KNOWLEDGE MANAGEMENT AND SIMULATION PROJECTS: A LITERATURE ANALYSIS

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ABSTRACT

The objective of this article is to analyze the relationship between Knowledge Management (KM) and computational simulation research. In spite of being separated in the literature, the two topics present a range of similar activities, such as collecting system knowledge and leveraging it in order to bring about improvements. In such a context, this work seeks to describe the relation between KM and computational simulation through an analysis of various academic research papers that have taken a look at the subject of combined applications.

KEYWORDS. Simulation, Knowledge Management, Soft Systems Methodology

Main Area: Simulation

1. Introduction

Computational simulation has been recognized as a useful tool in the study of complex process and system behavior within the area of Operational Research (OR). While other OR applications, such as linear and non-linear programming, serve in the modeling of many static problems, computational simulation brings the advantage of incorporation of randomness and interdependency within its models, thus considering the system's variation throughout time (BANKS *et al*., 2009).

Many authors in the literature claim that during simulation research, both the modelers and the simulation clients gain a greater understanding of the system under study and simulation itself (ADAMIDES and KARACAPILIDIS, 2006; ROBINSON, 2008; SARGENT, 2010). Such knowledge is valuable for project development and can be represented in the form of conceptual models, decision rules, time study data, relevant statistics, costing information, etc.

However, the knowledge acquired throughout the simulation is normally hidden between layers of programming within simulation software or remains in the minds of the modelers and the simulation clients. In turn, valuable information and details about the system and the model's programming are lost at the end of the project

(DUNGAN, *et al*., 2010; NEUMANN, 2007). Instead of wasting this knowledge upon the termination of each simulation project, which was obtained through the modelers and clients' hard work and effort, methods to retain such knowledge should be developed in order to guide future simulation research about the system while offering valuable information to the decision-makers (ZHANG, CREIGHTON and NAHAVANDI, 2008). Furthermore, there also remains the question of knowledge acquisition in order to understand the initial problem situation and define the study's objectives in its preliminary phases (KOTIADIS, 2007; ROBINSON, 2008).

Nevertheless few papers have proposed techniques which facilitate the acquisition, storage and leveraging of the knowledge generated during simulation research (HLUPIC, VERBRAECK and VREEDE, 2002; HOLLOCKS, 2004; KOTIADIS, 2007; LUBAN and HÎNCU, 2008; ZHANG, CREIGHTON and NAHAVANDI, 2008).

As such, knowledge management (KM) presents itself as a promising supporting technique for simulation projects. KM focuses on the collection, storage, maintenance, delivery and creation of knowledge for its competitive use within organizations (DAVENPORT and PRUSAK, 1998).

Yet on the other hand, simulation also may provide support for KM, such as in the cases of the simulation of KM strategies, information and knowledge flow analysis and organizational learning (EDWARDS, *et al*., 2004).

The authors Hlupic, Verbraeck and Vreede (2002) assert that while simulation and KM seem to be separated in the literature, the two subjects are inseparable in practice. To give a basic idea of the scarcity of papers regarding the relation of the two topics KM and simulation, a search was conducted by the paper's authors on April 28, 2011. The terms "Knowledge Management" and "Simulation" were sought for in the title, abstract and keywords from 2001 to present day within the data bases Science Direct and Emerald, both of which are fundamental in the area of industrial engineering and OR literature. 27 and 9 articles were found, respectively. It suffices to say that the combined application of these topics is a little-explored topic.

In this context, this article seeks to analyze the interdependencies and synergies between computational simulation and KM. In the second part of this paper, fundamental definitions of the two subjects will be presented. In the third part, the possible relations between KM and computational simulation will be discussed, based on a revision of relevant articles. Following this, some possibilities for future research will be pointed out and final conclusions will be offered.

2. Simulation and Knowledge Management

The interest in simulation as a tool in aiding decision making in sectors such as manufacturing, military operations and logistics has grown over the past decades (PIDD and ROBINSON, 2007).

In its broadest sense, computational simulation can be defined as the imitation of a system in a computer (ROBINSON, 2004). Banks *et al*. (2009) corroborates with this vision and asserts that, aside from imitating a system, simulation involves the generation of an artificial history and its observation in order to make inferences in respect to the operational characteristics of the system.

Chwif and Medina (2010) cite that the strongest aspect of simulation is its ability to respond to the question, "What would happen if…". Scenarios may be constructed to evaluate the effects of certain changes to decision variables over the system's behavior as a whole. Or rather, starting from a valid model of the real world (SARGENT, 2010), the modeler is able to conduct experiments in the computational system in order to make inferences about the real system without incurring additional costs or interrupting the system's functioning. The results generated offer a base from which clients can conduct analyses and in turn make more well-informed and knowledgeable decisions.

Figure 1 shows a flowchart adapted from Montevechi *et al*. (2010), in which the proposed steps for a simulation project are presented. In this diagram, the three phases which represent the stages of a simulation project are shown: conception, implementation and analysis.

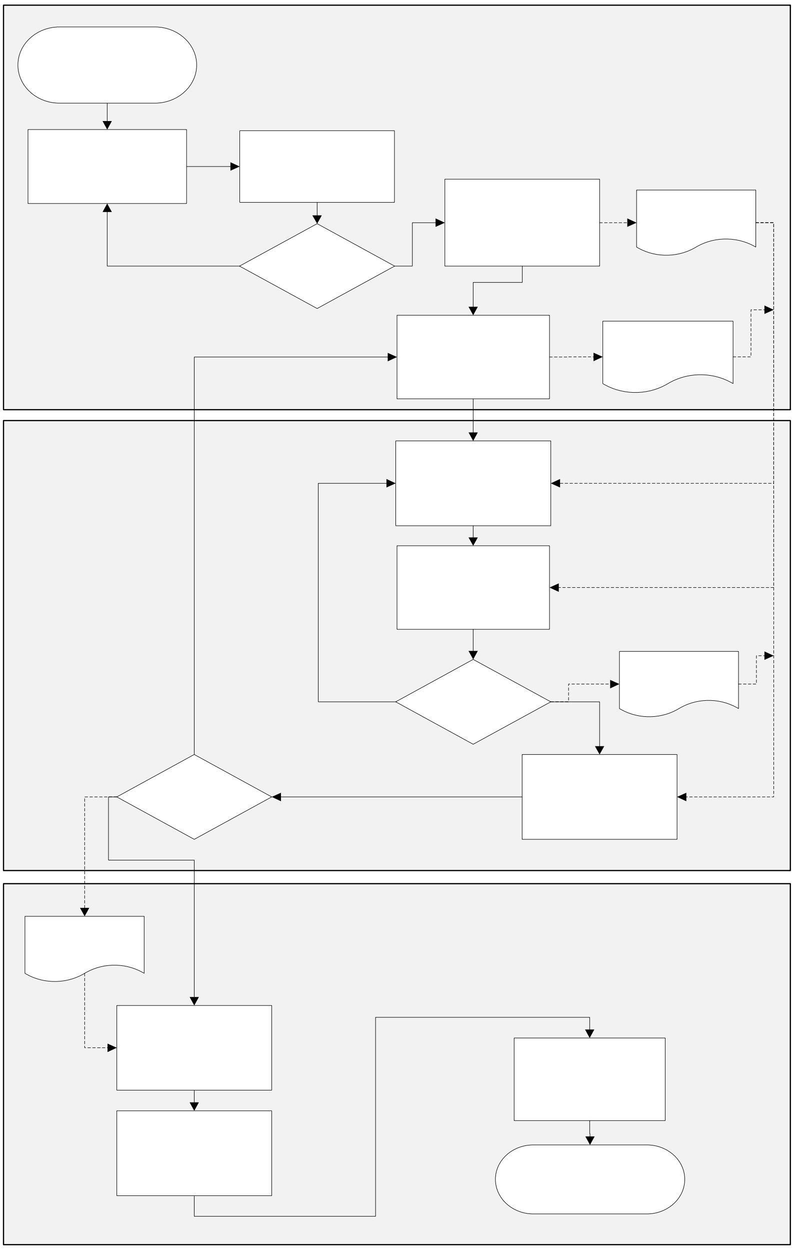

Fig. 1 – A flowchart of the three steps of a simulation study. Source: Montevechi *et al*., 2010.

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Certainly a simulation model presents itself as a useful tool in gathering specialized knowledge about dynamic system behavior. Many authors assert that simulation research involves the capture of data and information crucial to the model development, use and (at times) the reuse (ADAMIDES and KARACAPILIDIS, 2006; HLUPIC, VERBRAECK and VREEDE, 2002; HOLLOCKS, 2004; KOTIADIS, 2007; LUBAN and HÎNCU, 2008; NEUMANN, 2007; ZHANG, CREIGHTON and NAHAVANDI, 2008).

Aside from the necessary efforts to identify and collect data, modelers must establish a clear understanding of the system as a whole as well as the modeling objectives (ROBINSON, 2008; KOTIADIS, 2007) so that the model captures the most relevant problem and leads the decision-makers to the best decision.

The role of knowledge is central to simulation studies. According to Davenport and Prusak (1998), knowledge derives from information in the same way that information derives from data; or rather, from data, information is obtained through contextualization. For example, an isolated series of data will not make sense without knowing if it shows production figures, accounting numbers or sales forecasts.

However, the same authors assert that knowledge needs more than just contextual information, but also condensed experience, values and insight. Knowledge is usually engrained not only in documents and repositories, but also in routines, processes and organizational norms.

Therefore, in respect to organizational processes and routine improvements, a parallel can be established between KM (BEIJERSE, 1999; GUPTA, SHARMA e HSU, 2004) and simulation (ROBINSON, 2004; KUMAR e PHROMATTHED, 2006).

Although many definitions exist in the literature in respect to KM, the general consensus is that KM deals with the explicit managing of vital knowledge and processes which aid in the creation, collection, organization, dissemination, use and exploitation of knowledge. It is related to the leveraging of individual knowledge so that it becomes available as an organizational resource (ANAND and SINGH, 2011).

As such, managing knowledge necessary for simulation research becomes important. The topic of KM, like simulation, has grown in its use and popularity in the last few decades. In their definitive work, Nonaka and Takeuchi (1997) assert that KM has emerged through the evolution of competition and market volatility. They assert that, for business enterprises today, knowledge remains as one of the few stable and durable advantages. Beijerse (1999) cites that KM leads to increasing the value of economic processes.

There are two types of knowledge. Nonaka and Takeuchi (1997) call them explicit and tacit. Explicit knowledge can be expressed through images, texts and numbers. It is easily stored and processed in documents, spreadsheets and drawings. On the other hand, and in accordance with Davenport and Prusak (1998), tacit knowledge originates from actions, procedures, routines, commitments, ideals, values and emotions (NONAKA and von KROGH, 2009). It is difficult to be articulated and resides in the mind of the knower.

Nonaka and Takeuchi (1997) argue that the interaction between tacit and explicit is the key to knowledge creation within organizations. The same authors identify four conversion modes between tacit and explicit knowledge: Socialization, Externalization, Combination and Internalization. For a greater discussion on the subject, see Nonaka and Takeuchi (1997). Figure 2 demonstrated the Nonaka and Takeuchi's spiral of knowledge creation.

From/To	Tacit	Explicit
Tacit	*Socialization* Individuals acquire new knowledge from each other	*Externalization* Knowledge articulation into something tangible via dialouge
Explicit	*Internalization* Learning by doing, where individuals internalize knowlege from documents	*Combination* Combination of different forms of explicit knowledge, such as documents and data bases

Fig. 2 – Four knowledge conversion modes. Source: Nonaka and Takeuchi (1997).

Tacit knowledge may be accessible through the mind of the individual if the knowledge tends to possess more explicit aspects (NONAKA and von KROGH, 2009). For example, a machine operator in a production cell would be able to explain the steps that he or she follows to complete his or her tasks, however a wine taster would have much more difficulty to point out each step taken in order to distinguish a high quality wine. The vision offered by the authors cited above implies that simulation is able capture tacit knowledge that exists in industrial environments and in turn can make it explicit. Edwards *et al*. (2004) and Hollocks (2004) corroborate this position.

In their extensive literature revision in respect to the state of the art in the area, Anand and Singh (2011) conclude that KM is a tool that helps businesses to utilize their resources in a more efficient and intelligent manner in order to reach their goals in a productive way. According to these authors, among other applications, KM can be used to improve productive processes.

Some examples in the literature of KM strategies in practice include the identification of best practices and meetings driven by communities of practice (groups of professionals who belong to the same area), storage and codification of knowledge (SCHULZ and JOBE, 2001), identification of best practices, conduction of strategic studies and scenario development (BEIJERSE, 1999). Strategic studies and scenario development are directly aligned with simulation research, and the other mentioned KM activities possess at least an indirect link with simulation development processes.

Hlupic, Verbraeck and Vreede (2002) assert that, in spite of being separated in the literature, simulation and KM techniques are inseparable in practice, due to the level of understanding obtained of the system under study, the amount of data collected and stored and analysis of scenarios. In this context, it can be affirmed that there are many congruent activities in simulation studies and KM approaches.

While the literature generally views simulation from a very narrow standpoint as an isolated tool in decision-making (HOLLOCKS, 2004), simulation actually contributes to the identification, capture, use and leveraging of knowledge.

In the next stage of this paper, some academic works from the last decades which have proposed combining KM and simulation techniques will be presented. In order to present them in an organized manner, the papers will be separated according to the simulation project development phase in which the techniques are applied. First, the papers relevant to the conception stage will be presented, followed by those relevant to the implementation and analysis stages, respectively.

3. Combined applications of simulation and knowledge management

Although the literature in respect to the relation between KM and simulation is sparse, a handful of authors have taken a look at combining the two approaches. In following, the research papers relevant to this research question will be classified according to the three stages of a simulation project (conception, implementation and analysis) outlined by Montevechi *et al*. (2010) in which each approach is applied.

a. Conception

The conception phase deals with the abstraction of a real system using a visual representation, normally through a process mapping technique, such as IDEF-SIM (LEAL, 2008).

Knowledge acquisition in the initial phases of simulation research has been cited as a step of extreme importance – even as the most important in the research process (KOTIADIS, 2007). In the early steps of a simulation study, it is important for the modelers and clients first to establish an understanding of the system to be modeled so that they subsequently can identify the research objectives (ROBINSON, 2008).

In order to acquire existing knowledge from various intermediate health-care system specialists, Kotiadis (2007) used Soft Systems Methodology (SSM) to construct a simulation conceptual model and identify data collection ponits. SSM is a qualitative methodology that provides a holistic view of complex systems which contain many interactions and interdependencies through structured communication approaches and visual representation of these dynamic systems (CHECKLAND, 1990). This technique is commonly applied in KM strategies (SHANKAR, ACHARIA and BAVEJA, 2009; GILLIES and GALLOWAY, 2008).

Based on the structured conversations between system specialists and the modelers and the elaboration of system performance measures of efficacy, efficiency and effectiveness, the identification of modeling objectives and specifically data collection points were facilitated (KOTIADIS, 2007). The mentioned author affirms that the knowledge acquisition tool SSM enabled the modelers to collect data and conduct conceptual modeling with greater ease.

Other papers have utilized technological resources to facilitate the conversation between systems specialists and modelers. Both the research from Dungan *et al*. (2010) and Adamides and Karacapilidis (2006) developed technological platforms in which the specialists could access and edit conceptual models.

In Dungan *et al*. (2010), the authors proposed the use of a *wiki* web-page in the conceptual modeling phase, where the specialists could edit the models in a visual drag-and-drop format.

Adamides and Karacapilidis (2006) structured a technological platform to facilitate the collaborative construction of a simulation model in the area of logistics. In collaborative construction, the system specialists possess a larger role in the modeling process, being able to choose the aspects to be included or excluded from the model, and at times doing the modeling itself. The platform served to formalize the debate in respect to the conceptual model and its details, as well as establish the argumentation rules that would determine which specialist "won" each dispute in the case of disagreements about model content. Once a winner was determined or consensus was reached, the changes were incorporated in the computational model by the modeler, who administrated the on-line conversation.

The previously mentioned authors assert that the conceptual model construction is a creative activity which corresponds to the externalization phase of the knowledge creation spiral proposed by Nonaka and Takeuchi (1997). They also highlight that the majority of studies that have been developed in the area of OR treat knowledge principally from a technological perspective (Knowledge Based Systems and Information Systems), while forgetting the fact that systems are based in human activity and devaluing modeling as a tool for organization and social change.

b. Implementation

The implementation phase refers to the transformation of the conceptual model into the computational model. In this section, research which has proposed KM approaches in the implementation phase will be presented.

There is a synergy between the perspectives of simulation and KM (ZHANG, CREIGHTON and NAHAVANDI, 2008). The final result of simulation is the capture of organizational knowledge and its programming harmonizes system comprehension in an intuitive manner.

In the work cited above, the authors developed a Knowledge Server, constructed in the programming language Java, which was then implanted in the simulation model. This knowledge server analyzed the text report produced by the simulation, also known as tracing, in order to designate the following pallet scheduling in a large warehouse simulation.

Neumann (2007) asserts that, aside from bringing to surface important data for the simulation clients about their organization, the research generates new knowledge about the simulation techniques – such as conceptual modeling, data collection, programming and experimentation – for the modelers. According to this author, formalization of the simulation documentation might aid modelers in programming of future models, thus economizing time and efforts in subsequent research projects.

In her research, the author describes the development process of logistical service simulation research in which a formal documentation system is used. Aside from orienting the validation process, the documents left a trail of explicit knowledge of the evolution of the project so that future modelers would be able to access the model's programming with greater ease.

To guide the identification of necessary knowledge for simulation development, the author also identified the information that would be needed, and differentiated between subject-based knowledge (in this case, logistics, materials flow, ergonomics, accounting, etc.) and process-based knowledge (modeling, validation methods and statistics, etc.). Such efforts are related with the conception phase, but also helped in the structuring of documentation.

Yet on the other hand, some authors have used simulation in order to evaluate KM approaches. González, Giachetti and Ramirez (2005) investigated the implementation of KM strategies which aimed to resolve Information Technology (IT) problems in a help-disk simulation. A discrete event simulation model was constructed which evaluated information and knowledge flow and its effect on the help desk's overall performance.

To evaluate manufacturing scenarios in a fabrication process of personalized shoes, Daaboul, Bernando and Laroche (2008) mapped the information and data flow from client orders. Seeing as each request exhibited unique preferences particular to each individual client, the authors used agent-based simulation to simulate the varied knowledge generated by each personalized order.

Edwards *et al*. (2004) used a simulation model in order to acquire new knowledge and leverage it in the development of best practices, a common approach in KM. The simulation's clients, maintenance operations managers in the automotive company Ford, made decisions within the model to evaluate different management styles and to obtain best practices based on the results. The authors assert that simulation can serve for two functions within the context of KM: acquiring new knowledge and orienting organizational learning throughout the passage of time.

c. Analysis

The analysis phase refers to the construction of experimental scenarios within the validated computational model. In this section, research which presents the application of KM methods in the analysis phase will be presented.

Brady and Yellig (2005) used text analysis methods to locate interactions in the simulation trace. Using the geometric distances found between the key-words (such as resources, locations and entities) in the text, the authors identified the simulation's aspects which most demonstrated interactions, thus facilitating the identification of the most used variables and in turn, the most relevant ones for model optimization.

Using statistical data generated from a simulation from a public bus maintenance system, Adamson, Campbell and Orsoni (2005) utilized data mining to find interactions between the parts needed and determine scenarios for order quantities and stock levels. Variables identified in these interactions were used to optimize the model. Painter *et al*. (2006) implemented a similar approach in aircraft maintenance in the U.S. Air Force. This technique was called Knowledge Discovery by the authors.

4. Research Opportunities

Hlupic, Verbraeck and Vreede (2002) assert that the literature hasn't examined the interactions between simulation and KM. Sharing this viewpoint, Hollocks (2004) declares that there are almost no papers in the literature which evaluate the roles of simulation and KM in conjunction.

That being said, there is a lack of scientific undertakings which investigate combined KM and computational simulation approaches. Future research opportunities include analyses of SSM applications in a variety of sectors. Kotiadis (2007) comments in her work that applications of SSM in simulation projects have been limited to the health care sector so far. Other qualitative GC methods which offer a better understanding of the problem situation to be simulated and better clarification of its objectives should be investigated. The use of electronic platforms in collaborative modeling offers a manner for exchanging ideas about the system in the initial simulation phases, especially when system specialists are geographically dispersed (ADAMIDES and KARACAPILIDES, 2006).

Other opportunities for future research include the implementation phase. Few research studies have been published in respect to simulation documentation during the simulation research process (constituting knowledge externalization). Computer programming which feeds KM systems also presents an opportunity, such as the case of Zhang, Creighton and Nahavandi (2008). The use of simulation as an aiding tool in implementation of KM approaches is also a little explored area.

Moreover, in the analysis phase, more attention can be given to the leveraging of output data in the identification of variables which can lead to system optimization. Simulation models serve to create new knowledge about the system under specific scenarios, and the analysis of these output tracing reports supplies a rich source of new knowledge.

Therefore, many gaps can be seen in the literature in regard to KM and computational simulation both from qualitative methods and quantitative approaches.

5. Conclusions

This article has analyzed the interdependencies and synergies between computational simulation and KM. Through the analysis conducted, it might be possible to say that other OR techniques may offer the same advantages in system knowledge generation. However, due to computational simulation's amplitude, applicability and overall potential, it stands out against other OR methods in the context of KM (HOLLOCKS, 2004).

Simulation research identifies and brings to surface valuable information that is transformed into new knowledge, which is leveraged in order to make decisions. As was shown in this article, computational simulation approaches and KM overlap in many areas and exhibit synergies and interdependencies which, while existent in the literature, are still not completely understood or explored, and present much potential for further theoretical and practical development.

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