

MODELLING AND SIMULATING PROCESS-ORIENTED KNOWLEDGE MANAGEMENT

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Abstract

This paper presents a formal approach to modelling knowledge related processes and describes the simulation environment that has been developed to dynamically simulate KM activities. The conceptual framework behind the model can be used to model many types of companies. Simulating those models becomes very valuable when one wants to investigate different knowledge management scenarios.

Key words: process-oriented knowledge management, knowledge management business model, simulations, case study.

1. Introduction

Many researchers have made substantial contributions to the field of knowledge management (KM) since the 1990s. Research focused on topics like: what is knowledge and knowledge management (e.g., Wiig, 1995; Davenport and Prusak, 1997); the inevitability and necessity of KM for a firm's survival in the knowledge era (Boisot, 1999); the search for better KM strategies and tools facilitating KM (Tiwana, 2000), and measurement of intangible assets and their impact (Sveiby, 1995; Edvinsson and Malone, 1997). However, a formal approach to evaluate efficiency and effectiveness of knowledge related processes or knowledge "flows" is underrepresented.

This paper presents an approach to create a formal and executable model of a company that includes business processes, knowledge processes and the relationships between these processes. The availability of an executable model that includes the flows and stocks of knowledge in a quantifiable way presents a promising opportunity for researching the impact of knowledge management and is possibly a significant step towards establishing knowledge management as a scientific discipline.

Formalising knowledge management relevant business models requires the following: a) a generic way to model a business, its knowledge processes, and the relations between them (Section 2); b) a specification of how knowledge management interventions and events affect the knowledge household (Section 2.3); and c) a simulation environment in which the models can be executed (Section 3).

The modelling approach is being tested in the KM Quest knowledge management game. This case study (Section 4) consists of creating a model for a fictitious chemical company, defining a set of events that influence this company, and a set of knowledge management interventions, which can be selected by KM Quest players to improve the performance of the company.

2. Conceptual model

2.1 Modelling assumptions

Models are always designed for specific purposes. When modelling a system assumptions are made, which usually take the form of mathematical or logical relationships. Together these relationships constitute the model that can be used to gain some understanding of how the corresponding system behaves (Banks, 1998).

The goal of the described conceptual model is to support understanding of the importance of knowledge and KM activities for a company, by exhibiting strong relationships between knowledge properties, knowledge processes and organisational outcomes. To realise this goal the following principal assumptions were made:

- Knowledge is a quantifiable object that can be measured using relative scales.
- Performance of any business unit depends on the level of knowledge and the level of knowledge usage or utilisation. (Consequently, the business results also depend on the level of knowledge.) The ideal situation for a company is to have highly knowledgeable employees and an effective organisation of work processes, i.e. effective application of knowledge.
- Knowledge naturally depreciates due to ageing and volatility. If there is no increase and renewal of knowledge in a company, the performance declines over time.
- Changes from outside or inside a company influence both the individual knowledge as well as organisational knowledge.

2.2 Core of the model

In the model, the level of knowledge (knowledge “stock”) is introduced as the level of competence in a certain knowledge domain. The level of knowledge utilisation is introduced as the efficiency of the process comprising of the effectiveness and speed of the process. Several knowledge “flows” contribute to the level of competence. Basically knowledge “flows” contribute to the level of knowledge, which together with the level of knowledge usage influence business processes, and determine the performance of the company. Thus, our modelling approach resulted in a four-level model (Fig. 1) consisting of:

1. **Organisational effectiveness variables.** These variables represent the relation between the organisation and its environment. They reflect the competitive characteristics of the company and are introduced by variables like profit or level of sales.
2. **Business process variables.** These variables reflect the quality of internal processes – the ways things are done and how well they are done inside the company. An example is the production level.
3. **Knowledge variables.** They represent the levels of knowledge in relevant knowledge domains (e.g. marketing or production) and the quality of applying knowledge for each domain. An example is the level of competence.
4. **Knowledge process variables.** Reflect the properties of processes involving knowledge in the organisation. An example is the efficiency of knowledge transfer.

It is important that the knowledge process variables exhibit decay behaviour. Propagation of values from knowledge processes (via knowledge and business process variables) to organisational effectiveness variables makes the overall performance of the company deteriorate over time as well.

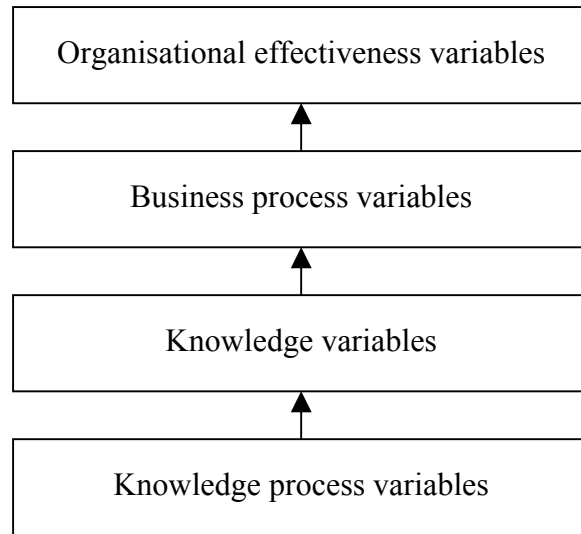


Figure 1. The core of the conceptual model

Any company and any business unit can be modelled in this way. The differences between several models or customisation of this model for different organisations lie in issues like: what kind of knowledge processes and business processes to model? These issues are discussed in the following section.

2.3 Knowledge management relevant business model

2.3.1 Knowledge domains

Since it is not feasible to create a model that covers every organisation, a decision has to be made concerning the type of organisation. These decisions drive the modelling work. As the starting point for creating a KM relevant business model we took the classification proposed by Treacy and Wiersema (1995). This classification, though not ideal, gives criteria by which organisations can be defined at an abstraction level. They distinguish three main strategic views on a company, which can be used to identify core areas for knowledge management:

- *Operational excellence*: a company competes mainly in terms of costs. It tries to streamline processes in such a way that, while keeping the required quality, the costs of operating are minimised.
- *Product leadership*: a company competes by rapidly bringing innovative products to the market. This implies short product life cycles and innovative research and development.
- *Customer intimacy*: a company competes by trying to become a partner with a limited number of other companies by providing customised solutions.

A possible definition of knowledge domains for those types of companies and examples of business process variables can be found in Table 1. More precisely knowledge domains can be defined on several organisational levels by using basic knowledge analysis, knowledge mapping or other techniques (Wiig, 1995).

Table 1. Examples of knowledge domains and business processes variables

Type of the company	Knowledge domains	Examples of variables
Operational excellence	<ul style="list-style-type: none"> • Manufacturing • Logistics • Suppliers and purchasers • Research and development 	<ul style="list-style-type: none"> • Equipment downtime • Operational costs • Time of production cycle
Product leadership	<ul style="list-style-type: none"> • Marketing • Research and development • Manufacturing 	<ul style="list-style-type: none"> • Time of bringing a new product to market • Number of new patents
Customer intimacy	<ul style="list-style-type: none"> • Marketing • Services • Customer relation 	<ul style="list-style-type: none"> • Number of contacts with the customers • Number of services • Number of new customers

This step gives information about knowledge stocks that can be modelled. There are many examples of how knowledge stocks can be measured and evaluated (Edvinsson and Malone, 1997; Sveiby, 1995). Those measures reflect knowledge areas by presenting results of knowledge usage (e.g. number of patents) or personal properties (e.g. years in the profession, educational degree, etc.). Such measures do a better job at approximating gains emerging from effective handling of knowledge, but they still underestimate the actual gain as they measure “knowledge stock” and not “knowledge flows” (Tiwana, 2000).

2.3.2 Knowledge processes

The next modelling step is to define relevant processes involving knowledge and to model those processes. We focus on the processes which we consider the most important for process oriented KM. Those processes have been frequently pointed out in the literature:

- **Knowledge gaining.** The process of getting new knowledge that is relevant for the company from the outside world.
- **Knowledge development.** The process of disseminating and enriching individual and organisational knowledge inside a company.
- **Knowledge utilisation.** The process of applying knowledge to the job performance.
- **Knowledge transfer.** The process of passing on specific knowledge to other business process areas or making it available for further use in other business process areas.
- **Knowledge retention.** The process of preserving knowledge that is relevant for the company.

Modelling how knowledge processes impacts on organisational performance, we are supported by Tiwana (2000): “Successful companies develop knowledge velocity, which helps them overcome knowledge sluggishness, to apply what they learn to critical processes at a faster rate than their competitors. Underlying this concept is the integration of a company’s knowledge processes with its business processes to substantially enhance business process performance”.

Hence, in the model, the description of the knowledge process consists of speed, effectiveness, and efficiency characteristics:

- **Speed** of a knowledge process is determined by the time that is needed for the knowledge process. Speed is a relative notion, that in our view, refers to the ability to do things faster or slower;
- **Effectiveness** of a knowledge process shows the knowledge process results; and
- **Efficiency** introduces the ratio of the results of the process to the time related to the specific process.

How are the knowledge processes linked to the organisational outcomes? The *level of competence* in a specific knowledge domain is influenced by the variables of knowledge gaining, knowledge development and knowledge retention. *Speed* and *effectiveness* of knowledge utilisation, *efficiency* of knowledge transfer from related domains and *level of job satisfaction* index influence *efficiency* of knowledge utilisation.

Level of competence and efficiency of knowledge utilisation contribute to the business process variables. Performance in one domain influences other domains on the business process level. Organisational performance depends on the outcomes of each domain. For example, a “product leadership” organisation with the knowledge domains Marketing, Manufacturing and R&D, the *level of sales* is the minimum of the *production level*, the *level of sales determined by marketing*, and the *level of sales determined by R&D*.

Knowledge domains are related to each other on the business process level and by knowledge transfer between relevant domains. Fig. 2 shows the relationships between knowledge processes in a business unit and organisational performance.

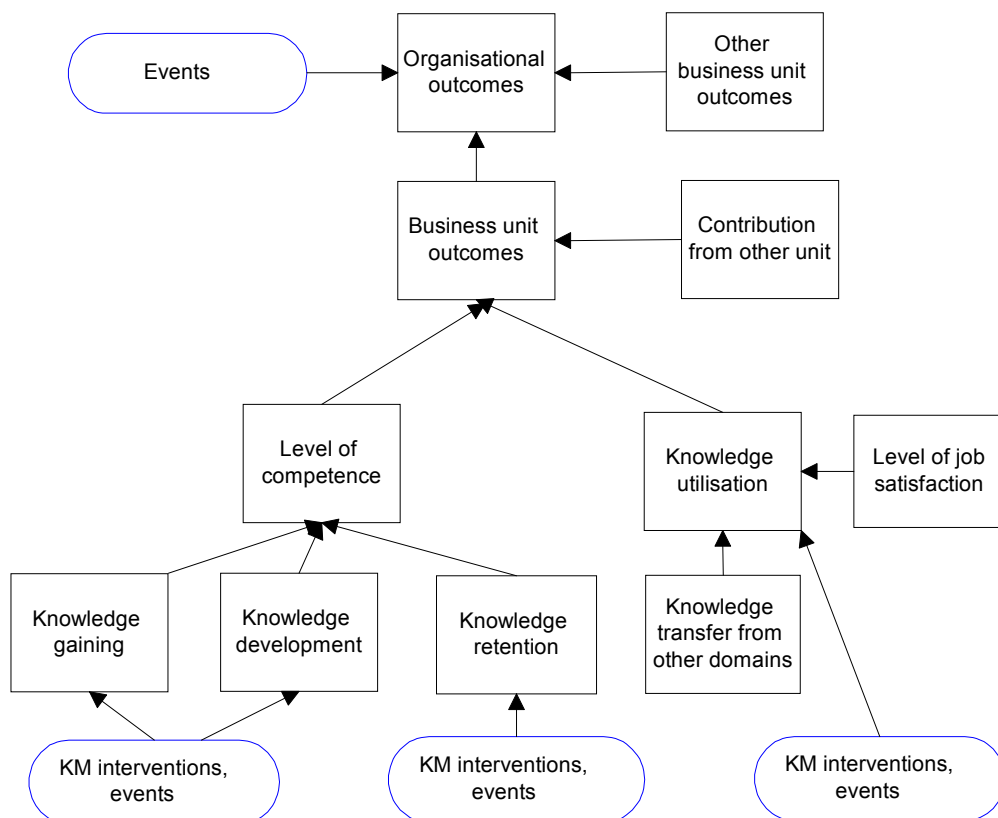


Figure 2. Influence relationships between KM interventions / events, knowledge processes and organisational outcomes.

2.3.3 Interventions and events

The properties of knowledge processes can be influenced by KM interventions - interventions that affect both human and other knowledge sources. Besides, external events can have an influence on the organisational performance by changing economical, political, and labour conditions. Consequently, those influences also need to be modelled.

In our model, specifications of influences are given as:

- Influence on variables reflecting one or more knowledge domains, one or more knowledge processes. We model influences on market share and level of job satisfaction;
- Immediate or delayed influence;
- Single or multiple influence (negative or positive);
- Magnitude of the influence.

It is clear that events in general cannot be modelled in advance. They have to be predicted or they have to be analysed when they occur. The most important part of this analysis, which is valid for the interventions as well, is to model or specify influences of the event/intervention on the company. In many cases concerning qualitative changes, managers do this job intuitively. Establishing a measurement system in which knowledge and knowledge flows are measured on a relative scale can help to model those influences. For example, there are training programs, which differ in efficiency. Influences of those programs can be measured according to their efficiency on a scale of 0 to 1. Implementation of one training programme will increase knowledge development on 0.7 on the relative scale, while another programme influences the knowledge development only by 0.5 points. Costs associated with those programs are measured on absolute scales.

3. Simulation environment

Simulation environments are ideal tools to observe and validate theoretical models. In a simulation environment one can study the behaviour of a model under various conditions and adjust details of the model if necessary. This section briefly describes KMsim, an environment that supports simulating KM relevant business models. Screen shots of some of the tools can also be found in the Section 4.

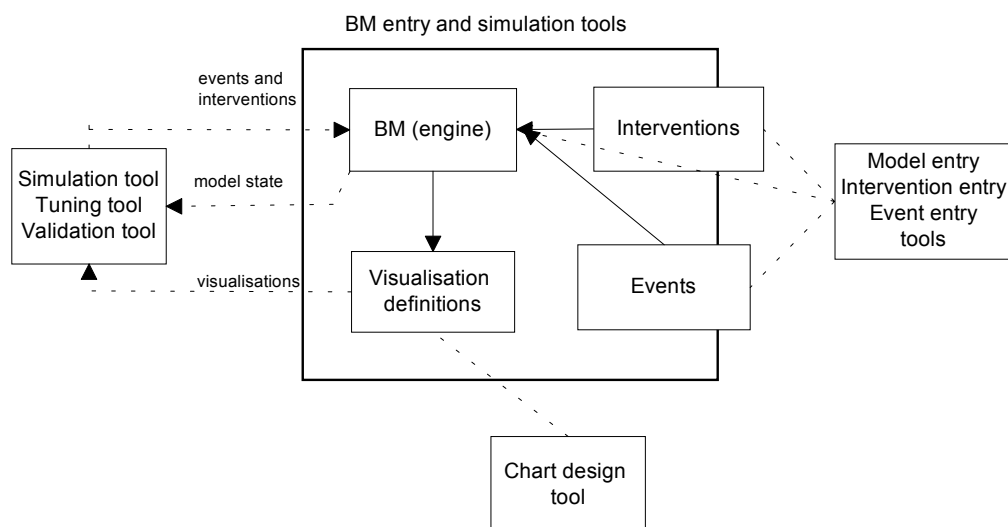


Figure 3. Tools in KMsim

Fig. 3 shows the tools part of the KMsim environment and how they relate to each other. The environment provides the modeller with the following functionalities:

- Creating and editing business models (BM) through easy-to-use dialogue boxes.
- Defining the impact of interventions and events on the BM.
- Simulating the behaviour of the BM. This comprises “running” the model using a simulation engine.
- Validating and tuning. The tuning tool randomly generates events and interventions and checks whether user defined assertions are met.

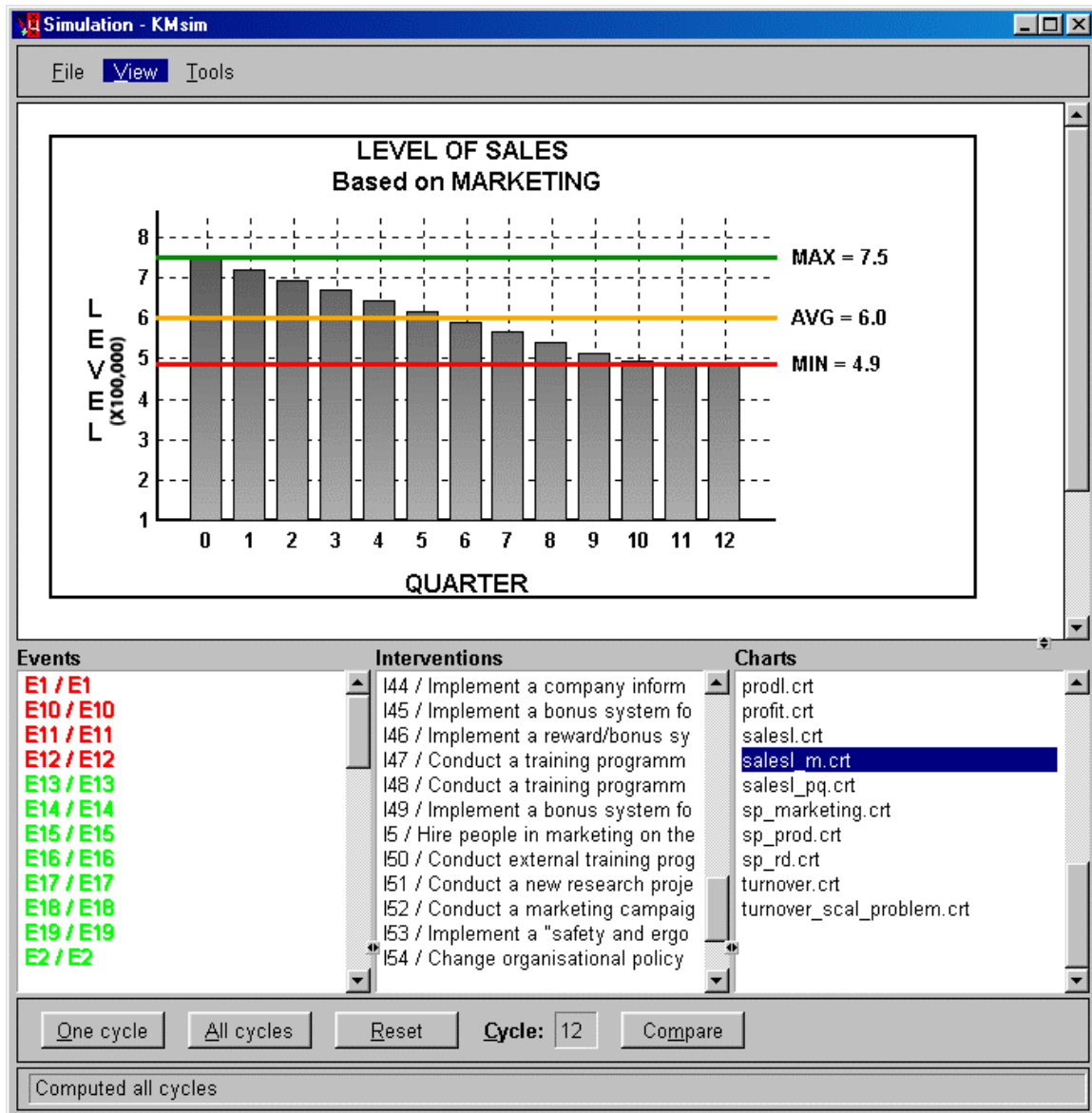


Figure 4. Interactive simulation tool

Creating a BM consists of instantiating the notions in the theoretical framework for a particular company (see also the case description in section 4). In practice this entails: (1) determining the appropriate organisational effectiveness and business process variables; and (2) determining the knowledge (process) variables and linking them to the business variables. This is supported by a *model entry tool*. The model entry tool is a dedicated dialog box in which the attributes of the variables can be entered and edited. A screen shot of the model entry tool is provided in the section below. (see Fig. 5). An underlying BM engine translates

the specifications (including decay, influence, etc.) to a mathematical model that is used in the simulation.

The *intervention* and *event entry tools* allow interventions and events to be defined. Here the user specifies the impact of an intervention or event on variables part of the BM.

The three entry tools suffice to create realistic models according to the theoretical model. In addition we have developed tools for visualising, validating and tuning BMs. Fig. 4 shows a screen shot of the interactive simulation tool. The user can activate and deactivate interventions and events using the browsers at the bottom and visualise the impact on variables in the BM using charts defined by a *chart design tool*. In the KM Quest game a BM server makes it possible to simulate BMs over the internet.

An important design principle underlying KMsim is that no programming skills are necessary to enter a model. This makes it possible for the designer of a model to enter it directly.

More details about the KMsim environment and the architecture can be found elsewhere (Anjewierden et al., 2002).

4. Case study: The KM Quest knowledge management business model

The model described above was implemented as a knowledge management business model in the KM Quest game. KM Quest is a learning environment that promotes learning of normative KM and acquisition of strategic KM knowledge. One of the main goals of the learning environment is to enable players to perform KM methodologically in their own setting and to find solutions for any kind of KM problem. Since knowledge management is not a goal in itself, any knowledge management effort should be linked to objectives that are relevant to the organisation. The KM Quest knowledge management business model is designed to represent the organisation and its environment. In the KM Quest game teams of players have to manage a fictitious chemical company called Coltec and collaboratively solve KM problems within that organisation.

Coltec attempts to be a product leadership company, and is characterised by innovative R&D, short product life cycles and bringing innovative products to the market quickly. Taking into account the characteristics of product leadership companies, the three knowledge domains for Coltec are: marketing and sales, research and development, and production. Making knowledge domains more specific would significantly increase game complexity and shift our efforts from the intended modelling of process-oriented KM towards content-oriented KM. External and internal changes which are presented in the game as events, bring into the game additional challenges. Players have to manage knowledge in the company by invoking available KM interventions from a predetermined set in order to react or respond to events.

Therefore, the KM Quest knowledge management business model is designed to simulate a product leadership organisation over three years (12 game periods/company quarters). The complete Coltec model comprises:

- 1) Case description;
- 2) Business model: set of variables with behavioural and functional characteristics;
- 3) External and internal events; and
- 4) KM interventions.

4.1 Case description

The case description provides players with general information about the company. It was taken from the so-called Coltec-case (De Hoog et al., 1999). Information about the company includes history and mission, structure of the company, products, main financial figures and information about personnel.

4.2 Business model

To design the business model we used the conceptual framework discussed in Section 2.1. The final model consists of:

- Case variables to set up the initial state of the model.
- Input variables (36) to calculate influence of KM interventions or events.
- Constants to calculate new values or increments.
- State variables:
 - Knowledge process variables (39). These variables formalise knowledge gaining, development, utilisation, retention, and transfer for the three domains and three dimensions: speed, effectiveness and efficiency of knowledge processes.
 - Three knowledge variables that formalise level of competences in each domain.
 - Business process variables. These variables characterise the quality of business processes. Some are visible to the players, others are hidden.
- Output variables. These variables mainly include financial figures of the company including statistics, information about personnel, market share and customer satisfaction index. All of them are visible for the players.

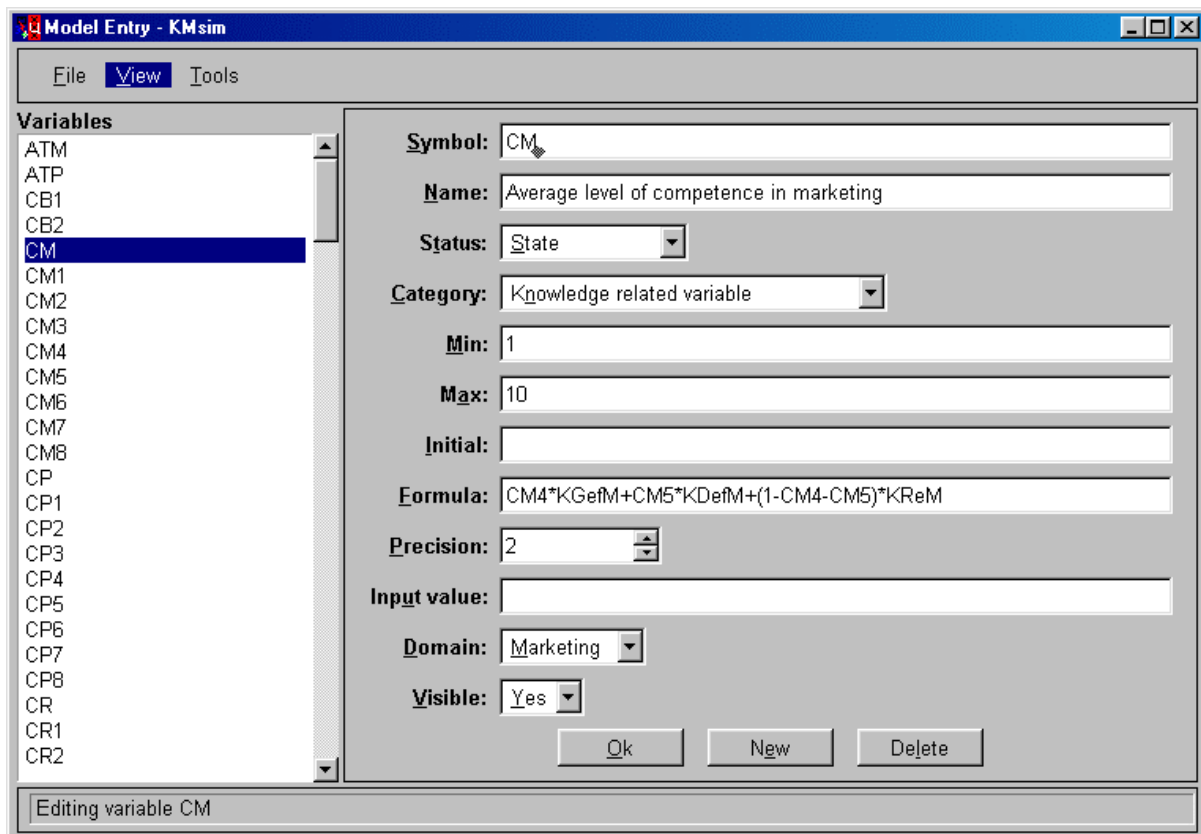


Figure 5. Business model entry tool

Each variable has several attributes which can be specified in the model entry tool (Fig. 5). Several attributes are predefined by the conceptual model (status of the variable: input, state, output, constant), category, and knowledge domain and can be selected by the user. The most

important attribute is a formula which explicitly specifies computation of the variable and implicitly defines an influence relationship with other variables. An example of influence between variables is the formula for competence in marketing:

$CM = KG + KD + KR$. The level of competence depends on knowledge gain (KG), knowledge development (KD) and knowledge retention (KR).

One of the important aspects of simulating the BM is the notion of time. This is modelled in discrete periods (quarters, months), which are called cycles in the tool.

As explained in section 2 the decay behaviour of the knowledge processes is fundamental to our modelling approach. Decay functions can fall into several classes:

- Linear decay: the decrement is the same for each cycle
- Concave decay: the decrement is small at first, and increases for later cycles
- Convex decay: the decrement is large at first, but becomes smaller over later cycles

Since the nature of knowledge depreciation has been not investigated by us, we kept the model simple by using the linear decay functions for all knowledge process variables with different magnitudes of the decrements.

For example, the decay function for speed of knowledge development is $KDs = KDs - D$, where D is a constant.

The knowledge process variables are scaled between 1 and 10. This is specified in the minimum and maximum attributes of a variable. Market share naturally lies between 0 and 100%. Formulae may contain all common mathematical, conditional, comparison and logical operators.

4.3 External and internal events

Coltec faces external challenges and a wide variety of events can influence its knowledge properties. Events can have a negative impact on the company, they can be irrelevant or they can present an opportunity. In KMsim the following attributes of events can be specified:

- Enabling and disabling conditions (only for gaming purposes)
- Variables which are affected by the event
- Type of the influence for each affected variable: delayed or immediate influence
- Magnitude and frequency of influence for each affected variable

In practice, event specifications cannot be defined in advance because of the unpredictable nature of events. Some events that are expected can be entered into the system in advance, but more often, a knowledge manager should specify the effect of events according to the measurement system of a company.

For the game we specified 50 events, from which the game engine selects one at random at the beginning of each quarter. The enabling conditions can take into account interventions implemented in a previous quarter or on threshold values of variables.

4.4 Knowledge management interventions

The set of 56 KM interventions was determined from a literature survey and covers many KM initiatives. The interventions that involve human knowledge agents and other knowledge sources can be classified as: organisational, training, rewarding, ICT, and co-operational interventions. Organisational interventions aim at improving work conditions and policies, training interventions reflect many training programmes, rewarding interventions aim at improving labour employment facilities, and co-operational interventions assume contracts

with external organisations for different business purposes, ICT interventions deal with the organisation of information and communication. In KMsim interventions are specified as follows:

- Frequency of implementation. This option is created for gaming purposes and states the maximum number of times that an intervention can be implemented during the simulation period. Some interventions, for example training programmes, can be implemented every period, other interventions can only be usefully implemented once, for example “Implement a back-up system” or “Change organisational policy towards self-managing teams”.
- Variables which are affected by the intervention
- Immediate or delayed influence on each of the affected variables
- Magnitude of the influence

Fig. 6 shows the specification of the intervention “Conduct external training programme in marketing and sales”. It can be implemented during each period. The intervention influences immediate knowledge development and with the one-period delay knowledge utilisation processes. The influences are specified as one time influences ranging from 0 to 1.

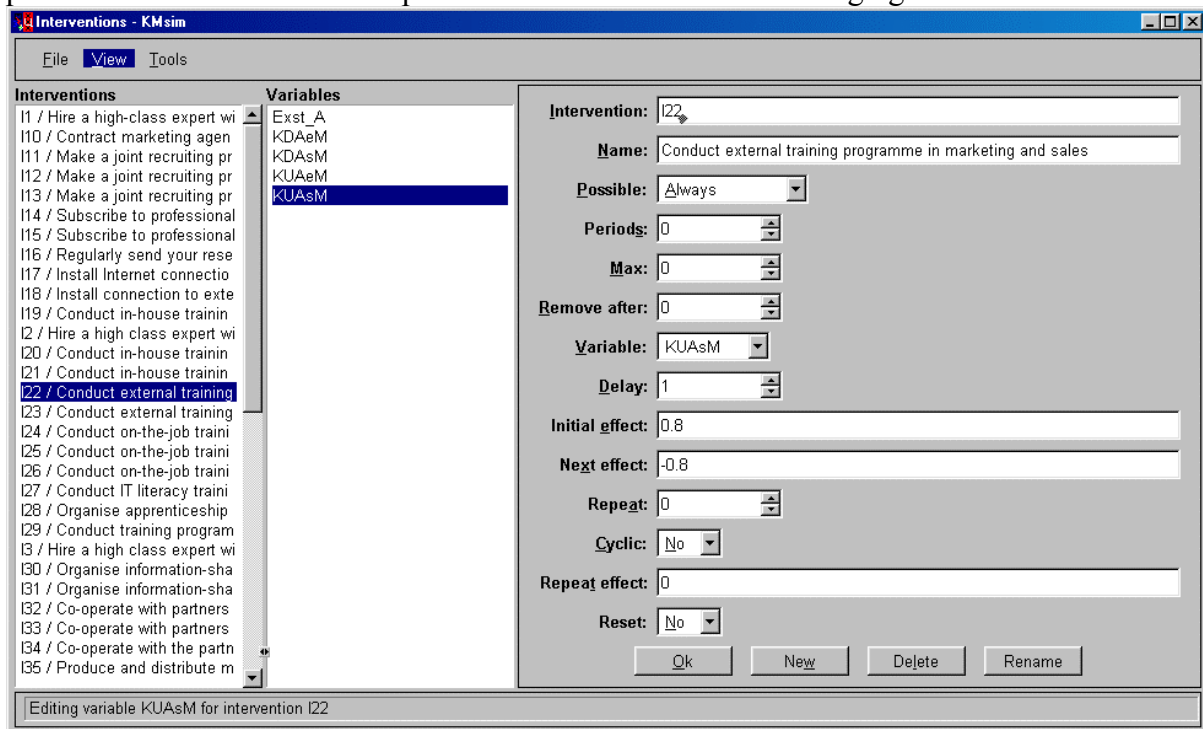


Figure 6. Intervention entry tool

Figure 7 shows the immediate influence of the intervention “Conduct external training programme in Marketing and sales” on affected variables. The relative influence is indicated by the symbols ▲ (positive influence), ▼ (negative influence) ● (neutral influence).

It is clear that the intervention has immediate influence on the variables of the knowledge development process. This influence propagates to *Level of competence (CM)* and *Level of sales based on marketing (SalesL_M)*. Profit drops because of the costs for additional training expenses. This representation is provided only for immediate influences. In addition, this intervention has a delayed one-period influence on variables of knowledge utilisation process, which consequently influence *Level of sales based on marketing. Level of sales (SalesL)*,

Turnover and some other variables depend primarily on the results of performances in all units; therefore, the influence of intervention on these variables is not shown.

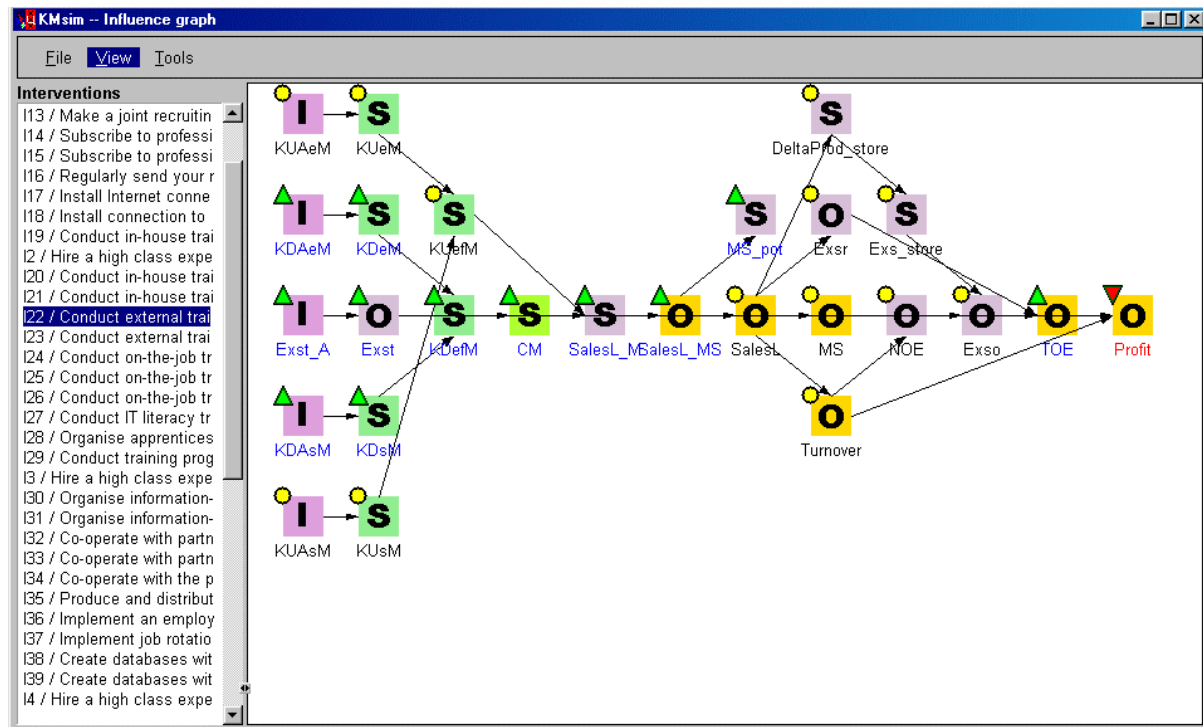


Figure 7. Influence graph of the variables affected by an intervention

4.5 Examples of games

We created two games to illustrate that 1) organisational outcomes as well as unit outcomes depend on knowledge processes, and 2) organisational performance depends on the level of knowledge in all units of a company. Both games take 5 game periods and contain the same random sequence of events. The number of KM interventions varies between 2 and 6 for each period.

The objective in the first game was to skip interventions for knowledge development (training interventions) and knowledge gaining in *Production*, but implement interventions related to training, organisation, co-operating and rewarding in *R&D* and in *Marketing*.

In the second game, we used the same events and most of the interventions from the first game, but skipped knowledge development and knowledge gaining interventions for *Marketing* and *Production*. The simulation results are given in Tables 2 and 3.

The results are discussed on the basis of an analysis of the most important indicators:

- Level of competence in all domains (CM, CR, CP) as the sum of the variables of knowledge development, knowledge gaining and knowledge retention processes;
- Efficiency of knowledge utilisation in all knowledge domains (KUefM, KUefR, KUefP) as a combination of knowledge utilisation itself, knowledge transfer processes and the level of employee satisfaction;
- Level of sales (Sales_L) as the result of work efficiency in *Marketing* (SalesL_M), *R&D* (SalesL_PQI), and *Production* (ProdL);
- Market share (MS), Profit (Profit), and the customer satisfaction index (CSI).

Table 2. Indicators for the first game

Game period Variable	Initial state	1 quarter	2 quarter	3 quarter	4 quarter	5 quarter
CM	7.45	6.82	7.51	8.30	8.86	8.85
CP	7.34	6.84	6.99	7.07	7.19	7.06
CR	7.62	7.21	8.08	8.39	9.07	8.84
KUefM	7.01	6.56	7.05	7.83	8.48	8.44
KUefP	7.38	6.95	7.16	6.96	8.01	7.71
KUefR	7.52	7.00	7.63	8.01	8.13	7.72
SalesL	750000	724177	778420	784283	839108	815248
SalesL_M	750000	724177	778420	848512	905810	916623
SalesL_PQI	770000	724741	801112	834671	879835	850324
ProdL	780000	753281	781114	784283	839108	815248
CSI	7.0	6.6	7.3	7.6	7.0	6.7
Profit	10000000	10822659	10066298	11160245	11205122	10870227
MS	27.0	26.1	28.0	28.2	30.2	29.3

In game 1, during the last three periods Level of competence in *Production* (CP) and Level of Knowledge utilisation in *Production* (KUefP) are low compared to the same indicators in other domains. The efficiency of the business processes is highest in *Marketing* (SalesL_M = 916623), because the Level of competence (CM=8.85) and level of knowledge utilisation (KUefM = 8.44) in this domain are high. Level of sales is limited by the Production level (ProdL=815248). Therefore, players have to improve Level of competence in *Production* and level of knowledge utilisation in *Production* by selecting relevant interventions.

In game 2, we skipped interventions aim at improving Level of competence and Level of knowledge utilisation in *Marketing*. Now, the organisational results, Level of sales and Profit, are limited by performance in *Marketing*, which has the lowest level of competence and the lowest level of knowledge utilisation. Market share is lower in the second game (amount of units sold is lower), although customer satisfaction is higher. Explanation of this phenomenon lies in the fact that the market demand in the first case was higher than the supply and customers were dissatisfied because of unavailability of goods.

In this game players primarily have to pay more attention to knowledge improvements in *Marketing* and, secondly, *Production*.

For both games it is clear that the model exhibits decay behaviour. This feature can be observed by comparing the indicators for initial state and after the first game period. Consequently doing nothing will result in the decline of the overall performance of the company. The level of knowledge and efficiency of knowledge processes are affected by the knowledge management interventions. In the third period a few interventions aiming at knowledge gaining (hiring experts, connection to professional networks) improve Level of competence in all domains. Comparing both examples, one can observe that implementing interventions for one knowledge domain is not a comprehensive solution and the knowledge manager simultaneously has to deal with all knowledge domains of the company.

Thus, the model exhibits the following:

- Organisational results depends on the performance in all areas of a company;

- Organisational and unit results depends on level of knowledge and efficiency of knowledge processes;
- Level of knowledge depends on knowledge management interventions.

Table 3. Indicators for the second game

Game period Variable	Initial state	1 quarter	2 quarter	3 quarter	4 quarter	5 quarter
CM	7.45	6.82	6.70	6.83	6.71	6.46
CP	7.34	6.84	6.99	7.07	7.19	7.06
CR	7.62	7.21	8.08	8.39	9.07	8.84
KUefM	7.01	6.56	6.75	6.57	7.30	7.35
KUefP	7.38	6.95	7.16	6.96	7.85	7.37
KUefR	7.52	7.00	7.63	8.01	8.01	7.47
SalesL	750000	724177	741127	750232	790061	797870
SalesL_M	750000	724177	741127	750232	790061	797870
SalesL_PQI	770000	724741	801112	834671	875087	840234
ProdL	780000	753281	781114	784283	830647	809425
CSI	7.0	6.6	7.3	7.6	8.0	7.6
Profit	10000000	10822659	9366181	10595453	10299701	10641553
MS	27.0	26.1	28.0	28.2	30.2	29.3

5. Conclusion and discussion

We have presented a formal approach to modelling knowledge related processes and outlined an environment in which such models can be simulated. Given that the underlying research is the first attempt to formalise process-oriented knowledge management, it would be premature to draw far-reaching conclusions. In contrast to many other knowledge management studies, our formalisation has the advantage that the effects of knowledge management can be measured. The developed simulation environment enables to find pertinent errors in models as well as confirming that reality matches the behaviour of a model.

We see many opportunities for further work. The next important step is to evaluate the plausibility and validity of the model. Ideally, the evaluation would confirm our hypothesis that knowledge related variables and knowledge management interventions are relevant both for learning knowledge management and for usage in companies. Another line of research is to define and experiment with additional models for other (types of) organisations.

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