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DESIGN PROCESS MODELLING AND COMPLEXITY: WHICH KEY SUCCESS FACTORS FOR THE IMPLEMENTATION OF A PDM TOOL?

B.Nicquevert, J. F.Boujut and S.Yami

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1. Introduction

This paper focuses on the observation of the way information tools are implemented in order to support the design process used in large scientific collaborations such as those acting at CERN, the European laboratory for particle physics. We first present a detailed description of a Product Data Management (PDM) tool implementation project for the various CERN design offices. Then we highlight some of the key dates and obstacles met during the process of such complex projects.
As a result, we revisit the list of key success factors from the literature, either generally speaking [Pinto and Prescott 1988] or more specifically for ERPs [Nah et al. 2001] or agile software [Chow and Cao 2008]. The latter, for instance, focuses on delivery strategy and team capability. However, these lists of critical success factors do not cover the specific case of PDM implentation, and they do not always pay full attention to the complexity of the organisational context or of the products themselves, as met in large scientific collaborations. In addition, they might well not be adapted to non-industrial contexts, where the ROI (Return on investment) is not a relevant criterion of a project's success.
In this paper, we focus on the process modelling and the way the requirements of the users are defined and caught in the PDM project. We emphasise the crucial role of the technical manager due to his interface position in the process. Indeed, in such projects, his added value is to manage the complexity, by linking two types of simplification: that of the management, aimed at the final milestones and output of the project; and that of the designers, which is focused mainly on the questions of the use of the tool. The technical manager helps reconcile the tension between these two contradictory views, by going beyond the dual vision and reintroducing some complexity in the implementation process. The result is a reunification of the views of the various stakeholders.
We claim that complexity is not an issue but the key towards success, and the management of this complexity, in opposition to the reduction of the complexity, is a way to deal with the contradictory views of the various stakeholders of complex design projects. And the ultimate aim is to enrich the list of success factors with new factors linked to the management of technical complexity, and the complexity of technical management.

2. Method

This paper is part of a wider research project, whose aim is to conduct a qualitative multiple-case study, as categorized by Yin [2009]. The question addressed is the role of the so-called technical manager in complex projects, either due to the complexity of the deliverable, or to the complexity of the organisational context, or both. The other linked cases of our multiple-case study cover the field of space management in a particle physics experiment, of project management of mechanical parts design and procurement, and of flow management of heavy magnets during the installation phase. In order to adapt the case study research to the field of design, we follow Blessing's Design Research Methodology (DRM) as articulated for instance in Bender et al. (2002): a first study on a given case is an a priori analysis called Type I Descriptive study. This paper belongs to this category, together with the three others on space, on project, and on logistics. Formulating a criterion to define the role of the technical manager, and leading to measure the success of their action is, however, not straightforward, and some more attention needs to be paid to this later, in order to better recognize the strategic role of these technical managers [Floyd and Wooldridge 1994].

The case we address here deals with the implementation of a PDM system. After a presentation of the complex context, we focus on the process modelling, and more specifically on the coordination challenges around the process of process modelling. Our question is then: *through which process is the process of process modelling defined*, and how are all stakeholders directed along the same line of action? In a more general way, according to the works on design method development like [Teegavarapu et al. 2008], we shall consider the process of process modelling as a design process itself, of organisational nature.

The particular position of one of the authors gives access to data from the inside of the project of implementation of a PDM tool, for which he held during almost two years a coordinating position. These data include the most detailed technical issues as well as the widest strategic questions raised during this crucial phase of the project starting after the installation of the software. Our observation starts with the first use case and goes back to questioning the users' requirements. During this process of learning by doing, many issues were raised which may be extended to other frameworks of large projects or large organisations having to deal with complex and not fully stabilised design processes.

At the end of the paper, some more prescriptive proposals are sketched out, and will serve as the basis and first elements of a Prescriptive study, currently in work. A more in-depth comparison of the results of the analysis of the present study will be performed with previous studies. Some ideas are discussed about the way the conceptual tools of complexity theory can be of great help in order to describe the behaviour of the organisation and of the various stakeholders.

The final stage of this case study is to use these prescriptions on a new project, started early 2010. This will be used in the DRM to feed a so called “Type II descriptive study”, aiming at analyse the same case a posteriori, where the differences with the first project will be scrutinised. This will be action research, following the recommendations of Avison et al. (1999). The overall multiple case-study on the role of technical manager will at the end contribute to build, as recommended by Eisenhardt (1989), a theoretical model on the potential use of complexity tools by the technical managers.

3. Presentation of the case study: implementation of a PDM tool for design offices

This section deals with the various stakeholders and the organisational structures in which they are embedded. It summarises the main phases of the project and the outcomes with regard to an ideal way.

3.1 Stakeholders and organisational structures

Located in Geneva astride the Swiss–French border, the aim of CERN is to build and operate large particle accelerators, and host huge experiments [Stapnes 2007]. These experiments are formed of large collaboration of physicists, engineers and technicians, and they are searching for the most hidden secrets of the Universe, like the origin of mass or the nature of dark matter. The first proton beams circulated in the Large Hadron Collider (LHC) [Brüning and Collier 2007] in September 2008, and the first collisions were performed one year later, opening a new era in the field of high-energy physics.

The designed systems include a variety of ultra-high vacuum, cryogenics, superconducting magnets, advanced materials, very high speed acquisition electronics, computing grids, and can undoubtedly be referred to as complex products and systems (CoPS) [Hobday et al. 2000] and large technical systems (LTS) [Giikalp 1992], since it is considered as the most complex machine ever created. The LHC and its experiments represent the flagship of Big Science. In this context of fundamental research, the engineering and design teams play a key role, often underestimated in the media. These large and complex technical installations have no equivalent in the world, and hence raised specific issues for design and development. At the same time, they have to comply with the requirements of the industries in charge of manufacturing each component, with some challenges of both a technical and organisational order.

Designing large scale devices such as an accelerator or an experiment implies the involvement of numerous expertises. To give some figures, the LHC accelerator, installed in a 27 km long tunnel, is made of 2000 superconducting magnets, two thirds of them are more than 15 m long and weigh 35 tons, and they are located within the geodetic framework with a precision of a few tenths of a millimetre. The question is not only to design the objects themselves, but at the same time take into account their interconnections, their support, their electrical and fluids feeding, and also their handling, their maintenance, and all phases in their lifecycle. The engineering fields involved range from civil engineering to electronics and control, and include mechanics, cryogenics, magnetic, specific handling, cooling and ventilation, electrical, and geometrical survey. The requirements upon the information system to support a common description of the designed CoPS are quite challenging. Moreover, some of the design offices were not located at CERN, leading to the management of the exchange and sharing of data among various information systems. For experiments and so-called physics collaborations, the challenge was even more demanding since the design teams were located all around the world, using different CAD software, with different technical cultures and different ways of managing and approving data. In the remaining part of this paper, we shall focus on the case of the design of an accelerator at CERN.

Today at CERN, about 100 professional designers work in structured design offices. Almost half of them deal with mechanics or cryogenics. The other half is made up of people involved in the design of detectors, or who take care of the technical facilities. The work of all these designers is then collated by the integration office, whose role is to check for inconsistencies or clashes between objects, and to virtually rebuild the machines and experiments. From the organisational point of view, these actors are not part of the same units. CERN is organised in departments, along an organisation which is mainly function-oriented, and is not completely based on the "technical domain" axis of the various design offices. Therefore, the stakeholders have to agree on a common tool at a relatively high decision-making level.

Beyond these relationships, the integration office is in close connection with the project management, mainly for configuration management issues (engineering change requests) in agreement with the Quality Assurance Plan. The data provided and managed by the integration office are the source of the baseline, that is, the dynamic set of data in the last approved state that describe the project. The PDM is therefore the input source for all subsequent data management operations on 3D models.

The next element of organisational complexity is that CERN provides to the designer and final user of CAD and PDM tool three different channels to send feedback to the software vendor. This is due to historical reasons within CERN, as well as to internal and external restructuring of the software company. The first channel is through the support teams (local support in each design office, CERN-wide CAD support teams either for use or for installation and running); the second one is hierarchical, through the head of the design office, group and department leaders. In parallel with these two channels, there are still various committees at CERN level, deciding on the strategy, choice of implementation or customisation of the tools. The co-existence of these various channels offers versatility, and at the same time, because they are made of several layers, they are sometimes perceived as counterproductive by the end user: how can his requirements be taken into account? This is one of the organisational challenges.

3.2 A theoretical roadmap of implementation

The present section describes what is considered by CERN stakeholders as the "normal" way to proceed when dealing with the implementation of an information system. The "User and Support requirements for CAD" at CERN in 2002 is based on some standard practices in the field of aeronautics, as formalised by the European Space Agency [1996]. According to this standard, "*all software projects shall have a life cycle approach which includes the basic phases [of]: UR phase - Definition of the user requirements; SR phase - Definition of the software requirements; AD phase - Definition of the architectural design; DD phase - Detailed design and production of the code; TR phase - Transfer of the software to operations; OM phase - Operations and maintenance*". There are

three lifecycle models: waterfall, incremental delivery, and evolutionary development. The choice of the approach shall be clarified from the beginning in the software management plan.
The first phase of definition of the user requirements "*is the 'problem definition phase' of a software project. The scope of the system must be defined. The user requirements must be captured. This may be done by interview or survey, or by building prototypes. Specific user requirements must be identified and documented in the User Requirements Document (URD)*". The internal business modelling is the input of this phase. It assumes that this modelling is known or pre-existing, and that software is a transcription of these processes.
For this theoretical roadmap of implementation, the basis is the user requirements, and whatever lifecycle model is chosen, the overall software development process is rather deterministic. On the contrary, a strategy which would start from an existing tool as the basis for defining the uses is not covered by these standards, and not considered as theoretically desirable or advisable.

3.3 Project phases and challenges

Implementing Product Lifecycle Management (PLM) software is a large undertaking, as it covers the whole lifecycle of the product, and more widely the whole organisation around the product. The case studied below is the implementation of a Product Data Management (PDM) tool, whose role in the overall picture of a PLM tool is to manage the data which describe the geometry and the structure of the product. This is a workgroup tool, made for the design offices to manage their CAD files, while PLM acts at the level of the whole organisation, to integrate these data in a wider context. The aim of the project here is to provide a PDM tool to deal with the data produced by the new CAD tool.

3.3.1 Launch and first phases

The project of the implementation of new PDM software for the design offices at CERN was triggered by the hard constraint to change the CAD software system: used since 1983, it was out-of-date and no longer supported by its supplier. There was then a hard deadline: no more data and design production with the former software after 2008. At the same time, the accelerator project was constrained by the requirement that the production of design data and their integration should be continued without disruption, and even without slowing down. Unfortunately, owing to some delays in the LHC project itself, the end of 2008 was also the launch date of the accelerator, and the last months before this launch were those of peak activity for all design offices, with all the last bids and pieces to be sorted out. On top of this, after a brilliant start on September 10^{th}, the LHC experienced a breakdown. Designers and engineers had then to go back into their data using the software which was being phased out. The challenge was therefore to design a new magnet protection system in the very last weeks of running of the old CAD software.
The next constraint on the project, after those of continuity in production, the hard deadline to be met, and the non-availability of most of the design teams due to the end of the LHC project, was that the PDM software itself had not been chosen by any of the stakeholders. A few years before, during the selection phase of the new CAD software, the various bidders offered the same PDM software to support their operation. At this point, the remaining questions were mainly to decide how to organise the effort in order to change the CAD and the PDM software at the same time; and above all, how to organise in order to carry this effort. In a word, the challenge was to *design the process of choosing the design tool aimed at designing the product.*
Because the PDM software had been chosen "by force of circumstance", the project started from the very beginning by installing the software on a server. One of the properties of this kind of software is its ability to carry out any process. The first consequence is that it cannot really run without a minimal set of parameters tuned for the customer. The concept of a software running "out of the box" seems to be a rational myth. You cannot "plug and play" with a PDM, because it is up to you to define how to play with it, and the game is yours. And the plugging phase can be even more painful than imagined.
After a first pilot project, and an audit of the users in order to better understand the expressed or hidden expectations of the final users towards the software with respect to their own practice, the CERN-wide support team offered a running environment that was the best it could understand. Unfortunately, at that time (2007) it did not have access to the most experienced users of the various

design offices, who were kept busy with the completion and repair of the LHC. The support team does not own the practices in use within the design offices, and the solution implemented was then far away from their best practices. This is one of the main failures, because in complete contradiction with the basic functioning of software development procedures starting from the users' requirements.

It was decided to set up a steering group in order to coordinate the implementation. The mandate of this committee, with representatives from both design offices and support team, was to "*hierarchize and implement the developments according to the needs expressed by the users, within constraints imposed by the existing tools and the available resources; and to deploy a PLM way of working and help the users to take over the related tools and concepts*" [mandate of the "PDM–Soft-coord" group, April 2008]. This group was convened by a new partner, not bound the previous stakeholders.

3.3.2 Coordinated phase

The first step of the steering group was to propose a schedule and plan for actions. Two parallel paths had to be followed. The first one, so-called "short term" (several months), was aimed at stabilising the functional perimeter of the PDM software, hence avoiding "on the fly" development: the final users were dissatisfied with a GUI and behaviour of the software which were changing every day and without prior notice. The other path of action for the "mid term" (one year) was to trigger the preparation of a set of users' needs, taking into account the various technical domains and the various expectations. This path was then supposed to yield to a phase of users' requirements definition (according to the recommendations of the ESA standard). This scheme was compliant with the ideal roadmap discussed in Section 3.3.

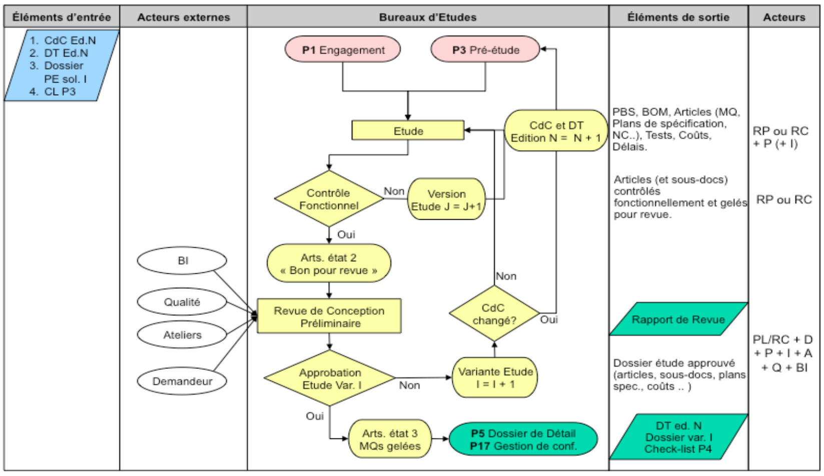

Figure 1. An extract of the mechanical design office process modelling

In order to get external and non-biased coordination, the group decided to hire two external advisors (consultants). The first one was recommended (and accredited) by the PDM software vendor in order to work with the support group. He helped to configure and customise the installation, and to develop a suitable data model within the constraints of the existing software. Further developments anyhow required a clear definition of the workflows and internal processes. The second external advisor was indeed invited to help the CERN community better express its expectations with respect to what a PDM or PLM software could offer, and formalise the functional specification of the end users. The aim of this expertise was to offer a data structuring method, regardless of the software used (based on known languages like UML or MERISE). The result of both consultancies was that CERN teams had to work on the definition of their internal processes, which was the basis for both short and longer term paths of development. In addition, the need for a powerful project management and redefinition of the mandate of the coordinating bodies was highlighted.

In the autumn of 2008, the design offices decided to prepare the description of their processes. About 30 designers and engineers were interviewed; a first draft was issued. This description gave an overview of the picture, and the actors were mentioned, as well as some workflow description (figure 1). This was, however, done at a rather high level of description, centred on the mechanical design offices, and the links with the other stakeholders like the integration office were hardly described. This document was welcomed as a decisive step forward, and was considered as a good start for a wide discussion. On the other hand, it was considered unusable by the Support team as a basis for a real description of the users' requirements. The same happened to the integration processes modelled by the integration office. A global and common effort turned out to be more challenging.

3.3.3 Beyond coordinated phase

During the spring of 2009, it was decided by the CAEC (Computer Aided Engineering Committee) to set up a new working group, putting forward the users themselves and giving them more scope for decision. This new group merged the activities of the groups in charge of the CAD software introduction and of the PDM software coordination, as the issues were too much linked together. This new users' group promoted three real end users as leaders of the coordination. The first decision of this users' group was to launch a wide review of the needs and expectations of the final users. One of the motivations was that more and more users were reluctant to use PDM software: the lack of clear guidelines was preventing a real full scale deployment, and was causing discrepancies in the way the data were structured. Duplication of data - a major source of confusion - could not be avoided, and even the validity status of the data was no longer clear. A last attempt to use BPMN (Business Process Modelling Notation) methodology came too late. Each stakeholder then pulled in his own direction according to what he believed to be his own best interest, and regardless of an overall optimisation.

Despite this rather dark picture, it is interesting to look back at several key points in order to draw some lessons from this experience. This is the aim of the following sections, where we shall see that the picture may finally appear less dark than perceived.

3.3.4 First lessons from the case study

What are the key success factors for implementing a PDM software project? This case is characterized by complexity for many reasons: the number of stakeholders, the time and resource constraints, the (sometimes new) concepts to deal with, the changes in daily operations for many final users. To some extent, disorder defeated any organisational effort to coordinate the various actions. Another characteristic of complexity was the simultaneous development of two paths, one being driven by the existing tool, the other being led mainly by the internal business processes, with no clear choice as to which should get priority. There was mutual influence, but no constructive interference. Was this due to a failure in the coordination task, or an intrinsic issue?

The final users were somehow frustrated by a system that did not meet their daily expectations (and sometimes did not even reach the level of the former system). The basic request was to save data in a safe manner, to retrieve and share them with colleagues. Even these basic features seemed too painful for a designer. One of them claimed: "*We are here to find technical solutions, not to manage data*".

As far as CERN as an organisation as a whole is concerned, PDM and in general EDMS (Engineering Data Management) issues are covered at the level of some department leaders, with the view that "it must be running", that is "produce drawings", and eventually 3D models; the management of data seemed to be a blind spot at this level. The eventual consequences on design quality were not considered as an issue that would trigger specific corrective actions; it might even be used as an argument to outsource the design work. Mainly quantitative indicators seemed relevant regardless of more qualitative ones. Seen from the top management, the designer's job is to produce drawings in order to manufacture and install technical devices. In order to reach this pragmatic goal, it is up to the middle technical management to make sure that the tools used in the design offices are coherent with the internal policy of the departments, and to take care of the issue of data management.

This emphasises the role of the coordination instances (CAEC) and of the first level of hierarchy, the technical manager: he stands at the intersection of a multilayer canvas. Amongst others, two key factors have to be mentioned and balanced: the overall return on investment, and the local return on investment (local being either individual or for a specific team). In our case, technical management partially failed to find the right balance between the various stakeholders, and the implementation project ended at a level where the tools were used, but far from the full satisfaction of end users.

However, the situation raises some questions: was it really a failure? How does one evaluate the success of such a project? Do we not see the consequences of an overestimated goal, and that designers can finally survive and do not want to invest more energy in a tool that they are not convinced of?

4. Lessons on success factors from the analysis of a PDM implementation project

The case of a CERN project described in Section 3 sheds light on some issues that can be turned in a more prescriptive way and summarised into a list of success factors. We briefly review those related to the organisational context, and spend more time on a concrete example linked to the design process modelling. We then end this section by discussing the question of strategic views and actions.

4.1 Organisational context

Of the constraints on the project, the time constraint is (as usual) a painful one. However, it must be recognised that business process modelling is a process *per se*, and that it requires a long *maturation*. Even in fields where daily practices are well established, it is not straightforward to formalise them in a systematic way. Everybody knows how difficult it is to sit down and watch oneself walking. The reflexive practice put forward by the famous work of Schön [1995] is very interesting from a theoretical point of view, but remains an illusion for most practitioners in design offices.

Facing a community of designers, their fear of being loaded with what they consider useless tasks must be considered. We believe that it is not a resistance to change which is the prime engine of their reluctance, but more the fear of the absence of an *individual return on investment*: they can see the personal cost (time and energy spent to learn a tool, to define requirements, to test software, to organise their data); it is harder for them to imagine a priori the rewards. Managing data is a must, and they can agree about this; but they cannot agree that this comes first.

Linked to this, the quality of the services delivered to the users during the implementation phase is of primary importance. This begins with a high-level and long enough training course - the first and key investment. Then there must be a follow-up in their working place, with dedicated supporting and mentoring people. A prerequisite is that some guidelines based on good practice be made available. But not in a fixed manner: out of these good practices, each user should have an opportunity to build up his own way of using the system, to take over the tools and the concepts, to establish his own use cases, whilst respecting the reusability constraints of these practices with those of other colleagues.

4.2 Design processes modelling: the case of the simplified 3D models

In this section, we focus on a specific case whose power of illustration can be ranked high: the case of the simplified 3D models. The integration office receives 3D models, at various states of maturity and of approval [Blanco et al. 2007] from all the other design offices. Whatever the state, and in order to get at least a first look at the effects of a new change, this 3D model must be incorporated in the overall integration scene, with all its neighbours (in order to detect possible clashes) and in an overall technical context (to check the interfaces and connections). Some of these 3D models can be rather heavy, and the weight can be of various types: the size of the file of course, but also the number of subcomponents, the number of interfaces, the methodology used, etc. In any case, after several full 3D models are put in a scene, the work of the integrator turns out to be undoable, either because of complexity, or because of CAD software performance. This of course jeopardizes the possibility to automate the reconstruction process, using a database of theoretical locations of elements, and another database (managed by the PDM software) of full and simplified models correctly correlated regarding the lifecycle and configuration. (A fully automated reconstruction might be another rational myth.)

Hence, there is a request that simplified 3D models should be produced for use by the integration team. And hence the problems: who will produce them? And with which methodology, that is, keeping which information and simplifying which other? The first question is linked to the second, because depending on the nature of information to be kept or simplified, it can sound more reasonable to request that the simplified model be produced by the initial owner, or by the final user at the integration office. However, independently of who produces the simplified model, the question remains: who is the owner of it, and by whom should it be approved?

This example shows that how to deal with interfaces between 3D models (and beyond this, between real objects) is linked to how to deal with interfaces between internal processes. To come back to the first attempt of the mechanical design offices to draw their processes, the production of simplified 3D models is not even taken into consideration, and they regard their process as ended once the full 3D model is released. On the other hand, the integration office tends to refuse to take care of the simplification process, because it must be based on a good internal knowledge of the content of these models, and that the consistency of the simplified with respect to the complete model cannot be guaranteed. So far, because this is the final link in the chain for which interest in the simplification process is highest, the integration office takes care of the operation, with consequences on resources and on the availability of the few integrators to focus on their integration work. The question of responsibility is not clarified when an important feature of the full model is removed from the simplified model. In order to handle this, a new intermediate object was proposed, the skeleton, which defines the interfaces of an object with its surrounding world. This skeleton is aimed at being used and embedded within both the complete and simplified 3D models. But this introduction of the skeleton raises many other questions regarding the CAD model structure management, which leads to enforced connections between design offices and integration office internal processes. With this case, the complexity can be seen at work. Dealing with CAD files is not sufficient. Considering the design and integration as sequential phases of a linear process does not take into account the semantic, knowledge content of these files, even if feedback loops are introduced in the process. Those phases have to be incorporated in a single, overall process, that will extend the links between design and integration to a much more elementary level. Complexity loops (in the recursive sense of Edgar Morin [2008]) occur at each and every level. The simplification process of an object must keep the whole of the semantic content of the elements of this object as far as the aim (here, geometrical integration) of the simplification process is concerned, in order to guarantee that the overall complexity of the system can be later modelled at full scale. The simplification process is not a simple process, because the meaning attached by each stakeholder is different and closely linked to his own goals. In order to get an overall picture of the system as a whole, made of complex objects, these objects need to be simplified. And it looks as if there is a need for a de-simplification process at work, whose aim is to re-inject some of the features lost in the simplification process, at the appropriate level, in order to keep the overall picture and the richness of interactions between objects alive at the level of the system.

This raises an important point that is mostly underestimated: we need to elicit expert knowledge, clarify some domain dependent points in order to understand the rational of the simplification process. It appears in this case that the stakeholders never shared any domain-dependent rules, nor expert knowledge. It mostly remained implicit. Happy is the one who can understand, for he has got enough experience and feedback; the others just see their own problems and cannot catch the needs of others. This re-injection operation is complex as it involves both the object and the system, both the whole and its parts, according to the complexity principle that the whole is more than the sum of the parts.

Complexity loops occur as well in the other direction: each design process modelling cannot be decoupled from the others, and requires that all technical domains be caught by the overall process modelling at the same time, along another more global complexity loop. The same re-injection process can be seen at work: after an attempt to draw the modelling of the design process and the integration process separately, at a too high level of simplification, there is a need to dive into the details of the sub-processes, because the coupling happens at each and every level. To come back to the question addressed in this section, taking into account this complexity coupling is a key success factor.

4.3 Which strategy to manage the implementation project

The aim of managing a project is simply to obtain a good end result, by guiding every stakeholder along a common path, sometimes called the roadmap. Literature on project management is full of good lessons on how to proceed to get to an overall coordination of the action. In the case studied in this paper, it was shown that, at several key milestones, the level of coordination was not always appropriate. In this section, we shall raise the question of the strategy to be adopted for a project, how and by whom. Our claim is that, here again, a complexity loop happens in the way the decision is taken on how to proceed in order to come to a decision on the strategy.

A blocking point happened early in 2009 when two approaches faced each other. This was on a decision to be taken to feed the users with a methodology on how to proceed with the management of data. The word “methodology”, as used at CERN in this context, must be understood as “a list of operations to perform in order to get what is expected in a proper manner”, in other words, a procedure. Some stakeholders were against any release of the procedure before it was fully complete and approved. Others claimed that you cannot get any full procedure before it is first released in a draft state, then tested in practice with real users, then improved before it can be finalised. On the one hand, the tenants of a “learn, then do” way of working; on the other hand, those believing in the “learning by doing” process. In the context presented here, we can highlight a third perspective. As the procedures are never final, and the internal processes too, there is always a need for adjustments. In this regard, an agile organisation is an organisation that keeps alive its procedures, its processes, in order to keep alive the stakeholders themselves. We could qualify this perspective as a “doing / learning” approach, to be seen as a dialogical complexity loop.

The strategic choice is a key dimension. Starting from the users requirements, several paths are possible: sequentially from the internal process modelling, as for instance explained in Section 3.2 on the theoretical roadmap, proceeding straight to the satisfaction of the users; a spiral strategy, with successive refinements on the same set of requirements; a strategy from the use case. There are existing standards, like EIA 632:2003 or ISO 15288:2008, which can be used in a context of a more formalised requirement management process [Messaadia et al. 2009].

The strategic question on the strategic choice is equally a key dimension. CERN was in a context where it was inevitable, and it was endorsed, that two contradictory paths had to be followed at the same time: the “tool-centric” strategy, consisting of developing use procedures to an existing tool, the use being restricted by the way the tool and its implicit data model is programmed (not to speak of the long-term durability of the software, and the non-genericity of those procedures); and a “user-centric”, or better, a “userS-centric” way, dealing with the development of a tool suited to so many different uses, and which can lead to endless discussion on the development of specific features and losing contact with the overall picture. Following either path has drawbacks.

Another way must be found, a higher way, in a sense. It consists of managing this superimposition, of allowing these complexity loops, of adapting the strategy to the context: a more agile strategy of strategies. Depending on the phase of the PDM-implementation project, on the scope of the production, on the user, the strategy should possibly vary. How to proceed with the elaboration of this method to elaborate a method, of a strategy for a strategy, is yet to be invented.

5. Future work: enhancing the key role of the technical manager

Throughout this paper and through the case study analysis, we have met indirectly but permanently the figure of an intermediate manager always at the interface of the technical, strategic and organisational levels, yet managing or supervising the real action of the ones who “produce” the designs and the machines. Our claim is that this technical manager plays a key role, which is underestimated and poorly documented in the literature, and which is often loosely supported in the real life of organisations. The technical manager, or project engineer, has to incorporate all the complexity elements discussed above. Beyond analytical capabilities, beyond skills of synthesis, he is the one through whom the dialogic complexity loops will work in a constructive way. The technical manager, first of all, is the stakeholder who is in contact with all the other stakeholders, in every direction, along every channel. Dealing with the final user on the one hand, with top management on the other; with the various technical domains, from engineering in design offices to computing, sales, support and development; with his peers as heads of design offices, chairperson of committees, support group leaders, and so on. The challenge is for him to build a common roadmap that can be shared by all stakeholders. In the other cases of our multiple-case study (space, project and flow management), the same central position is shown, and the same exposure to pressure from all around.

One of the apparently contradictory complexity loops he has to deal with is simplification. Simplify to deal with reality [Schwenk 1985], and then de-simplify in order to give more meaning, but insure that software stays simple enough with respect to the final users so that they use it, and do not bypass it. Our belief is that the technical manager must take into account the users' requirements in their variety, especially those that are not expressed, and help organising them in importance and in time, without losing contact with the motivation and commitment of any of the stakeholders.

We are therefore engaged in a work that aims at proposing some methodological elements, together with prescriptive recommendations that will form an agenda for the technical manager.

This is the challenge of complexity for the technical manager. “*Think it complex, keep it simple*”.

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Bertrand Nicquevert
Project engineer
CERN – Engineering Department
Route de Meyrin – CH-1211 Geneva 23 –Switzerland
Telephone: + 41 22 767 60 83
Telefax: + 41 22 766 90 45
Email: bertrand.nicquevert@cern.ch