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# Value network modelling and simulation for strategic analysis: a discrete event simulation approach

Joanna Daaboul[a]*, Pierre Castagna[b], Catherine Da Cunha[b] and Alain Bernard[b]

[a]*Laboratoire Roberval UMR CNRS 7337, Department of Mechanical Systems Engineering, UTC – Université de Technologie de Compiègne, Compiègne, France;* [b]*Ecole Centrale de Nantes, LUNAM université, IRCCyN UMR CNRS 6597 France, Nantes Cedex 3, France*

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The survival of a company nowadays depends on answering to a customer-driven economy, and therefore relies on the performance of its entire network of partners. Competition is no longer among companies nor among supply chains, but rather between networks of companies which form a value network. Thus, the need has arisen to analyse the performance of a network of companies, and include the customer-perceived value in the strategic decision-making process. This paper proposes a framework and a tool to model, simulate and analyse a value network as a decision support system. The method extends the SimulValor approach and language. The discrete event simulation tool relies on a developed value network simulation library. This paper presents a case study in the shoemaking industry to validate the proposed approach.

**Keywords:** value network; value; enterprise modelling; performance evaluation; strategic decision

## 1. Introduction

The competition today is not among individual companies but among networks of interconnected organisations (Peppard and Rylander 2006; Ivanov 2009; Allesina et al. 2010). The performance and behaviour of all its partners (suppliers, shareholders, distributors, retailers and customers) influence the performance of one enterprise. Thus, the management of one enterprise and the decision-making process should be done by taking into consideration all these partners. In recent years, this concept of interconnecting businesses has been widely developed (Ivanov 2009).

Today, the economy has evolved into a customer-driven economy. The customer does not buy what is offered by the manufacturer, but requires the manufacturer to produce what he/she wants to buy. Many factors such as technological developments, Internet, increased competition and shorter life cycle of products have induced this phenomenon. Thus, new paradigms appeared such as mass customisation (MC), customer-driven design and customer-driven supply chains. Hence, companies nowadays need to incorporate both customer perception and its entire value network in decision-making.

The model, generally used nowadays to support strategic decision-making for an enterprise, is the one formalised by Porter that considers value-adding activities: the value chain (Porter 1985). This model suited the economic reality of its time but is not sufficient today to support the decision-making in an extended enterprise, whereas the value network model does. According to Elhamdi (2005), the value chain model has several limitations. First, the value taken into consideration is limited to the financial dimension where the business value equals the turnover from which the costs of activities are deducted. Second, the activities of the value chain are structured sequentially and in order. This structure results from the general economic model of reference of the value chain. Finally, interactions between different activities and the effect of these interactions on the generated value are not considered because of the unidirectional linear approach of the value chain. Moreover, this linear approach does not incorporate feedback that comes from the interaction of the value chain with external parties.

Peppard and Rylander (2006) explained that the concept of a value chain is the dominant concept in the analysis of strategic industries. However, a particular logic of value creation structures the value chain. Adopting a network model offers a different perspective which is more adapted to the new organisations. The value network approach considers

*Corresponding author. Email: Joanna.daaboul@utc.fr

qualitative as well as quantitative aspects of value. It also analyses value from different points of view and for different partners. The generated value in a network differs from one partner to another (e.g. the company and the customer).

As products and services became dematerialised and as the value chain itself does not necessarily have a physical dimension, the concept of a value chain is an inappropriate tool to analyse many industries today and discover the value sources (Normann and Ramirez 1994; Campbell and Wilson 1996; Parolini 1999; Tapscott, Ticoll, and Lowy 2000). This is also true since business connections play an important role in the strategic performance (Madhavan, Koka, and Prescott 1998). The value chain concept focuses on the activities producing the physical product, whereas the value network focuses on all activities creating value, even those with no physical input/output. A value network is defined as a set of collaborating partners, each responsible for a set of activities creating value (Elhamdi 2005). It is a model of creation and transformation of values within a network of collaborating partners. These generated values relate to the company itself but also to other partners. The value structures the network model while the activity structures the chain model.

By adopting a network approach, organisations do not focus on one company, but rather on the system of value creation in which different economic actors (suppliers, partners, customers, etc.) are working together to co-produce value. Jaehne et al. (2009) propose the use of a value network approach to overcome the lack evaluation for 'the quality of social relationships, the effectiveness and efficiency of communication and information sharing, the satisfaction of the relevant people or groups and also potentially interfaces, misunderstanding'. Their network level extends the supply chain view and covers the relationship view and management. Mizgier, Jüttner, and Wagner (2013) also advocate the necessity to use the concept of networks rather than of chains in performance evaluation. Furthermore they stress the necessity of considering the performance of all partners of a network in decision-making. They define supply chain network as a complex system of interconnected firms and propose a method for bottleneck identification based on this concept.

Even though the literature agrees that decision-making in an enterprise should be made by enlarging the perimeter of analysis (to supply chain, value chain and eventually value networks) and by including customer perception in the analysis, few existing methods and tools support this type of analysis. The main contributions of this article are a value network modelling approach and a discrete event simulation (DES) tool for strategic evaluation and decision.

When discussing value networks, it is necessary to define value and the value creation process. Thus, in the second section, a review of works defining value is presented, and secondly works that propose value network modelling languages are detailed. In the third section, the proposed modelling framework and simulation tool are described. Finally, Section 4 presents a case study in the shoemaking industry.

## 2. Related works: value, modelling languages and simulation methods

### 2.1 *Value*

Even though researchers agree that focusing on value generation is necessary to compete nowadays, they do not fully agree on a definition of value. Zeithaml (1988) defines value as the consumer's overall assessment of the utility of a product based on perceptions of what is received and what is given. Monroe (1990) states that buyers' perceptions of value represent a trade-off between the quality and benefits they perceive in the product relative to the sacrifice they perceive by paying the price. According to Anderson, Jain, and Chintagunta (1993), value in business markets is the perceived worth in monetary units of the set of economic, technical, service and social benefits received by a customer in exchange for the price paid for a product, taking into consideration the available suppliers' offers and prices. Gale (1994) defines customer value as market-perceived quality adjusted for the relative price of the product. While Butz and Goodstein (1996) define customer value as the emotional bond established between a customer and a producer after the customer has used a salient product or service produced by that supplier and found the product to provide an added value. In microeconomic terms, customer value is the difference between the consumer's willingness to pay and the actual price paid, which equals the 'consumer surplus,' the excess value retained by the consumer (Hinterhuber 2004). Finally, and according to Elhamdi (2005), value defines itself as the satisfaction of a need or an expectation of a beneficiary party expressed by the appreciation of the performances realised by the company. Mauchand (2007) adds to Elhamdi's definition that various indicators of results (performance indicators of the industrial company) measure value. Thus value is multi-criteria.

These definitions have many similarities. At first, most of these definitions tackle consumer value (Monroe 1990; Gale 1994; Butz and Goodstein 1996; Hinterhuber 2004) and agree that value is a trade-off between what is given and what is received. Value relates to each beneficiary party (Elhamdi 2005) or depends on a point of view (in particular value for the company is not the same as value for consumers). Furthermore, they show that consumer value is determined subjectively by customers and not defined objectively by the seller. The literature agrees that value has many criteria. Value from an economic point of view is not equivalent to value from a marketing viewpoint, or from a design point of view. These definitions differ mainly by the chosen beneficiary party, only Elhamdi (2005) and Mauchand (2007) propose a general definition of value regardless of the beneficiary party (customer, manufacturer, etc.). Anderson, Jain, and Chintagunta (1993) discussed value in business markets. Since the aim of this work is to analyse value for all partners in the network, a more generic definition should be considered. Another difference between the definitions of customer-perceived value is that most of these define value at the moment of buying the product. Only Butz and Goodstein (1996) define customer-perceived value after the use of the product.

Moreover, and based on the extensive literature review done by Gallarza and Saura (2006), most researchers and studies agree that perceived quality and price influence customer-perceived value, while perceived value influences satisfaction, behaviour intention and loyalty. In addition, customer-perceived value is not constant; it differs depending on the circumstances (Woodruff 1997). These previous definitions are combined to propose the following generic value definition that will be used for the generation of value models: value is 'the amount of satisfaction created, by fulfilling a certain physical, biological, or psychological need of a beneficiary party. It is influenced by many criteria such as cost, delivery time, perceived quality and perceived price. It can be objective or subjective, and is dependent on the circumstances and tied to the specific goals of the beneficiary party. Finally, when it cannot be directly measured, performance indicators are used as its measurement'.

Even though value has different points of view, its creation is not achieved by one party. According to traditional perspective, value is created by one party and consumed by another (Mizik and Jacobson 2003; Anderson and Narus 2004). According to Grönroos and Helle (2010), value for the customer and value for the supplier are mostly discussed and analysed as separate phenomena. Nevertheless, this perspective is no longer adopted by contemporary literature (Jaakkola and Hakanen 2013), and value is considered as a jointly created phenomenon emerging in interaction through integration of resources between actors (Grönroos and Helle 2010; Gummesson and Mele 2010; Lusch, Vargo, and Tanniru 2010).

Regardless of the adopted definition of value, few modelling and simulation frameworks used for strategic analysis for value chains, extended enterprises or value networks enable the evaluation of the impact of a certain decision on the customer-perceived value. And the few frameworks, incorporating customer-perceived value, limit it to its economic aspect. In the following section, a review of value and performance evaluation methods is presented.

### 2.2 *Modelling languages and frameworks*

Modelling a value network consists of modelling the:

- Activities/processes: activities are the core of value creation.
- Resources: the lack of required resources might lead to reduced performance of the network, and thus reduced generated value.
- Flows: of both physical and informational entities.
- Organisations: modelling the different partners of the network.
- Decisions: decisions impact the performance of an activity, a process, a partner or the whole network. Thus, they impact the generated value.
- Value: not only value for the different beneficiary party but also their inter-influence.

Table 1. Comparison of modelling languages.

| Language | Activity/process | Resource | Flow | Separation of information and physical flow | Organisation | Decision | Value |
|---|---|---|---|---|---|---|---|
| IDEF suite | X | X | X | | | | |
| BPMN | X | X | X | | X | | |
| UML | X | X | X | | X | | |
| SYSML | X | X | X | | X | | |
| GRAI grid and GRAI nets | X | X | X | X | X | X | |
| CIMOSA/ISO 19440 | X | X | X | X | X | | |

Before reviewing the models dedicated for value networks, a brief review on enterprise modelling languages is presented. The most famous enterprise modelling languages used are: CIMOSA, IDEF suite (IDEF0, IDEF1x and IDEF3), BPMN, UML, SYSML and GRAI method (GRAI Grid and GRAI nets. They are compared based on the needs for modelling a value network in Table 1.

Many other languages are used for business process modelling. A detailed review of these languages is presented in Aguilar-Savén (2004) and Vernadat (1996). These authors describe and compare most known and used languages for business process modelling. Other languages dedicated for mapping value exist, such as the value stream mapping (VSM). Bertolini et al. (2013) proposed an extension of the VSM in order to analyse the performance of a chain under mixed push/pull strategies. VSM lacks the incorporation of intangible variables in the estimation of value and focuses on indicators such as delays, inventory level, stocks, efficiency, etc.

As shown in Table 1, the GRAI method and to a larger extend CIMOSA, which has been the basis of ISO 19440 (2007), are the most adapted to the needs specified previously.

### 2.3 *Value networks models*

To evaluate the performance of a value network or to improve decision-making, a model is needed (Camarinha-Matos and Afsarmanesh 2008). Several approaches enable a value network to be modelled, such as the e3-value modelling framework, the c3-value modelling framework, the Allee's modelling framework and SimulValor. These will be detailed in the following Sections (2.3.1–2.3.5). Also, different existing tools can be used to model a value network (or an aspect of a value network) without developing a specific value network framework. For example, Pirard, Iassinovski, and Riane (2011) proposed a simulation-based framework for decision-making in supply chain networks. But, they only considered quantitative performance indicators, such as costs, revenue, delays, rate of production, etc. Fassi, Awasthi, and Viviani (2012) modelled and evaluated car-sharing network growth strategies through DES. They evaluated network members' satisfaction level, but included only tangible variables. Verdecho et al. (2012) proposed a methodology based on the analytic network process (ANP) to identify and measure, from an integrated approach, both factors and inter-enterprise performance, taking into consideration their reciprocal impact. The result of their method is the priorities of the relevant factors on collaborative relationships and inter-enterprise performance elements. This method may be used to prioritise the network objectives. In addition, Macedo and Camarinha-Matos (2013) proposed a qualitative approach, based on fuzzy causal maps and graphs, and supported by a web based tool, to assess the alignment of value systems in collaborative enterprise networks. Their approach aims to detect as early as possible the potential for conflicts among network members. These proposed methods aid in choosing members of a value network, and in defining common objectives of the network; but approaches are needed to evaluate the performance of value network configurations.

#### 2.3.1 *e3-value modelling*

The e3-value main focus is on identifying and analysing how value is created, exchanged and consumed within a multi-actor network (Gordijn and Akkermans 2003). The e3-value core elements which are presented in Figure 1 are the following:

- An Actor is an economically independent entity representing a company, an organisation, or an individual.
- A Value Object represents what is being exchanged between actors. It could be a service, goods or money that

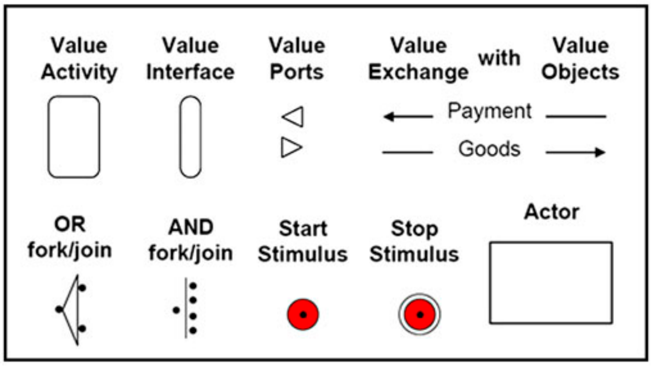


Figure 1. Elements of e3-value model.

has an economic value to at least one of the Actors. This exchange is achieved via value ports and is bi-directional.
- A Value Port is the medium allowing the exchange; it is a connection point between the Actor and the outside world.
- A Value Interface is a group of value ports.
- A Value Activity is performed by an actor motivated by a potential profit.
- A Market Segment is a clustering of actors that assign economic value to the object equally (Gordijn, Akkermans, and Vliet 2000).

The e3-value approach focuses on the business model, more precisely, on the e-business model which is the conduct of business on the Internet, including selling, giving service to customers and collaborating with business partners. The e3-value approach describes the ‘what’ of the business model, but not the ‘why’ (strategic rational) (Weigand et al. 2007), and it also lacks a clear strategic focus which weakens its ability for prescriptive strategic insights. Also it does not consider the exchange of information which may lead to a creation of value and is thus crucial in assessing value in a value network. Moreover, and in some cases, the lack of correct information exchange may lead to reduced value.

#### 2.3.2 *c3-value modelling framework*

The c3-value modelling scheme extends the e3-value model developed to cope with its limitations (Weigand et al. 2007). It includes, for example, the exchange of information as a value object. Geared towards strategic analysis, it focuses on three dimensions: competition analysis, customer analysis and capability analysis (Weigand et al. 2007). They divide value objects into different categories: primary value objects and complementary value objects. Only the complementary value objects may be intangible. They represent an additional service or product or information provided with the primary value object. This can be a manual for example. This framework focuses on the direct competitor and the direct customer and thereby neglects the inter-dependencies inherent in the current global economy and the potential given by the network perspective (Biem and Caswell 2008).

#### 2.3.3 *Allee's modelling framework*

This framework considers the value network as a continuously changing system that reproduces itself (Allee 2002). The entities of the Allee’s model are:

- Participant representing an individual or group of people.
- Transactions referring to a transfer of a deliverable from one participant to another. Transactions are considered unidirectional.
- Exchange which is a bi-directional transaction. Exchanges are drivers of value. The exchange notion is similar to that in the e3-value modelling framework.
- Deliverables that can be tangible such as goods, services and revenue, or intangible such as knowledge and benefit.

Two characteristics limit the model potential for strategic analysis: its strong assumption on the unmanageability of the network, and its focus on exchanges without assigning a purpose to the network (Biem and Caswell 2008).

#### 2.3.4 *SimulValor*

SimulValor is a value network modelling approach for strategic decision-making. It may be applied for decisions such as selection of a facility location, choosing suppliers, purchasing pieces of production equipment, pricing, designing manufacturing systems or offering MC. It uses system dynamics (SD) (Elhamdi 2005). It focuses on the generated value and on the influences of the performance of the different partners on this value. Thus, it manipulates quantitative and qualitative variables through their influence on the performance of a certain activity. It measures the impact of a strategic alternative decision on the enterprise generated value. In addition, the cause/effect relationships between variables are also influenced by certain delays of the influence of one variable on another or on an activity.

Using SimulValor, it is possible to model in one graph the physical flow and the causal influences between what Elhamdi calls immaterial information. In this modelling approach, there is one direction of material transformation. The worth of a flow (the quantity of circulating entities) can be either positive or zero if the stock from which it is generated

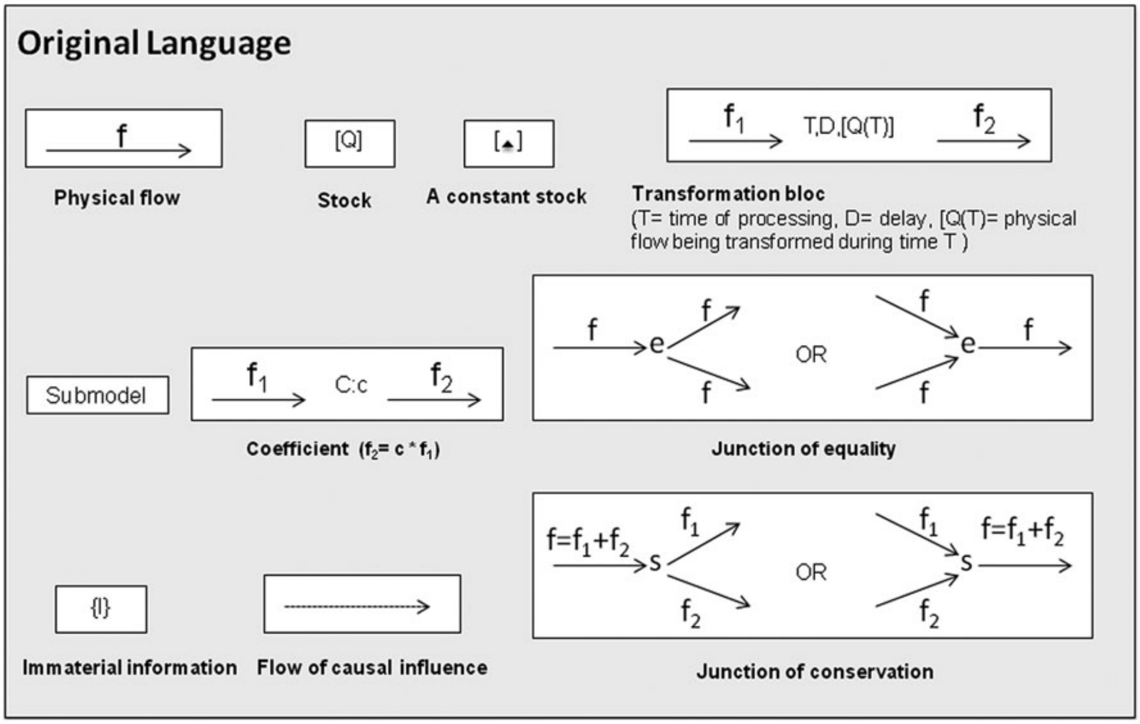


Figure 2. Elements of the SimulValor language (Daaboul, Bernard, and Laroche 2012) adapted from Elhamdi (2005).

is empty. Also, it allows a hierarchical modelling by the possibility of using sub-models. Figure 2 presents the SimulValor modelling language which includes the following:

- Physical flow which designates the circulation of entities of type material (raw materials, semi-finished products, products, etc.).
- Stock that represents an accumulation of a number of entities of type material.
- A transformation block which represents an activity.
- A coefficient that represents a relation between the values of two flows.
- A junction of equality which imposes the value of an input flow to a set of outflows, or the value of an outflow to a set of input flows.
- A junction of conservation which imposes a relationship of equality between the value of an incoming flow and the sum of values of a set of outgoing flows, or between the value of an outgoing flow and the sum of values of a set of incoming flows.
- A flow of causal influence that indicates a direct causal influence between two variables.
- Immaterial information which intervenes in the causal structure of the industrial system modelled, but does not necessarily concern a specific stock: the image of the company for example. It represents the variables of the modelled system except those related to a stock such as stock level. These variables are of two types: those influencing the performance of the system and those used to measure it.


Figure 3. Modifications on SimulValor language (Daaboul, Bernard, and Laroche 2012).

2.3.5 *Modified SimulValor*

Daaboul, Bernard, and Laroche (2012) proposed modifications on SimulValor to better model value networks based on their needs. These modifications (Figure 3) are:

(1) Separating informational and physical flows.
(2) Adding a new element modelling resource to the SimulValor language. It is represented by the symbol [R]. It manages the problem of resource allocation. Also, this enables the evaluation of the resources' performance, by linking it to different immaterial information such as capacity.
(3) Including the representation of partners by adding the symbol (A). A partner is any entity or organisation that benefits from the value generated by the network and/or which may affect this value. A partner contributes to the creation of value. It may be a company, a supplier, a distributor, a customer, a vendor, etc. A partner is responsible for the performance of an activity.

2.3.6 *Discussion*

Modelling and simulating a value network aims to support a company in strategic decision-making. Nevertheless, the main decision variables are not restricted to economic value. It is necessary to integrate in the analysis all other forms of value: value for the customer, value for suppliers, value for all partners of the network and the subjective value for the company including its image, its ranking, etc. In addition, it is necessary to include not only the execution activities but the decision activities in the analysis and assessment of the generated value. Thus, it is important to include operational and tactical decisions in the model to assess their impact on the value network performance and, thus, on the generated value. Finally, a strategic decision has a major impact on the performance of the entire network and on the generated value for all partners in this network.

In brief, what is needed is a language to model: partners, value (not only economic value), activities (execution and decision activities), resources, flows between activities and variables impacting and measuring the performance of the network or allowing the measurement of value.

As shown in Table 2, the modified SimulValor is the most suited language since it enables the modelling of value network elements except for decisions. Moreover, SimulValor enables the modelling of influences or inter-dependencies between different values (or variables impacting value) in value networks. In addition it supports the philosophy of value jointly created by collaborating partners. Thus the modified SimulValor is the most suitable language for the requirements, yet it needs additional modifications to satisfy all value network modelling needs.

### 2.4 *Choice of a modelling language/framework*

From the analysis reported in Sections 2.2 and 2.3, the GRAI method (GRAI grid and GRAI nets) and modified SimulValor are the most suited for the specified modelling needs. According to Aguilar-Savén (2004), GRAI grids and nets have major disadvantages:

- Many partial diagrams to describe a process.
- Need lot of data.

Table 2. Mapping between required elements and available frameworks.

| | | | | | | | Value | | |
|---|---|---|---|---|---|---|---|---|---|
| | Part. | Act. | Res. | Phy. flow | Dec. | Info. flow | Tang. | Intang. | Int. D. |
| e3-value modelling | X | X | | X | | | X | | |
| c3-value modelling | X | X | | X | | X | X | X | |
| Allee's modelling framework | X | X | | X | | | X | X | |
| SimulValor | X | X | | X | | | X | X | X |
| Modified SimulValor | X | X | X | X | | X | X | X | X |

Note: Part. = Partner; Act. = Activity; Res. = Resource; Phy. = Physical; Info. = Information; Tang. = Tangible; Intang. = Intangible; Int. D. = Inter-dependencies.

- Time consuming when modelling.
- Complexity.

SimulValor is a language dedicated for value network modelling. It includes the modelling of intangible as well as tangible nature of value. More importantly, it incorporates the modelling of the SD. It is less complex than GRAI grid and GRAI nets to implement. It also requires less time when modelling. Finally, it is easier to integrate the GRAI decision model in SimulValor than to integrate the value model in GRAI. Thus, the modified SimulValor has been chosen for the modelling and simulation of value networks.

## 3. Value network modelling and simulation of value networks for strategic decision-making

### 3.1 *Modifications on SimulValor*

Even though SimulValor was the most appropriate language and it had the methods to model a value network for strategic analysis, some modifications and additions were necessary. These are the following:

(1) Addition of a new type of flow called trigger: a trigger is an informational flow that stimulates an activity, i.e. information about a job waiting to be executed, a production order, a result of a decision, etc. The same trigger may stimulate more than one activity, and one activity may be stimulated by more than one trigger. Moreover, a trigger may interrupt the current processing of an activity. The trigger was necessary to model what stimulates an activity: a production order, a customer order, a decision, etc.
Both CIMOSA and ISO 19440 say that 'an event (a trigger) initiates one or more Business Processes (and thus their enterprise activities) and an event can be associated to an Object View (information) if it carries information' (see Figure 4). Figure 5 explains the difference between the two meta-models (ISO 19440 and modified SimulValor). Both models represent the same logic, but the ISO meta-model does not model the information, while in our proposition the event is not modelled.

(2) Distinction between execution and decision activities by adding a new decision block (Figure 6): decisions, such as procurement, influence the performance of the value network. Thus, it was necessary to integrate

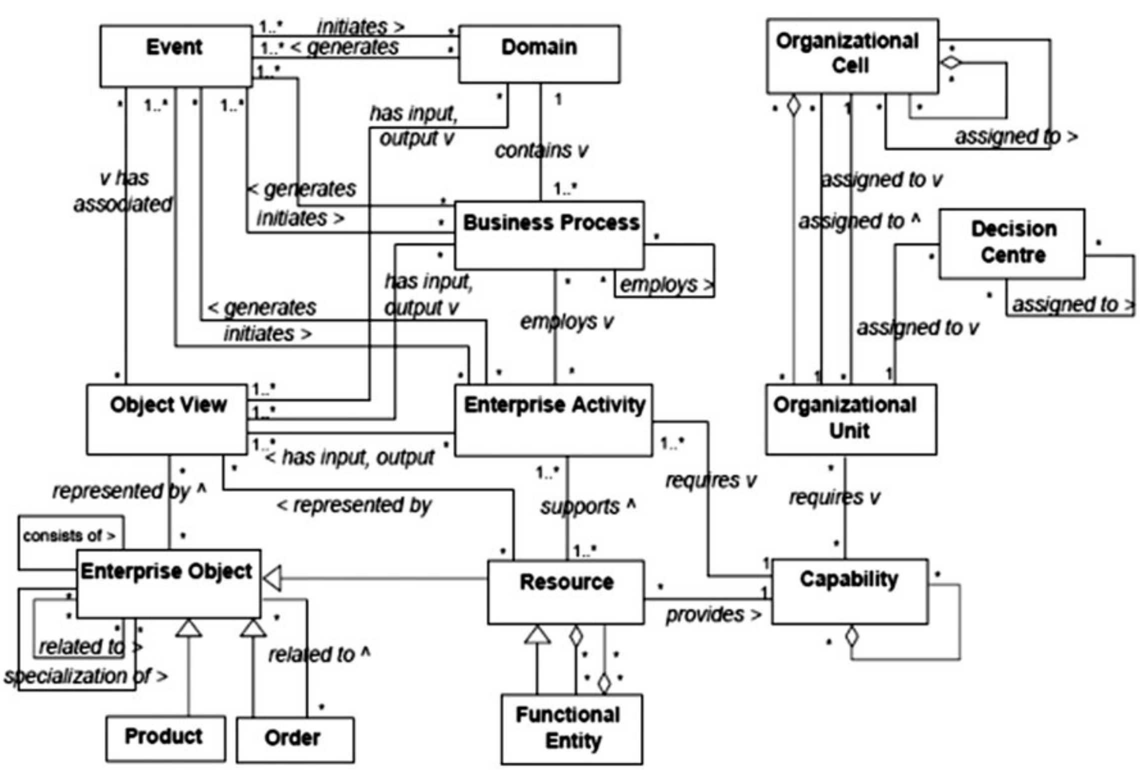


Figure 4. ISO 19440 (2007) meta-model.

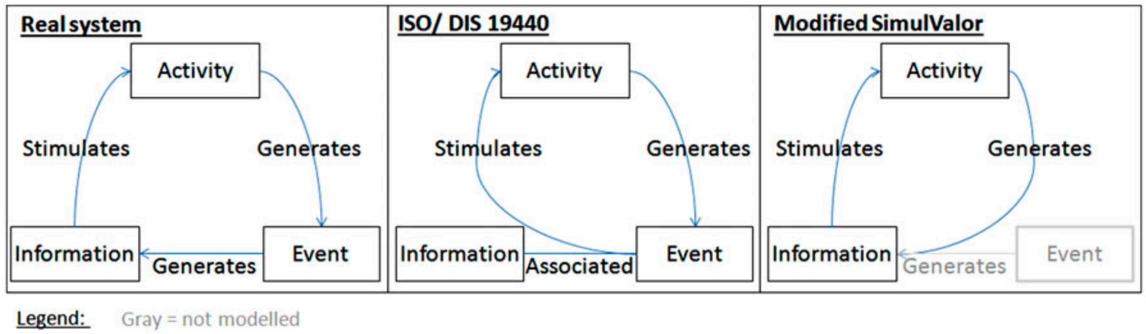


Figure 5. Modelling the stimulation of an activity.

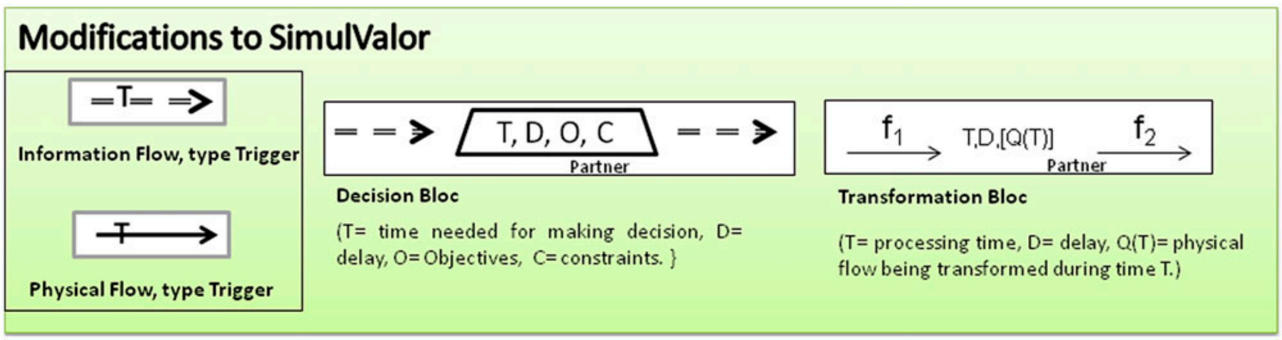


Figure 6. Modifications to the modified SimulValor language.

these decisions into the analysis, i.e. in the modelling of a value network. An activity is a block of flow transformation, mobilising resources, time and methods. It is triggered by a physical or informational flow. It creates value and is divided into two types: execution activities and decision activities. For this distinction as well as the modelling of a decision activity, the GRAI model (Doumeingts 1984) is used and integrated within SimulValor. A decision is thus modelled as an activity having as input and output an informational flow and utilising resources and being stimulated via a trigger. It includes a set of decision variables, and of constraints. It also has an objective. A decision activity does not create value by itself but supports the creation of value via the decisions taken and the actions resulting from these decisions. These decisions impact the performance of execution activities, the costs, delivery time and many other indicators used in measuring value.

(3) Modification of the representation of an activity or transformation block: the partners responsible for the execution of the activity have been added to the model.

### 3.2 *Synthesis of modelling elements*

The main elements of a value network are: the partners, the activities, the flows, the value and the variables referred to as immaterial information in SimulValor. These are presented in Figure 7. All classes, connections and relations coloured in light grey are proposed by SimulValor, while all those in dark grey represent the additions and modifications to this language (Resources, Differentiation between execution and decision activities, and Differentiation between different types of flows).

A value network is formed of a set of collaborating partners, each responsible for a set of activities creating value. Yet the same partner may be part of several value networks.

Immaterial information is system variables that either influence or measure performance. The performance of an activity is influenced by variables called action variables and is measured by state variables. These variables (state and action) are related to all model elements. Symmetrically each model element (partner, resources, activities, etc.) is

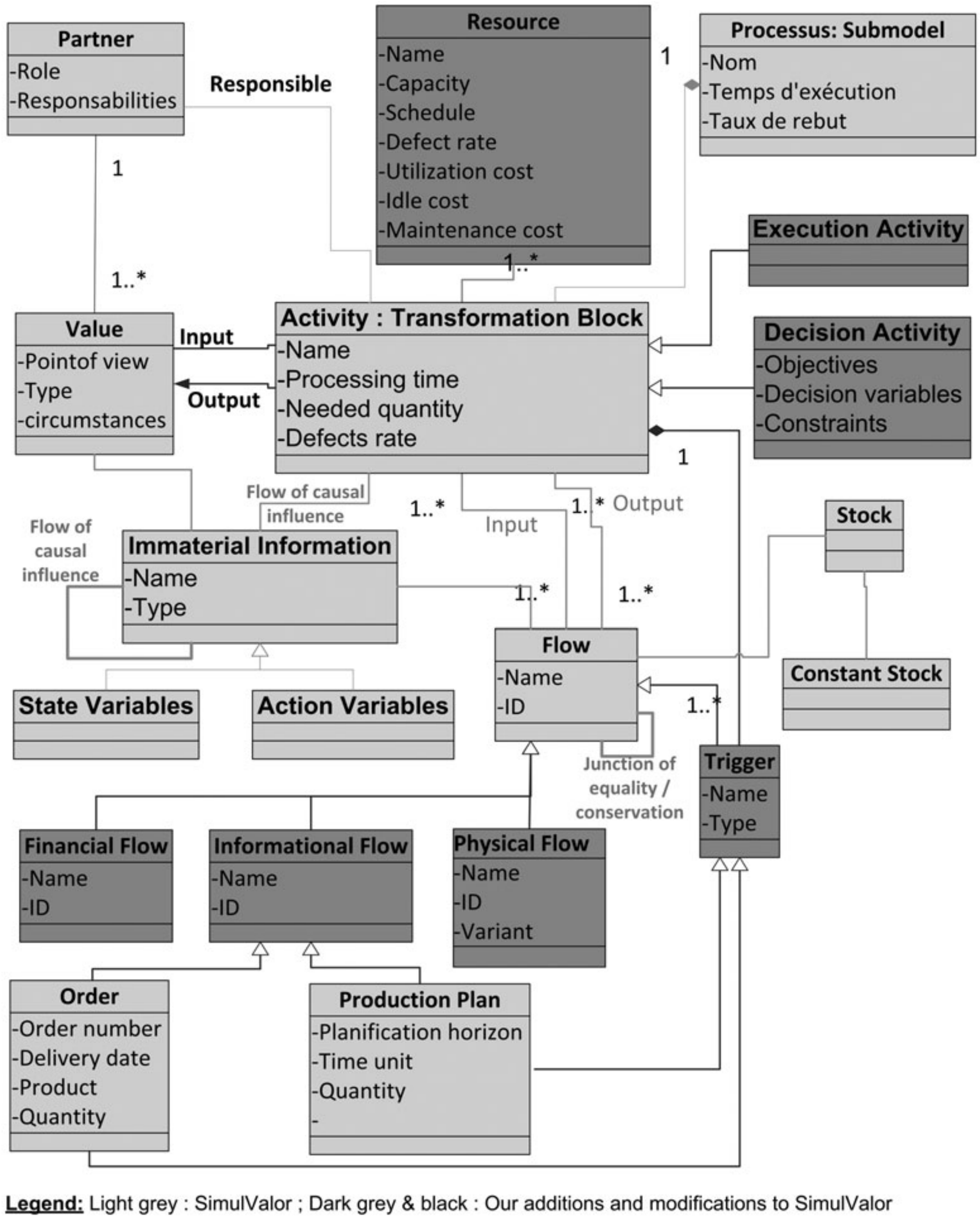


Figure 7. UML class diagram of the modelling elements.

related to action variables and to state variables. For example, a state variable related to the model element 'resources' might be, among others, the utilisation rate, the busy cost, the idle cost, the usage cost, the scheduled utilisation and the job satisfaction rate, and an action variable may be skills, capacity, cost parameters, working conditions or defect rate. For an informational flow, type order, a state variable, might be the order delivery time, the number of satisfied orders, the number of satisfied orders on time, the number of backlogged orders, the number of lost orders and the total number of orders. For a partner, a state variable might be the total cost induced, the total revenue collected, the total profit, the image or reputation, the ranking among competitors, the environmental evaluation, etc. But action variables for a partner are: image/reputation, ranking among competitors, environmental evaluation, reliability, etc. Thus, the same variable might be a state and an action variable at the same time. For example the current image of a company influences the customer-perceived value, whereas the customer-perceived value impacts its future image. Thus, image of a company or its reputation is at once a state and an action variable. A state variable of a physical flow is its quality which is assessed using other variables. A state variable for a stock is the actual stock level per variant of physical flow. The system action and state variables are the core elements of the model impacting the behaviour of the system, and thus the creation of value. The state variables are the elements of the model used for the calculation of value for the different partners: main manufacturer, supplier, distributor, customer, retailer, etc.

The variables are expressed via mathematical equations, whereas their inter-dependencies are modelled via an influence graph incorporated in the model also via mathematical equations. These variables may be deterministic or stochastic.

Using this modelling approach, value may be created via execution activities having no physical flow as input/output. For example, the after sales services may be modelled using an execution activity having only informational flows as inputs and outputs. And this activity creates value and thus is linked to the value model and included in the value calculation via immaterial variables such as the cost of the activity, the execution time of the activity that influences customer-perceived value, etc.

According to ISO 19440 (2007), a process is a partially ordered set of corporate actions executed to achieve business objectives in order to achieve a desired result.

A flow is a set of entities of physical (product, raw material, intermediate product and product component), or informational nature (production plan, result of a decision, order, data about the customer, etc.) that circulate in the network (adapted from Elhamdi 2005). A flow is the input/output of all activities (decision or execution) and may play the role of an activity stimulator. A flow impacts the created value by its quality, accuracy of information, etc. Physical flow is linked to a stock. There are different types of stocks: safety stock, work-in-progress stock and defects stock. Moreover, when an order is not able to be completed due to unavailable stock, a decision activity states whether this is backlogged or considered as lost sales.

Value, as stated in Section 2.1, is measured by various performance indicators. For example, modelling the subjective value for a company is not possible except via different performance indicators, such as the ranking of the company among competitors, the number of loyal customers and the market share. Another example would be the value of a service for the customer. It is measured via performance indicators such as the time needed for choosing and paying, the complexity of the buying process, the quality of advice received from the salesmen, etc.

## 3.3 *Value network modelling and simulation tool*

### 3.3.1 *Simulation method and simulation tool*

Among the available simulation tools, none permit modelling all the objects described in the previous section. Moreover, no simulation support was provided and usable for SimulValor. A simulation tool supporting the previously proposed value network conceptual model was thus developed. Among the available simulation software, Arena seems to be the most adapted. Moreover, Arena of Rockwell offers an interface for developing a customised simulation library facilitating the development of the value network library.

In addition, DES has many advantages, mostly due to its ability to capture the dynamics of a system which is not possible in the same way with a static analysis (Thiede et al. 2013). According to a literature review by Tako and Robinson (2012), out of 127 papers, 86 (68%) used the DES approach, 38 (30%) the SD approach, while just 3 (2%) papers used hybrid DES and SD modelling. This suggests that DES is the most frequently applied simulation approach in the logistics and supply chain management (SCM) context. They have also shown that DES is also used more for analysis at a strategic level. Some of the advantages of DES listed in Law (2007) and Banks (2010) are:

- The possibility to explore new policies, operating procedures, decision rules, information flows, organisational procedures, etc. without disrupting ongoing operations of the real system.
- Testing new hardware designs, physical layouts, transportation systems, etc. without committing resources for their purchase.
- Testing of hypotheses about how or why certain phenomena occur.
- Obtaining insight about the interaction of variables is possible.
- Obtaining insight about the importance of variables to the performance of the system.
- Performing a bottleneck analysis.
- Contributing to the understanding of how the system actually operates.
- Possibility to evaluate 'What-if' scenarios.

Finally DES, and based on Table 3, is more suitable to the proposed conceptual model than Agent-Based Simulation (ABS), since the core element of the model is the activity and the focus is on the whole system. Each of the value network elements (partner, informational flow, physical flow, execution activity, decision activity and resources) impacts

Table 3. Attributes that define the model type (Siebers et al. 2010).

| DES models | ABS models |
|---|---|
| Process oriented (top-down modelling approach); focus is on modelling the system in detail, not the entities | Individual-based (bottom-up modelling approach); focus is on modelling the entities and interactions between them |
| Top-down modelling approach | Bottom-up modelling approach |
| One thread of control (centralised) | Each agent has its own thread of control (decentralised) |
| Passive entities, that is something is done to the entities while they move through the system; intelligence (e.g. decision-making) is modelled as part of the system | Active entities, that is the entities themselves can take on the initiative to do something; intelligence is represented within each individual entity |
| Queues are a key element | No concept of queues |
| Flow of entities through a system; macro-behaviour is modelled | No concept of flows; macro-behaviour is not modelled, it emerges from the micro-decisions of the individual agents |
| Input distributions are often based on collect/measured (objective) data | Input distributions are often based on theories or subjective data |

the creation of value. Moreover, the industry still has issues regarding the credibility of the simulation results in the case of ABS (Siebers et al. 2010).

Arena is a DES software developed by Systems Modelling in the 1980s and now marketed by Rockwell Automation. It is a flow-oriented simulator. In Arena, the user builds a model by placing modules that represent processes or logic in the user interface. Connector lines are used to join these modules together and specify the flows of entities. These flows of entities enable the modelling of both physical and information flows. Arena enables the user to develop his/her own modules. The Arena tool is often used to study SCM (Jack and Kleijnen 2005). Arena allows interfacing with different programming languages such as C, C++, VBA, Java, etc. with databases and with spread sheets. Vamanan et al. (2004) propose to combine Arena and CPLEX to study inventory-/logistics-related problems.

### 3.3.2 *Value network library*

The developed library enables the modelling and simulation of more than one value network, and generates an analysis of the generated value per partner. It is formed of 7 modules presented in Figure 8. The 'Partner' module models the different partners of the network. The 'Physical Flow' module models the different physical flows of the network including the flowing entity and their stocks, the different variants of the physical flow, the characteristics of the physical (flowing) entity (such as aesthetics (ex. colour), design, material, size, volume, etc.), the possible values for every

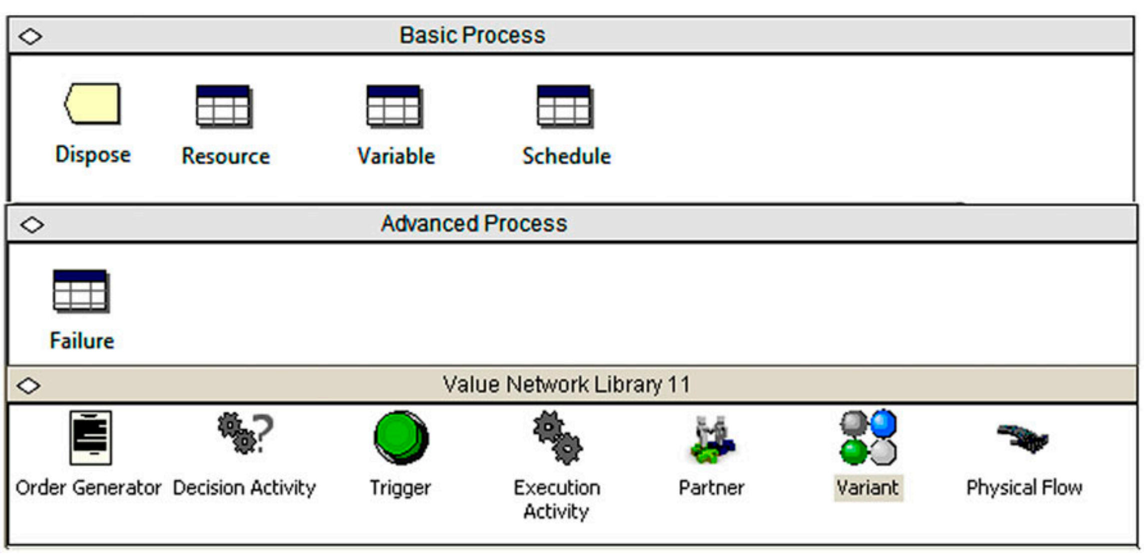


Figure 8. Modules of the value network library and used modules of ARENA standard 'Basic Process' and 'Advanced Process' libraries.

characteristic (such as red, black and white for colour), the stocking cost, the partner inducing this cost, and the actions to be made when out of stock: (1) order from supplier or produce the needed quantity by triggering the corresponding activity (the name of the activity is specified, as well as the minimum quantity), (2) make a decision (the name of the concerned decision module is specified) or (3) do nothing. The 'Execution Activity' module enables the modelling of all execution activities of the network by defining the different activity duration parameters, the needed resources, the inputs and outputs of the activity (physical flows), the costs, the partner inducing the cost and, if any, the partner collecting the revenue. The execution activities are not linked to each other directly but indirectly via the physical flows (inputs/outputs).

The 'Decision Activity' module is used to model different decisions by defining the decision variables, the constraints and the actions to be done. A decision activity takes state variables as input and triggers an activity as output. The mechanisms of algorithms used can be as simple as an 'if then' and as complex as capacitated scheduling. The module 'Trigger' stimulates the execution activities. Moreover, other modules such as the modules of 'Physical Flow' and 'Decision Activity' act as a trigger when sending a physical or an informational flow to an 'Execution Activity'. The 'Order Generator' module randomly generates orders. Finally the 'Variant' module defines the characteristics defining the variants of the different physical flows. This technical module facilitates the identification of different variants of physical flows. In addition to the 7 modules in the developed library, 4 modules are used from the 'Basic Process' library of Arena: resource, schedule (defines resources schedules), Variable (to model variables or immaterial information) and Dispose. Also, one module is used from the 'Advanced Process' library of Arena: failure which is used to model failures of resources. The variable module is used to specify the mathematical equation which can determine the value of immaterial information.

The interactions between these modules are presented in Figure 9 which shows the calculations and what is defined in each module. The interactions are presented in the figure as lines, whereas the parameters and the defined elements are presented by arrows. In the physical flow module, as an example, the initial stock for every product variant, the holding cost (the associated price of storing inventory or assets that remain unsold), the partner inducing this cost and the action to take when a certain requested quantity is not available in stock are defined. Moreover, the levels of virtual stock (planned stock) and the real stock (actual inventory) are calculated.

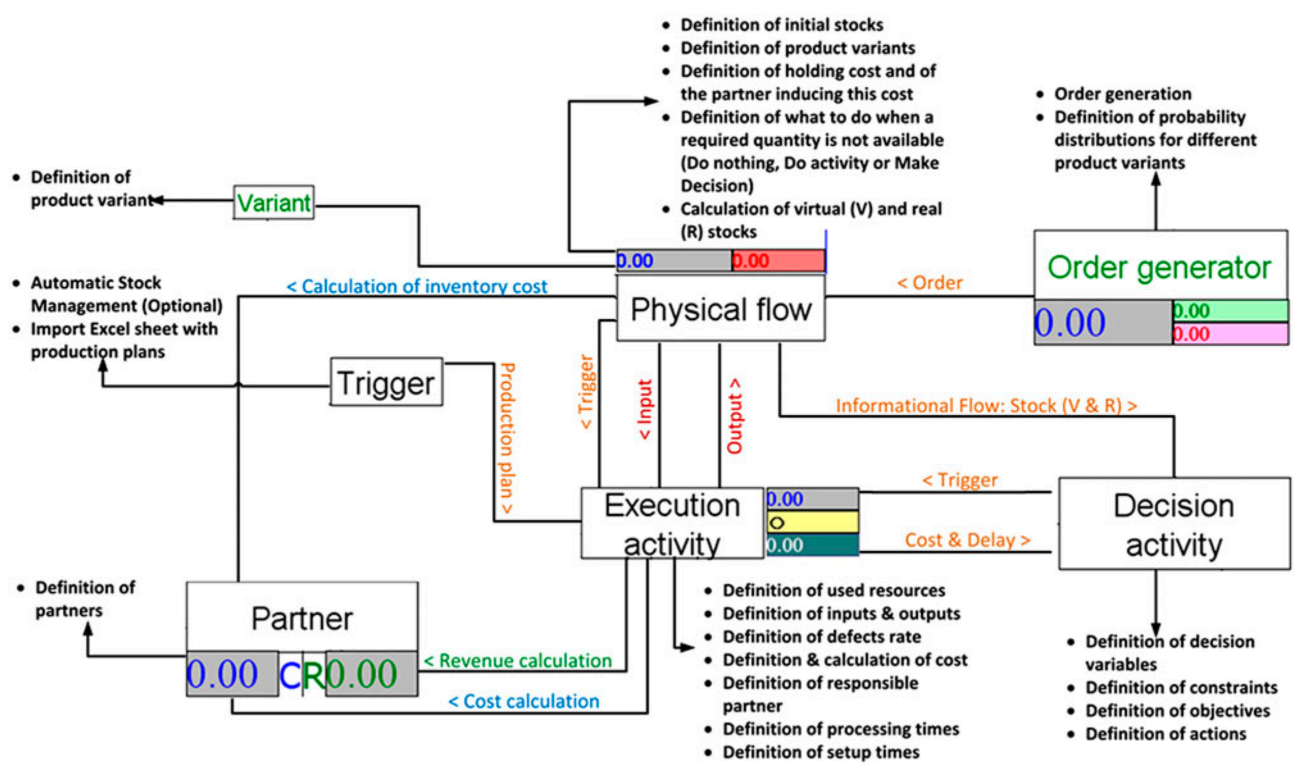


Figure 9. Logic and relations between the value network library modules.

This library fits the conceptual model presented in the UML class diagram in Figure 7. This conceptual model supports the development of the library as well as the entire methodology. This is illustrated further in Table 4.

The library is generic and can be used to model and simulate one or more value networks. The model is created simply by placing the modules in the user interface and filling their different parameters. The user does not have to create any simulation logic (meaning the interactions and links between different modules). The library embeds the simulation logic. This facilitates the use of the library and does not require high skills in the use of the Arena software. Moreover, any change in the library is easily modelled by adding a new module or retrieving one, since no link is directly made in the interface by the user.

### 3.4 *Value network modelling and simulation steps*

To use the proposed library in the best way possible, the user is encouraged to follow the steps described in Figure 10. For the last step concerning the results analysis, the analytical hierarchy process is proposed as one analysis method. The users may use any analysis method and easily put it in place in the generated excel sheet report. AHP, which was developed by Thomas L. Saaty (1980), relies on the expertise of the user to generate the weights of attributes. It relies on the comparison of pairs of options and criteria. It has found widespread applications in decision-making problems involving multiple criteria in systems of many levels (Liu and Hai 2005).

## 4. Case study: the shoe industry

The proposed modelling and simulation approach has been validated in a Slovenian shoemaking industry case study at Alpina[1]. The strategic decision was the definition of the best MC strategy to be adopted. Since MC is a customer-driven strategy, the customer-perceived value becomes one important decision criterion. Thus, a value network approach, enabling the analysis of generated value for all partners in the network, is necessary. When implementing MC, two main decisions are made: the customisation offer and then the customer order decoupling point position (CODP). The CODP is defined as 'the breaking point between productions for stock based on forecast and customisation that responds to customer demand. It is also the breaking point between made-to-stock (MTS) and made-to-order (MTO), namely activities before CODP are driven by the forecast while activities after CODP are driven by real customer order demand' (Ji, Qi, and Gu 2007). In fact the customer may customise his/her shoe by additional goods/services (such as putting a signature on the shoe), by choosing the colour and the material of the shoe, by only choosing the colour of the laces, or by demanding that the pair of shoes is made for his/her feet size.

In the Alpina case study, the main decision concerned changing the value network structure of the Binom line of products from MTS to MTO or assemble-to-order (ATO) combined with the relative customisation offer. Alpina's value network includes the following:

- 20 partners (Alpina, customer, shop, distribution company and 16 suppliers),
- 88 physical flows,
- 100 execution activities,
- 30 decision activities.

Table 4. Mapping between the conceptual model and the simulation library.

| Element of the conceptual model | Corresponding module in developed library |
|---|---|
| Partner | Partner |
| Execution activity | Execution activity |
| Decision activity | Decision activity |
| Trigger | Trigger |
| Order | Order generator |
| Physical flow | Physical flow |
| Stock | Integrated in physical flow |
| Informational flow | Integrated in all modules |
| Resource | Integrated in execution activity |
| Production plan | Integrated in trigger |
| Immaterial information/variable | Integrated in all modules |

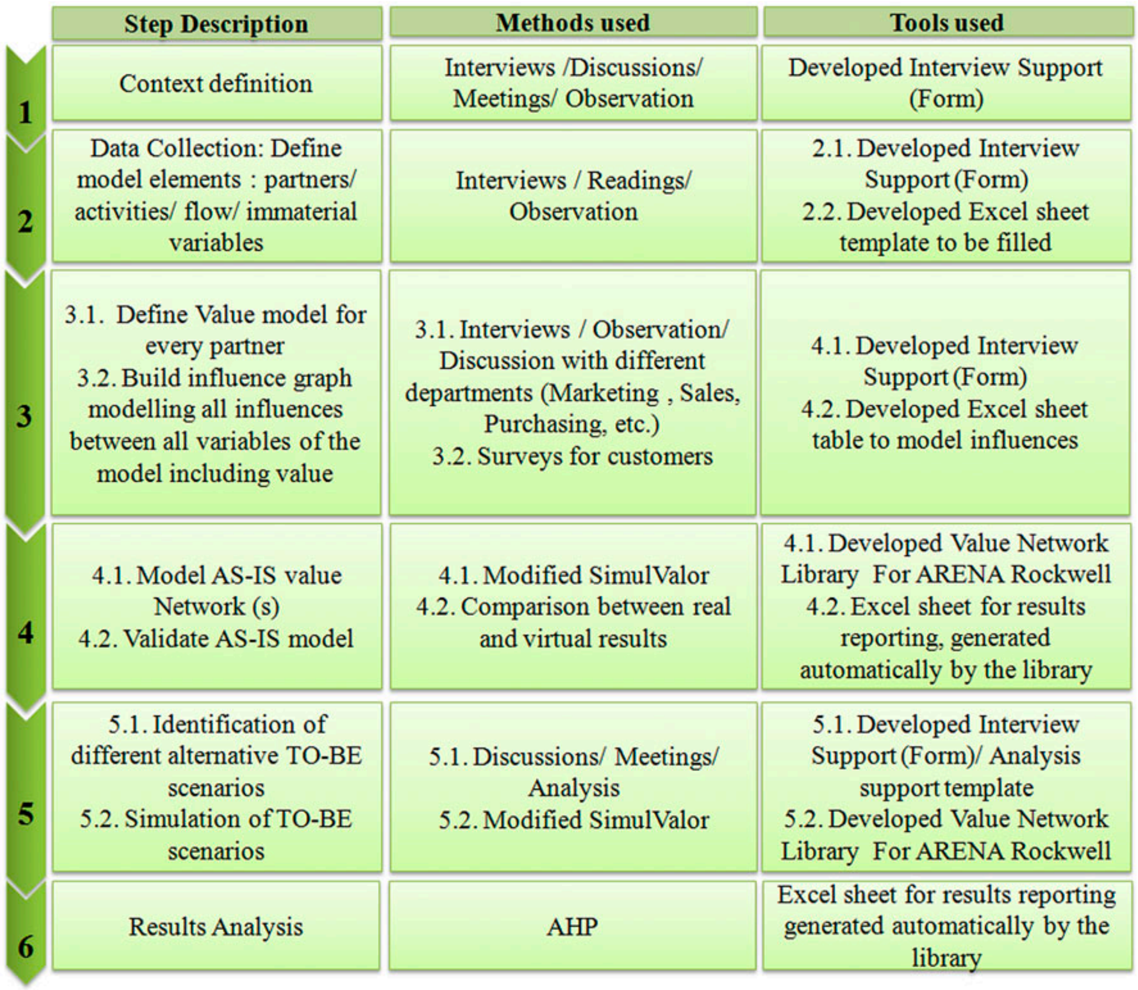


Figure 10. Steps, methods and tools for value network modelling and simulation.

In a very simplified manner, the production of a shoe consists of the following main activities: outsole production, insole and midsole production, cutting upper parts, stitching upper parts, lasting upper, assembling upper to soles, cleaning shoe and finally adding laces.

Alpina provided all the necessary data for modelling its value network. Also, an analytical analysis was conducted to model the value perceived by the customer. The orders result from a forecasting based on the sales history provided by Alpina. The production plan was provided by Alpina, as well as the different decision parameters in the network. Contracts were the base for modelling the different partners (cost, delivery time, penalties, etc.).

Table 5. Alternative TO-BE scenarios for Alpina case study.

| Alternative | Network structure | Inventoried item | Reaction time |
|---|---|---|---|
| 1 | A mix between MTS and MTO | Lace, outsole, insole, leather | 1.5 weeks |
| 2 | A second mix between MTS and MTO | Lace, outsole, insole, leather, upper components | 1 week |
| 3 | ATO (assemble-to-order) | Lace, outsole, insole, leather, upper components, upper | 1 week |
| 4 | Complete MTO | Lace, leather | 2 weeks |

After validation of the AS-IS model by Alpina, four different alternative TO-BE scenarios were identified as shown in Table 5. These alternatives offer the same customisation options, but differ in the offered service and specifically in the reaction time.

In alternative 1, cutting the leather is an MTO activity, while in alternative 2 it is an MTS activity. In alternative 2, all the different leather components are cut before an order is received but the assembly and stitching of these components is made after an order reception.

Two values for two main partners in the network were analysed; these were the value for the customer and the value for the shoemaking company (Alpina). Although efforts were made to include the suppliers in the analysis of the generated value, this was not possible due to lack of needed data from the suppliers. With the available data, it is possible to calculate some but not all performance indicators needed to evaluate the generated value for suppliers from this value network. But using the conceptual model and the developed library enables the evaluation of value for all partners in the network including the main manufacturer, suppliers, distributors, sub-contractors, retailers and customers.

Customer value was calculated by dividing perceived quality on price, while the value for Alpina represents its profit. In the profit calculation, the fixed costs are not included. For the customer-perceived value, which has no unit, data on quality attributes, their weight of importance for customers and their different quality levels were collected from Alpina. These attributes included the main functions of a shoe such as fitting, aesthetics, material, thermal comfort, flexibility, weight, stability, breathability, durability and waterproofing. It also included other quality attributes such as the brand name, ecological level, shop assistance, customisation time and number of proposed product variants. A matrix of five quality levels (very poor quality, poor quality, average quality, good quality and very good quality) for each attribute was filled in with the marketing department of Alpina. When a product is to be delivered to a customer a scan of the quality level for each attribute enables the calculation of the customer-perceived quality using the following equation:

$$Q_{p_i} = \sum_{j=1}^{n} Q_{A_{ij}} * W_{A_{ij}}$$

- $Q_{pi}$ is the total perceived quality of product $i$; $1 \le i \le n$; $i \in \mathbb{N}$
- $Q_{Aij}$ is the quality of attribute j of product $i$; $1 \le j \le m$; $j \in \mathbb{N}$
- $W_{Aij}$ is the weight of importance of attribute $j$ of product $i$.

The simulation results (Figure 11) show that the accumulated customer value increases in the case of ATO or MTO structure. Nevertheless, with its current relationships with the network partners and specifically its suppliers, it is not

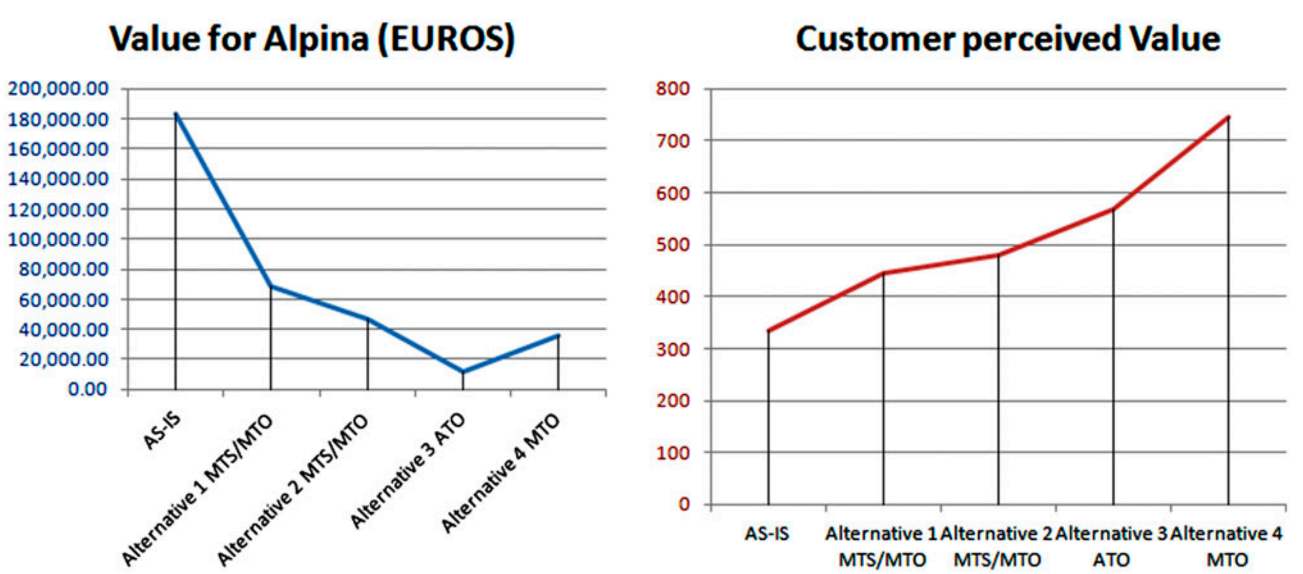


Figure 11. Simulation results.

profitable for Alpina to move to an ATO or MTO structure and the main changes to be made concern the supply network. Alpina has to re-analyse its entire supply strategy especially in terms of agreements with suppliers such as replenishment time and minimum quantity to order. If no changes in the partners' relationships occur, it is best for Alpina to keep its current MTS structure. In this case study, it was not necessary to use AHP to analyse the results, since there are two decision criteria with equal importance to Alpina.

## 5. Discussion

The case study provides an illustration of the methodology proposed as well as its different steps. It validated both the language as well as the usability of the simulation library. Since few hypotheses were made, and as all the data used were real, the model was validated rapidly: its behaviour was similar to the real network with a maximum of 5% error. This was calculated by comparing the virtual results (regarding costs, time delivery, etc.) for the base (AS-IS) scenario obtained via the simulation with the real results obtained from Alpina. For example, the simulation resulted in an average of 347 pairs of shoes produced per day whereas in reality the average number of pairs produced per day is equal to 350. The simulation result for a product cycle time is 104.25 min compared to 105.62 as real value. The model was also validated by Alpina.

During this case study, the hardest task was data collection. A data collection methodology and templates were developed. However, the data were not always available, or it was not clear where to get these data from. Moreover, sometimes data were provided but were different from what was needed. Also, the data format had to be changed many times to include it in the database.

Once the data were collected and treated, the model was easily created. No specific simulation skills were required. The user had only to place the different modules in the interface and set its parameters. However, this task requires some time due to the large number of objects and their parameters. The automatic model creation from the database is a planned development. In addition, the different alternatives were also easily created. It only required small modifications in the objects' parameters since no partners nor were activities added.

## 6. Conclusion

In this article, a framework for value network modelling and simulation has been proposed as a support for strategic decision-making. The proposed approach enriches the SimulValor language. Moreover, a value network library was developed in the discrete simulation software Arena of Rockwell Automation. The proposition was validated by a case study in the footwear industry. Future work would be to include the analysis of risks to the evaluation of the performance of a value network, as well as automating the simulation model creation from a database. In addition, problems related to data sharing between partners need to be addressed to assure the collection of all needed data for the modelling, simulation and analysis of the value network.

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### Note

1. http://www.alpina.si/en/alpina/

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