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Product Development Plan Monitoring: Towards a Business Process Digital Twin

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Abstract: Nowadays, companies increasingly want to be able to follow the manufacturing process of their products in development in order to be able to anticipate any unforeseen event as soon as possible. To this purpose, the Product Development Plan (PDP) is increasingly being developed. And therefore, the real-time monitoring of the PDP becomes an interesting solution to explore in order to overcome this problem. As a result, it is proposed, in this paper the beginnings of a Digital Twin that allows to follow the PDP in real time and to go further to be able to anticipate any deviations that may appear during the execution of the process. In this context, the proposed approach allows to ensure a continuum of the PDP from design phase, in build time, to runtime monitoring phase. Then, the final objective of the Digital Twin will be to allow the detection of some deviations that may appear between the PDP model and real life.

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Keywords: Business Process Model, BPMN Standard, Product Development Plan, Digital Twin, Monitoring Model.

1. INTRODUCTION

In recent years, process modeling has become an important first step to better understand the actions and activities involved in companies. And to go further, the construction of processes around product development is becoming more and more common. However, product development is a complex process (Smith *et al.*, 1999), whose development begins to appear through proposals such as the Product Development Plan (PDP). Indeed, PDP is a standard that can be used by companies to develop new products. PDP encompasses activities and actions that starts from market research to the product delivery with feedback regulation (Cooper *et al.*, 2001). PDP is defined with many stages where the output of each stage can be used as the input of another stage. These stages can be represented as activities and, as well, can form a Business Process (Van Kleef *et al.*, 2005).

This work is part of the ONEWAY project which aims to ensure digital continuity throughout an aeronautical program. The overall vision of this project is to provide a Digital Twin of the PDP. The objective here is to allow the continuous monitoring of PDP in real-time, and more precisely in order to make it possible to remedy any deviations that may appear during the execution of the PDP. In this way, this paper presents a method to construct a Digital Twin of PDP modeled in BPMN and the beginning of qualification and detection of deviations that can appear.

The paper is structured as follows. After this brief introduction, Section 2 describes a state of the art about PDP and Digital Twin. Section 3 introduces the proposed approach to construct a Digital Twin and ensure monitoring of PDP with support deviations. Then, the beginnings of proposals for detection of deviations is presented and detailed in section 4. To illustrate the proposed method, examples of deviations that can appear

are given in section 5. Section 6 presents discussion related to the limits of this research work. Finally, section 7 presents a conclusion and some perspectives for this research work.

2. STATE OF THE ART: DIGITAL TWIN FOR PDP

The current competitive market encourages companies to achieve certain objectives related to their products. These objectives can be related to the quality of the product, the manufacturing cost and finally the loyalty of the customer (Roemer, 2000). In order to achieve these goals and ensure long-term product success the product development process has become an area of continuous research for the industry (Dröge, 2000; Tyagi, 2013). Therefore, it is interesting here, to focus on the construction of a PDP and its real-time monitoring. Thereby, the two following sub-sections respectively present a state of the art on the PDP and the Digital Twin.

2.1 Product Development Plan

A PDP is a process describing the activities to be followed for the development of a product in a company. In fact, a PDP starts from the ideation of a product to its commercialization. The PDP is divided into three parts based on time: pre-development, development, and post-development. Furthermore, it contains six main processes from analyzing consumer demand to product commercialization/recycling (Cooper *et al.*, 2001). Indeed, new product development usually follows a process divided into stages, phases or steps, by which a company conceives a new product. From there, the ISO/TR 14062 defines a generic structure with six major development phases: ideation, product definition, prototyping, details design, validation/testing and production market launch/commercialization (Da Luz, 2018).

The first step of PDP is called “ideation” and it is the most important step for brainstorming a new product. Following the

best practices, companies form a small team to explore the product roadmap and perform it. The second step is related to the product definition. This step involves refining the definition of the product concept and ensuring that the team really understands customer requirements. Then, in the prototyping step, the team justifies the company's investment in the development of a product by requiring the team to create a detailed business plan. After, the focus is on product design but also refinement of the prototype of the product. Afterwards, validation and testing mean ensuring the prototype works as planned. And finally, the commercialization represents the end of the PDP. In this final step, the team realizes everything required to bring the final product to market (Da Luz, 2018).

As shown, the PDP is a complex process that may encounter difficulties during its execution. In order to solve these obstacles and difficulties, it is proposed, here, to develop a Digital Twin that can follow the PDP in real time and anticipate or remedy the problems/events (deviations) that can occur. As a consequence, next sub-section presents a state of the art of Digital Twin.

2.2 Digital Twin

In recent years, the design and production industry is moving towards a global digital era. In this context, the emergence of the Digital Twin has become a possible avenue for improving traditional product design and development processes (Tao, 2018).

The Digital Twin is one of the main concepts associated with the industry 4.0 wave (Uhlemann *et al.*, 2017). The industry is increasingly using this concept and has made it a new area of research. Indeed, the Digital Twin concept appears more and more in the literature and has been, since 2016, one of the 10 best technologies according to Gartner. However, research work around this concept focuses, for the most part, on the development of a virtual system that represents a physical system with interactions between the two systems especially for manufacturing systems. In fact, systems such as services are not taking into consideration for the development of Digital Twin (Zhang *et al.*, 2019).

In the case of Business Processes, Digital Twin research work is just beginning to emerge and is still at the basic stage. Especially, in the case of PDP, Digital Twin can play a great role in simplifying the design processes by employing digital prototyping, testing simulation and prediction with many potential applications in the product design stage (Lo, 2021). Elements of Digital Twin and enabling technologies (Data Mining, Visualization, Simulation, etc) are now widely used in the product development process to reduce development costs and time. However, contrary to the broad applications of Digital Twins to the design and predictive maintenance of production systems, the concrete achievements of Digital Twins for the improvement of Business Processes have been little studied. The first work, at this level, concerns a Digital Twin for Organizations which is a Digital Twin representing

objects and processes belonging to organizations (Parmar, 2020).

Several approaches have been proposed or used to create a Digital Twin of an organization or a Business Process. (Dorrer, 2020) proposes a Digital Twin prototype for numerical parameter prediction with simulation models as a solution to organizational management. More recently, work by (Park, 2021) proposes a Digital Twin for Organizations (DTO) using action-oriented process mining, a set of techniques to assess constraint violations and produce required actions. More specifically, a Digital Twin interface model is proposed as a transparent representation of an organization describing the current state of Business Processes and possible configurations in the underlying information systems. By interacting with the representation, process analysts can identify constraints and actions that will be monitored and triggered by an action engine to improve the Business Process (Park, 2021).

As presented here, currently, there is very little knowledge about creating Digital Twins of Business Processes and more apparently as part of a PDP. In this context, the rest of this article presents an approach for developing a Digital Twin for the PDP in order to allow its real-time monitoring and to detect any deviations that may appear during its execution.

3. DIGITAL TWIN FOR PDP: PROPOSED APPROACH

This research work is developed at the crossroads of Business Process, Digital Twin, and service industry. The targeted Digital Twin as defined by (Rabah *et al.*, 2022) will allow real-time monitoring of Business Processes, PDP in our case. The potential of the development of Digital Twin for Business Process is to allow stakeholders to show and to flow in real time what happens in the real world, make real time decision and predict various situations (Eramo *et al.*, 2021). To go further, the real impact factor of Digital Twin is to detect some possible deviations that can occur during runtime and propose some solutions to readjust the Business Process.

The presented research work aims to develop an architecture of a Digital Twin of Business Process and especially, a PDP. Figure 1 presents our proposed Digital Twin architecture for PDP. In this case, this paper initiated a conceptual representation and a discussion to allow to identify new perspectives for the industry 4.0. It is a part of the development of a Digital Twin for Service (DT4S) of an aircraft PDP whose long-term objective is to enable real time monitoring of Business Processes to enhance the service aspect in Digital Twin in the frame of administrative or service workflows that require to be "digitally twined" (Rabah *et al.*, 2022).

In this context, new challenging activities should be developed to detect some deviations and readjust them in real world to prove the overall DT4S Concept. In this case, future work will focus, in the first step, on the development of Digital Twin for Business Process based on DT4S concept. In a second step, this work will focus on the detection of possible deviations of the established process compared to the real process that takes place in real life.

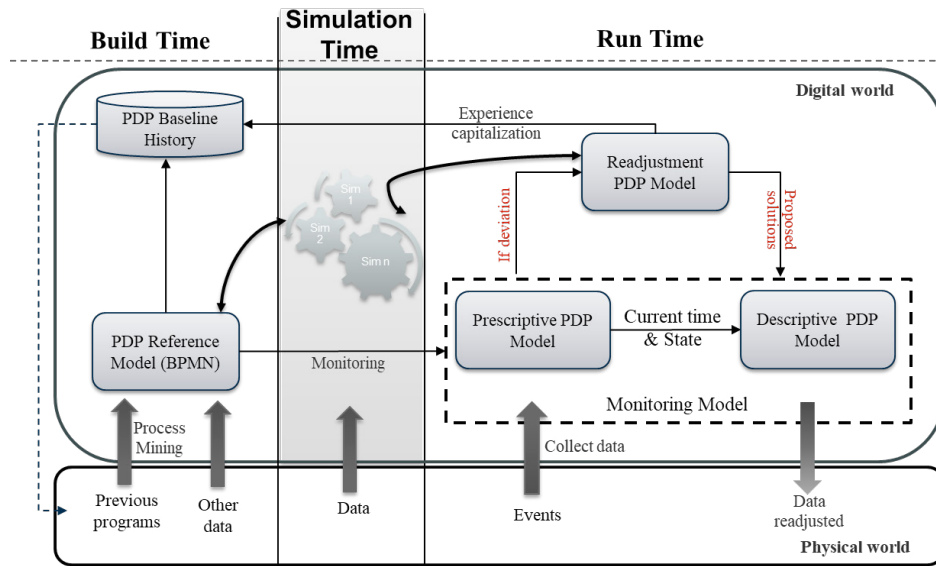


Figure 1. Digital Twin architecture of PDP.

In the build time phase, the first step of the proposed approach is related to the generation of a Business Process Model based on previous programs, especially the planification models that are represented with Gantt Charts. Thus, a first skeleton of the reference PDP is generated according to some transformation rules defined to go from Gantt charts model to BPMN model (Mallek-Daclin *et al.*, 2022). Then, this model is completed and instantiated with some new data to generate a new PDP for a specific aeronautical program. This model will be saved in a database to keep track of it after ensuring that the generated model is indeed the one expected with a simulation. This first step takes place in build time phase to construct the reference model. This model is then sent for monitoring during the run time phase in order to allow real-time monitoring of the PDP model in real life.

In the run time phase, the monitoring model is made up of a prescriptive model and a descriptive model (Combemale *et al.*, 2021). The prescriptive model is the model that receives events from the real world such as starting and stopping activities. This model becomes the descriptive model if everything goes as planned. Otherwise, if a deviation is detected at the level of the prescriptive model, a readjustment model is proposed in order to compensate for this deviation with the proposal of solutions that can subsequently be applied in the real world. In this way, BPMN (BPMN, 2022) is a pivot language used here to be transformed with a more formal language dedicated to simulation. This first idea makes it possible to link the world of modeling and that of simulation. Research works related to (El Kassis *et al.*, 2022) is part of this connection. In this way, with the connection between modeling and simulation, some solutions can be proposed to possible deviations which may appear during execution. of the process (PDP in our case) in real time.

Finally, this model will be capitalized and saved in a database in order to allow its reuse in the event that the same deviation is detected in order to facilitate the implementation of solutions during run time phase.

The proposed Digital Twin fits perfectly with the definition of the Digital Twin proposed by (Camara Dit Pinto, 2021) as a “dynamic representation of a physical system using interconnected data, models, and processes to enable access to knowledge of past, present, and future states to manage action on that system.”

In fact, as presented previously, the PDP reference model is based on previous programs (past states of the system). And, the real objective of the development of Digital Twin for Business Process is to ensure that what is expected in the monitoring model (more precisely the prescriptive model) corresponds at what happen in the real time (present states of the system). In this way the detection of possible deviations represents the heart of the Digital Twin for Business Process to propose some solutions for the future PDP (future states of the system).

Next section focuses on the qualification and the detection of deviations.

4. DEVIATIONS: QUALIFICATION AND DETECTION

The main objective of the development of the Digital Twin for Business Process is the detection of deviations that may occur during the execution phase. When executing a PDP in real life, the activities of the process can be performed by human actors, which introduces an error factor. The detection of deviations therefore becomes a crucial step in the establishment and execution of Business Processes. Both their grip and their correction and the viability and smooth running of the whole process are at stake. Doing this automatically, continuously and in real time will provide users with the tools necessary to better understand and manage these unexpected situations.

First, it is essential to be able to determine the degree of severity of the deviations. Indeed, not all deviations have the same consequences on the process. In this case, a classification can be proposed by considering two categories: minor and major. Qualifying the deviations according to their severity can help the decision on the solutions to be applied to these

deviations and to prioritize the most impacting ones. From there, it is possible to formulate a first hypothesis which considers that the sum of several minor deviations can generate a major deviation.

Deviations are unexpected actions that may appear during the course of a Business Process. These are actions that violate the constraints present on a process model. Deviations can occur because of different strengths that are not acceptable. Three main categories of deviations can be distinguished:

- **Topological deviations.** These deviations are related to the structure of the BPMN model. As an example, the order of tasks is not respected.
- **Time deviations.** These deviations are related to the duration of tasks, activities and processes of the BPMN model. As an example, if a task ends after the scheduled date, then the task's time is greater than its defined lead time.
- **Resource deviations.** These deviations are related to availability and/or the performance of the allocated resources to tasks, activities and processes of the BPMN model. As an example, these deviations can be generated either by human resources, material resources or IT resources.

Furthermore, deviations can be characterized by different criteria such as the type, the cause, or the time of occurrence (Smatti et al., 2015). There are different approaches to deal with deviations. Most of them act upon two points: how to detect them and how to handle them (Smatti et al., 2015).

Today there are two main methods used to detect deviations (Bendraou, 2012). In the first one, the detection is done at predefined interval (milestone, ex. at the end of each activity). The drawback is that the deviation can be detected lately leading so that corrective actions cannot compensate the drift. The second one consists in representing a model that includes all the modifications than can be implemented during the process execution (Bendraou, 2012). This method avoids having a long period of time between the moment when the deviation happens and the moment when it is detected. However, it requires to have much more detailed process models which can be laborious.

For the detection of deviations several research works have emerged. For instance, PSEEs (Process-Centered Software Engineering Environments) are developed to support software development (Gruhn, 2002). They define which software activities should be carried out as well as when, by whom and using which tools. They remind users of the activities that are to be done and those done automatically (Gruhn, 2002). More recently, another PSEE named PRAXIS was developed (Stirna, 2012). It keeps tracks of different types of information such as the actions that are carried out by the user, the activity that is currently executed (Bendraou, 2012). It uses Praxis Rules, a rule-based language, to detect deviations when the process is executed. It is a Domain Specific Language whose main goal is to specify whether an action performed during the execution of an activity is acceptable or not. This PSEE is based on a set of rules automatically extracted from the process model. Then, the process modeler must associate a risk level, based on his knowledge, to each rule. When the process is enacted, Praxis monitors what happens and generates a deviation report that lists all the deviations that were detected as well as their risk level.

In this research work, at the run time phase, the monitoring model is used to ensure that the process, often expressed in BPMN, is taking place correctly by verifying that the activities are taking place in the right order and within the time limits set as well as the resources are allocated to the right stakeholders. This step should take place continuously, at the same time as the process is taking place in order to be able to correct the identified deviations as soon as possible. This limits their impact on the rest of the process and therefore improves the organization of the process and avoids the risk of project failure and delays (Stirna, 2012).

When a deviation is identified, a simulation is launched, then, a human entity is allowed to make a decision in order to overcome this problem. Then, a new model taking account of this modification is generated: the readjustment model.

To illustrate these remarks and more particularly the type of deviations that can appear, the next section presents some examples of deviation according to their type.

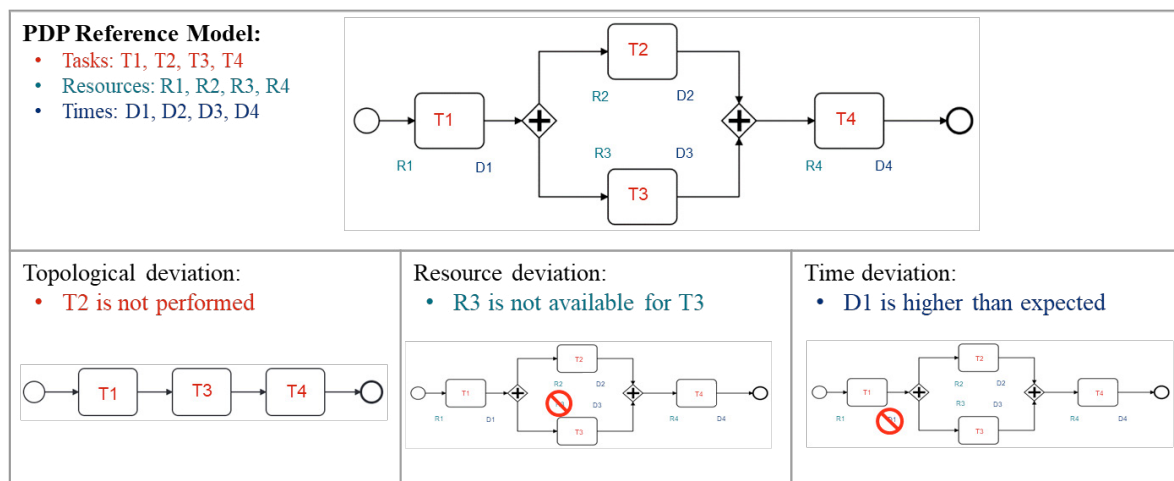


Figure 2. Examples of deviations during monitoring of a Business Process

5. DEVIATION CHARACTERISATION: EXAMPLES

Figure 2 presents an example of a simple Business Process modeled by BPMN representing the PDP reference. This PDP reference model can have some deviations.

The presented PDP reference is performed by four Tasks where T2 and T3 are performed in parallel at the same time. Furthermore, each task has an allocated resource and has to be performed with a given time. In run time phase, some deviations can appear regarding to (1) the structure of the BPMN model, (2) the allocated resources and (3) the required time to perform each task.

The first deviation that can occur is related to the structure of the PDP reference modeled with BPMN. Figure 2 presents a case where T2 is not performed as expected. In fact, after task T1, the Digital Twin expects to receive task start events from T2 and T3. However, it only receives the event from T3. So, T2 does not occur as expected and a topological deviation is detected. Also, T4 starts up with no input from T2. After the detection of this deviation, it is necessary to qualify if it represents a minor or a major deviation and how can this deviation be remedied. Can T2 be done later than planned or can another task replace T2 in order to remedy its absence or can the other tasks (T3 and T4) absorb the work that should have been done during the implementation of T2.

The second deviation that can occur is related to the allocation of resources. For example, R3 is allocated to T3 as presented in Figure 2. However, during the run time phase, an event expected by the Digital Twin on the R3 resource goes up indicating that the person assigned to the R3 is absent, for example. In this case, a resource deviation is detected. In order to remedy this deviation, another resource could replace the missing resource, but care must be taken not to generate a time deviation which could occur while finding a qualified resource for the replacement.

Finally, a deviation related for the time aspect can occur as shown in Figure 2 with the time allocated to T1. In fact, T1 may have a longer duration D1 than expected and in this case lead to a time deviation. To remedy this deviation, it is necessary to check whether the other tasks will be impacted by this delay. In the event that this delay does not impact the other tasks, their allocated time respectively could remedy this delay if these can occur in less time than what was expected.

The solutions to remedy these deviations and their implementation are still being developed as part of the research project.

6. DISCUSSION AND FURTHER WORKS

The presented research work aims to develop an architecture for a Digital Twin for Business Process. The objective is to enable real time monitoring of Business Processes and to detect possible deviations (topological, temporal or for resources allocation). However, after the detection of these deviations, it is necessary to be able to propose adequate solutions.

In fact, it is possible to detect and to qualify deviations, but the question that arises is: what to do after detecting a deviation? What solutions to provide? and how to apply them to a PDP in real life?

In this way, the future objective of this research work is to propose some solutions of these detected deviations. These solutions must be adapted locally at the level of the detected deviation while making sure not to impact the PDP more generally by generated other deviations.

This last step is still under development and represents an important limitation of this research work.

7. CONCLUSION

This research work focuses on the proposition and the presentation of an architecture of a Digital Twin for Business Process especially a PDP. The proposed Digital Twin aims to provide real-time monitoring and decision support functionalities.

Digital Twin will have to retrieve data from the real world in real time to verify what is happening in real life has been foreseen in the generated PDP. Otherwise, if deviations are observed, the Digital Twin will propose solutions to the users for decision support. This decision will consider the most effective PDP possible. Thus, this paper presented a big picture representing the architecture of a Digital Twin for Business Process.

Future works are related to the proposition of methodology to detect the deviations and the proposition of solutions for the detected deviations.

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