Consistency Management Of Simulation Information In Digital Factory

Vincent Cheutet, Samir Lamouri, Thomas Paviot, Ronan Derroisne

CONSISTENCY MANAGEMENT OF SIMULATION INFORMATION IN DIGITAL FACTORY

Vincent CHEUTET, Samir LAMOURI, Thomas PAVIOT, Ronan DERROISNE

LISMMA / SUPMECA
3 rue Fernand Hainaut
93407 Saint-Ouen Cedex - France
vincent.cheutet@supmeca.fr, samir.lamouri@supmeca.fr, thomas.paviot@supmeca.fr, ronan.derroisne@supmeca.fr

ABSTRACT: *The Digital Factory aims to design, simulate and optimize the production system as early as possible in the product development process, by taking advantages of available software tools and 3D digital representations. Nevertheless, the multiplicity of simulation models and representations induce heterogeneity of data and information available, which make complex the information consistency management. This article proposes a framework based on a set of multi-layered models representing a production system at the different necessary scales, to ensure consistency between the simulation models.*

KEYWORDS: *Digital Factory, information consistency, multi layered framework.*

1 INTRODUCTION

In a context of increasing competition and reducing time-to-market, the Digital Factory is born to design and simulate the production systems in parallel of the product design process. It can be defined as a set of software tools and methodologies allowing to design, simulate, initiate and optimize the production systems (Bracht and Masurat, 2005), (Kühn, 2006) (Chryssolouris *et al.*, 2009). This approach, coming from the concurrent engineering and from the Computer Integrated Manufacturing (CIM), aims at reducing validation loops by ensuring, as early as possible in the product lifecycle, the integration of the product manufacturability and productibility towards the enterprise constraints. This approach takes part of a Product Lifecycle Management (PLM) approach that aims at sharing information relative to a product in each phase of its lifecycle (CIMdata, 2008).

One purpose of the Digital Factory is to support the planning process, in case of modifications of the production processes (introduction of a new product or a new workcenter, modification of the production rate, etc.) with a series of tools, such as, e.g. 3D modeling programs or simulation programs. Using these tools the planner or planning team can create a digital image of individual workplaces or even a complete factory, along with the respective production processes. By means of simulations, examinations into possible weaknesses in the planned system can be carried out. Thus, the dynamic factory occurrences can be played through, analyzed and improved. Necessary structural changes can also be carried out and changed directly in the computer model.

Previous research has highlighted the role of virtual engineering tools in the development of manufacturing machinery systems. Simulation models created for this purpose can potentially be used to provide support for other tasks, such as operational planning and service and maintenance. Furthermore, the models must be able to communicate with other business software (De Vin *et al.*, 2004).

Although, with available technologies and systems in CIM or Digital Factory and their related technologies, their application in manufacturing enterprises is still not a reality and cannot meet the need of the enterprises (Nagalingam and Lin, 2008). Today managers in many enterprises are confused with varying technologies and new terminologies that prevail in the public domain.

Thus, the Digital Factory is based on a large number of very different digital simulation tools, based on various representation levels of the production system. It is thus possible to realize a flow simulation at the level of a production line, in order to determine stock level necessary to obtain a satisfying customer performance criterion, or to realize the offline programming of a robotic cell, part of the same production line.

This heterogeneity of tools and methods implies major problems to ensure the consistency available inside the Digital Factory, in particular between the different simulations. This consistency problem slows down the validation process included in the development process of the product and its production system. The objective of the article is to make an overview of the information management inside the Digital Factory and to propose a model allowing the information consistency management.

The article is structured as following. Section 2 presents a definition of the Digital Factory and its sources of heterogeneity. Section 3 overviews some existing models or approach dealing with consistency in a digital environment. Section 4 proposes the specifications of a system ensuring the simulation information consistency inside the Digital Factory. Section 5 finally presents the conclusions and perspectives of our approach.

2 DIGITAL FACTORY – DEFINITION AND HETEROGENEITY

For (Wöhlke and Schiller, 2005), Digital Manufacturing links product development (Ullman, 2009), production planning and facility planning (Fleischmann *et al.*, 2008) (figure 1). As a consequence, the Digital Factory is attached to all enterprise layers and all time horizons, from strategic planning to operational optimization.

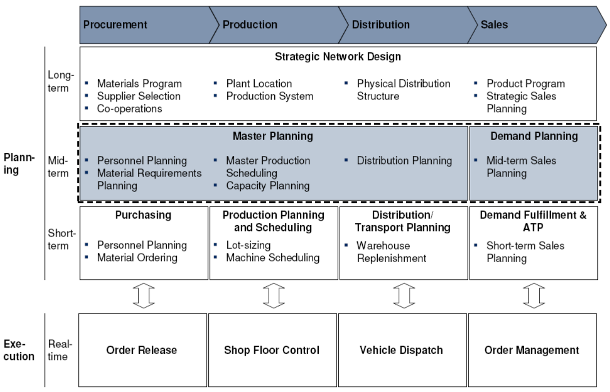

Figure 1: Matrix of supply chain planning (Fleischmann *et al.*, 2008).

In this context, the projects Digital Factory (Boime, 2005) and Digital Factory 2 (UN2, 2008), from the SYSTEM@TIC Paris-Region cluster, have proposed a structured representation of the Digital Factory on six levels of details, corresponding to an aeronautic vision of the extended enterprise (figure 2).

Figure 2: Different layers in the Digital Factory (Boime, 2005).

These layers correspond to specific needs for the design and simulation of the production system behavior, and so to specific actors of the production system development process, with their own tools and methodologies. For example, at level 1 or 2, the objective can be to determine the physical supply flows inside the extended enterprise. At level 3, the objective can be to validate a physical layout inside the plant and a line rate. At level 5 or 6, the objective can be to validate the settings of a manufacturing program in the production environment (robots, CNC machining, etc.).

For all layers, one can find specific simulation tools corresponding to specific actors, with different geometric representations and different simulation structures.

Two main families of simulation tools can be defined in the Digital Factory:

- <u>*simulation based on events*</u>: it is constituted by elements that react to some events: flow simulation, control simulation (GRAFCET for instance), virtual reality, etc.
- <u>*prescriptive simulation*</u>: it describes the behavior of the production systems according to the time, i.e. the realization of an action is done at a given instant: layout analysis, offline programming of MOCN or robots, ergonomics simulation, etc.

The main reasons to use simulation based on events for system analysis in supply chain management are (i) the possibility to include dynamics and (ii) the simplicity of modeling. Discrete event simulation is suited for these kinds of studies where time-dependant relations are analyzed, whereas prescriptive simulations are suited to analysis where time is a key entry.

One can find in the literature many references or examples of simulation and analysis, at each of the previously defined levels, which can be mostly positioned according to figure 3.

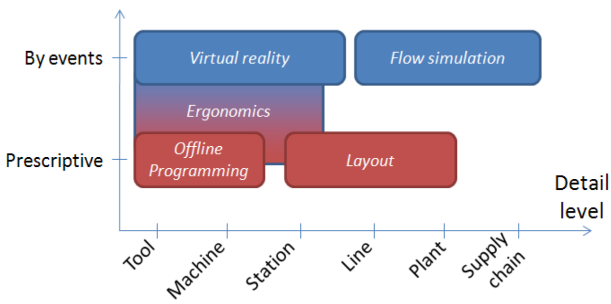

Figure 3: Positions of main simulation types.

As an example of simulation by events from levels plant-supply chain, (Longo and Mirabelli, 2008) present an advanced modeling approach and a simulation model for supporting supply chain management. The first objective is to develop a flexible, time-efficient and parametric supply chain simulator starting from a discrete event simulation package.

As an example of prescriptive simulation from levels plant-line, (Vitanov *et al.*, 2007) present a decision support tool that can be used by practitioners and industrialists to solve practical cell formation problems. The tool is based on a cell formation algorithm that employs a set of heuristic rules to obtain a quasi- optimal solution from both component routing information and other significant production data.

As an example of prescriptive simulation from levels machine-tool, (Fernandez-Madrigal *et al.*, 2008) propose a framework for the integration of heterogeneous robotic software through a software engineering approach: the BABEL development system, which is aimed to cover the main phases of the application lifecycle (design, implementation, testing, and maintenance) when unavoidable heterogeneity conditions are present.

In the idea of multi-layered consideration of the digital manufacturing with a simulation by events approach, (Zülch and Grieger, 2005) describe an occupational health and safety approach that does not focus only on ergonomic analyses and examinations of single workplaces, but have a macro-ergonomic point-of-view to digital work systems planning which considers all elements of a work system and their interactions.

In the same way, one can cite (Honglun *et al.*, 2007), for who ergonomics analysis is the important step for product validation in the process, and the virtual human is key to the computer-aided product ergonomics. In this paper, ergonomics simulation system is studied based on some elements of ergonomics analysis and assessment.

All these examples illustrate the diversity of simulation objectives, methods and tools that can exist in the Digital Factory. All of them contribute to define and optimize the production system and the supply chain of the extended enterprise, and so each actors participating to this development process should have access to the right information at the right moment.

3 DIFFERENT REPRESENTATIONS AND MODELS FOR THE DIGITAL FACTORY

These different simulations, based on different simulation core models, need several representations of the factory, either for the level of details of the desiderate simulation than for the constraints of the simulation core model. (Drieux *et al.*, 2007) have enlightened the need to have an adequate representation according to current point-of-view, especially according to the simulation constraints.

According to these needs, several works have proposed models that take into account some aspects of the diversity of simulation models and representations.

3.1 Consistency between representations

The first source of diversity is the diversity of digital representation of the enterprise. 3D digital representations for production systems are more and more used to take both benefit of the product virtual mock-up and 3D visualization, for a better communication and understanding. In order to take into account this diversity, several approaches can be cited.

The notion of Levels Of Details (LODs) inside a digital geometric representation is a well-known notion in the domain of Computer Sciences. This type of representation has been introduced for the digital design mock-up by (Chu *et al.*, 2009), who present a scheme for collaborative 3D design using product model at various levels of detail (LODs). Design features are selectively hidden at each level from certain participants, depending on their actual needs and individual accessibility in the collaboration. This type of approach is needed to have consistency between the different digital representations of the Digital Factory, in particular to keep linked the different layers. In the same way, (Do *et al.*, 2008) proposes a comprehensive procedure for engineering change propagation in order to maintain consistency between various product data views (product design, manufacturing or customer support). Unfortunately, these approaches only take into account the static description of the product, and not the complete production system implied by the product.

In order to manage all the simulation models, several solutions have been proposed from the point of view of simulation data exchange.

One can cite the approach of (Song *et al.*, 2009) who suggests a Computer Aided-Engineering (CAE) data exchange method for the effective sharing of geometric and analysis data. The method relies on heterogeneous CAE systems, a virtual reality system, and a developed lightweight CAE middleware for CAE data exchange. They also designed a generic CAE kernel, which is a critical part of the CAE middleware. The kernel offers a way of storing analysis data from various CAE systems, and, with the aid of a script command, enabling the data to be translated for a different system.

In the same way, the concept of Simulation Lifecycle Management (SLM) has been developed by CAE software editors (SIMULIA, 2007), but this concept only deals with complete integrated environment, that is not our case.

But these two approaches are only for the domain of product behavior simulation, and so in the product development process. Such a framework has to be developed in the production system development process.

3.2 Consistency between models

The second source of diversity is the heterogeneity of models used for simulation. This diversity originates first from the two simulation families described in section 2, but also from the diversity of simulation tools and the lack of manufacturing simulation standards.

Anyway, several approaches propose standardized framework for subsets of Digital Factory simulations.

(Wenzel *et al.*, 2005) present an approach, which introduces modeling conventions based on a common world view of its users by applying the metaphor of the Electronic Catalogue as well as a well-defined workflow in order to simplify the work with Digital Factory models as a substantial step towards the application of the Digital Factory to meet practical requirements.

In (Lin and Harding, 2007), a general manufacturing system engineering (MSE) knowledge representation scheme, called an MSE ontology model, to facilitate communication and information exchange in inter-enterprise, multi-disciplinary engineering design teams has been developed and encoded in the standard semantic web language. The proposed approach focuses on how to support information autonomy that allows the individual team members to keep their own preferred languages or information models rather than requiring them all to adopt standardized terminology. The MSE ontology model provides efficient access by common mediated meta-models across all engineering design teams through semantic matching.

(Mahesh *et al.*, 2007) propose a framework for distributed manufacturing to facilitate collaborative product development and production among geographically distributed functional agents using digitalized information.

(Ryu and Yücesan, 2007) have developed a novel modeling method referred to as Collaborative Process Modeling (CPM) to describe collaborative processes. CPM models can be transformed into marked graph models so that we can use the analysis power of Petri Nets.

(Kojima *et al.*, 2008) propose a method based on manufacturing case data that has a direct relation to manufacturing operations. The data are represented in XML schema, as it can be easily applied to Web-based systems on the shop floor.

(Vichare *et al.*, 2009) propose a Unified Manufacturing Resource Model termed UMRM. UMRM not only has the novel capability to provide the information to define the various elements of the CNC machining system, but also has the added capability to provide support for automation of process planning decision making.

This problem of simulation model diversity is also present and tackled in the product development process, incorporating both design and industrialization.

In particular, in (Tseng *et al.*, 2008), the effect of a design change is analyzed by evaluating the affected components and the distributed manufacturing operations from a cost-and-value perspective. The presented model is useful for analyzing the effect of a design change case in a collaborative manufacturing environment.

In (Woerner and Woern, 2005), new methodologies for computer-supported co-operative development engineering (CSCDE) are developed. Environmental constraints for a successful application of CSCDE are identified and classified.

Nevertheless, all these approach lack to identify a management system that ensures the simulation information consistency in the complete Digital Factory. They only cover a restrictive part of the field, either in terms of levels or in terms of simulation family.

In the production and supply chain domain, one standard is currently emerging to model and simulate the supply chain behavior: the SCOR model (Supply Chain Operation Model) that is a reference model with standardized terminology and processes (Cohen and Roussel, 2004). The SCOR model defines the Supply Chain behavior in four levels: Top Level (Process Types), Configuration Level (Process Categories) Process Element Level (Decompose Processes) and Implementation Level (Decompose Process Elements) (figure 4).

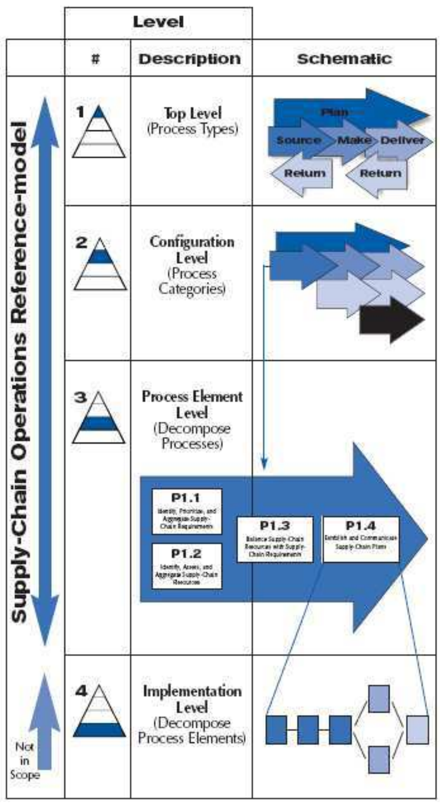

Figure 4: SCOR model decomposition (SCOR, 2009).

This model has been used with success to model and simulate supply chain behavior (Persson and Araldi, 2009). But it does not take into account the digital representation of the production system elements and so the consistency between them.

4 SPECIFICATIONS OF A CONSISTENCY MANAGEMENT SYSTEM

As stated in the previous sections, the consistency problem in the Digital Factory originates from two different sources: digital representations and simulation models. Moreover, this problem is enforced by the multi-layers framework of the Digital Factory and the heterogeneity of actors participating to the production system development process. Most of the approaches presented before are tackling the problem by managing only a part of simulation results (as rate, tack time, stock levels…), but without taking into account the simulation preparation process and in particular the 3D models that are more and more used in the Digital Factory simulations.

All these heterogeneities imply different semantics for the actors, which make the communication between actors more and more complex. Nevertheless, these different semantics are necessary for the development process, as (Léon *et al.*, 2005) demonstrated how various categories of semantic can enhance the design process within virtual environments.

In order to structure the simulation models and specify the possible exchange between them (especially between the 3D representations used in the Digital Factory simulations), we propose to extend an existing model framework with three layers, which is able to describe any shape in context. This model framework is based on the decomposition of a shape in three layers: geometry, structure and semantics, established by the European network of excellence AIM@SHAPE (Falcidieno *et al.*, 2004).

This layered architecture shows the models and processes involved when upgrading low-level shape information to high-level shape knowledge representations (figure 5). Tools and processes are links between the different layers of such architecture. A first organization of the shape data into a computational structure gives access to the ***geometric level*** of representation. The ***structural level*** is reached by organizing the geometric information and/or shape data to reflect and/or make explicit the association between parts/components of shape geometric models or shape data. At the ***semantic level***, which is the highest level of representation, there is the association of a specific semantics to structured and/or geometric models through annotation of shapes, or shape sub-domains according to the specific application domain. The layered architecture emphasizes the separation between the various levels of representations, depending on the knowledge embedded as well as on their mutual relationships.

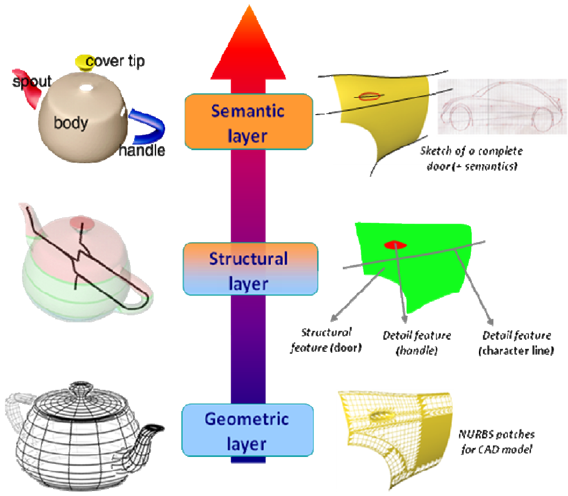

Figure 5: Multi-layered model for shape description.

This architecture has been proposed with success to the data and information exchange between different points of views in the product development process by (Cheutet *et al.*, 2007) (figure 6). If the semantic layer takes into account the knowledge environment of the actors, the concurrent engineering constraints can be successfully taken into account inside the structural level. The model communication between software is more efficient with the product shape than with the product geometry, since each actor needs his/her specific geometric model. It is also more efficient than with the semantic level, since each actor has his/her own point of view on the product. Similarly, the structural layer improves model sharing between different actors.

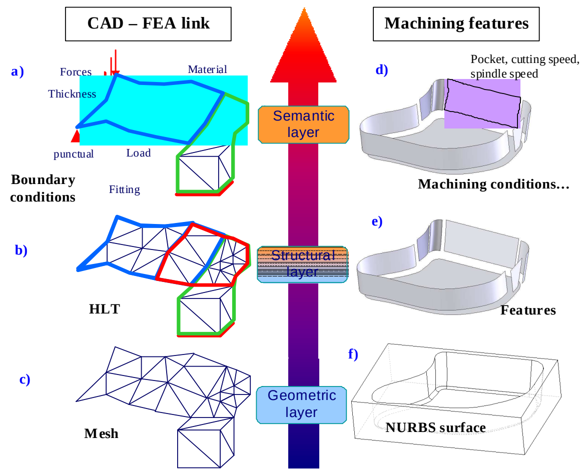

Figure 6: Application of structured representation model to views "models preparation for FEA" and "representation by machining features" (Cheutet *et al.*, 2007).

This layered model is compatible with the hierarchy data / information / knowledge, based on definitions proposed by (Tsuchiya, 1993): when ***datum*** is sense-given through interpretative framework, it becomes ***information***; when

information is sense-read through interpretative framework, it becomes ***knowledge***. With these definitions, we can draw a parallel between geometry and data, structure and information and semantics and knowledge (figure 7).

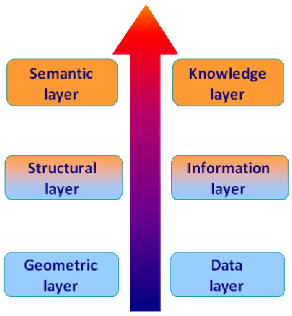

Figure 7: Correspondence between the multi-layered model and data/information/knowledge hierarchy.

As a consequence, the exchange between different point of view is more efficient between two structural layers than the other ones, i.e. between information layers than data layers (all the conceptual model has to be rebuild to completely perform the exchange) or knowledge layers (knowledge belongs to a specific actor or point of view on the product). This is why, in the Digital Factory, the framework consistency will be based on simulation information and not simulation data nor simulation knowledge.

The structural layer is also adapted to develop a LOD model between two different levels of the Digital Factory, by using a recursive structure like tree architecture, SADT models, etc.

This approach is compatible with the one proposed by (Gunendran and Young, 2006). To support flexible integration between multiple views, the authors present a novel framework that capture the combination of information and knowledge in two separate but related layers. This approach provides a flexible environment that is easy to maintain and can operate on new perspectives as they are introduced and as new knowledge is identified. The purpose of our approach is to add the geometric layer (and so data) in the framework, to take into account the diversity of geometric representations, like B-Rep NURBS model, meshes or 2D sketches.

As an application, we can apply this layered model to two simulation models used in the Digital Factory (figure 8). On the left of the arrow of figure 8, we present the model applied on a flow simulation, realized with 3DCreate tool of Visual Components[1], which simulates the behavior of an aeronautic assembly line, in order to optimize the use rate of the different resources dedicated to the production line. On the right of the same arrow, we present the model applied on a robotic simulation, realized with DELMIA V5 tool of Dassault Systèmes[2], which simulates the behavior of an automobile robotic cell, in order to validate the layout of the cell and to program off-line the robots.

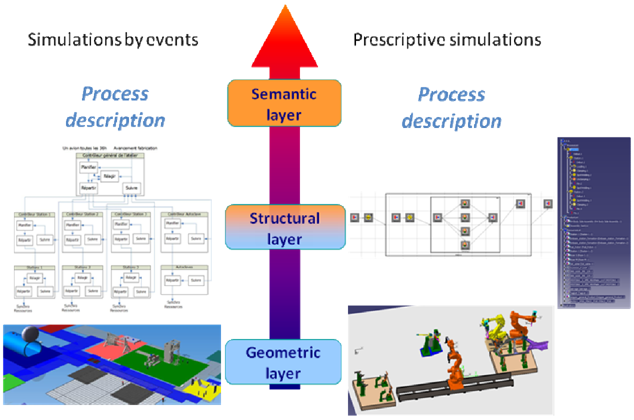

Figure 8: Application of the multi-layered model to two types of simulation models in the Digital Factory.

In the flow simulation model, the geometric layer is composed on the digital representation (based on mesh) of 3DCreate. The structural layer is based on a production activity control architecture proposed by (Huguet and Grabot, 1995). This architecture is constituted by a set of decision centers that can be defined at different levels, with four main functions: plan, distribute, follow and react. Finally, the semantic layer contains all the semantic description of the simulation (especially the name of each station, product or resource).

In the robotics simulation, the geometric layer is composed on the digital representation (based on B-Rep NURBS model classically used in CAD tool), the structural layer is composed of the PPR (Process Product Resources) tree model and of the PERT model of the activities defining the complete process of the cell, and the semantic layer contains the same type of semantics as before.

In order to ensure the consistency between these two types of simulation, the links have to be established between the two structural layers, i.e. between the production activity control architecture and the aggregation of PPR tree and PERT models.

The validation of the multi-layered model for the information consistency management will be developed in the project OLDP (On-Line Digital Production) from the SYSTEM@TIC Paris-Region cluster (OLDP, 2009), which continues the projects Usine Numérique and Usine Numérique 2.

5 CONCLUSIONS AND PERSPECTIVES

The Digital Factory is characterized by the diversity and

[1] http://www.visualcomponents.com/index.php?id=141

[2] http://www.3ds.com/fr/products/delmia/welcome/

heterogeneity of simulation models that are used to design, simulate and optimize a production system as early as possible. Moreover, the problem is more complex due to the different levels of details that are necessary to perform such simulation. As a consequence, the construction of the different simulation models can be time-consuming and very few information validation tools are available to ensure the consistency of the simulations between them.

To overcome this issue, this article proposes a framework defined by a set of multi-layered models of the product and its production system, linked through their structural representations.

The next step of this work will be to define the different multi-layered models for the different simulation models that are used in the Digital Factory and to create links between all the structural layers. To obtain such results, two main domains should be invested.

The first one is the methodology proposed by (Curran *et al.*, 2008), for the systematic integration of digital manufacturing through Digital Lean Manufacturing (DLM). DLM offers a new management methodology for production operations integration that achieves vertical and horizontal integration of process, tools and systemic manufacturing effort.

The second aspect, in a very different scientific field, treats of the integration of different simulations from very different levels: the multi-physics and multi-scale modeling and simulation (Michopoulos *et al.*, 2005). This approach takes into account all phenomena, coupled between them, acting on the system. On the physics aspect, the approach takes into account coupling between elementary phenomena at different scale of different field. This type of modeling aims at giving a description of the phenomena at different scales. In this field, (Gravemeier *et al.*, 2008) propose a step towards a taxonomy for multiscale methods in computational mechanics, that can be used to draw a parallel with our field of interest. This approach will be further explored to understand how it could enrich the proposed model.

REFERENCES

Boime B., 2005. Le projet Usine numérique : Un projet du pôle de compétitivité SYSTEM@TIC Paris Région. *Revue internationale d'ingénierie numérique*, 1-4, p. 393-402.

Bracht U. and Masurat T., 2005. The Digital Factory between vision and reality. *Computers in Industry*, 56 (4), p. 325-333.

Cheutet V., Léon J.C., Giannini F., Falcidieno B., 2007. Vers une structuration des représentations de composants dans une vue produit : application à la création de lignes clés esthétiques. *10ème Colloque National AIP PRIMECA*, La Plagne.

Chryssolouris G., Mavrikios D., Papakostas N., Mourtzis D., Michalos G., Georgoulias K., 2009. Digital manufacturing: history, perspectives, and outlook. *Proceedings of the I MECH E Part B Journal of Engineering Manufacture*, 223, p. 451-462.

Chu C.H., Wu P.H., Hsu Y.C., 2009. Multi-agent collaborative 3D design with geometric model at different levels of detail. *Robotics and Computer-Integrated Manufacturing*, 25 (2), p. 334–347.

CIMdata, 2008. Product Lifecycle Management (PLM) Definition. Disponible à l'adresse http://www.cimdata.com/plm/definition.html.

Cohen S. and Roussel J., 2004. *Strategic Supply Chain Management*. 1st ed., McGraw-Hill.

Curran R., Collins R., Poots G., Edgar T., Higgins C., Butterfield J., 2008. Digital Lean Manufacture (DLM): A New Management Methodology for Production Operations Integration. *Collaborative Product and Service Life Cycle Management for a Sustainable World*, Springer London, p. 551-571.

De Vin L.J., Ng A.H.C., Oscarsson J., 2004. Simulation Based Decision Support for Manufacturing System Life Cycle Management. *Journal of Advanced Manufacturing Systems*, 3(2), p. 115-128.

Drieux G., Léon J.C., Guillaume F., Chevassus N., Fine L., Poulat A., 2007. Interfacing product views through a mixed shape representation - Part 2: Model processing description. *International Journal on Interactive Design and Manufacturing*, 1 (2), p. 67-83.

Do N., Choi I.J., Song M., 2008. Propagation of engineering changes to multiple product data views using history of product structure changes. International Journal of Computer Integrated Manufacturing, 21(1), p. 19 – 32.

Falcidieno B., Spagnuolo M., Alliez P., Quak E., Houstis C., Vavalis E., 2004. Towards the semantics of digital shapes: the AIM@SHAPE approach. *European Workshop on the Integration of Knowledge, Semantic and Digital Media Technologies*, IEE Royal Statistical Society, London.

Fernandez-Madrigal J.A., Galindo C., Gonzalez J., Cruz-Martin E., Cruz-Martın, A., 2008. A software engineering approach for the development of heterogeneous robotic applications. *Robotics and Computer-Integrated Manufacturing*, 24 (1), p. 150–166.

Fleischmann B., Meyr H., Wagner M., 2008. Advanced planning. In: Stadtler H and Kilger C (eds). *Supply chain management and advanced planning: concepts, models, software, and case studies*. Springer: Berlin, p. 81–106.

Gravemeier V., Lenz S., Wall W.A., 2008. Towards a taxonomy for multiscale methods in computational mechanics: building blocks of existing methods. *Computational Mechanics*, 41 (2), p. 279-291.

Gunendran A.G. and Young R.I.M., 2006. An information and knowledge framework for multi-perspective design and manufacture. *International Journal of Computer Integrated Manufacturing*, 19 (4), p. 326-338.

Honglun H., Shouqian S., Yunhe P., 2007. Research on virtual human in ergonomic simulation. *Computers & Industrial Engineering*, 53 (2), p. 350–356.

Huguet P. and Grabot B., 1995. A conceptual framework for shopfloor production activity control. *International Journal of Computer Integrated Manufacturing*, 8(5), p. 357 – 369.

Kojima T., Ohtani S., Ohashi T., 2008. A manufacturing XML schema definition and its application to a data management system on the shop floor. *Robotics and Computer-Integrated Manufacturing*, 24 (4), p. 545–552.

Kühn W., 2006. Digital Factory – Integration of simulation enhancing the product and production process towards operative control and optimisation. *International Journal of Simulation Systems, Science & Technology*, 7(7), p. 27-39.

Léon J.C., Giannini F., Falcidieno B., Brunetti G., Graf H., Stork A., Véxo F., Thalmann D., 2005. Acquiring, structuring shapes and annotating them with semantics to improve design activities. *Proceedings of Virtual Concept 2005*, Biarritz.

Lin H.K. and Harding J.A., 2007. A manufacturing system engineering ontology model on the semantic web for inter-enterprise collaboration. *Computers in Industry*, 58 (5), p. 428–437.

Longo F. and Mirabelli G., 2008. An advanced supply chain management tool based on modeling and simulation. *Computers & Industrial Engineering*, 54 (3), p. 570–588.

Mahesh M., Ong S.K., Nee A.Y.C., Fuh J.Y.H., Zhang Y.F., 2007. Towards a generic distributed and collaborative digital manufacturing. *Robotics and Computer-Integrated Manufacturing*, 23(3), p. 267–275.

Michopoulos J.G., Farhat C., FishJ., 2005. Modeling and Simulation of Multiphysics Systems. *Journal of Computing and Information Science in Engineering*, 5 (3), p. 198-213.

Nagalingam S.V. and Lin G.C.I., 2008. CIM—still the solution for manufacturing industry. *Robotics and Computer-Integrated Manufacturing*, 24 (4), p. 332–344.

OLDP – On-Line Digital Production, 2009. http://systematic-paris-region.org/prive-systematic/BD/03outilsconceptionBD.pdf

Persson F. and Araldi M., 2009. The development of a dynamic supply chain analysis tool — Integration of SCOR and discrete event simulation. International Journal of Production Economics, 121 (2), p. 574-583.

Ryu K. and Yücesan E., 2007. CPM: A collaborative process modeling for cooperative manufacturers. *Advanced Engineering Informatics*, 21 (2), p. 231–239.

SCOR 9.1, 2009. www.supply-chain.org

SIMULIA, 2007. The case for Simulation Lifecycle Management. *SLM whitepaper*.

Song I.H., Yang J., Jo H., Choi S., 2009. Development of a lightweight CAE middleware for CAE data exchange. *International Journal of Computer Integrated Manufacturing*, 22 (9), p. 823–835.

Tseng Y.J., Kao Y.W., Huang F.Y., 2008. A model for evaluating a design change and the distributed manufacturing operations in a collaborative manufacturing environment. *Computers in Industry*, 59 (8), p. 798–807.

Tsuchiya S., 1993. Improving Knowledge Creation Ability through Organizational Learning. *Proceedings of International Symposium on the Management of Industrial and Corporate Knowledge ISMICK'93*, Compiegne.

Ullman D.G., 2009. *The Mechanical Design Process*. Mc Graw-Hill, 4th edition.

Usine Numérique 2, http://www.systematic-paris-region.org/fr/UserFiles/File/USINE%20NUMERIQUE%202.pdf

Vichare P., Nassehi A., Kumar S., Newman S.T., 2009. A Unified Manufacturing Resource Model for representing CNC machining systems. *Robotics and Computer-Integrated Manufacturing*, 25 (6), p. 999–1007.

Vitanov V., Tjahjono B., Marghalany I., 2007. A decision support tool to facilitate the design of cellular manufacturing layouts. *Computers & Industrial Engineering*, 52 (4), p. 380–403.

Wenzel S., Jessen U., Bernhard J., 2005. Classifications and conventions structure the handling of models within the Digital Factory. *Computers in Industry*, 56 (4), p. 334–346.

Woerner J. and Woern H., 2005. Security architecture integrated co-operative engineering platform for organised model exchange in a Digital Factory environment. *Computers in Industry*, 56 (4), p. 347–360.

Wöhlke G. and Schiller E., 2005. Digital Planning Validation in automotive industry. *Computers in Industry*, 56 (4), p. 393–405.

Zülch G. and Grieger T., 2005. Modelling of occupational health and safety aspects in the Digital Factory. *Computers in Industry*, 56 (4), p. 384–392.