Developing a Universal Numerical Control Machine based-on an Enterprise Multilevel Framework and its IPPMD Reference Map & Methodology

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Abstract: Nowadays more manufacturing enterprises are requiring the adoption of a structured process to improve their practices in a product development project. Using an enterprise multilevel framework, this paper introduces an Integrated Product, manufacturing Process and Manufacturing system Development (IPPMD) reference map and methodology to create a particular product development model and setting-up based-on it a successful concurrent product development process that is independent of the enterprise industrial sector and focuses on specific issues such as: market opportunities, technological constraints, stakeholders’ interrelations and declared goals related to the enterprise strategies. Furthermore, a study case is presented following the IPPMD methodology, which is supported by a reference map as part of the enterprise multilevel framework, and starts with a project scope definition and moves forward to the establishment of a particular product development model for a specific project, in this case: the development of a Universal Numerical Control (UNC) machine © 2009 Elsevier Ltd. All rights reserved.

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1. INTRODUCTION

Trends on methodologies for product development processes are introducing new design challenges that call for a novel systematic approach which should take into account the integration of diverse product and manufacturing design processes related to the entire product development lifecycle as suggested by different concurrent engineering initiatives. Typically, Concurrent Engineering (CE) is considered as the integration of product and manufacturing design processes in order to reduce the product development lead-time by overlapping activities and reducing the required time for each activity (Yazdani & Holmes, 1999). In addition: “as more lifecycle concerns enter into the product development process, established design procedures become more complex and can even take longer to complete” (Eppinger, 1991); therefore, this paper aims to offer an integrated methodology as concurrent engineering approach involving a product, manufacturing process and manufacturing system integration for a rapid configuration of a particular model for the entire product development process. The IPPMD methodology proposed in this work aims to apply in a proper manner a particular product development project in order to reduce the product development lead-time. The IPPMD methodology is proposed with a strong focus on SMEs manufacturing processes, since these small and medium-sized enterprises have been continuously looking for an interaction with their customers, suppliers and partners in order to obtain the advantages of concurrent engineering by changing their product development process in order to achieve real improvements in the product manufacturability.

In general, the final objective of any manufacturing enterprise is to combine depth knowledge regarding the product manufacturability with an understanding of the product functionality in order to develop better products and manufacturing processes. For this reason, new methodologies based-on concurrent engineering principles are focusing on integrated product, manufacturing process and manufacturing system approaches to achieve a concurrent product development process as a source of competitive advantage.

As mentioned before, to respond to the described challenge, an analysis in three levels has been carried-out to attain the complexity in a concurrent product development process in order to reduce product development lead-time. The general description of the manufacturing enterprise and its product development projects approach is presented through an enterprise framework (an enterprise triggering projects over the time), where a reference map is added to analysis in a proper manner a particular product development project (middle enterprise level), and where the individual-activity level (detailed enterprise level) is used for modelling purposes.
As a result, a systematic approach is proposed for the correct use of the enterprise multilevel framework linking its three levels of abstraction to obtain a particular product development model by following the IPPMD methodology.

In a simplified manner, the objective of this paper is oriented to the middle enterprise level of abstraction where the IPPMD reference map and methodology stand for a guide to obtain a particular product development model.

2. THE ENTERPRISE MULTILEVEL FRAMEWORK, AND THE IPPMD REFERENCE MAP & METHODOLOGY

To clarify the importance of a framework for modelling purposes, a modelling framework is defined as “a generic approach which may be applied for modelling any situation within its scope, but which in itself provides only general insights” (Browning et al., 2006). At the holistic level (highest level of abstraction), the concurrent development, lifecycle, and enterprise integration concepts are the main axes of the enterprise framework (see Fig. 1, LEFT). Instantiation process is another fundamental concept and concern to be included in an enterprise framework to achieve the stated goal related to the configuration/reconfiguration of a product development process/project.

Inside the enterprise entity, different activities are being carried-out to configure or reconfigure a set of product development projects over the time. Fig. 1 (LEFT) explains how different activities are being carried-out before a project acceptance, during it to configure the given accepted project, and after it to reconfigure the project if necessary to face any uncertainty during its execution. It is considered that inside the enterprise entity, several projects are being managed at the same time, including all business process activities. Only one product development project is represented in this case, but some other projects can be exhibited using the enterprise framework besides the existing integrated product development project. The holistic level of abstraction represented in Fig. 1 (LEFT), generates a three-dimensional space to characterize the main aspects of a product development project from the highest abstraction level to the detailed level. X axis is used to signify: What is needed to be developed at the time (concurrence axis)? Y axis is utilized to represent the time aspect of a project and answer the question: When is it being realized? and Z axis is used to define the project organisational aspects such as: project owner, clients, suppliers and partners representation. All these three axes together generate a 3D space for the product development activities depiction and their interconnection by information flows for modelling purposes (at the detailed level). Z axis (enterprise integration axis) answers the questions: Where and who is developing each part of the project? The entire 3D space answers the question: How a project is being developed? It is in this manner that a multilevel perception is required.

Based-on the multilevel perception depicted in Fig. 1 by decomposing the enterprise framework presented in Fig. 1 (LEFT), the complete framework introduces each one of its levels of abstraction. In Fig. 1 (CENTER), the IPPMD reference map is located as a middle level of abstraction inside the enterprise framework, and will be observed in a detailed manner in order to analyse an integrated product development project. The IPPMD reference map describes an integrated product development project using an axis for the concurrent product development process/activities (X axis) and another axis for the product development lifecycle phases (Y axis). In Fig. 1 (RIGHT), the detailed level is included as well and represented by the modelling in detail of any part of the IPPMD reference map by using the individual- activities depicted and interconnected inside the 3D space. Furthermore, an individual-activity is defined as an activity being carried-out by a single actor, using software and methods, hardware and materials, and receiving, processing and sending information, and it is considered as a building block (a module) of the whole integrated product development project.

The integration of different abstraction levels is a requirement and challenge in today’s manufacturing scenarios (Mesihovic et al., 2004). For the enterprise level, integration in every domain is required for taking into account every project as a whole according to the enterprise strategies. Furthermore, at the enterprise level, enterprise transformation has been deeply studied and a framework for this intention was proposed by Rouse (2005).

In addition, enterprise integration references about trends in this field are presented by Vernadat (2002) and Molina et al. (2007). On the other hand, at the project level (middle level), a well known discipline is Project Management (PM), and it is responsible to assure that the project is being realized according to the enterprise strategies. The Project Management Institute is a solid reference about this intermediate level of abstraction (IEEE Guide, 2004). For our purpose, the most convenient level of abstraction is the detailed one, and it is recognized as Product Data Management (PDM), a discipline which attempts to cover the entire enterprise environment including theories and commercial tools for the Product Lifecycle Management (PLM).

In relation with the product lifecycle, according to Ulrich & Eppinger (2008), the product development process is a sequence of phases that need to be realized in order to conceive, design and introduce a product into the market.

Considering this last definition, and taking into account the concurrent engineering principles as a primordial guide, the configuration of a product development process/project using the IPPMD reference map and methodology, and based-on the enterprise multilevel framework is going to be presented in a systematic and synthesized form. This approach considers an initial project scope definition for the configuration of a particular concurrent product development model based-on the enterprise strategies. For the configuration of an integrated product development project and as a contribution to the concurrent engineering principles, the IPPMD reference map (adapted from Aca et al, 2004) is introduced in order to describe the concurrent product development process using three fundamental entities: (1) the product entity, (2) the manufacturing process entity, and (3) the manufacturing system entity (see Fig. 1, CENTER).

A brief description of each reference map entity is followed for a better comprehension, and in addition, a previous work by Pereda et al (2008) can be utilized for this purpose too.
Past
• Knowledge was captured and stored to be reused for the configuration or reconfiguration of present projects.

Present
• A project is being triggered and being initially configured or reconfigured using stored knowledge acquired from past or ongoing similar projects.

Future
• Inside the enterprise entity, the project is still being configured depending on changing requirements or information evolution within or around the project.
• New knowledge is being acquired using the structure proposed in the reference map. Planned project development process is compared with the real product development process.

HOLISTIC Level (Enterprise Framework)
e.g. The enterprise entity is included, and a given project is being triggered as a subsystem inside the enterprise.

MIDDLE Level (IPPMD Reference Map)
e.g. Managing a given Integrated Product Development Project.

DETAILED Level (A Particular Model)
e.g. A 3D development process model using the space structured by the Holistic and Middle Levels.

Figure 1. Enterprise Multilevel Framework
Simultaneously with the product entity, the manufacturing process entity is followed, based-on the product idea and the feasible manufacturing processes identification, as one of the most critical activities in the concurrent product development process. After the manufacturing processes feasibility evaluation at the initial point, and based-on a selected product concept, an individual component analysis is required to figure-out which parts need to be acquired from a vendor, which technology is needed to be manufactured at home, and what special features (e.g. molds) need to be designed to complete the product development requirements.

Depending on the parts that need to be manufactured at home, the manufacturing processes selection is followed to join parts and subsystems while developing one product. At the end of this entity, the manufacturing process plan is determined taking into account the individual components, systems and interfaces related to the incoming new product. A detailed manufacturing process plan/chart is the logical delivery of this entity.

In concurrence with the product and manufacturing process entities, the manufacturing system entity is recommended to be realized as follows: Together with the product idea and feasible manufacturing processes identification, existing supply chains and preferred manufacturing systems need to be considered at the beginning of the integrated product development project. Preferred manufacturing systems can be considered the new generation manufacturing systems. Depending on the analysis done through the manufacturing process entity, the manufacturing system entity is responsible for managing the consecution of vendors, technology suppliers and the identification of special features to be integrated into the product development project. Next in this entity, through the materialization of the manufacturing process plan, the layout as part of the operation plan can be installed based-on the technology acquisition, and special features integration if any. Once this occurs, the ramp up production its being experimented.

In general, as a concise description for the concurrent product development process involving current demands or challenges, Giudice et al (2006) explain that it is possible to identify activities and elements that a great variety of possible product development processes have in common although there is no existence of a single model that can include all them.

In addition, for enabling the future product development processes evolution (reconfiguration), Giudice et al (2006) also add: “the identification and understanding of these shared factors, as well as allowing a descriptive summarization of the main activities involved, and a reference modelling for the comprehension, management, and control of the entire process, is also considered as the most effective guide”. As a contribution to enhance the last explained goal, and based-on reference models like: CIMOSA, GERAM and PERA, as well as in established methodologies for product development processes (e.g. Ulrich & Eppinger, 2008), a systematic approach known as the IPPMD methodology, consisting in six steps was generated in order to obtain in a rapid and agile manner a particular concurrent product development model for each integrated product development project (see Fig. 2). The IPPMD methodology it is proposed as a guide to aim a better use of the enterprise multilevel framework by integrating the three enterprise levels of abstraction introduced previously.

In other words, the IPPMD methodology is added to answer the question of How to use the described framework, and it is the main goal of this paper to explain its six steps. The enterprise framework uses six steps in sequential order (the IPPMD methodology) classified in two phases; one for project requirement analysis and another one for project instantiation. Before project definition <step 4>, the project requirements need to be analysed to determine the project scope. These first three steps are fundamental actions for the effective consideration of the integrated product, manufacturing process and manufacturing system development within the concurrent product development process.

Dynamically, inside the enterprise entity (see Fig. 1, LEFT) where the integrated product development projects are being triggered and configured/reconfigured, the first three steps are occurring before and during the project acceptance; and <steps 4 to 6> are occurring mainly after the integrated product development project has been accepted. This dynamism is depicted in Fig. 1, where the enterprise framework takes into account the project that is being authorized in a given moment in time (Y time axis).

At the <step 1>, project scope - enterprise strategies and stakeholders are defined in order to recognize all high level requirements related to the entire concurrent product development process. Understanding the project requirements related to the product, process and manufacturing system entities is useful to simplify the thoughtlessness of one entity depending on the stakeholders involved in the project. Next at <step 2>, the project idea status - is assessed to determine its current level of development in order to decide the project starting point: (a) product ideation or (b) product conceptual design stage with the aim of NOT including unneeded stages in the concurrent product development process. At <step 3>, named project identification - the project type is recognized and classified as (a) original design, (b) adaptive design or (c) variant design in order to include or exclude the initials stages represented in the IPPMD reference map (e.g. conceptualization and basic design) taking into account the concurrent development of the three entities, saving again unneeded processes.

At this point, with the information obtained by a manufacturing enterprise during the first three steps, the integrated product development project can reach a full determination and a proper selection of the entities involved in it and their stages to lead us to the project instantiation phase.
Additionally, during the project instantiation phase, the next questions should be answered in order to reach a successful integrated product, manufacturing process and manufacturing system development process for the integrated product development project: What knowledge is hold at this moment based-on existing platforms or other products experience? What is the rationale (logical interaction) of the design processes required for the incoming project realization? How can these processes be conceived in a concurrent system and represented for management purposes (using the detailed level of abstraction)?

Finally, during the integrated product development project it is important to consider the possibility of reconfigurations to the concurrent product development process as a way to take into account certain elements of uncertainty.

3.1 Project Scope: Goals & Stakeholders

In this first step, the product development scenario is recognized using the extended enterprise structure illustrated in Fig. 8. In this manner, the project objective is settled while stakeholders’ roles and their responsibilities are recognized.

The stakeholders analysis described will provide a general overview about the role that each stakeholder is going to play in the integrated product development project, focusing on the recognition of high level requirements related to the integrated product, manufacturing process and manufacturing system development process. Stages related to each stakeholder, depending on their relation with the IPPMD reference map, can be designated in each case bearing in mind the duty-bound among them. For instance, the ‘design supplier’ is related to the product development entity stages, the ‘process supplier’ is related to the process development entity stages, the ‘component and technology supplier(s)’ is/are related to the manufacturing system development entity stages, and the ‘project owner’ is responsible for managing the entire concurrent product development process at any stage. If a stakeholder is not selected (see Fig. 8), could signify that the project owner is in charge of that function, or that the function is not required in the project at all. The project owner is always selected.

3.2 Product Idea Status

In order to assess the product idea, which is being developed even before to the project acceptance, a set of questions are offered as a guide based-on Ulrich & Eppinger (2008): Is there a well defined product description? Are the benefits of the product recognized and properly described? Are the key business goals defined? Are the primary and secondary markets identified? Is there a general stakeholders’ relation analysis?

After questioning/assessing the product idea, depending on its status, and if the project is approved to be started, the product idea and the product conceptualization stages represented in the IPPMD reference map can be completed based-on the results of its status analysis. If a complete project conceptualization has been realized already or is in existence, the IPPMD reference map indicates (through the basic design phase) which stages are next to be developed by following an ideal concurrent approach considering an integrated product, manufacturing process and manufacturing system development process.
3.3 Project Complexity Identification

Depending on the project nature for an integrated product development, the implications and complexity can vary. Therefore, it is a fundamental step in the IPPMD methodology to recognize the incoming project, identify what is the basis for it, and what are the necessary activities to be developed to complete the entire product development demands.

A product development process may be required to be developed from scratch, or could be started based-on a determined platform for a well established and experimented product family. As well, requirements about changes of an existing product can be the nature of an incoming integrated product development project. These changes can require the adaptation of an existing product to another in a similar situation, or the changes can consist in a little variation of an existing product to maintain it competitive. Using a well known project complexity classifications proposed by Pahl et al (1995) and Ulrich & Eppinger (2008), a synthesis is presented in Fig. 9.

3.4 Project Definition (based-on Reference Map)

In order to start with the instantiation of a particular model as a final goal for a specific product development project, it is necessary to realize a project definition. During this step, the information about the enterprise requirements for the project realization <steps 1 to 3> is used to select stages for each stakeholder and the project goals are defined in accordance with the IPPMD reference map for each stakeholder involved in the integrated product development project.

The tasks to be realized in this step are: (a) adequate stages selection based-on the project requirements and span determination for a given stakeholder, and (b) project development process path (stages realization sequence) based-on the idealized IPPMD reference map.

For the adequate stages selection task in a particular integrated product development project, the project objectives, the product idea status and the project complexity will dictate which stages need to be developed. For instance, in a new integrated product development project, all stages from all entities need to be considered. In the opposite case, for incremental improvements to existing products, there is not a real difficult problem to solve, and only the prototype stage could be required.

For the stages realization sequence, an idealized stages realization scenario is presented in Fig. 3 using each stage code represented in the IPPMD reference map. The last stage sequence chart indicates the ideal concurrent development approach which is the primary proposed configuration to follow by the project owner and the other project stakeholders. Fig. 4(a) illustrates another possibility based-on the ideal scenario, where at some point during the concurrent product development process, the information was not enough to follow the extreme concurrent approach. As a not desired situation, the opposite extreme scenario is also presented through Fig. 4(b).

3.5 Partial Model Definition

If in existence, a partial model is considered in this step to facilitate the particular model generation which is the final goal as part of the concurrent product development process configuration. Each specific project, while being configured and realized, can generate or aggregate knowledge for an industrial sector which is considered as a partial model.

A partial model is the result of the instantiation of a general reference model (a framework including a knowledge repository). The partial model is obtained by capitalizing previous knowledge, inside an industry model, to be reused and applied to facilitate the modelling process for a particular project, depending on its industry or sector type. The content of each partial model consists, at the time, in a repository of experiences including a set of resources, methodologies, models, structures and processes that can achieve the goals (in a determined industrial sector) based-on successful cases and improvement suggestions. For this purpose, an example of a codification approach is exhibited in Fig. 11.

In order to generate a repository of partial models, a classification approach needs to be defined to store and retrieve partial models in an effective and efficient manner. A partial model signifies for this purpose, a defined model for a specific industry sector being identified by a code.

3.6 Particular Model Definition

A particular model is the selection of specific resources, methodologies, regulations and methods for the integrated product, manufacturing process and manufacturing systems development process depending on a specific integrated product development project.
Particular models could be constructed using activity building blocks approaches. As explained before, at the same time, particular models could generate partial models by capturing and organising experiences or knowledge over the time. As part of the last meaning, a modelling framework based-on activities, mainly the detailed enterprise level of abstraction, was chosen to signify the particular model representation. In relation with existing process modelling approaches, very significant literature reviews can be encountered already (e.g. Baabak et al, 2007; Wynn, 2007; Browning & Ramasesh, 2007; and Jun & Suh, 2008), where it is found that: “different modelling frameworks are used for different purposes depending on the stakeholders objectives, process nature (repetitive or project oriented) and process modelling approach applied for capturing complex characteristics appropriately or not” (Pereda et al, 2009). An application of a detailed modelling framework is presented in Fig. 6.

Fig. 6 is describing a three-dimensional depiction and it is considered the detailed enterprise abstraction level. This detailed level can be perceived as the decomposition of each stage, from the IPPDM reference map, into functional aspects (individual-activities), information flows, resources and organisational structures required to fulfil each stage for the total project development. All these considerations are included using the framework in its three abstraction levels (holistic, middle and detailed). In Fig. 6, an octahedron signifies that one individual-activity is triggering another required activity. The sphere icon represents that one individual-activity is sending or receiving information from another individual-activity or from the project development environment. A, B, C and D represent the integration issues among each individual-activity. In these spaces, requirements for each individual-activity are stored in an organised manner. For instance, in space “A”, engineers labour time, experience and capacities can be signified (stored). In space “B”, software tools and methods used to realize the activity can be attached. Hardware is signified using the space “C” (e.g. rapid prototyping machine, personal computer, etc.). “D” is utilized for materials required during product prototyping or for other reason during the progress of the activity. An important consideration in this detailed framework chosen for authors’ purposes, it is that in any given time, through the activity realization, a check-up can be realized by clicking in each letter place to obtain the activity status at that moment (based-on the future automation of this detailed framework).

A fundamental dynamic interaction between two individual-activities is depicted in Fig. 6. In this example, one activity (the electrical engineer’s activity) has been triggered by another activity (the mechanical engineer’s activity), which means that a sub-objective is being realized for the accomplishment of the higher order process/activity. As perceived, the electrical activity is in standby status at ‘week 22’ due to its objective accomplishment (sub-objective 10.1.1). In any manner, as occurs in engineering projects, a change could be requested and this activity could be reactivated with a variant of the original objective (another iteration will be need it). Therefore, knowledge can be gained by focusing on the integrated project development process (see Fig. 7).

In order to describe how to store experiences based-on a particular model to enhance partial models and to be reused in future particular models belonging to the same industry sector, in Fig. 7 it is represented a planned individual-activity compared with the same individual-activity already realized and which is ready to be stored. This representation includes iterations required to obtain an initial engineering solution and iterations to improve the existent solution.

4. DEVELOPMENT OF A UNIVERSAL NUMERICAL CONTROL MACHINE USING IPPMD METHODOLOGY

Vernadat (2002) and Molina et al (2007) expose trends to anticipate future integration problems and to solve existing problems in the Enterprise Integration (EI) field, where considerations about information systems, process modelling, organisational staff and technology standards are taken. Based-on these literature reviews and predictions, more suitable models can be constructed for today’s manufacturing challenges. In addition, by using a previous work related to the application of a concurrent product development methodology for a bamboo machine encountered in Riba et al (2005), the following example is described following the IPPMD reference map and methodology proposed.

The Universal Numeric Control (UNC) is an integrated product development project whose goal is to develop open platforms to reconvert old machine-tools to automatic machines and upgrade machine-tools with obsolete control for SMEs (see Fig. 5).

The main concerns in developing this kind of product are: (1) metal-working industry rarely has access to UNC machine-tools and they work with conventional machine-tools, and (2) there is an opportunity to develop UNC technology using low cost PCs, object oriented programming and a software base open system reference architecture implemented with real time OS (Ramirez et al, 2001; 2004).

An example of the UNC extended enterprise structure diagram is exhibit in Fig. 8, where the ‘project owner’ is an educational institution (e.g. a University Research Chair).
**ANALYSIS**

**A B C D**

Week. 16

Standby status

**Electrical engineer**

Sub-objective activity 10.1

Week. 17

Week. 18

Week. 19

Week. 20

Week. 21

Week. 22

Week. 23

**Mechanical engineer**

Sub-objective activity 10.1.1

- Information flows including:
  - Questions, and
  - Solutions or partial solutions

Octahedron. A node which represents a process/activity being triggered by other activity

Sphere. Represents the node for sending and receiving information

**SYNTHESIS EVALUATION**

Person's brain (labor time, experience, memory capacity, processing capacities, senses)

Data base

PC Magnetic disk

**Figures 6 & 7. Particular Model Representation Example**

(Based-on Pereda et al, 2009)

**Engineering Process/activity planned at the beginning and through the project realization**

Analysis step

Synthesis step

Evaluation step

(solutions or partial solutions)

(only one iteration was required to obtain a feasible solution)

(an optimized solution was obtained and delivered)

(there was a delay experimented during this step)

- First iteration required to optimize the solution
- **Standby status (the goal was obtained in an optimized manner)**

* At this point, a reactivation of the activity has occurred due to an engineering change

* At this point, through week 24, a final requested objective was obtained

**Engineering Process/activity completed at the end of the project**

(incorporated for knowledge reuse and analysis)

First iteration required to obtain an initial feasible solution

(only one iteration was required to obtain a feasible solution)

(there was a delay experimented during this step)

**Figure 7. Comparison between the same Individual-Activity: Planned and Realized**

(Adapted from Pereda et al, 2009)
The UNC extended enterprise structure diagram depicts that neither the ‘design supplier’ nor the ‘manufacturing process supplier’ are considered as stakeholders for the UNC integrated product development process, which means that the ‘project owner’ is responsible for these functions. On the other hand, regarding the ‘components supplier’ and the ‘technology supplier’, these were selected as project stakeholders for the parts purchase and for the technology acquisition to allow the manufacturing of components at the ‘project owner’ facility. The ‘clients’ are recognized as SMEs consisting in machine shops which use traditional machine-tools for their day-to-day operation. The ‘project objective’ is to develop a UNC system as a low cost software to be applied to the traditional machine-tools in order to offer a disrupted automated and reprogrammable machine technology for an emerging market.

Figure 8. UNC Extended Enterprise Structure Diagram

4.2 Product Idea Status

Product description: A UNC machine based-on a low cost software technology.

Product benefits: An automated, reprogrammable and standardized machine-tool at low cost.

Key business goals: Developing in a low cost and rapid manner products for emerging markets, improving the products quality and incrementing the exportations.

Primary market: At least the 50% of the traditional machine-tools (existing in machine shops) are being transformed into UNC machines in Monterrey, Mexico.

Stakeholders’ relations analysis: Acquisition of subsystems as motors and sensors from Chinese suppliers.

4.3 UNC Project Identification

As a particular model, based-on the project complexity classification depicted in Fig. 9, the UNC is considered as a derivation of an existing product platforms, taking into account the amount of information and experimentation that has been obtained in relation with this integrated product development project, for emerging markets.

4.4 UNC Project Definition (based-on Reference Map)

Using the IPPMD reference map, the stages selection for the UNC development project are presented in Fig. 10, considering that a product idea is already in existence and that the complexity of the project is assuaged by experience and existing information. The stages from the product development entity were: product detail design and product prototype - where no stakeholders related to the product development entity are selected; these stages are going to be realized by ‘project owner’. Note: the product idea was identify as “existnet” and the product conceptual design considered as done by a research platform in were some concepts have been already developed and the product concept selection realized.

Figure 9. UNC Project Complexity Classification

Figure 10. UNC Project IPPMD Reference Map

The stages selection corresponding to the process development entity were: manufacturing process selection, and manufacturing process plan - in where no stakeholders related to the process development entity are selected and both stages are going to be realized by the ‘project owner’. Note: when the project type is classified as a “derivation of existing product platform”, normally it can be assumed that mainly the manufacturing process plan and ramp-up production (from the manufacturing system entity) stages are needed because there is already a platform as the basis in where a lot of information is in existence. In this case, the process selection stage is also required because these specifications have not been established yet.
The stages selection corresponding to the manufacturing system development entity and focused on the product transfer sub-entity were: manufacturing partner selection, and manufacturing & quality control. A stakeholder related to the product transfer sub-entity was selected and these stages mentioned were delegated or shared with the related stakeholder.

The stages selection corresponding to the manufacturing system development entity and focused on the technology transfer sub-entity were: equipment specification and system development entity and focused on the technology stakeholder.

After the industry sector/type recognition, the information related to the partial model (in this case, the metalworking industry) is retrieved from the original source.

4.6 UNC Particular Model Definition
A more detailed approach is needed to generate a particular model. Some functional (activities) detailed aspects are required and are exhibited in Fig. 12 as an example of typical engineering activities from an engineering project.

<table>
<thead>
<tr>
<th>Entity</th>
<th>Product Development Entity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage</td>
<td>Product Conceptual Design</td>
</tr>
<tr>
<td>Table</td>
<td>Sub-Activities</td>
</tr>
<tr>
<td></td>
<td>Activities</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>01 Mechanical</td>
<td>00 Not implied (e.g. Standard parts, Software)</td>
</tr>
<tr>
<td>02 Electrical</td>
<td>01 Metals</td>
</tr>
<tr>
<td>03 Software</td>
<td>02 Polymers</td>
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<tr>
<td>04 Industrial</td>
<td>03 Ceramics</td>
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<td>04 Composites</td>
<td></td>
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<tr>
<td>D____</td>
<td>M____</td>
</tr>
</tbody>
</table>

Figure 12. Product Conceptual Design Stage Activities

Generic activities and detailed activities are presented and decomposed based-on its nature (analysis, synthesis and evaluation) although analysis, synthesis and evaluation can happen always in a micro and macro process level. Besides the individual-activities recognition and adaption, information links, resources assignation and organisational structures need to be prescribed for the generation of the particular model. For this reason, the detailed modelling framework is going to be used for the planning work and an example for this case is shown in Fig. 1 (RIGHT). The main stakeholders in this study case are the ‘project management’ by the main Campus from the University and two more Campuses: “A” for the ‘mechanical engineering’ and “B” for the ‘electrical engineering’.

5. CONCLUSIONS & FURTHER WORK
The IPPMD reference map and methodology discussed in this paper shows a fast and easy way for creating a particular design model for a specific integrated product development project that is related to an integrated product, manufacturing process and manufacturing system development for the manufacturing of a (new) product in a concurrent way.

The UNC study case proves some of the IPPMD methodology benefits in a real integrated product development project, obtaining excellent results and providing some guidelines on
the way that integrated product development projects should be performed in order to reduce the product development time using concepts such as concurrent engineering and product development models instantiation.

Further work will focus on improving the IPPMD methodology and its tool box and creating more partial models for the mechatronic industry in order to avoid redundant processes and capitalize on previous knowledge regarding integrated product development projects.

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REFERENCES


SHORT-BIOGRAPHIES

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Professor Dr. Arturo Molina is the General Director of the Tecnológico de Monterrey, Campus Mexico City. He received his PhD degree in Manufacturing Engineering at Loughborough University of Technology, England (1995), his University Doctor Degree in Mechanical Engineering at the Technical University of Budapest, Hungary (1992), and his Master’s Degree in Computer Science from Tecnológico de Monterrey, Campus Monterrey, Mexico (1992). Professor Molina is a member of the National Researchers System of Mexico (SNI-Level II), Mexican Academy of Sciences, and member of IFAC TC-WG 5.3 on Enterprise Integration and Enterprise Networking, IFIP WG5.12 on Enterprise Integration Architectures and IFIP WG 5.3 Cooperation of Virtual Enterprises and Virtual Organisations.