Supply chain management analysis: a simulation approach to the Value Chain Operations Reference (VCOR) model

Yacine Ouzrout*
LIESP-Lyon2 Laboratory
Université of Lyon 2
160 Bd de l’université
69676 Bron Cedex, France
Fax: +33.478.006.328
E-mail: yacine.ouzrout@univ-lyon2.fr
*Corresponding author

Matteo M. Savino
Department of Engineering
University of Sannio
Piazza Roma, 21
82100 Benevento, Italy
E-mail: matteo.savino@unisannio.it

Abdelaziz Bouras
LIESP-Lyon2 Laboratory
Université of Lyon 2
160 Bd de l’université
69676 Bron Cedex, France
E-mail: abdelaziz.bouras@univ-lyon2.fr

Carlo Di Domenico
Hermes Reply S.p.a
Corso Francia
110 Torino, Italy
E-mail: ca.didomenico@reply.it

Abstract: The impact of globalisation and worldwide competition has forced firms to modify their strategies towards a real-time operation with respect to customers’ requirements. This behaviour allows the top management to move towards the concept of an extended enterprise in which a collaborative link is established among suppliers, commercial partners and customers. When the information flows involve each actor of the chain, from suppliers to the final distribution centres, the extended enterprise becomes a virtual firm, which can be defined as a set of stand-alone operational units that acts to reconfigure themselves as a value chain in order to adapt to the business
opportunities given by the market. The present work is intended to verify through a simulation approach the quantitative advantages obtained by the introduction of the *value chain* concept into the Supply Chain Management (SCM). The paper, after a description of the two most well-known SCM models – the Supply Chain Operations Reference (SCOR) and Value Chain Operations Reference (VCOR) – makes a comparison from the customer’s point of view. In the second part of the work, a simulation model is developed to verify the advantage that the VCOR model is able to obtain, validating it on an industrial case study.

**Keywords:** value chain management; supply chain; simulation; Supply Chain Operations Reference; SCOR; Value Chain Operations Reference; VCOR.


**Biographical notes:** Yacine Ouzrout obtained his PhD in Computer Science from the National Institute of Technology of Lyon in France. He is currently an Associate Professor at the Lyon 2 University. His research interests include simulation, information systems for the supply chain and product life cycle management.

Matteo Mario Savino is Professor of Industrial Engineering at the first- and second-level degrees in Information and Energetic Engineering at the University of Sannio, Benevento, Italy. He is also the Quality Manager for the University Quality Centre. This centre is in charge of the quality assurance for the research and didactic activities of the whole university. He is involved in several EU funded projects on quality, supply chain and higher education. His research interests are mainly focused on industrial operations, quality and supply chain management.

Abdelaziz Bouras is currently a Professor at the University of Lyon, where he has led the Supply Chain Group of the LIESP laboratory since 2000 and heads the CERRAL R&D Center of the Technology Institute of the university. He is a member of several European and international projects related to Supply Chain (SC) and Product Life Cycle Management (PLM). His work particularly deals with SC/PLM integration, reference models and open standards. He is the Editor-in-Chief of the *International Journal of PLM* and co-founder of the *International Conference on PLM*.

Carlo Di Domenico is a Consultant at Hermes Reply S.p.a, Italy. He obtained his Master’s degree in Automation Engineering at the University of Sannio, Benevento in 2006 with a thesis based on a project in collaboration with LUMIERE Lyon 2 University on supply chain management. He worked at the University of Sannio until the beginning of 2007 on operations management projects. With Hermes Reply he is currently involved in developing a manufacturing execution system.
1 Introduction

The scientific literature related to Supply Chain Management (SCM) is rich in publications, but the reality is that there is a lag between practice and theory (Balan et al., 2006; Simchi-Levi et al., 2000; Neubert et al., 2004). Mass media and the internet have speeded up the diffusion of new products; at the same time, technical innovation and severe market competition promote the rapid obsolescence of existing products and technologies. When a company succeeds in developing a new product category, competitors may soon emerge. The market originator must endure not only the substantial risk of whether the market would materialise or not, but also the difficulty of recovering major costs, such as research and development and advertisements. Increasingly, the Supply Chain (SC) becomes the mechanism for coping with these problems because it is often inefficient for any single company to produce a whole product (Al-Mudimigh et al., 2004; Feller et al., 2006).

Hence, modern business is essentially the competition of one SC with another. SC dynamics is the interaction processes of the participants from different departments and companies. A positive aspect of SC dynamics is effective collaboration, which may lead to higher performance. A negative aspect is independent decision making, which may create various delays and aggravate forecasting errors (Simatupang and Sridharan, 2002; Abu-Suleiman et al., 2005).

This research stresses the interest in the possible quantitative advantages given by the introduction of the value chain concept into the SCM through a simulation approach. Discrete-event simulation, continuous time-differential equations, discrete time difference models and operational research techniques are some of the commonly used quantitative modelling techniques to evaluate and design SCs (Christopher and Lee, 2002; Terzi and Cavalieri, 2004). The correct identification of key variables and their interactions, together with determining how the information can be better managed, enables the utility of the entire SC.

In this work we use discrete event formalism to model and study SCs. Discrete-event simulation is chosen for its capability to represent physical and information flows along with their respective delays in an information feedback control type of setting. Our main research interest is to clarify the critical factors for minimising the negative effects of SC dynamics and to gain insight on how to effectively manage them. To achieve these objectives we developed a simulation model to implement the Value Chain Operations Reference (VCOR) model and to verify the possible advantages that it is able to obtain.

2 The value chain management theory

An SC can be defined as a system network that provides raw materials, transforms them into intermediate commodities and/or finished goods and distributes them to the customers through a delivery system (Christopher and Lee, 2002). The aim is to produce and distribute the right quantities, to the right locations, at the right time, while reducing costs and maintaining a high level of service. SCM is concerned with smoothness, economically driven operations and value maximisation for the end customer through quality delivery. The limitations are due to the fact that SCM as a concept does not extend far enough to capture customers’ future needs and how these
will be addressed, and furthermore, it does not encompass the postdelivery, postevaluation and relationship-building aspects (Al-Mudimigh et al., 2004). Another important theory can be defined as strategic in the context of SCM: the concept of value chain management.

The value chain was described and popularised by Porter (1985) in his bestseller, *Competitive Advantage: Creating and Sustaining Superior Performance*. Porter defined ‘value’ as the amount that buyers are willing to pay for what a firm provides, and he conceived of the ‘value chain’ as the combination of generic activities operating within a firm, activities that work together to provide value to customers. Porter linked up the value chains between firms to form what he called a *value system*. However, in the present era of greater outsourcing and collaboration, the linkage between multiple firms’ value-creating processes has more commonly become called the value chain. As this name implies, the primary focus in value chains is on the benefits that accrue to customers, the interdependent processes that generate value, and the resulting demand and fund flows that are created.

Feller et al. (2006; Olhager et al., 2006) exposed some important considerations about the value concept. First is that value is a subjective experience that is dependent on the context. The same product or service does not have the same value in different parts of the world or in different situations. Second, value occurs when needs are met through the provision of products, resources, or services. Finally, value is an experience and it flows from the customer. Clemmer (1990) affirms that customer value is layered and has been described by three concentric rings. In the centre ring is the product value, which is the technical value derived from providing a source of supply. A second ring of service value is provided by the services that surround the product, such as personal care and warranty services. The third ring has been called the new service/quality battleground and was made popular by business thinkers such as Peters and Waterman (1982) in their work ‘In Search of Excellence’. This third level of value is achieved by providing enhanced service, to “make your customer successful” (Clemmer, 1990) rather than just satisfied.

The huge importance of focusing on the customer has forced the integration of the optimisation techniques of SCM, Customer Relationship Management (CRM) and Product Life Cycle Management (PLM), as shown in Figure 1.

Figure 1  Integration of PLM, SCM and CRM (see online version for colours)
The value chain theory focuses on the management of the product life cycle, which is a strategic business approach that helps enterprises to achieve its business goals of reducing costs, improving quality and shortening time to market, contemporarily innovating its products, services and business operation (CIMdata, 2002). By increasing an enterprise’s flexibility to respond quickly to changing market pressures and competitors, the value chain helps companies to:

- deliver more innovative products and services
- reduce costs
- improve quality
- shorten time to market while achieving the targeted Return on Investment (ROI)
- establish more collaborative and improved relationships with their customers and suppliers (Garetti et al., 2005).

The value chain management also includes CRM, which consists of the creation, development, palimony and optimisation of long-term relationships among consumers and the firm. The success of CRM is based on the understanding of consumers’ needs and desires, and it enables the setting of such desires at the centre of the business, integrating them with the firm’s strategy, people, technology and business process (Munari, 2004).

### 3 Supply chain and value chain modelling

The first general framework for SCM, the Supply Chain Operations Reference (SCOR) model was developed by the Supply Chain Council (SCOR, 2005); the model is rather general, defining the standard SC processes and establishing standard terminology in quite broad terms. SCOR spans customer and market interactions and the physical material transactions. This model can also help manufacturers to carry out benchmarking against other well-established companies, since the model proposes some best practices and Key Performance Indicators (KPIs). The SCOR model was developed to describe the business activities associated with all phases of satisfying a customer’s demand; it consists of Plan, Source, Make and Deliver process elements (level 1 of the model), which revolve around the entire SC. The main assumption of the model is that, by integrating the process elements along the SC, companies should become more competitive. But the support functions such as administration, R&D and customer services are not included (Bolstorff and Rosenbaum, 2003).

Nowadays manufacturing in Europe is undergoing a deep change. The increase in productivity has concentrated the attention on the approach for the achievement of competitive advantages through efficiency actions and process optimisation. Besides this the European enterprises have realised that a complementary kind of initiative is necessary for the product design and engineering processes. It is indispensable, in fact, to keep a better know-how in order to remain competitive and to be able to offer new and advanced products to the market. The introduction of concepts like PLM has become essential to acquire new clients and new market segments and to adopt concepts of value chain management all over the network.
In late 2003 and early 2004, a series of meetings culminated in the development of the first iteration of the VCOR model. Participants in these meetings came from a global pool of business process knowledge experts, many of whom worked for large end-user, consulting or software companies, domain-specific not-for-profit organisations, or academia; they created the Value Chain Group (VCG, 2005). The VCOR model is able to achieve some benefits for firms, as follows:

- a standards-based approach to define essential collaborations between trading partners
- agreement on product life cycle objectives and how to achieve them
- reusable process templates based on best practices
- the integration of existing and new information management systems
- a fast response to changes while maintaining and extending value chain performance.

3.1 The VCOR framework

The VCOR model was developed from the perspective of being a value chain framework with the development of seven performance attributes linking the three domains of product development, SCM and customer chain across the supply networks together. The structure of the VCOR model supports and enables companies to integrate these three critical domains: Product Development, Supply Network Integration and Customer Success, using one reference model to support the vision of an integrated value chain (Heinzel, 2005). To achieve this goal, the VCOR model uses a process-based common language of syntax and semantics while, at the same time, creating a base for the successful Service Oriented Architecture Game Plan. The main objective of this model is to increase the performance of the total chain and support the current evolution; for that, it proposes three different modelling layers:

1. **Strategic Level:** The top level of the model includes all the high-level processes in value chains and is represented through the process categories plan-govern-execute. The level is defined to be the Strategic Level of the model, meaning that this is where high-level decisions are made regarding how to gain a competitive advantage for the value chain in scope. The VCOR Strategic Level has three macroprocesses:
   - **Plan:** balances the current strategic objectives with the current asset status and produces decisions on activities to move the organisation towards the goals.
   - **Govern:** a decision-based process which identifies and enables a value chain by establishing the rules, policies and procedures to control the implementation of the Plan and Execute processes within the value chain.
   - **Execute:** transforms the customer requirements into production processes. The Execute processes operate within the limits of the management criteria and of the parameters defined by the Plan processes.

2. **Tactical Level:** The second level of the model contains ‘abstract’ processes decomposed from the Strategic Level to implement and fulfil the strategic goals. These goals are defined at the top level of the model hierarchy with a set of tactical needs to be developed and realised. The Tactical Level can be described as being
instituted for ‘horizontal value chain process reengineering’. The VCOR model processes decompose from the Strategic to the Tactical Level with Plan and Govern, keeping their respective naming in the first part of the process notations on this level as they influence each of the Execution processes.

Figure 2 illustrates the decomposition of the strategic level into component processes. The Market process has a deep impact on the entire chain and for this reason is extended over the diagram. The Plan and Govern processes have the same name (e.g., Plan Research, Govern Develop and so on). To describe these different processes, the VCOR model defines three main groups:

1. market, research and develop
2. acquire, build and fulfil
3. sell and support.

**Figure 2** VCOR Layers Diagram (see online version for colours)

3. Operational Level: The third level of the model represents specific processes in the value chain related to different activities still in progress. On this level the focus is usually on vertical business process improvements or business process reengineering, as it is usually named. In a value chain perspective this is the level where fine-tuning occurs.

3.2 VCOR versus SCOR: metrics and performances

In order to measure the performance of the chain, the Supply Chain Council has introduced five metrics (see Table 1) and KPIs in the first level of the SCOR model to test SC reliability, responsiveness, flexibility, costs and efficiency in managing assets (working and fixed capital). For the remaining processes (level 2) and elements (level 3),
there are specific KPIs to test the performance of each part of the SC configuration. Moreover, for each process, some best practices are defined to simplify the analysis of the chain. These are reliable points of reference to follow, given by the experience of enterprise leaders in their own field, in order to improve the performance without trying unpredictable strategies that could be dangerous. A company cannot be the best in all metrics, so it should wisely target its strength and differentiate itself in that market, while ensuring that it stays competitive in other markets (Bolstorff and Rosenbaum, 2003; Hausman, 2002). Actually, most companies do not choose to improve all indicators, but they focus on some of these, building up their strong points. According to the definition of the VCG, a metric is “a quantifiable variable that reflects a specific state of business performance during process execution within a strategic value chain context”. In the VCOR model a metric is characterised by different features: Metric Name, Metric Definition, Priority Dimension, Metric Class & Sub-Class, Formula, Input Requirements, Dimension, Calculation Rules, etc. Table 1 describes the definition of the seven dimensions defined in the VCOR model and compares them to the SCOR model’s definition.

Table 1 SCOR strategic performance metrics versus VCOR priority dimension

<table>
<thead>
<tr>
<th>Performance</th>
<th>Model</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery/Reliability</td>
<td>SCOR</td>
<td>Definition: the performance of the SC in delivering the correct product, to the correct place, at the correct time, in the correct condition, packaging and quantity, with the correct documentation, to the correct customer</td>
</tr>
<tr>
<td></td>
<td>VCOR</td>
<td>Description: the ability to deliver the correct product to the correct market and customer on time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metrics: delivery performance; fill rates; perfect order fulfilment</td>
</tr>
<tr>
<td>Responsiveness/Veloc</td>
<td>SCOR</td>
<td>Definition: the velocity at which an SC provides products to the customer</td>
</tr>
<tr>
<td></td>
<td>VCOR</td>
<td>Description: the cycle time taken to deliver a product or service to the customer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metrics: order fulfilment lead times</td>
</tr>
<tr>
<td>Flexibility/Adaptability</td>
<td>SCOR</td>
<td>Definition: the agility of an SC in responding to marketplace changes to gain or maintain competitive advantages</td>
</tr>
<tr>
<td></td>
<td>VCOR</td>
<td>Description: the capability of responding to market changes to gain or maintain competitive advantages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metrics: delivery adaptability; value chain agility; ideation yield</td>
</tr>
<tr>
<td>Costs</td>
<td>SCOR</td>
<td>Definition: the costs associated with operating the SC</td>
</tr>
<tr>
<td></td>
<td>VCOR</td>
<td>Description: the cost associated with operating a value chain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Metrics: cost of quality; design cost ratio; logistic cost ratio; manufacturing, sales and marketing cost ratio</td>
</tr>
</tbody>
</table>
Table 1   SCOR strategic performance metrics versus VCOR priority dimension (continued)

<table>
<thead>
<tr>
<th>Performance</th>
<th>Model</th>
<th>Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness/Asset</td>
<td>SCOR</td>
<td><strong>Definition:</strong> the effectiveness of an organisation in managing assets to support demand satisfaction (fixed and working capital)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Metrics:</strong> cash-to-cash cycle time; inventory supply; asset turns</td>
</tr>
<tr>
<td></td>
<td>VCOR</td>
<td><strong>Description:</strong> the effectiveness of an organisation in managing assets of the value chain to support market and customer satisfaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Metrics:</strong> asset turnover; cash conversion cycle; design realisation; inventory supply</td>
</tr>
<tr>
<td>Innovation</td>
<td>SCOR</td>
<td><strong>Definition:</strong> Void</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Metrics:</strong> –</td>
</tr>
<tr>
<td></td>
<td>VCOR</td>
<td><strong>Description:</strong> the ability to strategically leverage internal and external sources of ideas and introduce them to the market through multiple paths</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Metrics:</strong> product innovation index; R&amp;D profit contribution</td>
</tr>
<tr>
<td>Customer</td>
<td>SCOR</td>
<td><strong>Definition:</strong> Void</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Metrics:</strong> –</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Description:</strong> the capability to develop positive collaborative customer relationships</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Metrics:</strong> customer growth rate and retention rate; market share</td>
</tr>
</tbody>
</table>

3.3 VCOR versus SCOR: synthesis

The two models were created in order to give a reference point to those companies that applied the principles of SCM and value chain management. The SCOR model is an affirmed and reliable model and preceded the VCOR model by a few years. For this reason they have some analogies inherent in their structure and differences in their scope. Both models were defined as standards, improved by the Supply Chain Council and VCG respectively, to simplify their correct realisation in real cases and facilitate the communication between trading partners. Moreover, they are based on high-level generic process categories to better fit all types of firms. But the feature that perhaps is the reason for their success is the capability to calculate the level of performance for every single process of the chain in a very simple way and, at the same time, to introduce best practices to facilitate the management of productive processes. It is crucial to find strategic choices on objective data that can be compared with the metrics filed during years of activity or with the performance indicators of other companies, if possible. The differences between the SCOR and VCOR models are that the latter is an enterprise model using a framework and taxonomy that feature governance and the decision-making processes at its highest levels with interconnectivity to all Enterprise processes. The interaction of process elements in the SC domain are mostly ‘transactional’ as opposed to the interaction of enterprise business process elements involving higher-order information processing in the decision-making process.

A question has arisen: does a company that successfully implements the SCOR model really need to change its framework in the face of other efforts? The answer is not trivial, but it is possible to state that the paybacks gained with VCOR can benefit an enterprise enough for it to exceed its competitors and extend its market. Furthermore, the extension from SCOR to VCOR is not very intricate because VCOR’s basic design uses the framework and methodology of a unified general systems model that can be applied
to most organisational types (Feller et al., 2006). Expansion occurs by reaching out into existing vertical domains of SCM, PLM and CRM to integrate their respective business process elements into a unified value chain model similar to SCOR. In this sense, VCOR can be considered the natural extension of the SCOR model.

In the next sections we will describe a simulation model realised to allow companies to evaluate in advance the possible advantages of the value chain implementation. This model includes some of the metrics and KPIs presented in the first part of the paper.

4 The simulation of the value chain processes

In this section we confront the problem of the development of a simulation architecture for the implementation of a VCOR model. Nowadays, in the literature, there are few examples of a global simulated SC because it is not easy to model the entire chain and implement it with specific and dedicated software (Christopher and Lee, 2002; Kleijnen, 2005); moreover, the number sensitively increases if we consider the examples that apply the SCOR model (Boucher et al., 2003; Jain and Leong, 2005; Herrmann et al., 2003).

This section presents first the advantages of the simulation in comparison to the mathematical models and next the realisation of a generic architecture to simulate the VCOR model. Many researchers have tried to solve the production-distribution issues in the form of analytical problems. The objective of this type of method is to minimise the overall production and distribution costs in multifacility, multiproduct and multiperiod problems. The algorithms are mainly based on heuristics or the network flow; but it is obvious that the complexity of the problem grows as a function of the number of elements in the chain: number of products, resources, constraints, etc…. If we also introduce the uncertainty, the modelling and the problem solving become prohibitive.

In this context of dynamic, stochastic and complex systems, it is difficult to analytically model the problem, but the limits of the mathematical analysis can be solved by computer simulation. The benefits of using simulation in SCs can be summarised as follows (Kelton et al., 2004):

- the capacity to capture data for analysis: users may model unexpected events in certain areas and understand their impact on the SC
- it can drastically decrease the risks inherent to changes in planning: users may test several alternatives before making the planning change
- investigating the impact of innovations within the SC; eliminating an existing infrastructure or adding a new one within the SC; strategic operational changes, such as process, location and use of new facilities, the fusion or the separation of some components of two SCs; manufacturing products inside the company; creating new suppliers or subcontracting some processes
- investigating relations between suppliers and other components of the SCs to rationalise the number and size of order lots, using as a basis the totality of costs, quality, flexibility and responsibilities
- investigating the opportunities to decrease the variety of product components and standardise them throughout the SCs.
These main reasons have led us to choose a simulation approach to analyse the SC dynamics and behaviour and to define a simulation model to implement the VCOR processes. The next paragraphs describe the generic SC simulation model that we propose, from the configuration to the description of the different blocks in ARENA.

4.1 Model implementation

The objectives of this section are to describe the VCOR model simulation architecture and to illustrate the implementation of its different elements.

Since we want to track not only the material flow but also the information and cost flows in order to obtain metrics and performance indicators, we propose to store all the simulation data in a database which leads us to save the parameters and input data for the initialisation and the simulation execution.

To better explain the application of VCOR to our chain, we started from level 1 of the model, i.e., the top level, following a top-down approach. Once we have defined the macroprocesses involved in each element of the chain, we choose its configuration and later depict the level 3 elements implicated in the process. To describe the model we will use the example in Figure 3.

We started from the central element of the chain: only the firm has a production process that transforms raw materials into finished goods (three products). For this reason the firm is the only participant that has a Make process in its configuration. The other members, like the retailer and suppliers, have only package processes that can simply be included in the Deliver process. For some products the production follows the rule of the Make-to-Stock, whilst for other products a Make-to-Order production is assigned. These considerations are summarised in Figure 3: the processes P1, P2, P3 and P4 represent the development and the establishment of activities over specified time periods that represent a projected appropriation of SC resources (materials, production and delivery) to meet SC requirements.
One of the most important aims of the VCOR model is to describe and manage information, costs and material flows. In order to achieve this goal, the simulation tool is based on orders management. When any member needs a certain quantity of products, it becomes a client and sends an order signal to its predecessor (i.e., the provider) in the chain. An order is characterised by its identifier, quantity of product, product type, timestamps and status. When a client makes an order, it updates the Demand database of its provider. Every time there is a change in the status of the order, the information is updated in the database. This mechanism allows us to know exactly the real position of commodities, monitoring both the material and information flows.

To build our simulation model, we used the discrete event-oriented ARENA software; the necessary SCOR/VCOR level 3 elements were realised in ARENA blocks and then gathered and organised in submodels in order to set up the different processes. In the following subsections we describe, as an example, the implementation of different actors of the chain in the model.

4.1.1 Retailer

The retailer is composed of a Source and a Deliver process with two different configurations: Make-to-Stock and Make-to-Order. An ARENA block is implemented with a rule which involves that each request made by the consumer becomes an order of the retailer to the firm. In Figure 4 some elements of the Source process are shown. The element called Schedule Product Deliveries S2.1 has the role of checking periodically the three inventory levels stored in the database. If the effective level is under an ‘s’ value (chosen by the managers), this module sends an order to the firm, writing information as the ‘order id’, ‘client id’, ‘quantity’, ‘product type’, etc., in the firm’s Demand database.

Figure 4 Retailer VCOR Source process (see online version for colours)

With the application of the VCOR model, the retailer configuration defines a new process: the Support process, which has the objective of solving the customers’ problems when a delivered lot is defective because of the transport or a bad installation. Figure 5 illustrates this process.
The Manage Incident U2 has the role of registering in the Support database a defective order, the related quantity of products returned, the customer identifier and the timestamps. The Resolve Problem U3 resolves the problem with writing a new order in the Retailer Demand database with a quantity equal to the number of damaged products. Once the order is delivered, the Monitor Experience U7 registers the operation and modifies a variable in the Customer Behaviour model that increases the vote. The Educate Customer U5 simulates a call centre. It has the important task of decrementing the percentage of defective products, decrementing the value of a variable in a Customer ARENA module.

4.1.2 The firm

The firm has the role of transforming raw materials coming from suppliers into products for the retailer. Its configuration includes a Source, a Deliver and a Make process. The following figure describes the ARENA representation of the ‘A5-Receive Order’ process.

Figure 6  Firm’s Receive Order process (see online version for colours)
The firm also has four processes derived by the PLM and CRM of the Value Chain Management. The Market, Research and Develop processes belong to PLM, while Sell and Support belong to CRM. With these new processes a company tries to analyse the market and consequently takes strategic decisions, like the restyling of a product or the acquisition of new technologies. Since it is very difficult to reproduce a complex market analysis or a restyling of a product, the ARENA blocks simulate these events in terms of required time and associated costs.

The Analyze Market M1 (Figure 7) periodically checks the Customer satisfaction level in the Retailer Demand database and, if the vote goes down under a specified threshold, activates the Architect Solution M4 module. This block finds the product type that has the least number of sales and decides to adopt it. In order to change a product, the firm needs to modify its production line with the introduction of new technology. Once the new equipment with R3 and R7 modules has been acquired, Introduce Technology R8 changes the production process in the VCOR Build Product B3, which corresponds to the M2.3 element.

**Figure 7** Firm Market, Research, Sell and Develop processes

The Develop process materially changes the Bill of Material of the product and is responsible for launching the product. In fact, the D8 sets the variable ‘Innovation Factor’ in the Customer Behaviour model and, as a consequence, the customer’s vote increases considerably. The Sell process tries to identify the clients in the market in order to develop relationships and proposals. The Qualify Target S2 classifies the clients on the basis of their priority and determines which of them can be supplied by the firm. It calculates the total number of products required by the clients and finalises the contracts (S8) that must not exceed the fixed percentage of the dedicated production capacity.
4.2 The customer behaviour model

In the simulation model, the customers are able to express an opinion, in the form of a vote, which represents the satisfaction level for each single order delivered. This is necessary because it is at the base of the value chain philosophy, in which the main goal is to give to the market what it needs, obtaining feedback for the improvements introduced on the product and/or for the introduction of new products. For this reason the VCOR simulation needs a consumer behaviour model. Some models used questionnaires (Chen and Hughes, 2004), others applied complex neural networks (Wen-Bao, 2007). In our simulation approach we adopted the Adaptive Learning Model (Hopkins, 2006), which consists in a mathematical model which is able to simulate the satisfaction level of the consumer and to pass the data to the corresponding simulation blocks.

According to the Adaptive Learning Model, two customers generally express their level of satisfaction through a vote for each type of product. This vote decrements its value in an exponential way which is coherent if we consider that a product has a life cycle and that at the end it becomes obsolete. The consumer satisfaction can increase if the support service, introduced in the VCOR example, is able to resolve the clients’ problems. The factor that can drastically increase the customer satisfaction level is the introduction of a new product as a result of a market analysis. This is possible in the mathematical model thanks to an ‘Innovation Factor’ that is enabled when an old product is modified to meet the demand of the market. Our model differs from the Hopkins one for the following two main aspects:

1. the introduction of a forgetting factor $\alpha$ in place of the coefficient $\delta$, in order to model the behaviour of the customer to ‘forget’ the improvement on a product with time

2. the input function $u_i(k)$, which in the original model expresses the input of the customer, has been modified taking into account the following variables:
   - the product cost variation $\Delta p$: expressed in percentage, according to the market rules
   - the delay $d$: expressed in percentage with respect to the delivery lead time of the product
   - the quality parameter $q$: expressed as a ratio of conforming products over the total product purchased (KPI).

The adopted consumer behaviour model can now be expressed with the Hopkins notation, taking into account our modifications:

$$x_i(k+1) = (1 - \alpha) \cdot x_i(k) + \alpha \cdot u_i(k)$$

where:

- $x_i(k)$ = the vote at instant $k$ of the $i$-th customer
- $\alpha$ = forgetting factor ($0 < \alpha < 1$)
- $u_i(k)$ = the user input function.

In our model $u_i(k)$ has the following expression:

$$u_i(k) = f(k) \cdot I_a + \xi \cdot s + \beta \cdot \Delta p + \delta \cdot d + \phi \cdot q + \eta \cdot \chi(k)$$
where:
\[ s \] indicates if the last request for support was correctly satisfied or not
\[ \xi \] takes into account how important the quality of service is
\[ I_n \] a Boolean parameter which indicates if the product delivered is a new one (1) or not (0). It changes its status to 1 when a new product is introduced in the market and to zero after a first order for this product is delivered.
The purpose of the parameter is to increase the customer’s vote.
\[ y_i(k) \] the output of the system (i.e., the vote): \[ y_i(k) = x_i(k) \]
\[ f(k) \] = a specific function depending on the vote given at time \( k \). It is based on the specific industrial context and depends essentially on the customer satisfaction detection system adopted by the firm in its quality management system. In our application case a measurement system will be adopted with respect to the firm’s customer satisfaction requirements.

5 The case study

Our value chain simulation model has been tested on an SC related to a major agro-food firm in southern Italy that produces fruit and tomato juices. This firm is involved in a SC and uses an Enterprise Resource Planning (ERP) system to integrate the information systems of its different sites. In this case study, we propose different scenarios related to three types of products (Figure 8), which represent 30% of the entire production of the firm and have a market share up to 15%.

Figure 8 The products chosen for the simulation test (see online version for colours)

Here SCOR will also be used to model and analyse the different processes of the chain.

The firm receives fruits, vegetables and chemicals for product preservation from three different suppliers and provides their treatment, packaging and distribution to the retailers. The firm has a set of ten big retailers that distributes the products to the final customers (supermarkets and small stores). In this study, we have selected only one retailer with the highest number of customers (seven big supermarkets) and, among the customers, the two customers with the highest value of products sold (two supermarkets that have a sales rate of up to 20%). The supplier has one warehouse, while the firm and the retailer have two warehouses each. The described SC can be structured as shown in Figure 9, where the material flows can be seen too.
Supplier 1 is specialised in the production of only one component (named Raw 1), the Supplier 3 for the Raw 3 component, while Supplier 2 can supply the other two types of components (Raw 1 and Raw 2). The entire configuration of raw materials distribution necessary for the production of finished goods is given in Table 2.

**Table 2** Production of raw materials by suppliers

<table>
<thead>
<tr>
<th>Production of raw materials</th>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw 1</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Raw 2</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Raw 3</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
</tbody>
</table>

Based on a first analysis, we obtained data related to the demand of the three described products. To do this we have monitored the demand of the two customers during a period of one year, divided into observation periods of one month; the data retrieved are shown in Table 3 for customers 1 and 2, in which $M_i$ are the observation months. The reported values are in number of boxes for each product. We can see that, for product 1, the demand can be assumed as constant, while it is variable in a seasonal behaviour for products 2 and 3.

**Table 3** Product demand for customers 1 and 2

<table>
<thead>
<tr>
<th>Dem. 1</th>
<th>$M_1$</th>
<th>$M_2$</th>
<th>$M_3$</th>
<th>$M_4$</th>
<th>$M_5$</th>
<th>$M_6$</th>
<th>$M_7$</th>
<th>$M_8$</th>
<th>$M_9$</th>
<th>$M_{10}$</th>
<th>$M_{11}$</th>
<th>$M_{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod. 1</td>
<td>250</td>
<td>260</td>
<td>245</td>
<td>247</td>
<td>255</td>
<td>257</td>
<td>250</td>
<td>251</td>
<td>253</td>
<td>255</td>
<td>250</td>
<td>241</td>
</tr>
<tr>
<td>Prod. 2</td>
<td>550</td>
<td>659</td>
<td>580</td>
<td>650</td>
<td>770</td>
<td>850</td>
<td>890</td>
<td>790</td>
<td>700</td>
<td>650</td>
<td>590</td>
<td>500</td>
</tr>
<tr>
<td>Proc. 3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

| Dem. 2 | | | | | | | | | | | | |
| Prod. 1| 300   | 310   | 312   | 295   | 311   | 320   | 301   | 305   | 313   | 300      | 295      | 297      |
| Prod. 2| -     | -     | -     | -     | -     | -     | -     | -     | -     | -        | -        | -        |
| Proc. 3| 70    | 165   | 140   | 145   | 250   | 355   | 397   | 410   | 380   | 371      | 280      | 210      |
5.1 SCOR/VCOR model simulation

The validation of the simulation model has been conducted with an experimental campaign, before with SCOR model and then with the extension of the VCOR ARENA modules. This section presents the most important results of the experiments conducted and some comparisons with the real data of the firm. The unit time of the run is expressed in hours and the run length is two days. The most important parameters of the participant are shown in Table 4, where the numbers in square parentheses refer respectively to products 1, 2 and 3.

Table 4 Parameter values used in the simulation

<table>
<thead>
<tr>
<th>Participant</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retailer</td>
<td>Products inventory level [1, 2]</td>
<td>[0, 0]</td>
</tr>
<tr>
<td></td>
<td>Rescheduling frequency deliver</td>
<td>2 h</td>
</tr>
<tr>
<td></td>
<td>Rescheduling frequency source</td>
<td>2.5 h</td>
</tr>
<tr>
<td>Firm</td>
<td>Finished Goods Inventory (FGI)</td>
<td>[500, 500, 300]</td>
</tr>
<tr>
<td></td>
<td>Raw inventory level (kg)</td>
<td>[200, 200, 200]</td>
</tr>
<tr>
<td></td>
<td>Rescheduling frequency deliver</td>
<td>2.5 h</td>
</tr>
<tr>
<td></td>
<td>Rescheduling frequency source</td>
<td>3 h</td>
</tr>
<tr>
<td></td>
<td>Rescheduling frequency make</td>
<td>3 h</td>
</tr>
<tr>
<td></td>
<td>Max daily production capacity</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>FGI inventory level</td>
<td>500</td>
</tr>
<tr>
<td>Suppliers</td>
<td>Rescheduling frequency deliver</td>
<td>4 h</td>
</tr>
<tr>
<td></td>
<td>Rescheduling frequency source</td>
<td>4 h</td>
</tr>
</tbody>
</table>

Figure 10 illustrates the retailer delivery time obtained by the run of the simulations. It is possible to note that the peak at the 11th order (18 h) is caused by the lead time for the replenishment of inventory; the mean time is 5.32 h.

Figure 10 Retailer delivery time (see online version for colours)
The following figure represents how the simulator has calculated the delivery time for the firm. There are few orders delivered because at the end of the simulation, some orders were in the FGI, ‘Open’ or ‘In Transit’ status. The mean time is rather low, due to the FGI initial stocks.

**Figure 11** Firm delivery time (see online version for colours)

![Delivery Time](image)

Note: mean time: 2.97 h.

We have compared the data obtained with some historical data of the firm, obtaining a satisfactory congruence with the results of the simulation, whose difference with real data has never been less than 12% in the worst case. As a further experimental validation of the model, we have noticed that during the entire simulation, supplier number 2 has never sent an order to its supplier because of the inventory level calculated by the simulator, which was enough to satisfy the firm’s demand. In fact, a survey conducted on the warehouse holding costs of supplier number 2 has shown that they compose up to 87% of the total SC costs.

### 5.2 VCOR specifications and customer satisfaction scenario: simulation results

The VCOR specification has been added through the Market and Research processes. In this case we have made a previous survey related to the customer satisfaction level with the previous model for product 1 (the one with the highest numbers of sales). The data have been acquired through the customer satisfaction questionnaires distributed to the customers during the period in which the orders were set. Figure 12 shows the results obtained, in which we can see a progressive decrease in the vote related to the product with the increase in the number of orders.
The extension to the VCOR model has been made through a particularisation of the Customer Behaviour model presented in Section 4.2; in our model Function (2) related to the vote at instant $k$ has a particular expression for the $f(k)$ relation, in order to accomplish the specification of the votes found on the Customer Satisfaction modules used by the firm in its quality management system. In this application the relation $u(k)$ has the following expression:

$$u(k) = \left[9 - \frac{6}{5} \cdot (1 - \alpha) \cdot x_i(k)\right] \cdot \frac{\ln}{\alpha} + \xi \cdot s + \beta \cdot \Delta p + \delta \cdot d + \phi \cdot q + \eta \cdot x_{ji}(k) \quad (3)$$

in which the notations are the same as in Equation (2), with the following additional considerations:

- The function $f(k)$ has its values included in the range [0–10], according to the customer satisfaction system of the firm.
- The $\Delta p$ variation has to be expressed as a percentage of the previous price and the weight $\beta$ has to be positive.
- The delay $d$ has to be expressed in percentages with respect to the mean lead time of the product.
- The quality level $q$ has to be expressed in percentages with respect to the mean quality level.

The simulation model has been run for the subsequent 19 orders. Figure 13 shows the customer satisfaction level in the simulation with the VCOR model from the order number 20 to the order number 39, including the Support process in the retailer and the whole PLM part in the firm. The simulation has generated a high elevation of the trend after the 20th order due to the introduction in the market of the renewed product (a new taste and nutritional features have been added due to surveys conducted with the customers and an additional survey database introduced by the CRM module).
As a further validation of the proposed simulation model, a postsales survey has been conducted on the product for which the simulation has been run. In Figure 14 we can see the real data coming from the above-mentioned customer satisfaction questionnaires. We can see that the values and the related trend reflect the simulation analysis with a maximum error of not more than 20% in the worst case.

Figure 14  The results of the survey on customer satisfaction (see online version for colours)

5.3  Delivery times scenario: simulation results

Another interesting result from the value chain simulation is related to the delivery times of the retailer. In the histogram of Figure 15 we report the simulation result of the entire period (from the first to the 37th order). With respect to the SCOR case, we have noticed an increase in the mean delivery time (7.84 h); this increase has been investigated inside the firm and these main two factors were found:
With the introduction of the Sell process, the firm decreases its FGI level to satisfy the new customers’ demand, slowing down the retailer’s orders.

The Support process of the retailer increases the mean to 2.3 h; this is due to the support time.

Figure 15 Retailer delivery time (see online version for colours)

The firm’s behaviour is more complex and for this reason two simulations have been necessary. The first one analyses the firm without the value chain part, in which the mean time is 5.36 h (Figure 16), and the second one investigates the whole performance.

Figure 16 Firm delivery time (see online version for colours)

With the introduction of the Sell process in the firm, we can notice that in the previous case the firm has satisfied about 15 orders, and now, with the application of the CRM part of the VCOR model, more than 30. The high increment is mainly addressed to the acquisition of new customers, which guarantees fixed financial entrances, to which the retailer’s demand must be added. Moreover, the production increases from 296 to almost 500 finished products, motivating the productive cycle to a higher level. To sum up, there are some benefits deriving from the adoption of the VCOR model. To better understand the improvements obtained by this choice, some indicators have been calculated to test the performance of the chain:
• stock rotation indicator: This shows the sales rapidity of the commodities. It is calculated as:

\[ SRI = \frac{Sales\ Profit}{Mean\ value\ of\ the\ stock} \]

in which a big value indicates the capability of the company to use their products.

• stock mean time: This indicates the mean time of undelivered materials or goods. It is calculated as:

\[ SMI = \frac{Period}{SRI} \]

where \( Period \) is the simulation timeline, expressed in hours.

• sales profitability indicator: This gives an idea of how the costs influence the effective profit. It is calculated as:

\[ SPI = \frac{Sales\ Profit - Costs}{Sales\ Profit} \]

In Table 6 the enhancements can be seen; we can notice a huge improvement in all of the firm’s indicators, especially for the \( SMI \) for the finished goods and the raw materials inventory.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>VCOR</th>
<th>SCOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRI for FGI</td>
<td>22.4</td>
<td>12.34</td>
</tr>
<tr>
<td>SMI for FGI</td>
<td>2.13 h</td>
<td>3.88 h</td>
</tr>
<tr>
<td>SRI for raw materials</td>
<td>1.2</td>
<td>0.69</td>
</tr>
<tr>
<td>SMI for raw materials</td>
<td>39.8 h</td>
<td>68.8 h</td>
</tr>
<tr>
<td>SPI (%)</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>

This last indicator underlines that, with the VCOR, many commodities are used (sold or used for production). While with SCOR simulation, this needs more time (about 50% more). We can also see that the \( SPI \) remains almost unchanged. However, if we consider that in the second simulation there are also the Support costs, the fact that the \( SPI \) is constant means that the Support costs do not affect the total costs of the Retailer much.

6 Conclusions

This paper has discussed a study of the two most well-known models used to implement the concepts of SCM and Value Chain Management, SCOR and VCOR, through a simulation approach. Starting from an analysis of their standard architectures, and using a bottom-up approach, their performance indicators and metrics, a simulation framework has been developed under ARENA. Once the SCOR model was implemented, the tool was extended to VCOR.
The simulation models have been applied to an agro-food firm in which the main experimental results given by the simulation runs have been compared with the real data of the firm. This was done to assess the model proposed and to verify the difference between the simulated data and the real ones. As confirmed by the results of these simulations, the adoption of the VCOR model needs bigger financial and organisational efforts, but these efforts can be fully repaid by the benefits in terms of quality of service, market extension, competitiveness, flexibility, ‘quick response’, innovation and other features essential for the firms to survive in the global market.

Finally, the results of some simulations have been presented, including a comparison of the two models in terms of the main KPIs that are crucial for the SC analysed. A future work could complete the implementation of the templates to all the processes of the VCOR model, extending the flexibility and the reusability of the realised tool.

References


