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Towards knowledge capturing and innovative human-system interface in an open-source factory modelling and simulation environment

C.L. Constantinescu[a]*, E. Francalanza[b], D. Matarazzo[c]

[a] *Fraunhofer Institute for Industrial Engineering (Fh IAO), 70569 Stuttgart, Germany*
[b] *CERU, Department of Industrial and Manufacturing Engineering, Faculty of Engineering, University of Malta, Malta*
[c] *Fraunhofer Joint Laboratory of Excellence on Advanced Production Technology (Fh J_LEAPT),*
Dept. of Chemical, Material and Industrial Production Engineering, University of Naples Federico II, Piazzale Tecchio 80, 80125 Naples, Italy

* Corresponding author. Tel.: +49 711 970-2282; fax: +49 711 970-2299 *E-mail address*: carmen.constantinescu@iao.fraunhofer.de

Abstract

The capital value of knowledge is fundamental in modern cyber-physical systems. The user is provided with information from multiple and sometimes conflicting sources. This large amount of information must then be analyzed and interpreted by the human brain. Information must be used in a profitable way, and transformed into useable knowledge, which can then be effectively used in decision making activities. It is therefore critical to provide the required information and knowledge in order to support digital factory activities such as modelling and simulation of manufacturing systems. The advent and implementation of Industry 4.0 will make it a requirement for virtual planning and real systems within smart factories, to interact and share large quantities of information with each other. In this respect, one of the major challenges is making sure that the right people have the right information, at the right time to make the right decisions. The aim of this research is to provide a multi-level just-in-time simulation tool to support decision making in digital factory planning. The tool makes use of a suitable means for the capturing and representation of manufacturing system knowledge in several types of industrial sectors and types of companies (large, SME). Furthermore, to support the modelling activity, the human-system interface of the simulation tool makes use of just-in-time information retrieval (JITIR). The aim of JITIR is to proactively yet non-intrusively provide the required information at the right time based on the users' context during the modeling and simulation activity.

Keywords: Digital Factory; JITIR; SysML

1. The Dream Platform

Manufacturing companies, especially Small and Medium Enterprises (SMEs), face several barriers in the adoption of advanced simulation decision support technologies. In order to address these challenges this research aims to develop methodologies to address system knowledge management and human-system interaction.

This research was carried out as part of the development of the DREAM simulation platform ("simulation based application Decision support in Real-time for Efficient Agile Manufacturing", http://dream-simulation.eu/). DREAM is an EU research project funded in FP7 whose ultimate objective is to provide industrial practitioners with easy-to-use, reconfigurable and efficient simulation based decision support tools for cross-functional decision processes at multiple hierarchical levels. The aim of the DREAM platform is to increase the competitiveness of European Manufacturing Companies through the provision of multi-level just-in-time simulation based application decision support [1].

In order to meet these aims this research also aims to promote simulation based applications to European Manufacturing Companies, IT consultants, the Open Source community and Researchers. The focal ambition of this project is to develop a semantic open source simulation application platform. This platform will implement a novel application to support decisions at multi-levels in European Manufacturing Companies. Thus DREAM will help to support on-time and real-time simulation applications and system analysis.

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2. Challenges in Factory Modelling and Simulation

In order to develop good decision support systems one must first understand the challenges. Decisions regarding the design and operation of factories and manufacturing systems require technical understanding and expertise together with the ability to satisfy certain business objectives [2]. At the base of this expertise is the stakeholders' knowledge of the manufacturing system. This knowledge can be described as an appropriate collection of information as depicted in the Data-Information-Knowledge-Wisdom (DIKW) hierarchy [3]. It is therefore implicit that the stakeholders in the decision making process need to possess the knowledge and information required if a good decision is to be made.

The reality is that decision makers in the manufacturing industry frequently face the problem of assessing a wide range of alternative options, and selecting one based on a set of conflicting criteria [4]. Therefore, an important requirement in the development of manufacturing simulation applications is to provide stakeholders with information and knowledge support during decision-making activities. Decision making activities occur throughout the factory life cycle and include site and network planning, material handling and equipment design, process planning or factory operation [5].

2.1. Capturing and Modeling System Knowledge

System knowledge is of strategic importance for companies, and the design and implementation of specific information systems is always challenging for developers [6]. The challenges in system knowledge capturing and modelling can vary from the acquisition, the organization and the communication of knowledge, within the context of the production environment. All these aspects need to be supported in order to design more effective and productive manufacturing processes.

In order to make good decisions based on simulation results it is fundamental to understand how the manufacturing system operates and behaves, and to model this appropriately. Errors or misrepresentation of the manufacturing system made at the system modelling stage will have major impact on the simulation results. Another major challenge that is encountered in system knowledge modelling is the retrieval of information [7].

2.2. Retrieving and presenting information

During system knowledge modelling it would be ideal for the users of the system to check all the information available at the moment of taking a decision. Since a lot of information is available within the simulation application environment, including product requirements, machine specifications, scheduling information and process information, it is very difficult if not impossible for the stakeholders to review all the information available.

At best, stakeholders are limited to searching and gathering the information, which is required. This can be done by searching different databases where information is stored, searching the internet for information about machine requirements or searching email archives for supplier communications. This said the simulation application stakeholders may not always be aware that information is available and accessible for them to search.

This problem has been further exaggerated with the advent of Industry 4.0 and the internet of things. In the smart factory, [8] cyber-physical systems will be continuously collecting data from the shop floor that may be relevant to the factory planner who is reconfiguring a plant layout.

This data from the real factory will be available together with data being generated by the simulation application tools in the virtual factory during the factory planning process. These combined activities generate a very large data set that is difficult to store, access and analyse. Therefore it can be concluded that the smart factory paradigm brings along the challenges associated with Big Data, especially in the decision making stages [9]. Data management and information retrieval will therefore become an essential element of the factory planning process.

This said factory planning stakeholders cannot continuously be presented with large amounts of available information to process. This is because human stakeholders are limited by their mental brain capacity in what is defined as the human brain's working memory [10]. Only information which is of high relevance to the task and decisions currently being made needs to be presented to the stakeholders, otherwise there is the risk of information overload.

2.3. Motivation

It is therefore critical for stakeholders using the simulation application to be provided with the right information and knowledge, at the right time, and in a non-pervasive manner in order to take good decisions. These interesting challenges were the driving motivation of this research.

3. Study and selection of best practice for the modeling of system knowledge

This aspect of the research focused on the identification and selection of a tool, further on called best practice (BP), that is suitable for the capturing and modeling of system knowledge in several types of industrial sectors and types of company's (large, SME). There are many state-of-the-art best practices for system knowledge capturing and modelling available at both research and commercial levels. A candidate list of potential suitable BP was established based on recognized studies and benchmarks. This list consists of Systems Modeling Language (SysML), Business Process Modeling Notation (BPMN), Integration Definition Language (IDEF) and Core Manufacturing Simulation Data (CMSD).

3.1. Defining the selection criteria and rating

The objective of this aspect of this research was to define, identify and establish a list of selection criteria. These criteria represent the main capabilities which have to be fulfilled by the BP with respect to system knowledge capturing. The criteria are presented in detail in Table 1 [1].

Table 1: Knowledge Modelling Selection Criteria

Criterion 1 - Pragmatic (practical, realistic) usability
Can the BP easily be used, learned and employed in practice? Is the BP practicable and realistic to be used for capturing the system knowledge?
Criterion 2 - Applicability in daily business with low overheads
Is the technology related to the BP widely applicable and not just to a subset of problems or domains? Does the BP bring reasonable/reduced overheads?
Criterion 3 - Zoom capability
Does the BP provide a zoom function, i.e. to enable the users to start at a high level like the factory and then to "zoom down" to levels with more detail like the production line/cell or machine?
Criterion 4 - SME Customization
It addresses the capability of the BP technology to satisfy the needs of the SMEs. Does the BP allow customization and tailoring to SMEs' needs?
Criterion 5 - Specificity
Does the BP demonstrated effectiveness within specific system knowledge modelling domains?
Criterion 6 - Comparability
Has the BP been compared positively to other BPs in already performed/published studies?
Criterion 7 - Degree of Independence
It concerns the platform and the implementation independence of the Efficient Agile Manufacturing. Is the BP platform or implementation independent?
Criterion 8 - Coupling
Is the BP's adoption independent of other BPs, i.e. does the adoption of this BP necessitate the adoption of another?
Criterion 9 - Sustainability
Is it cost effective to sustain the BP after adoption?
Criterion 10 - Scalability
Is the BP scalable to projects of different sizes (SME, large companies)?
Criterion 11 - Agility
Can the BP adapt readily to changing conditions, e.g., organization changes, contextual changes, etc.)?
Criterion 12 - Legal aspects
Is adoption of the BP free of difficult legal/proprietary aspects?
Criterion 13 - Consensus
Is there widespread community acceptance of the BP?
Criterion 14 - Cost Elasticity
Do the benefits of the results outweigh the cost of adoption of the BP?

3.2. Evaluation and selection

The criteria presented in the previous section were rated by importance. This rating was established following several discussions and interviews with researchers, developers and industrial stakeholders. The rating results are presented in the second column of: 1 is less important and 3 is more important.

Following this exercise a number of interviews were carried out with experts in order to score each state-of-the-art modelling language with respect to the DREAM criteria. The answers to the criteria questions are called score. The score can take only two values, 0 – for not fulfilling the criteria or 1 – for fully fulfilling the criteria. The score was then multiplied by the rate of the criteria in order to support the decision making activity. The overview of the criterion rate and the evaluation of the BP candidates are presented in Table 2 [1].

Table 2: Final Score

DREAM Criteria	Rate	SysML	BPMN	IDEF	CMSD
Usability	3	0	1	0	0
Applicability	3	0	1	0	0
Zoom Capability	3	1	1	1	1
SME Customization	3	0	0	0	0
Specificity	2	1	1	1	1
Comparability	2	1	0	1	1
Degree of independence	3	1	1	1	1
Coupling	3	1	1	1	1
Sustainability	2	1	0	1	1
Scalability	2	1	1	1	1
Agility	3	1	0	0	1
Legal aspects	1	1	1	1	1
Consensus	1	1	0	1	1
Cost elasticity	2	1	1	1	1
SCORE		**24**	**22**	**21**	**24**

3.3. Selection results and the corresponding open source tool

As results from Table 2 the selected BP was System Modeling Language (SysML). The next step of this research was the choice of the corresponding open source tool to use in conjunction with this system knowledge modelling language.

Following the evaluation of several tools it was decided to adopt TOPCASED. TOPCASED uses the infrastructure of the Eclipse IDE development platform for requirements gathering/analysis, modeling, simulation, implementation, testing, validation, reverse engineering and project management of complex safety-critical real-time systems. TOPCASED also contains graphical editors for SysML and follows the Eclipse release schedule.

3.4. System Knowledge capturing guidelines

The DREAM System Knowledge Modeling Guidelines aims at supporting the DREAM partners in understanding how the knowledge of their system and main business can be captured in order to create the model of their manufacturing system.

This guideline can be used as a base for the development of simulation applications. It is simple and gives an overview of the main goals, the roles of the stakeholders involved in the modeling process and the main steps which have to be followed. It is a useful instrument to support the users in the use of SysML and TOPCASED in the system knowledge modeling process.

4. A just-in-time-information retrieval-driven approach

The concept of information has been assimilated over time, compared and contrasted to that of data, knowledge, wisdom, and the other way the words information, text, document, are often used interchangeably [11].

Just-in-time Information Retrieval (JITIR) is an approach based on using as an input the users' environment and activity, and providing as an output to the user information retrieved, suggesting documents, which potentially match users' interest and, furthermore, which can be marked as relevant [12].

The information retrieval takes place by using queries generated from words. Such queries are then processed in a search engine, which can be both web based and/or local. One of the main technical issues encountered in typical information retrieval through search engines is that queries are too rich in keywords due to type of input and therefore might diverge the information retrieval action too much in a short time frame [13].

4.1. Just-in-Time Information Retrieval agents

Just-in-time Information Retrieval agents (JITIRs) are software agents that base their action on the user's local environment in order to retrieve real time information, which is relevant to the users. The strength of JITIRs is the way they operate: they are easily accessible and work in the background. JITIRs take their input from users' context, giving as output nonintrusive information, not in the sense of a normal search engine but in a larger way [13].

The study of JITIRs covers various different branches of knowledge that can be summarized as follows:

- A psychological point of view (by answering questions such as "How does the use of a JITIR affect the way a person seeks out and uses information?"),
- A relation among JITIR and Information Retrieval (IR) (by answering questions such as "How can a JITIR agent automatically find information that would be useful to a person by looking at that person's current environment?"),
- The relevance of information: the information gathered must be as relevant as possible to the users (by answering questions such as "How should a JITIR agent present potentially useful information?").

Therefore JITIRs can be summarized as a class of software agents that proactively present potentially valuable information based on a person's local context in an easily accessible yet non-intrusive manner supporting the user through [14]:

- Encouraging the viewing and use of information that would not otherwise be viewed,
- Reducing the cognitive effort required to find, evaluate and access information,
- Providing useful or supporting information that is relevant to the current task,
- Contextualizing the current task in a broader framework,
- Providing information that is not useful in the current task but leads to the discovery of other information that is useful,
- Providing information that is not useful for the current task but is valuable for other reasons.

4.2. The psychological aspect to JITIR

Douglas Engelbart [13] describes how humans use their capability to approach complex problems in order to solve them. In this regard, he provides a short list of actions that people usually perform, described as follows:

- explicit-human process capabilities,
- explicit-artifacts process capabilities,
- composite process capabilities.

According to the goals of this analysis, the greatest interest for this research is in the third action: these are processes that JITIRs facilitate. These emerge from an interaction between people and artifacts, where artifact is the simulation application.

Making decisions with the best cost/benefit trade off related to time is the main goal of JITIR. JITIR provides the user the best performance in terms of time, trying to minimize the users' total future work. Time affects highly the perception of a user; a small increase in the time to perform a task (such as the response to a query) might result in too long of a waiting time according to his/her perception. Robert Miller [14] argues that there is not a linear decrease in efficiency as response delay increases. Miller's theory also suggests that information retrieval should not to be performed if the cost of retrieval is more than the expected value of the information itself.

Furthermore, thanks to their structure, JITIRs agents are able to work automatically and thus to reduce significantly the cost of search. On the other hand, queries are auto-generated and so there is not the accuracy that a human-query might have. JITIRs are not just a time-saver search; they also provide a real-time information retrieval when the user is not willing, capable or aware that performing a search would provide fruitful information.

In order to introduce the JITIRs from the second disciplinary point of view, a definition of Information Retrieval (IR) is required.

In computing language, information retrieval can be properly defined as "the tracing and recovery of information from stored data in electronic format" [15]. This definition can be enlarged to the whole set of methods focalized to retrieve electronic information. But "information" must be mined in the meaning of the documents, metadata, and files which are in database, the World Wide Web or on the cloud. IR algorithms, such as the Boolean Retrieval Model and the Vector Space Model, can then be evaluated from the point of view of relevance to a given query. The main problem is that the judgments of these must then be made by a human for each document retrieved. A kind of ranking could be obtained with a language modeling approach to Information Retrieval, e.g. using statistics on hyperlinks. In this way, the user can feel the control over the system, e.g. hiding the basic ranking mechanism [16].

JITIR agents are based on queries that are implicit in the user's context and formulated from the understanding of the user's activity [17]. JITIRs watch an environment and can act basing themselves on that environment without direct user interaction.

By the use of queries, JITIR agents are able to find useful information for the user just by sensing the users' context. This is made possible by the use of employing Information Retrieval techniques where the semantics of a query is defined by an interpretation of the most suitable results of the query itself. JITIR therefore adds to the IR the feature that "queries" are generated based on a users' local context, using a domain-specific technique.

The definition of context is given by the Concise Oxford English Dictionary: it encloses the conditions and the circumstances that are relevant to an event, a fact, in fuzzy terms, the set of features not explicitly intended as input into the system being discussed [12]. Therefore a context-aware application, as mentioned by Rhodes, is a system that works independently from a direct input but, at the same time, depends on the intent of the user [15].

4.3. Relevance of information

Accessing the provided information must be a secondary task that does not divert the attention of the user from his/her primary task. A way has to be found in which the information is gathered but, at the same time, must be ignorable. This means that the simulation application must have an "ignorable" element to the user-interface yet the information must remain easily accessible.

To design an interface that achieves both of these contradicting goals two different cognitive processes have to be taken into account. These are "focused attention" and "divided attention".

Firstly there is the focused attention, which is intended as the ability of a person to focus their attention on the task being performed, whilst ignoring others. Paying attention to a JITIR whilst concurrently carrying out a planning task might result very difficult.

Another cognitive process is the divided attention, which concentrates on the ability of a user to focus on various tasks. Unfortunately this is mainly possible only if the tasks involve the different abilities of the human brain, such as concurrently listening and focusing attention. That is why it is possible, and results easy, to drive whilst listening to the radio.

JITIRs therefore need to use both focused and divided user attention at the same time. Users must be allowed to focus their attention on the primary task but also to recognize the information gathered, diverting attention for a while. In order to allow focused attention, a JITIR agent should use tools which involve an ability of the brain not being used at that time. Furthermore, the information must be linked to the environment where it results most useful. By making divided attention easier, JITIRs must present the information gathered without deviating the users' attention from the environment it relates.

The objective of JITIR agents is therefore to provide information basing their action to the users' local context, independently from the task performed. They are not a substitute of a traditional search tool since JITIR agent modifies the way in which people retrieve and use information.

5. Identification of the human system interaction features

This section attempts to generalize the JITIR-approach in a way that it is applicable to the development of Human-System Interface (HS-I) for factory planning and simulation. In order to do this the features needed to enable a smart support system in production planning, were determined based on the use case requirements. [14]

The first feature of HS-I is proactivity. As previously explained, for a system to be proactive the user need not have a query in mind, or even know that information relevant to his situation exists. This feature means that the H-SI should automatically provide the information required by the user during a particular planning task.

Due to the limitations in the technology available, and since it is impossible to read the human brain and sense what information is required, the query used to find useful information is limited to what can be sensed in the user's contextual environment. Hence the interface of the simulation application must be carefully designed in such a way so that unrequested information does not become a distraction from the user's primary task.

The second feature pertains to how the information is presented to the user. In order for the H-SI not to unnecessarily disturb the focus of the user, information should be presented in such a way that it can be ignored. At the same time it should still be easy for the user to access the information should it be desirable. Rather than presuppose whether or not a particular piece of information is important or urgent, the H-SI system should allow the user to decide whether to view or ignore the information depending on his current task and level of cognitive load.

The last feature of the H-SI is the user's local context. The H-SI needs to be provided with information from a source that may or may not be changing, based on relevance to a user's rapidly changing local context.

Local context is the user's spatially local environment, including his current task. As previously explained the information provided by the H-SI is not meant to pull the user out of his current context, but rather to add additional information that might be useful within that context, such as real-time information on machine failure data during the setting up of a simulation study.

5.1. H-SI Guidelines

Proactive

The factory planning and simulation system has to proactively provide information to the user. The user should not need to search or query the system, or even know that information relevant to the current planning or simulation activity exists in order to gather such information. The system should therefore sense the user's environment/activity and provide information thereof [14].

This may lead to an information overload so it is important that the interface be carefully designed so that unrequested information does not become a distraction to the user's primary task.

Non-intrusive, yet Accessible

The simulation application H-SI has to present the information in such a way that it can be ignored, but is still easy to access should it be desirable. The user has to be allowed to decide whether to view or ignore a particular piece of information depending on his current task and level of cognitive load in the case this information is whether or not important or urgent [14].

Locally Contextual

The H-SI has to provide information from dynamically changing sources, based on relevance to a user's rapidly changing local context/activity. This would require the H-SI to capture the local context of the user's spatially local environment, including his current task. The H-SI should therefore provide the user with additional information that might be useful to the user within its context, but not pull the user out of his current context [14].

6. Conclusions

The overall aim of this research project is to provide tools to increase the competitiveness of manufacturing companies, providing a multi-level just-in-time simulation, applied to the decision making process. This paper supports the decision making method by developing methodologies to address system knowledge management and by proactively yet non-intrusively providing the required information at the right time based on the user's context.

This research has contributed towards establishing a set of guidelines for knowledge modelling and H-SI for the development of factory planning and simulation software. These guidelines establish a road map for the system knowledge capturing and modelling through a deep analysis of the open source tools available on the web. The H-SI guidelines are based on the JITIR approach for information retrieval and future research will further develop these concepts to further augment and support the factory planning and decision making activities.

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