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Modeling of system knowledge for efficient agile manufacturing: Tool evaluation, selection and implementation scenario in SMEs

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Abstract

In the manufacturing world, knowledge is fundamental in order to achieve effective and efficient real time decision making. In order to make manufacturing system knowledge available to the decision maker it has to be first captured and then modelled. Therefore tools that provide a suitable means for capturing and representation of manufacturing system knowledge are required in several types of industrial sectors and types of company's (large, SME). A literature review about best practice for capturing requirements for simulation development and system knowledge modeling has been conducted. The aim of this study was to select the best tool for manufacturing system knowledge modelling in an open-source environment. In order to select this tool, different criteria were selected, based on which several tools were analyzed and rated. An exemplary use case was then developed using the selected tool, Systems Modeling Language (SysML). Therefore, the best practice has been studied, evaluated, selected and then applied to two industrial use cases by the use of a selected opens source tool.

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Keywords: System Knowledge; SysML; Simulation

1. The challenge of system knowledge capturing

Knowledge has capital value because it increases productivity. Building on this base, knowledge management is an approach whereby information is transferred from one person to another [1]. One of the major challenges of knowledge management systems is making sure that the right people have the right information at the right time to make the right decisions [1]. This paper gives an overview of system knowledge capturing and modelling, whilst identifying why it is of interest to the manufacturing simulation community.

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 a research project 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.

To address the multi-faceted barriers to the adoption of advanced simulation decision support technologies by manufacturing companies, especially SMEs, by developing methodologies to address system knowledge management and human-*system interaction challenges.*

In order to meet these aims this research aims to promote simulation based applications by European Manufacturing Companies, IT consultants, the Open Source community and Researchers. This research aims to develop a semantic free simulation application platform. This platform will implement a novel application to support decisions at multi-levels in

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European Manufacturing Companies. DREAM will help to support on-time and real-time simulation applications and system analysis.

2. Assumptions and process flow

The planned activities to be performed in the framework of this research aim at answering to the main question:

"What are the best pragmatic tools and methods that can be used in SMEs and large companies to capture systems knowledge and store it for future reuse?"

The initial requirements identified by the European Industry, in several sectors specify that the systems for knowledge capturing have to feature the following:

„pragmatic instruments … to support the management of system related knowledge under special consideration, …, applicability … at SMEs to improve decision making. …NOT … highly sophisticated, … by requiring high efforts for usage and maintenance, but instruments applicable in daily business with low overheads, … 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 [DREAM Project]".

The main objective of the research activities is to recommend, based on a good founded decision, which instrument, tool, further on called best practice (BP) is suitable for the capturing of system knowledge in several types of industrial sectors and types of company's (large, SME). For validating the process, the selected BP is employed for the modeling of the manufacturing processes in several SMEs. The performed activities have been structured as follows: 1) Study of best practice for the modeling of system knowledge; 2) Defining the selection criteria; 3) Evaluation and selection of the suitable best practice; 4) Modeling of two use cases.

Based on the requirements analysis and of two pilot case specifications the study of the best practices in the domain of system knowledge capturing is running in parallel with the definition of selection criteria. The evaluation of an initial list of BP against the selection criteria gave as result the suitable BP witch was used to model the two pilot cases.

3. Defining the selection criteria and system rating

The research was focused on BPs that fit in several types of industrial sectors and types of company's (large, SME) [2]. The list of potential candidate consists of Systems Modeling Language (SysML), Business Process Modeling Notation (BPMN), Integration Definition Language (IDEF) and Core Manufacturing Simulation Data (CMSD) [3 – 5].

The objective of this Section is to define, identify and establish a list of selection criteria, which are suitable for the Efficient Agile Manufacturing purposes. These criteria have been then rated by allocating weights.

The main activities describe as follows: a) Set-up the first version of the criteria; b) Weighting them, giving priorities according to the scope of the work and c) Update the catalogue.

3.1. Selection criteria and overview

A collection of selection/evaluation criteria have been established in order to evaluate the use of Efficient Agile Manufacturing tools and methods for knowledge capturing.

The criteria can be classified into three different types as follows:

Type A: formulated following the Efficient Agile Manufacturing guide lines;

Type B: additional criteria considered relevant by RTD and developers and

Type C: these types of criteria were identified by the Industry Partners that filled in a small questionnaire about their needs.

In Table 1, there is an overview of the criteria for the Efficient Agile Manufacturing tools, with a classification by type.

Table 1: Efficient agile manufacturing selection criteria overview.

DREAM Criteria	Type
Pragmatic usability	A
Applicability in daily business with low overheads	A
Zoom capability	A
SME Customization	A
Specificity	B
Comparability	B
Degree of Independence	B
Coupling	B, C
Sustainability	A, B, C
Scalability	B, C
Agility	B, C
Legal aspects	B, C
Consensus	B, C
Cost Elasticity	B, C

3.2. Definition and classification of the criteria

In this section the criteria are presented in detail: the main capability which has to be fulfilled by the BP on system knowledge capturing (the question to be answered in the evaluation process) is described and a classification for each criterion (according to the capabilities and the type A, B, C) is given.

The answer to the criteria question fulfilling is called score and it will be multiplied by the rank of the criteria in order to support the decision making. The score can take only two values, 0 – for not fulfilling the criteria or 1 – for fully fulfilling the criteria.

Criterion 1: Pragmatic (practical, realistic) usability

It belongs to the Type A and the corresponding question is the following:

– Can the BP easy be used, learned and employed in practise? Is the BP practicable and realistic to be used for capturing the system knowledge?

Criterion 2: Applicability in daily business with low overheads

The criterion belongs to the Type A and the defined question is:

– *Is the technology related to the BP widely applicable and not just to a subset of problems or domains? Low overheads? Does the BP bring reasonable/reduced overheads?*

Criterion 3: Zoom capability

The criterion belongs to the Type A as well and meets the requirement of the following question:

– *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. The criterion belongs to the Type and the question is:

– *Does the BP allow customization and tailoring to SMEs' needs?*

Criterion 5: Specificity

The criterion has huge interest for RTD and developers (Type B) and the following question has to be answered:

– *Does the BP demonstrated effectiveness within specific system knowledge modelling domains?*

Criterion 6: Comparability

The Type of this criterion is B and it specifies which position the BP can hold in the scientific community:

– *Has the BP been compared positively to other BPs in already performed/published studies (or it could be)?*

Criterion 7: Degree of Independence

Being classified as Type B, is concerning the platform and the implementation independence of the Efficient Agile Manufacturing:

– *Is the BP platform or implementation independent?*

Criterion 8: Coupling

This criterion defines the independence of BP to other BPs, the Type is B and C and the question is the following:

– *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

It refers the capability of BP to be effective from the costs point of view, Type is a hybrid of A, B and C. The scoring question is:

– *Is it cost effective to sustain the BP after adoption?*

Criterion 10: Scalability

It is key criterion for Types B and C. This criterion specifies the suitability of BP to be scaled to different types of projects running at different types of factories:

– *Is the BP scalable to projects of different sizes (SME, large companies)?*

Criterion 11: Agility

This criterion represents how the BP reacts to changes, it is of Type B and C, and can be scored as follows:

– *Can the BP adapt readily to changing conditions, e.g., organization changes, contextual changes, etc.)?*

Criterion 12: Legal aspects

This criterion must be taken into consideration from both, Developers and Industry; it belongs to Type B and C:

– *Is adoption of the BP free of difficult legal/proprietary aspects?*

Criterion 13: Consensus

The Type of this criterion is B and C, and its topic is the acceptability and reflection of the BP:

– *Is there widespread community acceptance of the BP?*

Criterion 14: Cost Elasticity

It concerns the induced cost adoption of the BP; it is Type B and C:

– *Do the benefits of the results outweigh the cost of adoption of the BP?*

3.3. Criteria weighting – rate allocation

Each criterion has been then weighted: a rating system based on which criterion from the collection of the criteria have to be rated. In Table 2 is given the rating system: 1 is less important and 3 is more important.

Table 2: Efficient agile manufacturing criteria rating.

DREAM Criteria	Rate
Pragmatic usability	3
Applicability in daily business with low overheads	3
Zoom capability	3
SME Customization	3
Specificity	2
Comparability	3
Degree of Independence	3
Coupling	2
Sustainability	2
Scalability	2
Agility	3
Legal aspects	1
Consensus	1
Cost Elasticity	2

4. Evaluation and selection of the suitable DREAM Best Practice for the modeling of system knowledge

4.1. Evaluation of the BP candidates according to the DREAM evaluation criteria

Each BP from the initial list is in following sections evaluated against all criteria by answering to the main criterion-specific question and by justifying the accorded score, 0 or 1. In order to have as many as possible contributes to the evaluation of the tools, the Fraunhofer IAO Team (IAO) has signed in to two different free online forums and posted questions to the surfers. In the first forum, were posted a question about the free available tool to use and the Questionnaire in the IAO had a direct answer to the Questionnaire from a MagicDraw customer contact person.

Table 3: Evaluation overview of the BP candidates.

DREAM Criteria	SysML	BPMN	IDEF	CMSD
Pragmatic usability	0	1	0	0
Applicability in daily business	0	1	0	0
Zoom capability	1	1	1	1
SME Customization	0	0	0	0
Coupling	1	1	1	1
Specificity	1	0	1	1
Comparability	1	1	1	1
Degree of Independence	1	1	1	1
Sustainability	1	0	1	1
Scalability	1	1	1	1
Agility	1	0	0	1
Legal aspects	1	1	1	1
Consensus	1	0	1	1
Cost Elasticity	1	1	1	1

The evaluation of this Best practice, CMDS, has been performed by the research group from University of Limerick, represented here. This tool is suitable for the activities of the

Task 3.3 and it is employed for the purposes of data mining aims into the DREAM Platform.

The overview of the evaluation of the BP candidates is presented in Table 3.

4.2. Multiplying the rates by the weightings and calculate the final score

The final score is presented in Table 4.

Table 4: Final score.

DREAM Criteria	Rate	SysML	BPMN	IDEF	CMSD
Pragmatic usability	3	0	1	0	0
Applicability in daily business	3	0	1	0	0
Zoom capability	3	1	1	1	1
SME Customization	3	0	0	0	0
Coupling	2	1	1	1	1
Specificity	2	1	0	1	1
Comparability	3	1	1	1	1
Degree of Independence	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
Final SCORE		**24**	**22**	**21**	**24**

4.3. Select the suitable BP and the corresponding open source tool. Results presentation

After a long discussion with all the colleagues and the SysML google Forum it was decided to use TOPCASED. The aim from TOPCASED is to provide the necessary tools from requirements analysis to implementation. TOPCASED contains graphical editors for UML and SysML. All modeling languages are associated with requirements management and document generation. TOPCASED follows the Eclipse release schedule. TOPCASED uses the infrastructure of the IDE Eclipse development platform for requirements gathering/analysis, modeling, simulation, implementation, testing, validation, reverse engineering and project management of complex safety-critical real-time systems.

5. Exemplary modeling of the system knowledge

5.1. Leotech general appearance use case

Leotech GmbH (LEO) is a small enterprise and its main interest is in a decision support system, in order to optimize its core business process: the Injection Moulding Business Process (IMBP). DREAM is required to support LEO in the area of planning mould manufacture for the injection moulding prototype and pre-production business. It is a SME with only 10 people. Each employee reports directly to the Management and is able to work in every technology and must carry out the whole appointed project.

LEO main products are Rapid Prototyping, Rapid Tooling, Metal Casting, HSC (5-axis) and Injection Moulding. In order to offer customers the whole rapid prototyping process, the company can internally manage the entire production chain: Stereo lithography, Laser Sintering, Vacuum Casting, Metal Casting, Rapid Tooling and Injection Moulding. To perform these activities the company structure has been divided in three main areas: Rapid Prototyping Department, Rapid Tooling Department and Injection Moulding Department.

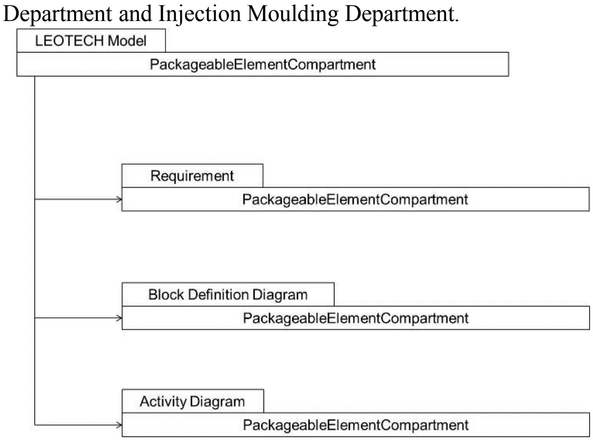

Figure 1: Leotech IMBP - Package Diagram.

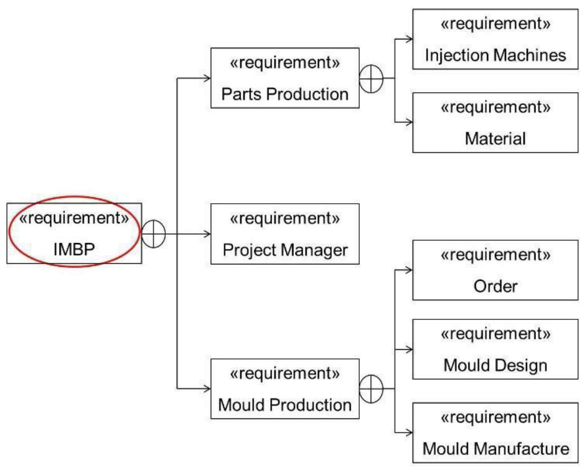

Figure 2: Leotech IMBP - Requirement Diagram.

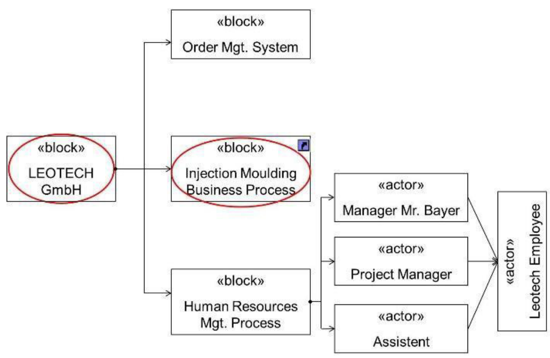

Figure 3: Leotech IMBP - Back Block Definition Diagram.

The LEO core business is the IMBP that consists of two subprocesses: Moulds Production, Parts Production: a new production starts with the approval, by the Management, of a new order that comes from customers. Orders include a Draft of the part to be realized, these have to be integrated by complementary CAD design and then sent to the appointed employee. After this first phase the Mould can be produced. In order to afford the Moulds production process each employee has available two machines: a milling Machine and a machine for the Electrical Discharge Machining (EDM); the use of the EDM is not always required and depends by the complexity of the Mould design. After the production of the Mould, the Plastic Parts have to be produced: firstly the material has to be retrieved, secondly starts the actual production. For the production LEO has two injection machines (a small one and a big one), that can be used separately and to perform different tasks. The appointed employee must decide which machine to use, considering the lot size and the Mould shape.

Following the description of the Pilot Case and a visit to the plant site in Leonberg (Germany), the current IMBP has been modelled by the use of SysML Tools. The SysML Tool used is the open-source TOPCASED v5.3.1 [7].

In order to model the LEO Use Case, two phases have been performed as follows: 1) Manual Modelling and 2) Software Tool Modelling.

Phase 1: during this phase, the IAO has worked with LEO in order to analyse the structure and extract the Requirements for the IMBP. Possible solutions and the As-Is situation have been drawn in a first draft, the LEO structure has been defined and then detailed, from a Top Level (Top Definition Diagram), to a more detailed level, the Back Definition Diagram. Activity Diagrams have been also implemented in order to represent the flow for the Moulds and Parts Production and the Order Management as well.

Phase 2: the drawn models have then been in TOPCASED converted. All the diagrams and the flows have been enhanced using the tools provided by the software and the structure of the models deepened.

The structure of the model realized can be summarized as follow [7 - 10]:

- Package Diagram, which contains:
  - Requirements;
  - Block Definition Diagram:
    - Back Block Definition Diagram;
  - Activity Diagram:
    - Order Management Activity;
    - Parts Production Activity;
    - Moulds Production Activity.

Figure 1 is a screenshot of the top level diagram of the model: Package Diagram. It represents the whole organisation of the IMBP hierarchy structure and so it is composed by the other sub-packages [6]. Under the Package Diagram, Requirement Diagram, Activity Diagram and Block Definition Diagram stand on the same definition level. As illustrated in Figure 2 the Requirement Diagram provides all the relations needed to perform the IMBP. It includes physical requirements, personnel activities and designs, and it provides a graphical view of the set [6]. Three main sub-sets compose the Requirement Diagram:

- Mould Production;
- Parts Production;
- Project Manager (PM).

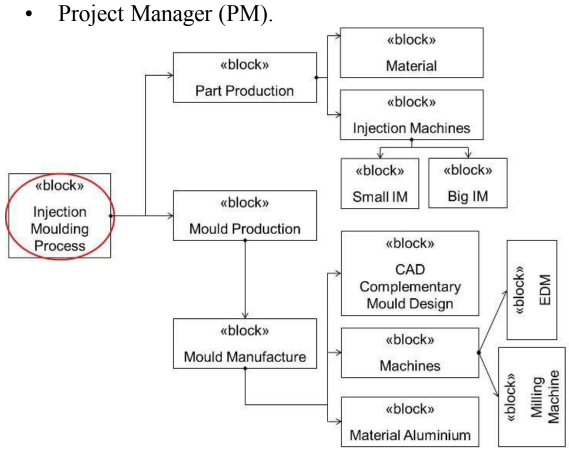

Figure 4: Leotech IMBP - Back Block Definition Diagram

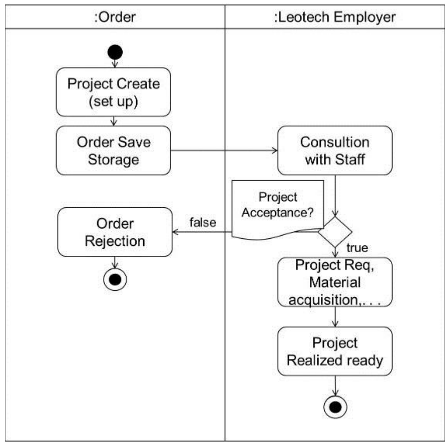

Figure 5: Leotech IMBP - Order Management Activity Diagram

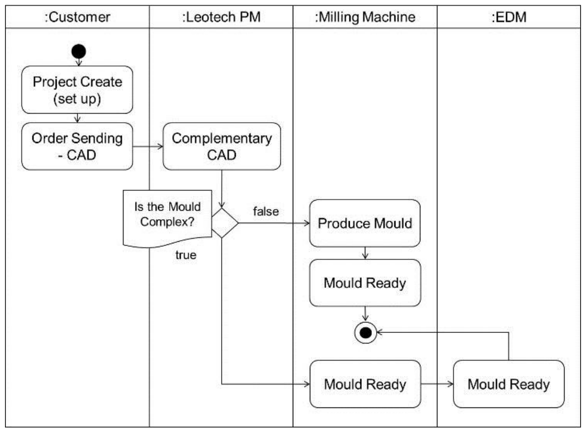

Figure 6: Leotech IMBP - Moulds Production Activity Diagram

The Block Definition Diagram has two different levels: a Top Level and a Back Level. Both are composed by Blocks, which contain Operation Descriptions, Constraints and Values

[6]. Each Block is a structural element of the LEO organization; the Top Level is illustrated in Figure 3.

Figure 4 instead represents the second level: the Back Block Definition Diagram. It is an in-depth analysis of the LEO system of interest: the Injection Moulding Process (IMP). It is composed by two main Block structure that compose the IMP: Moulds Production and Parts Production, wh[ich are then detailed in all their sub-sets.

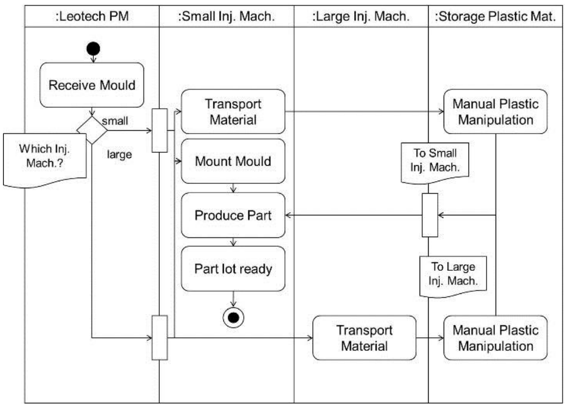

Figure 7: Leotech IMBP - Parts Production Activity Diagram.

Activity Diagrams are the representation of the steps carried out in order to perform an action, or to describe the actors' process behaviour; by the support of activity partitions, they give an advice in recognizing responsibilities for each activity [6].

Three different Activity Diagrams have been made: Order Management, Moulds Production and Parts Production. Each Diagram starts from an Initial Node (that is usually the reception of a new order, of the finished mould as well), goes through steps and decision node, up to the Activity Final (such as Production of the Moulds/Parts or Realization of the Project).

The screenshot in Figure 5 illustrates the Order Management Activity Diagram. It describes the Activities and the behaviour of the LEO Management, after receiving a new Order from a Customer. The diagram includes the acceptance of the Project and all the steps to be performed in order to collect Project data, determine Requirements, order Material and make the Project ready to be realized.

Furthermore, Figure 6 specifies the process to produce the Mould: it starts from the input (given by Customers, Order and CAD Draft). The flow goes through an integration of the CAD designs and a decision about the complexity of the Mould (a decision on which Machine to use is required) and ends with the output, which is the physical realization of the Mould.

The Mould is then received by the appointed PM: he has to decide which type of Machine (Small or Large) to use and then to follow the process up to its end, the realization of the entire lot. Figure 7 illustrates the process with the whole steps and the Activities to be performed.

5.2. Balkan machinery use case

Balkan Textile and Cotton Gin Machinery Ltd. (BAL) serves both Turkish and international customers. Its main manufacturing facility, located in Aydın, occupies over 10,000 square meters of land with approximately 8,000 square meters of manufacturing space.

Balkan group consists by three companies;

- Balkan Textile Machinery Ltd.
- Balkan Cotton Gin Machinery Ltd.
- Balkan Import & Export Ltd.

Textile machine manufacturing and ginning machine manufacturing take place in separate but linked facilities. The group employs about 200 individuals, but in high season this number may increase by 10-20%. About 50% of this manpower is allocated to ginning machinery manufacture and 40% to the textile machinery production line. The remaining 10% is allocated to administration. There is also the option to temporarily reallocate resources from one facility to another if required, but it is generally considered to be undesirable by the company. In case the current working capacity is not enough to fulfil the orders with overtime, Balkan tries to outsource part of the work.

In the same way of the Leotech use case, two phases have been followed to model the Balkan Use Case and the structure of the model realized can be summarized as follow [7 – 10]:

- Package Diagram, which contains:
  - Requirements;
    - Block Definition Diagram:
      - Back Block Definition Diagram.

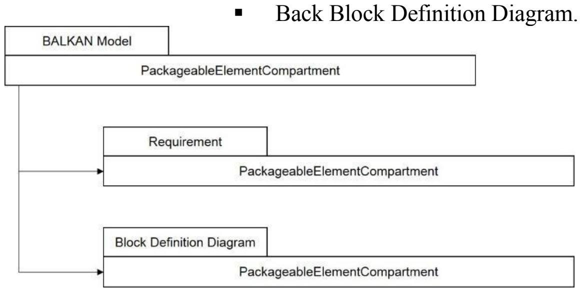

Figure 8: Balkan Machinery - Package Diagram.

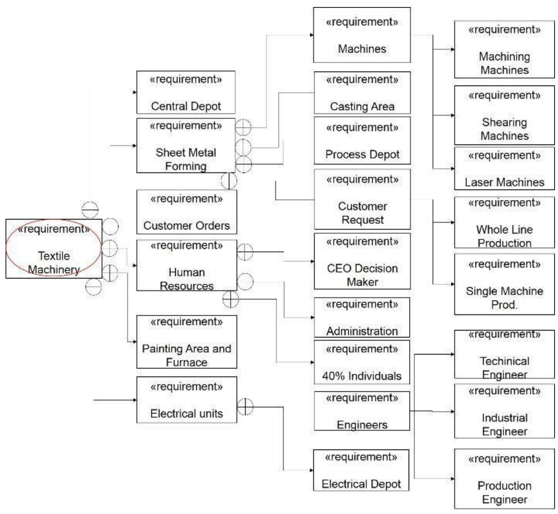

Figure 9: Balkan Machinery - Requirement Diagram.

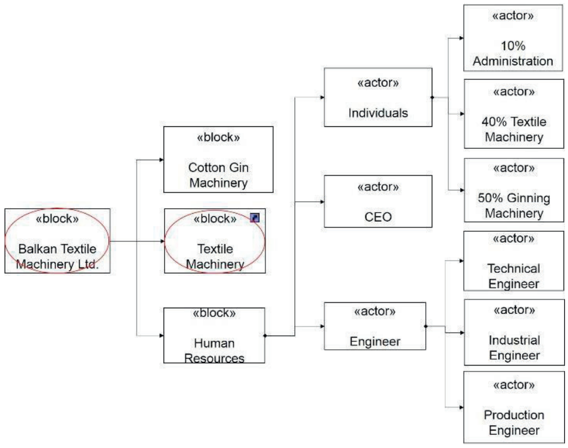

Figure 10: Balkan Machinery - Block Definition Diagram.

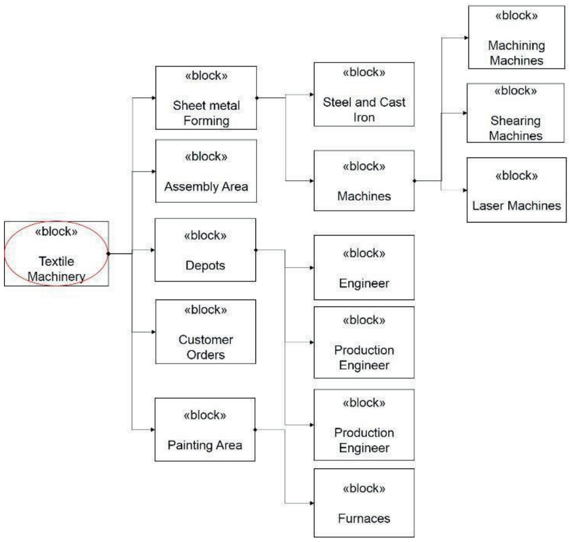

Figure 11: Balkan Machinery - Back Block Definition Diagram.

Figure 8 is a screenshot of the top level diagram of the model: Package Diagram. It represents the whole organisation of the Balkan Machinery hierarchy structure and so it is composed by the other sub-packages [6].

As for Leotech, also in the Balkan Use Case have been identified, under the Package Diagram, the Requirement Diagram, the Activity Diagram and the Block Definition Diagram: these stand on the same definition level.

As illustrated in Figure 9, the Requirement Diagram provides all the relations needed to perform the Textile Machinery Process. It includes all the physical requirements to perform the activities and the personnel activities and designs.

The diagram provides a graphical view of the set [6]. The Block Definition Diagram will provide two different levels: a Top Level and a Back Level. Both are composed by Blocks, which contain Operation Descriptions, Constraints and Values [6] and those are a structural element of the BAL organisation; the Top Level is illustrated in Figure 10. Figure 11 instead represents the "hidden" level, behind the first Block Definition Diagram: the Back Block Definition Diagram. It represents the analysis of the system of interest at Balkan: the Textile Machinery Process. It is composed by several main Block structures that compose the process: at each block is then assigned a specific function and a sub-set of blocks.

6. Conclusions

This research has contributed by establishing a road map for the system knowledge capturing and modelling through a deep analysis of the open source tools available on the web. In order to select the BP, several modelling language have been considered and, according to different criteria, rated. The criteria, that have also been rated, took into account several aspects of the tools, paying specific attention to their use by SMEs.

The System Modeling Language has been identified as the BP to match the features given by the criteria. The selection of the best practice brought the study to the selection of the corresponding suitable open source tool, TOPCASED [7]. By the use of the SysML, two exemplarily use cases have been modelled. The goal is to show that SysML is easily capable of capturing and modelling the internal structure and organisation of different types of companies, regardless the dimension, the core business and the market.

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. The paper supports the decision making method by developing methodologies to address system knowledge management, by paying special attention to SMEs.

7. Acknowledgments

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