent manufacturing strategies at the individual node, as well as at the entire network level (process of value delivery),
- Co-SISC is used for collaborative simulation-based supply chain/network design (process/chain design and improvement),
- Co-SOLVE supports problem solving and improvement forums (process/chain improvement) , and
- Co-LEAN-PE is the core of the suite and provides facilities for rate-based scheduling for individual products (value streams), as well as for dynamic mixed-model scheduling of product families by using the relations that exist between product component features and/or operations (flow and pull operation).

Co-LEAN has been developed over the last three years, initially as separate components that were later integrated through Co-LEAN-PE. Co-INOV and Co-SOLVE are based on *Knowledge Breeder*, a web based software system that implements the G-MoBSA (Group Model Building by Selection and Argumentation) problem solving methodology (Adamides and Karacapilidis, 2005a, Adamides and Karacapilidis, 2005b). *Knowledge Breeder* is collaboration supporting tool that uses a systemic problem-knowledge representation scheme and an evolutionary problem-resolution methodology that supports the "breeding" (development) of the knowledge necessary for the resolution of a specific organizational issue. Co-SOLVE is a stand-alone environment which is used as a platform for discussion and argumentation forums centred around specific lean supply chain improvement issues. On the other hand, Co-INOV implements a more refined and domain-specific version of Co-SOLVE. It can support the innovation and product development process in its entirety, enabling the gradual "breeding" of innovation concepts towards their realisation as products. In Co-INOV, the innovation process is viewed as a sequence (not necessarily being executed in linear fashion) of issue/problem resolutions/solutions (Leonard and Sensiper, 2003), in which cause-effect-like models are used to represent organisational cognitive schemata of issues and their possible resolution(s). The social and knowledge dynamics of innovation are supported by the co-evolution of models with respect to the shared knowledge. A formal argumentation language is used to facilitate participant interaction.

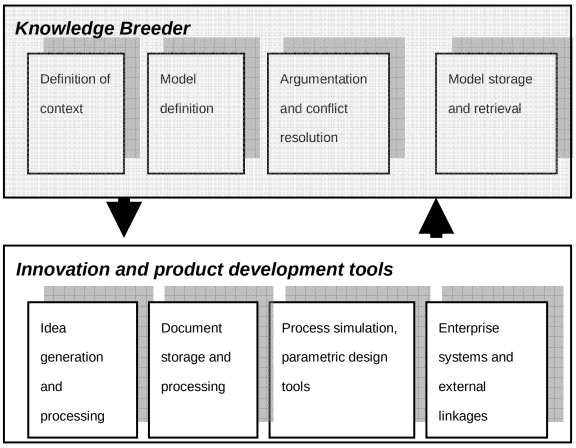

Figure 1: The functional structure of Co-INOV (based on Knowledge Breeder).

The kernel of Co-INOV is its knowledge base that stores models under consideration, as well as models of already closed discussions. Any form of electronic information (text, hypertext, drawings, photographs, etc.), as well as direct links to individual tools (e.g. to tools supporting the engineering design phase of product development) can be attached to the model(s) and transferred to other actors (Fig. 1). Models are stored and selected hierarchically using a meta-model of the issues addressed (context definition). Users can upload the current issues under consideration in which they wish to be involved, see the current state of the dialogue and contribute accordingly. They can then move into other issues through the navigating meta-model. By taking into account the structure of the model, the arguments placed and the argumentation rules, the inference engine of the computer-assisted argumentation module, determines the defensibility of each model of problem-solution. The interface of Co-INOV (as well as that of Co-SOLVE) is in hyper-textual form with menus associated to the features provided, and diverse functionalities related to visualisation (folding/unfolding of model components, view/hide of inputs, creators, dates, etc.)

Co-SISC is also a collaboration-enhancing software environment that implements a language and dialoguing structure specific to supply chain design by means of simulation modeling (Karacapilidis *et al.*, 2004). It deploys a generic systems-oriented language (activities, resources, decisions and their parameters), thus enabling different commercial simulation environments to be easily used with. Again, argumentation on model items and their attributes is supported by the system, while storage and retrieval of discussions/argumentations as well as simulation models is possible. The construction, validation and verification of the simulation model are accomplished by a simulation specialist (technical facilitator), whereas the other decision makers can see its structure and results and experiment accordingly with different parameters (Figures 2 and 3).

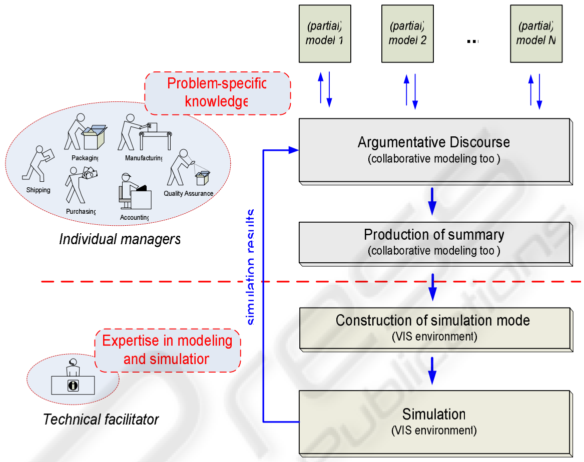

Figure 2: The operational architecture of Co-SISC.

The use of the Co-SISC environment in the lean supply chain design/re-design process augments shared understanding, transparency of individual decisions and trust building along the supply chain through an improved, in terms of quality and buy-in, modelling and simulation process (Karacapilidis *et al.*, 2004). In connection with Co-SOLVE, it provides the means for assessing activities, and eliminating those which do not provide value to the end customers (i.e. achieving leanness).

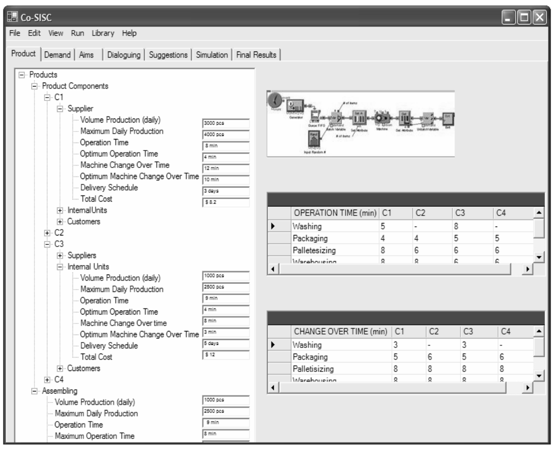

Figure 3: The main interface of Co-SISC.

Co-MASS is a computerised knowledge management system for assisting in the formulation of manufacturing and operations strategy (Karacapilidis *et al*., 2006). It supports the social and knowledge processes of collaborative manufacturing strategy development by integrating a domain-specific issue-modelling formalism based on the resource based theory of the firm (Wernerfelt, 1984), an associated structured dialogue scheme, an argumentation enabling mechanism, and an efficient algorithm for the evaluation of alternatives. As sourcing is one of the principal decision areas of manufacturing strategy, the direct provision of knowledge from diverse sources across the supply chain enhances the quality of the strategies produced initially at the focal firm level, and then at the whole of the supply network.

Finally, Co-LEAN-PE is the suite's core module that is responsible for the planning and execution (rate-based) of the lean supply chain. It uses forecasted and actual demand data, as well as information from a continuously updated supply database concerning products, suppliers and supplier relations to produce a production and/or delivery schedule (rates) for the focal company's demand. Demand information can be transmitted to all suppliers in the network if needed. Schedules (production and/or delivery rates) are calculated and broadcasted to all nodes (Fig. 4, top window). The feasibility of realisation of these schedules is then examined by the software using the information stored in the supply database. Additionally, suppliers may contest schedules on the basis of their current state. Should a schedule for a product is not feasible by invoking the *Relations Manager* module, the focal company may exploit the relations that exist among products and suppliers at two levels: capacity and capability. *Capacity* refers to the ability of a different node that has the product in its current schedule (or in its stocks) to supplement the initially selected supplier with additional capacity, whereas *capability* refers to the ability of producing the product requiring additional capacity (the product is not in the current production mix and there is no stock). The additional cost burdens that the exploitation of positive relations and the resolution of negative ones imply is then calculated.

The *Relations Manager* uses conventional as well as Artificial Intelligence techniques (representation and coordination of plans) to represent and manage the relations that exist between products and supplier processes. It considers the products' value streams as plans to be executed with possible alternative options for specific activities (e.g. two different suppliers can provide the same part with two different prices and delivery lead times), and by using the relations that exist between supplier operations and product characteristics tries to coordinate the value streams so that optimal use of resources along the whole of the supply chain is achieved (von Martial, 1992). Nevertheless, rescheduling and reconfiguration decisions frequently require additional qualitative information and discussion and argumentation using the features of the other modules of Co-LEAN.

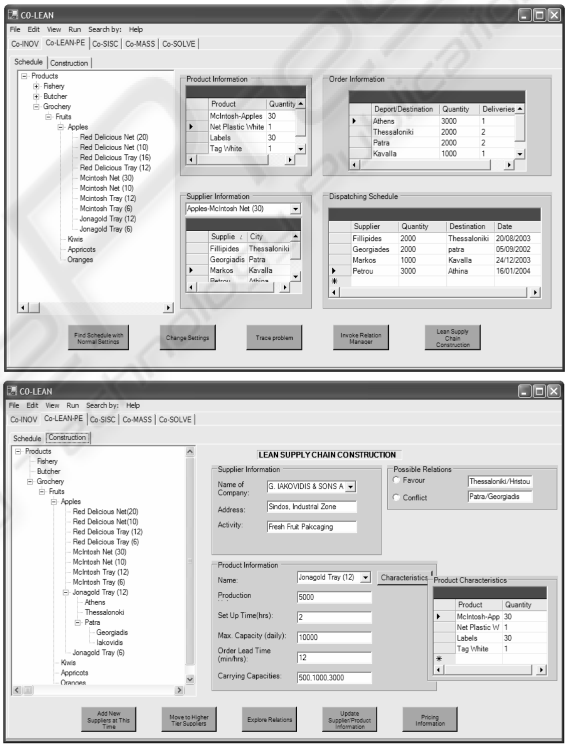

Figure 4: Co-LEAN-PE: the main screen (top window) and lean supply chain construction (bottom window).

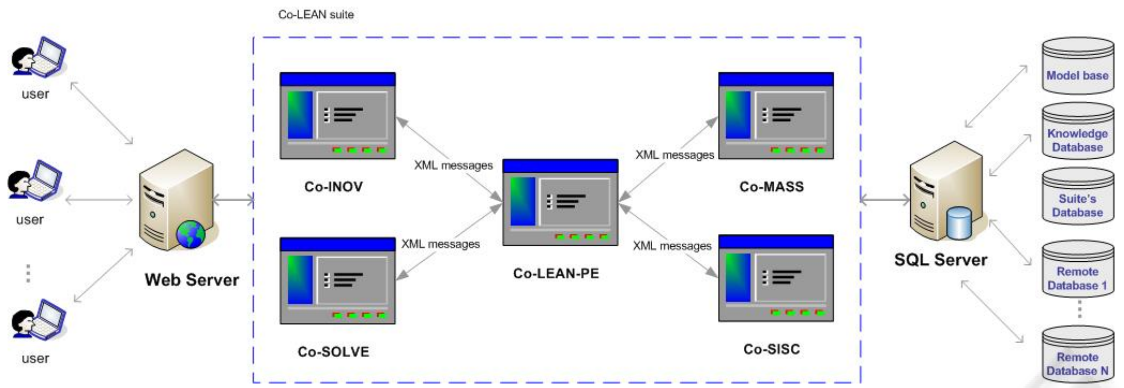

Figure 5: The architecture of the Co-LEAN suite.

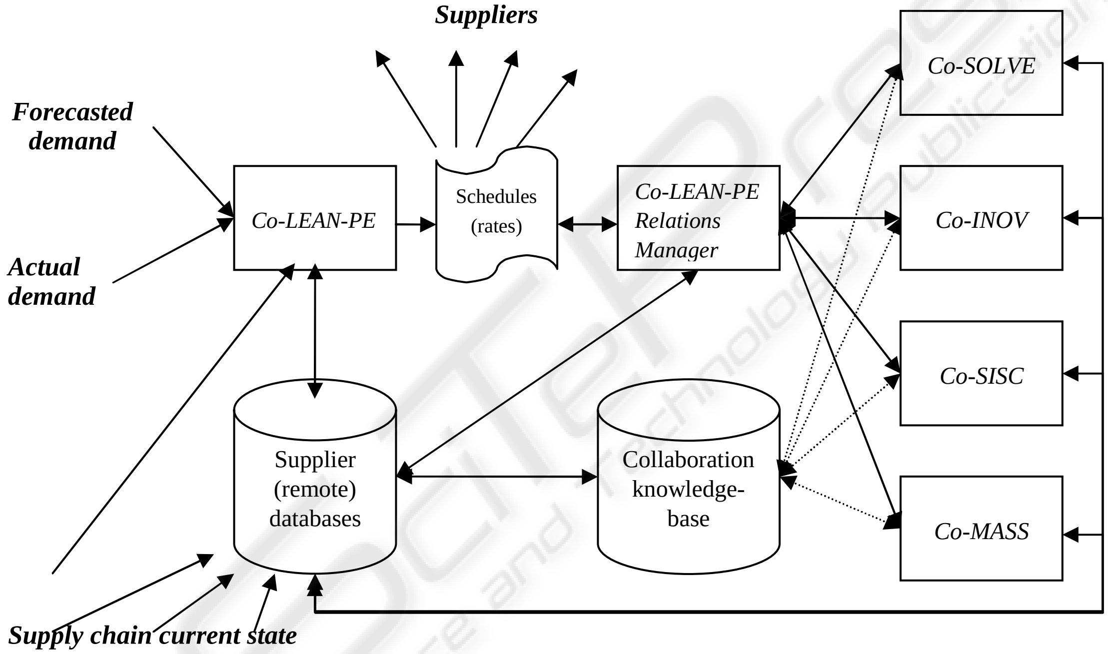

Figure 6: Coordination of Co-LEAN tools through the Relations Manager.

For the implementation of the proposed suite, we have exploited a series of technologies supported by the Microsoft's .NET platform, such as ADO.NET, XML Web Services, and Visual J#.NET (http://www.microsoft.com/net/). The suite's architecture is shown in Fig. 5. As illustrated, access to the tools of the Co-LEAN suite is provided through a dedicated Web server. To use the range of services provided, users only need a Web browser (i.e., there is no need to download any specific application at client side). Depending on the tool used each time, users may exploit some built-in templates and customize their working environment according to their profile and collaboration requirements. The interoperability of the suite's tool is achieved through the exchange of the appropriate XML messages. There is also a dedicated SQL server regulating the communication of the suite's tools with its proprietary database, model base and knowledge base, as well as the communication with remote databases, whenever there is a need to retrieve data concerning particular "pieces" of the supply chain. Connections with remote databases are achieved through the available and well-tried OLEDbControls of .NET platform.

4 USING THE Co-LEAN SUITE

The Co-LEAN suite is currently used, at a pilot stage, in a major supermarket chain in Greece. The objective has been to "lean" its fresh fruits and vegetables supply chain, so that its image of "freshness" in its products is enhanced. By using the system described above, the company aims at achieving small batch frequent deliveries in its shops through three regional distribution centres. This diverts from its previous operations where large quantities of fruits and vegetables were delivered and stored in one refrigerated warehouses before being distributed to the selling points.

Using Co-LEAN, the supermarket chain can now adjust deliveries to current demand, thus avoiding costly and risky inventories at both the warehouse and the shops. In addition, it can adjust the fruit and vegetable picking rates of the suppliers. By feeding Co-LEAN-PE with a weighted mix of forecasted and actual demand, the required rates are calculated and broadcasted to all suppliers, including the suppliers of packaging materials (Fig. 4). Deliveries are optimised using the *Relations Manager* to exploit any slack delivery capacity of suppliers, thus reducing the overall cost (Fig. 6). The *Relations Manager* has also helped in overcoming the inabilities of specific suppliers to deliver caused by bad weather. Alternative suppliers have been engaged in the most efficient way. The Co-SISC and Co-INOV tools have been used in the initial design of the supply chain, thus providing full transparency to all parties involved. Co-SOLVE, Co-MASS and Co-INOV have been used for developing in a collaborative manner new packages which are convenient for home deliveries of orders placed though the internet. At next stage, the same supermarket chain plans to use the Co-LEAN suite in a more demanding area, that of its own-label products produced by third-party manufacturers under its control.

5 CONCLUSIONS

In this paper we presented Co-LEAN, an integrated suite of software tools suitable for the design and operation of lean supply chains. In addition to providing full operational support in the planning and execution of the lean supply chain, including production and logistics optimisation, though its Co-LEAN-PE tool, the suite supports internet-based collaboration in the innovation and product design (Co-INOV), manufacturing strategy (Co-MASS), and supply-chain design and improvement tasks (Co-SOLVE, Co-SISC). The pilot application of Co-LEAN has provided an early indication of its usefulness in a specific application area (retailing). We are expecting that additional installations will trigger modifications and adjustments that will, in turn, lead to a more flexible and widely applicable system.

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