Production harmonizEd Reconfiguration of Flexible Robots and Machinery

Horizon 2020 – Factories of the Future, Project ID: 680435

Deliverable 5.2

The PERFoRM Migration Strategy for A Generic Migration Scenario and for Additional Show Cases within the Testbeds in WP6 1st Release

Lead Author: IPB

Version: 0.4
Date: 25.09.2017
Status: Public

Revision	Date	Comments
0.1	28.02.2017	Deliverable structure, ToC
0.2	31.07.2017	Draft document considering the contributions from the different partners for the several chapters. Inclusion of the several questionnaire results. Formatting the text.
0.3	08.09.2017	Integration of the received contributions from partners
0.4	25.09.2017	Final improvements and corrections.

Author List:

Ana Cachada (IPB)

Flávia Pires (IPB)

Paulo Leitão (IPB)

José Barbosa (IPB)

Ambra Calà (Siemens)

Nils Weinert (Siemens)

Vallhagen Johan (GKN)

Pierluigi Petrali (Whirlpool)

Arnaldo Pagani (Whirlpool)

Gregorio Iuzzolino (E-district)

Pietro Perlo (E-district)

Abstract

In the last years, many organizations intend to convert their existing production systems towards ones that are characterized by adaptability, openness, flexibility and modularity. This requires a redesign of existing information processing systems especially related to control, leading possibly to the implementation of Cyber-Physical Production Systems (CPPS). However, the implementation of new control technologies will have a direct impact on the normal operational status of production while engineers will also face several challenges and obstacles in adopting intelligent automation systems. New step-wise migration strategies are required to holistically support industries in their journey towards CPPS taking into account technical, economic and social aspects.

This document describes the definition of a migration approach for innovative production systems, particularly those CPPS that are developed under the PERFoRM ecosystem, establishing guidelines for a smooth migration from a traditional system to agile plug-and-produce systems in a secure and efficient way. The designed migration approach comprises five phases, namely Preparation, Options Investigation, Design, Implementation and Deployment, sustained by three different migration strategies, namely One-Shot, Parallel and Phased. The modelling of the migration process uses the Petri nets formalism taking advantage of its inherent capabilities to synthesize the process specifications but also to verify, simulate and validate the correctness of the system specifications during the design phase.

The designed migration approach was instantiated for the four industrial use cases, being detailed the instantiation for the Siemens use case.

This deliverable document provides input information for tasks T5.3, T7.3, T8.3, T9.3 and T10.3.

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1. Introduction

1.1 Contextualization

The main need of the current industry is the very rapidly introduction of the products into the market, which leads to an increase in the agilization of the production itself. The nature of the current industry is rather conservative, where the systems are characterized by being centralized and having hierarchical structures. These characteristics makes it operate in tight margins, not giving the possibility for making more complex and personalized products. This current system makes the business not cost effective in what concerns the consumer demands.

Modern markets are characterized by shorter product life-cycles, increased product variety and shorter time-to-market. Aiming to address these customer demands, industries need to adapt and reconfigure more frequently their production systems to offer new product variants, while maintaining high-quality standards and minimizing costs, moving their systems into plug-and-produced systems. These systems are dynamically adaptable in changing the production environment, providing a broad panel of features and functions. Through the implementation of Cyber-Physical Production Systems (CPPS) [1] will be possible to introduce a new business paradigm, that will impact production efficiency, enabling flexible and re-configurability of the systems architectures. To achieve these goals, it is necessary to develop a migration process and proper strategies, that will allow for a smooth transition from the current system into CPPS [2], [3]. In fact, the deployment of new automation technologies with decentralized control systems will have a direct impact in industrial environment, considering the current legacy systems and processes, and needs to be performed in a smooth manner. Therefore, a migration strategy is required to support industries to move from their traditional production systems characterized by rigid centralized control approach towards an agile plug-and-produce system that is dynamically adaptable to changing production environment, open to new features and functions, flexible to different processing tasks and modular to enable quick and economical changes [3].

Both the process as the strategies have one term in common, migration, which refers to the switch-over of technology, promoting the change from the older to a newer system, or technology, or a change in the business structure. The migration normally is performed to improve the performance of the business by making it more versatile, feature-rich and cost-effective [4]. The fact that today, the industry is facing an imminent change in paradigm, the transition to the Industry 4.0, is an opportunity for the companies to implement the CPPS systems, being the Industry 4.0 the trigger to the implementation of a migration procedure.

1.2 Objective of the document

Aiming to implement this vision for the factories of the future, and since the objective should be the gradual digital upgrade of the existing facilities and not only the development of new facilities, a process is required to migrate from the traditional systems into the new CPPS [4].

This deliverable contains the outcome of Task 5.2, entitled "*The PERFoRM Migration Strategy for a Generic Migration Scenario and for Additional Showcases within the Testbeds in WP6 1st Release*", which addresses the development of migration process and strategies for the smooth transition of the traditional systems into the CPPS systems. For this purpose, as illustrated in Figure 1, this task considers the requirements established mainly in WP2, WP3, WP4 and WP6, as well as the inputs from the tasks T1.2, T1.3, T7.2, T8.2, T9.2 and T10.2.

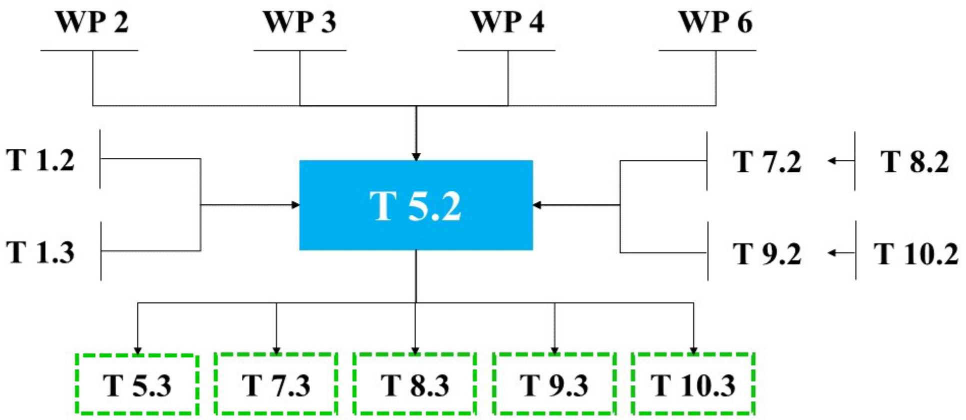


Figure 1 - Interconnection of the Task 5.2 with other WPs and Tasks.

The execution of T5.2 comprised the following main activities:

- Definition of a generic approach for the migration process (which is dependent from the PERFoRM system architecture but independent from specific scenarios).
- Adaptation of the generic approach for the migration process for the four industrial use cases.
- Test the instantiated migration process in the use cases.

The basic idea is to derive a generic migration plan that can be used by adopters of Industry 4.0, particularly using PERFoRM approach, to migrate the traditional production systems into the new CPPS. For this purpose, as illustrated in Figure 2, relevant documentation and expertise coming from industrial and academic partners will be considered and digested to establish the generic approach for the migration process, that later will be applied to the four industrial case studies considered in this project.

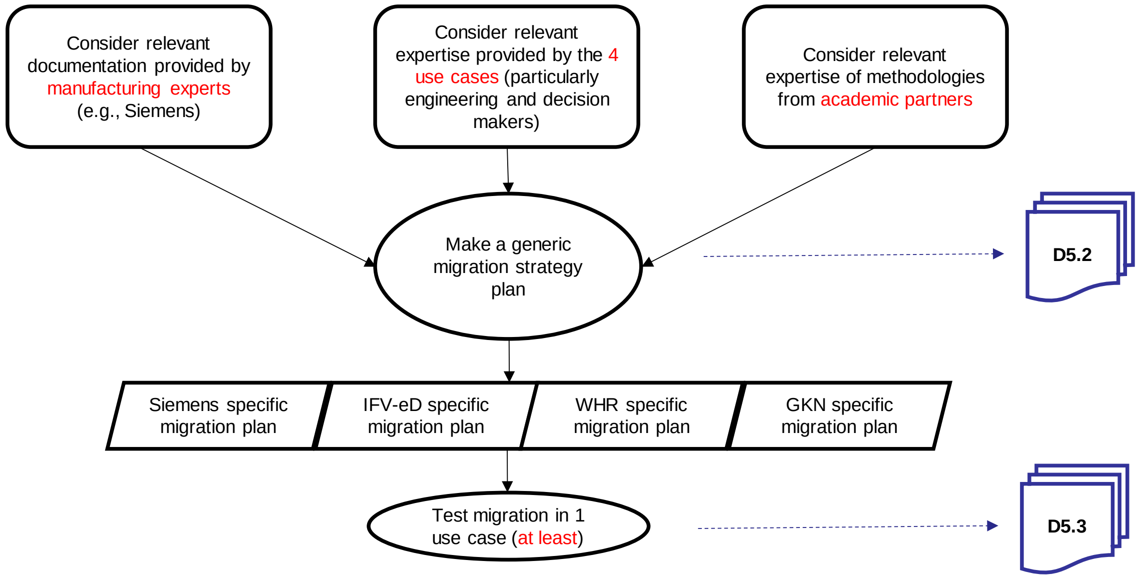


Figure 2 – Plan to design the PERFoRM approach for the migration process.

The results of this task will be used in different tasks according to different granularity levels:

- The migration approach will be used in T5.3 to support the control approach to perform the generic migration process.
- The migration approach will be used to support the implementation of the PERFoRM solution in the four industrial use cases, which will be performed in T7.3, T8.3, T9.3 and T10.3, aiming to demonstrate the applicability of agile and reconfigurable plug-and-produce systems in industrial environments.

Overall, the designed migration approach will enable existing factories to plan and realize partially or fully the migration into a smart and agile factory.

1.3 Structure of the document

The document is divided into 8 chapters. After this brief introduction, Chapter 2 overviews the state-of-the-art of the existing migration approaches and strategies in the literature, which were adopted mainly in previous research projects.

Chapter 3 describes the proposed approach for the migration process in the PERFoRM context and Chapter 4 presents the Petri nets formalism to model the different phases of the migration process, which is performed in Chapter 5, with special attention devoted to the model of the three migration strategies, namely One-Shot, Parallel and Phased.

Chapter 6 introduces a methodology to support the execution of the different phases of the migration process, based on a questionnaire template that constitutes an important tool to collect data and trigger the preparation and analysis of the different strategies to implement the transition in a smooth manner. Chapter 7 describes the instantiation of the general migration approach to the Siemens use case, presenting also its testing and validation.

Finally, Chapter 8 summarizes the conclusions of the document.

In Annex, it is included the acronyms, the questionnaire template used to collect information regarding the As-is and To-be systems for the four industrial case studies, and also the results of these questionnaires for each one of the case studies, and finally the validation of the designed Petri nets models.

2. State-of-the-art of Migration Strategies

This chapter overviews the need for a smooth migration towards the deployment of new CPPS, as PERFoRM is, mainly describing the different traditional migration strategies.

2.1 Migration Concepts and Approaches

A current challenge is to implement the new vision for the factories of the future, based on Cyber-Physical Systems (CPS), and since the objective should be the gradual digital upgrade of the existing facilities and not only the development of new facilities, a process is required to migrate from the traditional systems into the new CPPS. Broadly speaking the term "migration" refers to the switch-over of technology from older to newer systems or the change in the business structure, which will make the business more versatile, feature-rich and cost-effective [5]. In other words, the migration process is considered as a sequence of activities to achieve a migration goal, and strategies, defined as a set of methods and techniques to perform the activities [6], to change from the As-Is system to the To-Be system.

According to [7], the decision to perform a system migration has different triggering sources, namely i) new business opportunities become impossible to accomplish without a new system, ii) the system is no longer cost effective to support, iii) the system is inflexible and doesn't respond to customer demands, iv) the system lacks visibility that could prevent equipment breakdown and disruption in the supply chain, and v) the system is impossible to be expanded. In the advent of Industry 4.0, the need to implement the new CPPS systems also constitutes an opportunity to trigger the migration process.

The migration strategies to be presented below are going to be used to implement CPPS systems in the industry, by following several steps, making the migration smother. Before any strategy can be developed is necessary to establish a migration process that allows us to have a high-level idea of what are the steps to follow in a migration. This section presents the current research results achieved. The migration process is described followed by general migration strategies.

There are several other migration processes that have been developed in other projects that allow for a smooth migration between different systems. The work developed in the ArchitecturE for Service-Oriented Process - Monitoring and Control (IMC-AESOP) project is mainly focused in the implementation of Service Oriented Architecture (SOA) to change the existing systems in to distributed and interoperable systems. The migration of systems towards SOA has four major steps, such as, (i) Initiation, (ii) Configuration, (iii) Data Processing, and (iv) Control Execution. Also the migration process makes use of mediator technology to communicate with the legacy systems, i.e. the old systems. The four steps were designed to maintain the perception of conformity between the several interfaces [8].

The SOAMIG (Migration of legacy software into service-oriented architectures) project also mentions the development of a migration process towards SOA, which is developed as an iterative process and is represented by four phases, they are, (i) Preparation, (ii) Conceptualization, (iii) Migration and finally the (iv) Transition. This migration process model emphasizes the transformation-based conversion [9].

The Service-Oriented Migration and Reuse Technique (SMART) [10] performs the analysis to the legacy systems by determining if they can be "linked" to SOA. SMART is an iterative process comprising six steps: (i) Establish migration Context, (ii) Define Candidate Services, (iii) Describe Existing Capability, (iv) Describe Target SOA Environment, (v) Analyse the Gap and (vi) Develop Migration Strategy. This migration process is mostly used for migrating legacy Information Technology (IT) to SOA [11]. MASHUP (MigrAtion to Service Harmonization compUting Platform) is another technique that is responsible for migrating legacy systems into service oriented computing. This migration process proposes a six steps process, and they are (i) Model, (ii) Analyse, (iii) Map and Identify, (iv) Design, (v) Define and (vi) Implement and Deploy. This technique is mainly used to overcome the difficulties that come, e.g. from the Quality of Service [12].

The Cloudstep is a step-by-step decision process that supports the migration of legacy application to the cloud, identifying and analyzing the factors that can influence the selection of the cloud solution and also the migration tasks. It comprehends nine activities: (i) Define Organization Profile, (ii) Evaluate Organizational Constraints, (iii) Define Application Profile, (iv) Define Cloud Provider Profile, (v) Evaluate Technical and/or Financial Constraints, (vi) Address Application Constraints, (vii) Change Cloud Provider, (viii) Define Migration Strategy, and (ix) Perform Migration [13].

The XIRUP (eXtreme end-User dRiven Process) process follows the modernization of components based systems, in an iterative nature. This method was developed in the MOdel driven MOdernisation of Complex Systems (MOMOCS) project and comprehends four stages: (i) Preliminary Evaluation, (ii) Understanding, (iii) Building and (iv) Migration. The ultimate goal of the XIRUP process is to provide cost-effective solutions and tools for modernization [14].

The different migration processes found in literature present some similarities, regardless of the domain and target of migration. Generally, following a stepwise approach, firstly the legacy system and the target system are analysed and the requirements defined, then the target system is developed and finally the migration is defined and performed. Processes like SOAMIG and IMC-AESOP focus mainly on the technical constraints and characteristics of the migration, while SMART, MASHUP and XIRUP pay attention also on business requirements and involved stakeholders, and Cloudstep includes legal, administrative and organizational constraints. In addition, mostly of the described processes analyse the migration iteratively but only XIRUP process considers the integration of possible new features after the successful validation of the migrated components.

The existing migration processes or methods are all target based, taking only in consideration the target goal, e.g. service oriented architecture. For the implementation of a new business paradigm, in this case Industry 4.0, is necessary to have a migration process that allows for continuous improvement.

2.2 Migration Strategies

Nowadays, there are three main strategies migration strategies present in the literature, namely the Big Bang, Parallel Systems and Phased. Although general, they are normally applied to the migration of software, but they can also be applied to CPPS. Inside each migration strategy there are several stages that cover the main strategies and methodologies for the development of the migration project. Those stages include, the assessment of the current environment to migrate (legacy system or As-Is), planning for the development of a migration project, architecting a new target environment (target system or To-Be), implementing a migration by using available tools and processes and managing the newly migrated environment [5]. Also, two important steps are the analysis of the risks involved and the development of a contingency plan in case of migration failure [3].

In the following sub-sections, a brief description of these migration strategies is presented.

2.2.1 Big Bang Strategy

The Big Bang strategy can be described as a change in a single moment in time, switching off the legacy system, i.e. the As-Is situation, and switching on the target system, i.e. the To-Be situation, on a set date [15], known as the Go-Live date [16].

It is important to note that before any transition, during the pre-implementation stage, it is necessary to perform a planning and preparation of the migration. Once the planning and the preparation of the pre-implementation activities have been successfully executed, it is performed a virtual rehearsal where different scenarios are tested to prevent failure of the migration process. After these tests, the team responsible for the migration is equipped to deal with the various up-coming issues. At this point, the legacy system can be switch-off and the new system can be switch on. When this stage is reached it is impossible to roll back to the legacy system in case of migration failure [16], [17].

With this strategy some advantages come, in comparison with the others migration strategies present in the literature, as for example the amount of time spent for its implementation that is very short. The costs are lower since the whole transformation takes place at once, without the need to have intermediate programs and/or duplicated resources. Moreover, the training of the employees is centred in the new system, not wasting time in training transition programs [16].

However, this strategy has a huge risk for the enterprise given the difficulty of re-creating all the conditions of a live production environment [15]. Considering all the interdependencies, a failure in one element of the system can cause problems in other modules [16], [17]. In this case, a small failure may be very difficult to recover or even fatal. In addition, the available time to train the employees is very reduced [16]. Additionally, there is the need to have a deep knowledge of the legacy system, and it is very hard to recover from a migration failure since is not possible to rollback [16], [17].

The Big Bang strategy is therefore suitable for the migration of production systems requiring a complete organizational/technological change, for example, in a scenario where a new product model is introduced in the system (e.g., the introduction of a new model in the automotive industry) [3].

2.2.2 Parallel Systems Strategy

In this strategy, both legacy and target systems run at the same time, i.e. in parallel, for a certain period of time [15], [18]. This time corresponds to the migration execution time, in which the legacy system is designated as Master and the target system as Slave. The target system becomes the Master system only after is tested and validated and, then, the legacy system becomes the Slave system or is switched-off [7]. If the legacy system continues running as Slave, additional costs need to be considered in the migration process [7]).

Given the fact that both systems will run together, all transitions will be carried out in both systems, meaning that a synchronization is required. This synchronization can also bring additional costs to the migration process [7], [10]. Additionally, since the systems run together until the target one is validated, there is a low likelihood of problems, which means that this migration approach involves a small risk [10].

Having both systems, the old and the new running at the same time, bring certain advantages to the users. The comparisons between the legacy and the target systems can be performed in real-time and it is possible to improve the target system during the migration process. The most important advantages are [7], [8]:

- In case of failure it is possible to roll back to the legacy system.
- It is possible to improve the target system during the migration process.
- The comparisons between the legacy and the target system can be performed in real-time, having feedback in the present.

However, this strategy involves a huge number of resources and the duplication of the functional systems resulting in very high implementation costs [8]. An additional cost comes due to the need to synchronize both systems, legacy and target, while running together [15], [18].

Therefore, the parallel strategy is adequate for migration of critical (software) systems and small production lines that cannot survive with a major system failure [8].

2.2.3 Phased Strategy

The Phased Introduction strategy allows executing the migration through a gradual transition, following a well-planned sequence [10], which requires an intensive study of interdependencies and processes' priorities in order to know the correct sequence of the migration phases.

The implementation of this migration starts by introducing the target system block-by-block, taking into account the previous study, turning it on and shutting down the legacy system. This process is repeated until the target system is completely implemented, replacing all the legacy systems by the target system (e.g., in the entire factory) [7], [10].

Since this process is executed by replacing step by step smaller blocks, it is possible to get feedback between each phase, promoting a continuous improvement of the migration process [16]. This strategy also carries advantages as low level of complexity, which means a lesser risk and consequently lesser resources are required. The high implementation time makes possible to the employees to have more time to adapt to implemented changes [16]. Additionally, it is very easy to roll back to the old system in case of problems with the new system [16], [17].

Similarly to the previous strategies, this one also presents some disadvantages, namely very high implementation time [16], very time consuming strategy and high implementation costs [7].

An important aspect of this migration strategy is the definition application areas, followed by a definition of the secondary types of the migration strategies. In fact, for each phase, the previously described strategies, i.e. Big Bang, Parallel and also the Phased strategy, can be used independently. This represents a recursivity in the implementation of this strategy, meaning that it is possible to repeat recursively the choice of the migration strategies, namely Big Bang, Parallel and Phased strategies, according to the granularity of the factory level, as illustrated in Figure 3.

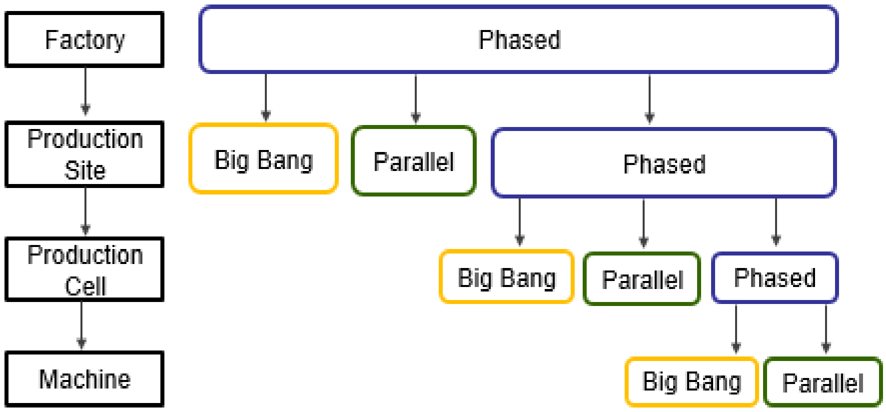


Figure 3 - Recursivity in the implementation of the Phased Strategy [2].

In this case, and selecting the Phased strategy for the migration at the factory level, the gradual migration at the production sites can be implemented by considering Big Bang, Parallel and/or Phased strategies for the different sites. If a phased strategy is selected for one production site, its implementation at production cell level can recursively use the same approach, being implemented by using Big Bang, Parallel and/or Phased strategies for the different cells [3].

This process is mainly used by large corporations who will build and test a core solution with common functionality and processes, before applying it as part of the Phased solution. For smaller corporations, it may not be useful to compromise to a highly staggered plan [17].

2.2.4 Comparative Analysis of the Migration Strategies

The selection of the best migration strategy to be adopted depends on the environment and the addressed technical, economic and social conditions. The comparison of the different strategies considers the assessment of several features, such as risks, migration design time, migration execution time, downtime and costs (effort), as summarized in Table 1.

Table 1 – Comparison of the migration strategies [15]**.**

	One-Shot	**Parallel**	**Phased**
Risk	HIGH	LOW	MEDIUM
Migration design time	HIGH	LOW	MEDIUM
Migration execution time	LOW	MEDIUM	HIGH
Down time	HIGH	LOW	MEDIUM
Cost (effort)	LOW	HIGH	MEDIUM

Briefly, it is possible to conclude that the Big Bang strategy has a low implementation cost but involves a higher risk, migration design time and downtime.

In opposite, the Parallel strategy has a low risk, migration design time and down time, but represents a high cost for the company. The Phased strategy is a kind of compromise between these two approaches, presenting the highest migration execution time.

3. PERFoRM Approach for the Migration Process towards CPPS

In order to achieve the Industry 4.0 goals towards the deployment of CPPS systems, it is necessary the definition of a migration process that allows its implementation in a smoothly manner. A "Process" can be defined as the logical sequence of steps that are performed to achieve a particular goal. The process tells us what needs to be done, not how each step is made [6]. The proposed migration process is a sequence of short-term goals that together work to achieve the main goal, the long-term vision, the migration of the present systems in to the future.

When planning the transformation of an existing production system towards a cyber-physical production system, a phased approach can mitigate risks and preserve current investments according to manufacturers' capabilities by implementing new features and integrating intelligent systems step-by-step (Figure 4).

The main objective of applying a migration process is to define the best path to the new system, to achieve the long-term vision, e.g., CPPS system, through the achievement of the short-term goals. This path should be a well-defined methodology, step-by-step, being every step a short-term goal. It is possible to identify a certain migration path, since several steps are followed to achieve one common goal. The various possible steps have to be investigated and evaluated to build the right migration path taking into account different decision aspects[3].

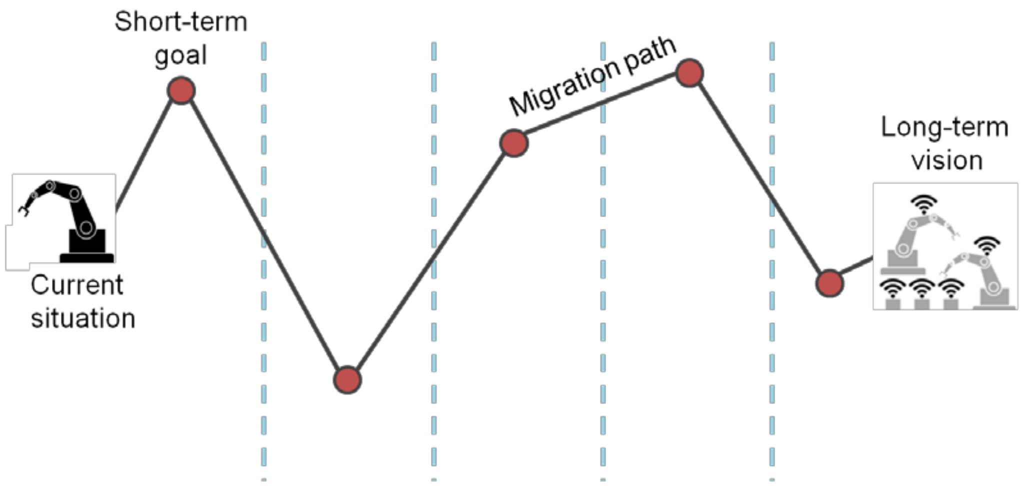


Figure 4 - Migration path towards CPPS

This migration process will offer to the user a guidance, a higher plan to follow, throughout the migration from the legacy into the target system. This will also make it possible for the user to have a better know-how of what is to expect next in the migration of systems.

The proposed/developed migration process is composed by five phases, *Preparation*, *Options Investigation*, *Design*, *Implementation and Deployment.* This process supports the stepwise and continuous migration towards a more flexible, intelligent and innovative system by breaking down the path towards the long-term goal in migration solution steps that are identified, designed and executed following an iterative and incremental approach.

In Figure 5 is possible to observe the main scheme for the representation of the migration process, his several phases and short-term goals.

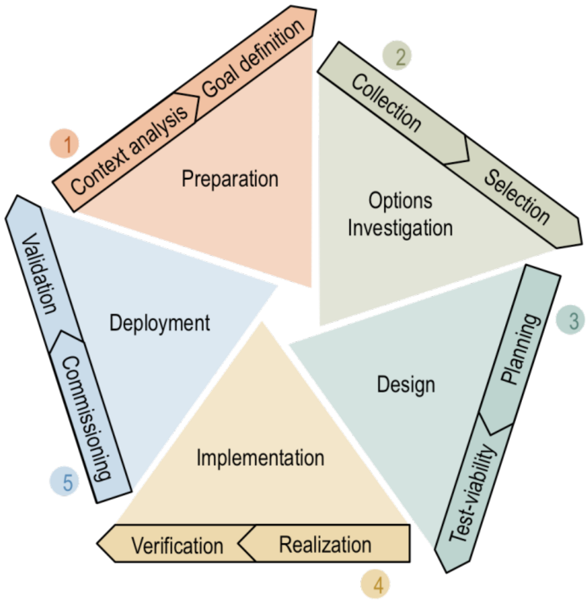


Figure 5 - The developed migration process and the respective phases [2].

The migration process starts with the Preparation phase, which is divided into two tasks, the *Context Analysis* and the *Goal Definition*. In this phase, the first task to be completed is the analysis and the definition of the legacy and the target system. Here, it is necessary to define parameters such as the motivation that is leading to the migration and what are the systems and parts that are going to be involved in the migration process. After this first step, it is required that a thorough investigation be conducted upon the migration solutions. The second phase Options Investigation is also divided into options *Collection* and *Selection*. In this phase, several options of existing technology, hardware and software are going to be investigated, namely those that are available and those that are necessary to implement the target system. In the end of this investigation of the available options, the appropriated technology is going to be selected. Also in this step, it is studied and selected the existing migrations strategies, i.e. One-Shot, Parallel or Phased, to see which one applies best to the specific migration case.

After the conclusion of the previous phase, the process enters in the Design phase, which is divided in *Planning* and *Test-viability*. In the Planning task, the first step is related to the conception and design of the components of the target system, namely, new tools, adaptors and Middleware. According to the migration strategy, selected in the previous phase, the migration plan is established. This plan will contain all the information related to the user-story-flow of the target system and a well-planned sequence of events to implement all the required components, in a stepwise approach. The established design of the migration plan is going to be subject to viability tests, to ensure that the next phase is not compromised by a faulty design solution. The solution only moves to next phase if it passes all the viability tests, proving that is viable in theory. If the results of the viability tests do not match with the expected benefits, the user can repeat the previous phases and select a different option or re-defining the goal of the migration [3].

The next step is the Implementation phase that comprises the *Realization* and *Verification* tasks. Since the design of the migration plan was proven in theory, it is going to be put in practice here. The plan will be followed according to the selected migration strategy, implementing all the required technologies, supporting the transition from the legacy system to the new CPPS system. The realization of the plan will be verified in the second task of the current phase, verifying if every step of the plan was completed with the expected success or if it is necessary a do over.

Finally, the Deployment phase, which comprises the *Commissioning* and *Validation* tasks, is related to the installation and further validation of the new system in a real environment state, to ensure that all the system's qualities are functional.

Ultimately, the migration path of the manufacturing systems is not a straightforward process, involves a very complex list of tasks and various steps, including the selection of a migration strategy. The created migration process was built around the migrations strategies, which makes the progression of the migration more secure since it is a stepwise process.

4. Petri Nets to Design the Migration Processes

The migration process is rather complex and requires a formal methodology that synthesizes the process specifications and capture, understand and validate characteristics like concurrency, asynchronous operations, and deadlocks. The representation of workflow of processes, as the migration process is, can be performed by using various techniques [19] [20].

ISAC (Information Systems Work and Analysis of Changes), DFD (Data Flow Diagram), SADT (Structured Analysis Design Technique), IDEF (Integrated DEFinition Methods) and BPML (Business Process Modelling Language) allow the representation of workflow processes but some do not define a formal model to express the process semantics, are more focused on the execution processes than modelling and do not allow the formal analysis, simulation and validation of the processes in the design phase.

The first method above mentioned is the ISAC that was developed by a research group in Sweden. This method starts with the analysis, making use of system graphs that are complemented with the tables for properties, processes and tasks. This method analyses from the high-level to the lowest required level. The second mentioned method is the DFD, which is mostly used when a high level analysis is required, and as the ISAC method, is also a graphical method that subdivides the system for analysis [21].

The SADT technique has been successfully used in the development of conceptual models in the software engineering area. This technique is a graphical language that is mostly used for describing complex systems. The notation used consists of box-arrow diagrams, blocks, defining the inputs, outputs, control and the mechanism and the related activity in the middle. This modelling technique uses the "top-down" approach for the hierarchical models, starting in the highest level and decomposing into the other lower-levels [22].

The next technique is the IDEF, which is a group of several techniques with a set of notational formalisms for representing and modelling process and data structures, such as IDEF0 (Function Modelling), IDEF1x (Data Modelling) and IDEF3 (Process Description Capture). Each modelling technique has a different method of representation, for example, the IDEF0 is designed for the representation of model decisions, actions and activities. The constructed models represent static diagrams, don't being very useful for the process analysis [23].

BPML is a formal model that is mostly known for expressing the executability of business processes. This method makes use of XML (eXtensible Markup Language) in two different situations: it is used as a format for presentation and serialization for business description and it is used to specify the data types that are used in the processes. BPML is a language considered to execute processes but it wasn't made for presenting descriptions of the processes [20].

Petri nets formalism is a modelling technique that was not initially designed as a business process modelling technique, but their characteristics makes them a useful asset [23]. One important characteristic is that they can represent the business logic through formal semantics but also through a graphical language, which allows to represent workflows in a natural manner. Additionally, Petri Nets use several analysis techniques that makes possible to validate business processes and new concepts [24], [25].

The Petri nets formalism [26] is a suitable modelling, analysis and validation tool for the design of the migration process taking advantage of its well-founded mathematical theory to graphically and formally model and validate process specifications, exhibiting concurrency, parallelism, synchronization and resource sharing features. The Petri nets formalism allows to design the control system behaviour, but also to validate and to verify the behaviour of the system, based in the powerful mathematical foundation embedded in the Petri net formalism.

For this purpose, a kind of Petri nets, proposed in [27], is used in this work to model the migration process. A Petri net is directed graph defined by a four tuple, $PN = \{P, T, I, O\}$, where:

- $P = \{ p_1, ..., pm \}$ is a finite set of places.
- $T = \{ t_1, ..., tn \}$ is a finite set of transitions.
- $I : (P \times T) \rightarrow N$ is an input function that defines directed arcs from places to transitions. Each element of I represents the weight of the input arc from the place p_i to the transition t_j.
- $O: (P \times T) \rightarrow N$ is an output function that defines directed arcs from transitions to places. Each element of O represents the weight of the output arc from the transition t_j to the place p_i.

Petri nets can be represented graphically, as illustrated in Figure 6, using circles to represent places and bars to represent transitions. Places and transitions are connected by directed arcs, pictured by arcs with arrows. It is not possible to connect places to places nor transitions to transitions. An integer value, adjacent to an arc, represents the weight of the arc; if there is no value associated to an arc, a unit weight is assumed.

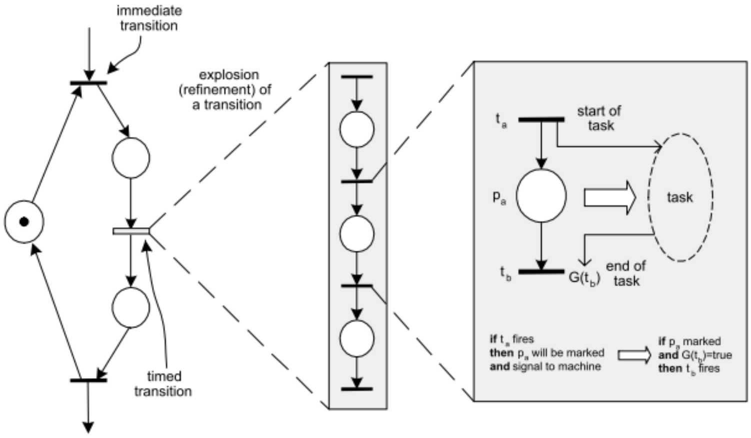


Figure 6 – Representation of a Petri nets model.

A marked Petri net contains tokens, pictured by black dots, in addition to the previous elements. Tokens reside in places, travel along arcs and their flow through the net is regulated by transitions [28]. The tokens, places and transitions have assigned a meaning for the proper interpretation of the model. In a manufacturing environment, and also in this work, they are interpreted as following [28]:

- *Places* represent the states of the system. The existence of tokens in a place indicates the status of a place (active or not), or the availability of the resources (for example the number of tokens can mean the number of empty spaces in a buffer).
- *Transitions* represents the logical aspects of the process behaviour, where the transition firing represents an activity or the verification of a condition.

A modelled system can comprise activities that take place at a much faster (or slower) pace than others. Additionally, it may be required the introduction of transitions that corresponds to purely logical aspects of the system behaviour, which has no associated time. In these circumstances, the temporised Petri net used in this work considers two distinct types of transitions [29]:

- *Immediate transition*, drawn by a thin bar, fires in time zero, i.e. the time between the event that notifies the beginning of the activity and the event that indicates its end is zero. This type of transition can be used to model atomic activities, such as sending a message or downloading a program.
- *Timed transition*, drawn by a thick bar, has associated the time that must elapse before the transition fires. This type of transition is used to represent time consuming activities, e.g. a machine repair.

In order to achieve a formal specification of the logic control structure, a top-down methodology is used, by refining step by step some timed transitions to include enough system operation details for implementation purposes, i.e. replacing a timed transition by a more detailed and refined sub-Petri net so that a large Petri net can be obtained, as illustrated in Figure

6.

Besides the capability to synthesize the process specifications, another great advantage of using the Petri nets formalism is the capability to verify, simulate and validate the correctness of the system specifications during the design phase by using several formal analysis methods. These qualitative and quantitative analysis methods can be used to prove properties and to check the correctness of the model (e.g., safety properties, invariance properties and deadlocks) and to calculate performance measures (e.g., response times and occupation rates) and to evaluate alternative workflows.

Combining the modelling and analysis methods and using the mathematical foundation associated to the Petri nets formalism, a formal procedure can be applied to design migration processes from existing production systems towards CPPS.

5. Modelling the PERFoRM Migration Strategy

As previously described, the PERFoRM migration comprises five main stages [3], i.e. Preparation, Options Investigation, Design, Implementation and Deployment, being these last two stages implemented by using the state-of-the-art migration approaches, namely Big Bang, Parallel Systems and Phased, which corresponds to the One-Shot, Parallel and Phased strategies. This new migration strategy is represented in the Petri nets model illustrated in Figure 7.

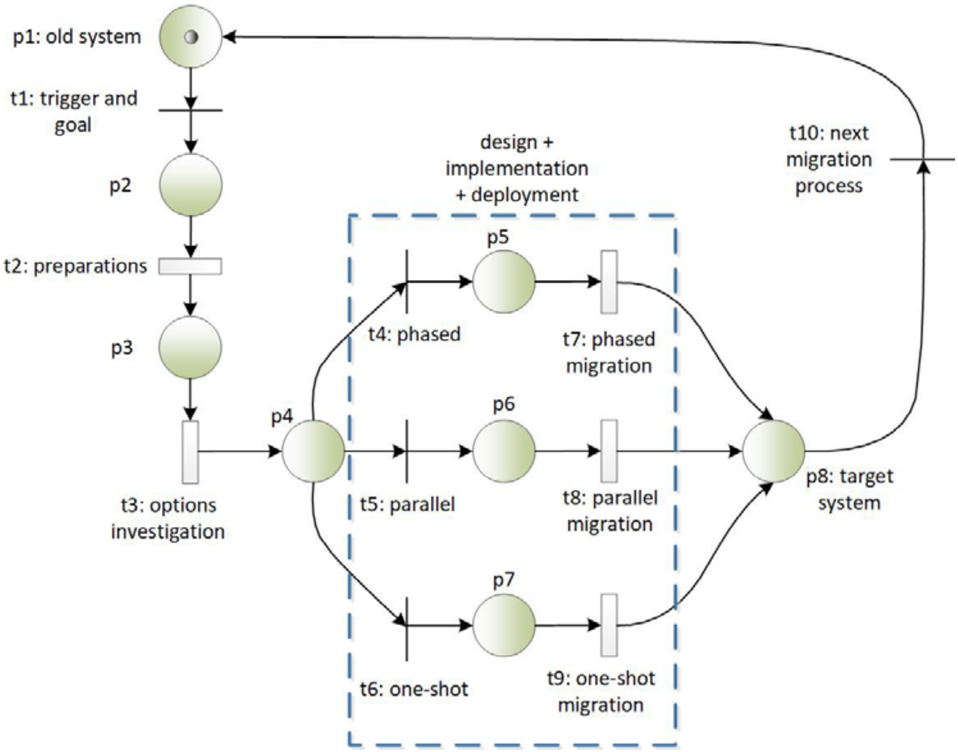


Figure 7 – Petri nets Model for the PERFoRM Smooth Migration.

The migration process starts with the Preparation phase, where the old system is analysed and the general structure of the target system is defined, considering the process main goal. The following phase is denominated as Options Investigation, where several technological design options are explored and the critical interdependencies that can affect the implementation of the target system are identified. After this exploratory step, the optimal migration strategy is selected, considering the advantages and drawbacks for the factory and the Design phase is initiated, here the planning of the selected migration strategy is performed (including the definition of the number of adaptors and new tools). Afterwards, the feasibility tests are carried out, followed by the Implementation phase. During this phase, the established migration plan is implemented and the target system is verified before the Deployment phase where the installed system is commissioned and validated.

In accordance with the literature, three migration strategies were considered in order to implement the Design, Implementation and Deployment phases, i.e. one-shot, parallel and phased strategies (represented by transitions *t7*, *t8* or *t9*).

Once the migration plan is successfully implemented and the commissioning of the target system has been achieved the migration process is completed, therefore the target system is ready to run (place *p9*). This process can be cyclical, meaning that a new migration process can be initiated if necessary and the environment that was defined as "target system" is now the "old system".

The following sections detail the modelling of each phase of phase defined in the migration process previously described.

5.1 Modelling the Preparation Phase

The Preparation phase is the first phase to be executed in the migration process and its main purpose is to analyse the existing system and define its next target condition in the direction of the business long-term vision. In this phase, the context of the system is defined, meaning that several details such as the motivation of the migration and what are the actors and systems involved in the migration process, are established. Furthermore, the long-term vision and, more specifically, the target condition in which the current system is going to migrate to achieve the goal, are established.

The Petri nets model for the Preparation phase, illustrated in Figure 8, starts with the identification of the business vision, which defines the direction of the migration in the long run. The following tasks are related to the assessment of the legacy system and the identification of the possible migration opportunities in the short-medium run (transitions *t2.t3* and *t2.t4* respectively).

The assessment of the current system intends to lead to a complete comprehension of the system and to identify what needs to be changed. In parallel, the assessment of the migration opportunities is also performed, where several details are defined, such as the motivation to execute the migration and what actors and systems are involved in the migration process. The assessment of the migration opportunities also includes the evaluation of several scenarios for the target system. Based on these assessments and coherently with the identified business long-term vision, the next target condition of the system is defined.

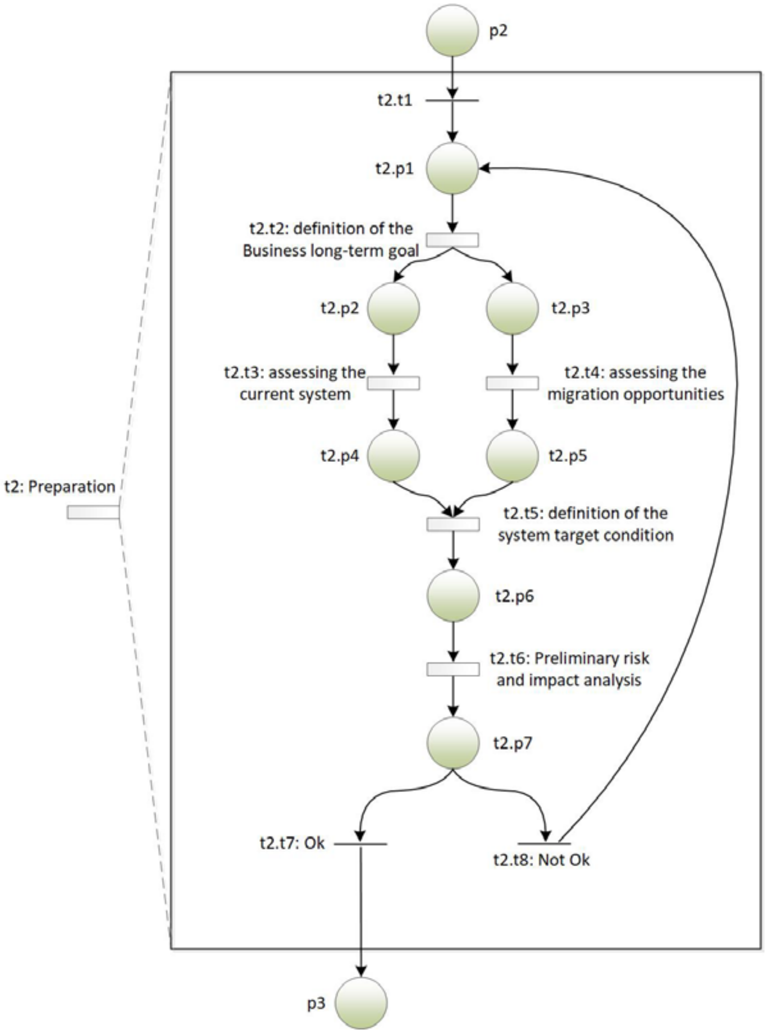


Figure 8 – Petri nets Model for the Preparation Phase.

The target condition of the system represents the next concrete short-term goal to be achieved in the direction of the long-term vision. Then, a preliminary risk and impact analysis is performed (represented by transition *t2.t6*). This analysis intends to verify if the desired migration presents risks that can be mitigated or instead if the migration is too dangerous to be performed. In the second case, it is necessary to start a new iteration in the preparation process. On the other hand, if the identified risks are admissible, the preparation phase is completed.

5.2 Modelling the Options Investigation Phase

In the Options investigation phase, the first step is related to the collection of information regarding the possible migration solutions to be implemented towards the system target condition. The collected information concerns the stepwise approaches that can be used to migrate the systems and is also related to the technology available at the moment. The selection of the optimal migration solution to achieve each short-term goal depends on the relevant impact aspects of the factory, defined in the preparation phase.

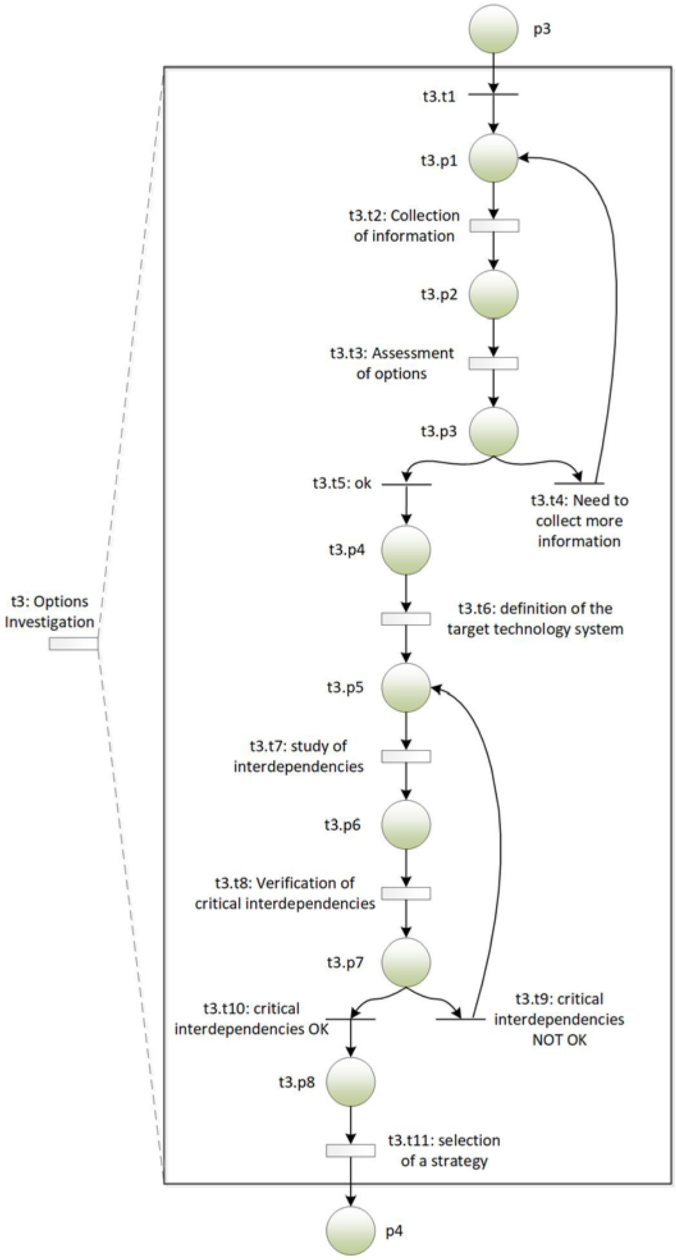


Figure 9 – Petri nets Model for the Options Investigation Phase.

Figure **9** represents the Petri nets model for the Options Investigation phase. As previously described, the first task of the options investigation phase is the collection of information regarding the possible solutions (transition *t3.t2*), which usually requires a significant amount of time.

Once the information has been gathered, it is necessary to make their assessment (represented by the transition *t3.t3*) in order to understand if the existing technology is suitable to achieve the established goal. If the technology does not fit the demands, the possibility of developing new technology should be studied.

After assessing the collected information, the selection of the needed technology and systems takes place (transition *t3.t6*). This is followed by the study of the system interdependencies in order to identify the critical interdependencies. The misidentification of the critical interdependencies, in a stepwise approach for the migration, can lead to failure in the migration process. Finally, the strategy to execute the migration is selected (transition *t3.t11*) by taking into account the assessed information (transition *t3.t3*) and the critical interdependencies (transition *t3.t7*), as well as the criteria defined in the previous phase.

5.3 Modelling the Design Phase

The design phase is common to the three different migration strategies that can be selected at the end of the options investigation phase, and its Petri nets model is depicted in Figure 10.

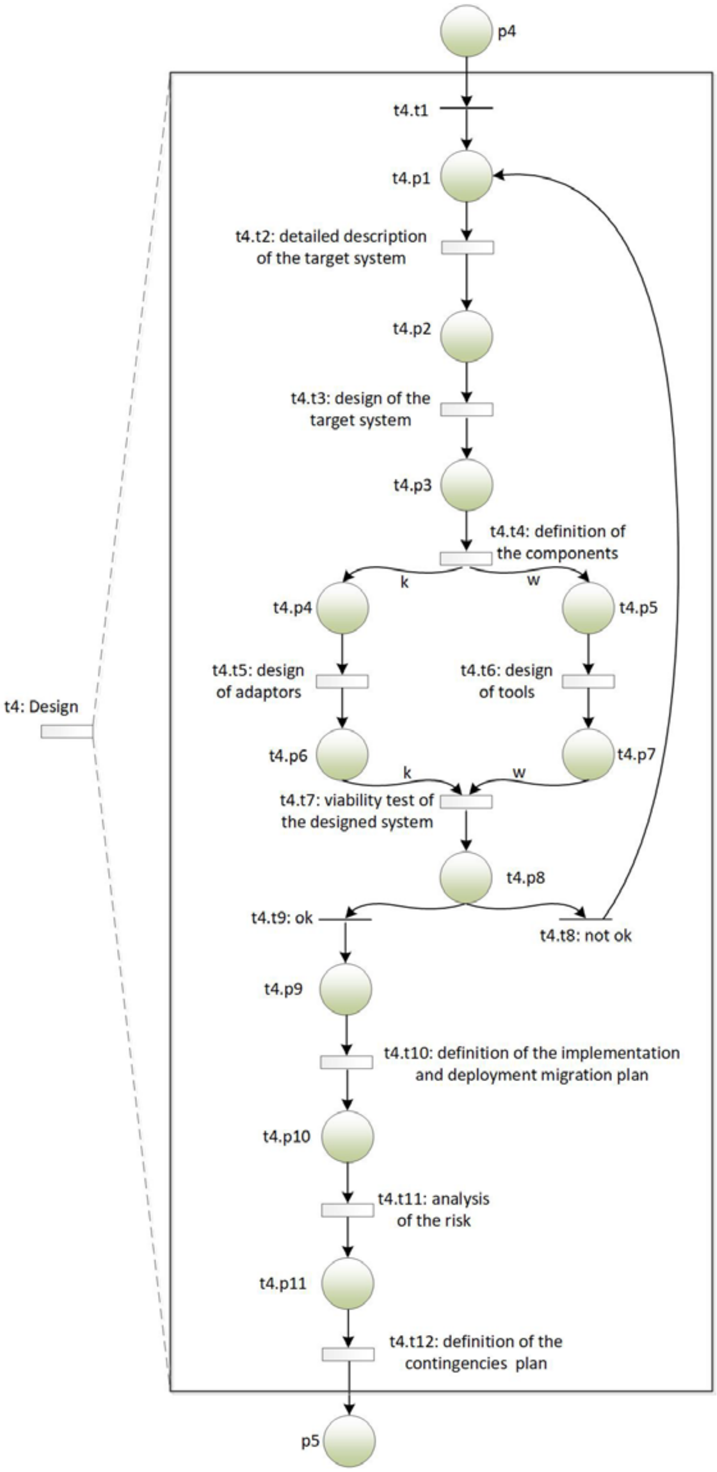


Figure 10 - Petri nets model for the "design phase" transition.

The design phase starts with the conception, definition and design of the target system and its system components. For this purpose, initially, it is defined the target system (transition *t4.t2*), namely defining its functionalities, e.g., data mining, scheduling and simulation, set of components (tools and legacy systems), information flows, and connection with legacy systems. The next step is related to the design of the several components previously identified, such as the new tools and the adaptors to connect the legacy systems.

The second main task of the design phase is related to the test-viability (transition *t4.t7*), where the viability of the designed system is tested to understand if the system is compliant with all required activities. In case of success in the viability test, the implementation and deployment migration plan is elaborated.

A risk analysis is also performed to ensure that the migration from the legacy system to the target system presents an admissible risk. The final task of the design phase comprehends the definition of a contingencies plan (to be used in case of failure).

5.4 Modelling the Implementation and Deployment Phases

The implementation and deployment phases are strongly dependent of the migration strategy selected during the options investigated phase for the migration process. Next sections will detail these phases under the perspectives of the three different migration strategies considered in the migration approach designed for the PERFoRM.

5.4.1 One-Shot Strategy

The One-Shot strategy was inspired in the Big Bang strategy, where all the changes to be executed happen in a single period of time, that comprises the time to uninstall the old system and the time to install and validate the target system. The application of this strategy requires that the target system has to be completely defined and validated off-line. With this system ready, the old system is switched off and the target system is deployed as an integrated solution, being commissioned only if successfully validated.

This strategy, broadly used e.g., in automotive industry, represents a high risk for the company since the old system is shut down which makes almost impossible to rollback.

Analysing the Petri nets model for the migration process (see Figure 7), the One-Shot migration strategy is performed when the transition *t10* is fired, which can be exploded into a sub-Petri nets model represented in Figure 11.

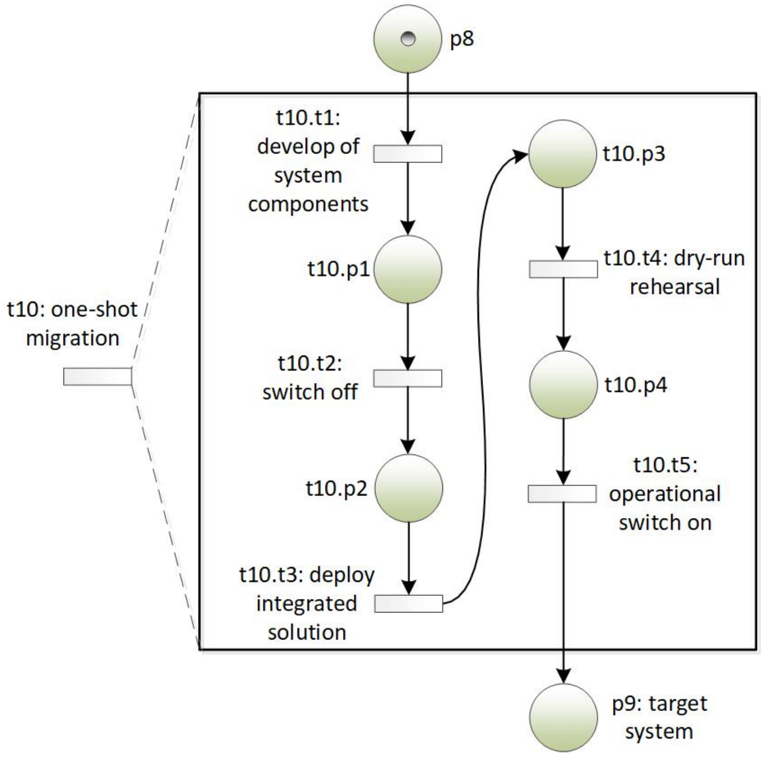


Figure 11 - Petri net model of the One-Shot migration strategy.

This migration strategy comprises the execution of a sequence of steps that starts with the development of the necessary system components based on new technologies or paradigms. After this stage, the system is ready to be deployed in the factory and the original system can be switched off (transition *t10.t2*).

Once the old system is shut down, the integrated solution is deployed and a dry-run rehearsal is performed to certify that the target system is ready to run (transition *t10.t4*). When the dry-run rehearsal is successfully completed, the system is switched on (*t10.t5*) and the migration project is commissioned.

Some timed transitions of the Petri net model can be also exploded to introduce more control details. As example, Figure 12 illustrates the sub-Petri nets model for the transition *t10.t1* that represents the development of system components, introducing particularities related to the PERFoRM environment.

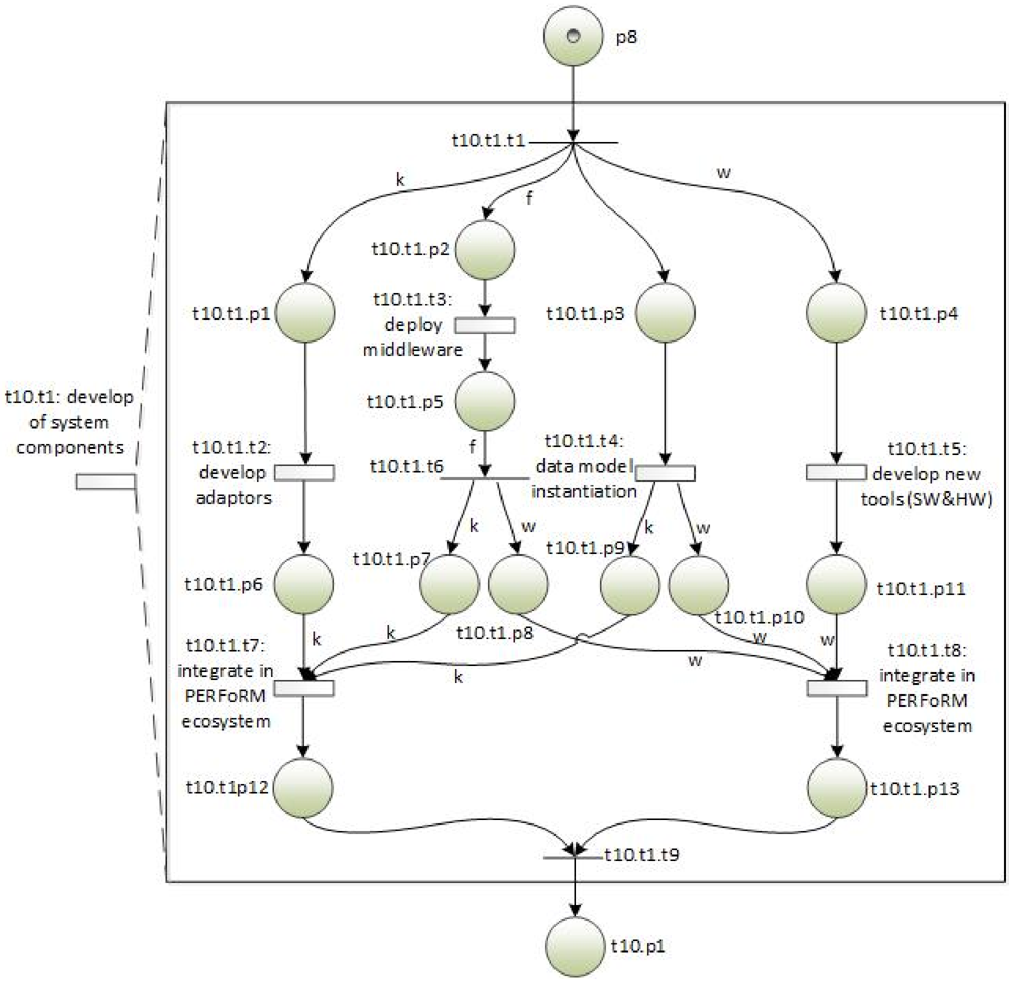


Figure 12 - Petri nets model for the "develop system components" transition.

Initially, several actions are performed in parallel, namely the development of *k* adaptors (transition *t10.t1.t2*), installation of *f* middlewares (transition *t10.t1.t3*) and development of *w* new monitoring and analytics tools (transition *t10.t1.t5*) and instantiation of the data model, which are key components in the PERFoRM system. Note that the *k*, *f* and *w* values are defined during the design phase and are mapped into tokens that populate the places that represents the four referred parallel activities.

Once the entire set of adaptors are developed, the data model instantiated and the middlewares installed, the legacy systems can be integrated in the PERFoRM ecosystem (transition *t10.t1.t7*). On the other hand, the new tools are integrated in the PERFoRM ecosystem (transition *t10.t1.t8*) once all new tools are developed, the middleware is installed and the data model is instantiated. When all these software and hardware components are integrated within the PERFoRM ecosystem, the next tasks of the One-Shot strategy can be performed, as previously described.

The “dry-run rehearsal” activity, detailed in Figure 13, is related to the final verification of the migration process.

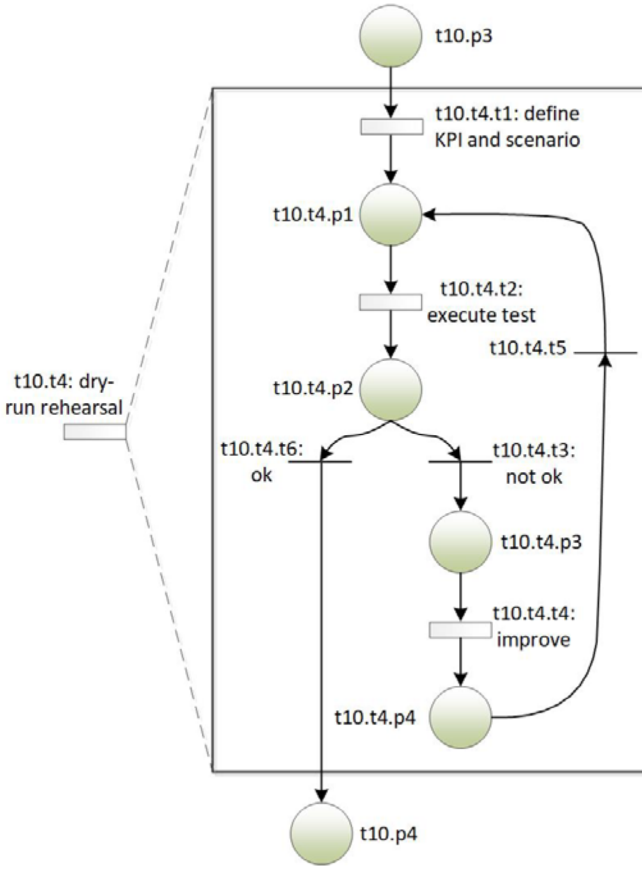


Figure 13 - Petri nets model for the "dry-run rehearsal" transition.

The first step of the dry-run rehearsal is the definition of the test scenario and KPIs (Key Performance Indicators), followed by the execution of a testing (transition *t10.t4.t2*). At the end of the test, two alternatives can happen:

- If "Not Ok", the system needs to be improved and posteriorly be tested again.
- If "Ok", the dry-run rehearsal is approved and the migration project is commissioned and the production resumed.

Note that this sub-Petri nets model can be used by all activities that require the execution of tests.

As previously referred, the implementation of this strategy implies the shutdown of the production site for a period of time. This down time is strongly dependent on the scope and magnitude of the migration: if the migration only comprises software systems, the down time is smaller, but if the migration also considers hardware devices, the down time is higher since the complexity to uninstall components and program and install new components is higher.

5.4.2 Parallel Strategy

The parallel strategy is based on the implementation of the target system, side by side, with the old system. This configuration must be kept running in parallel until the target system has proven its viability. Initially, the old system is considered the master system and the new system is the slave system, but once the target system is proven its viable it becomes the master system and the old system can become the slave system or switched off.

Since both systems are running together, the occurrence of problems in the target system (running as slave) is mitigated by the use of the old system and provides a safer period of time to correct its behaviour.

Figure 14 depicts the Petri nets model for the parallel strategy.

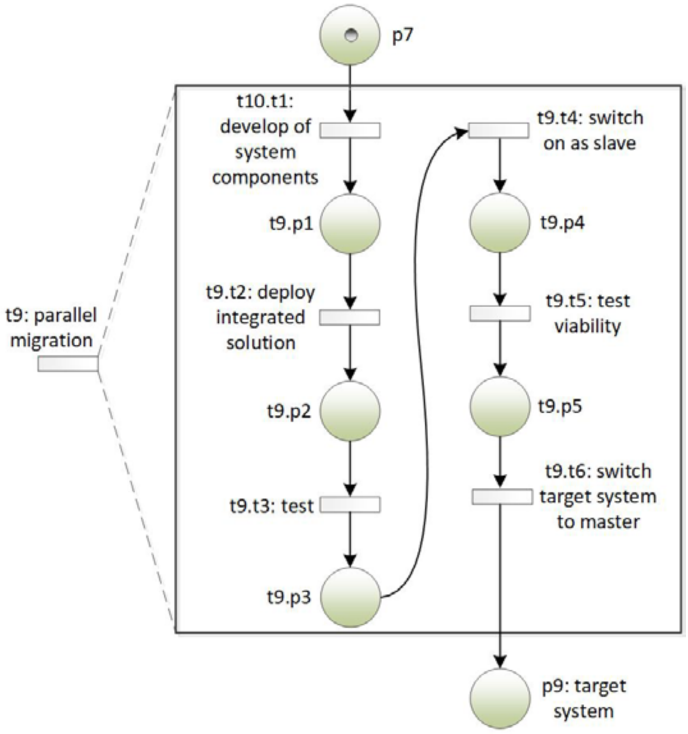


Figure 14 - Petri net model for the Parallel migration strategy.

As in the one-shot strategy, the first steps are related to develop the system components. After all components have been developed, the integrated solution is deployed (transition *t9.t2*), and posteriorly its functionality tested (improving the system if any problem arises). When the new solution is successfully tested and is fully improved, the next step is related to switch on the target system as slave system and maintain the old system as master. After concluding successfully, the viability tests, the target system is switched as master system, finalizing the migration process (transition *t9.t6*).

5.4.3 Phased Strategy

The phased strategy is applied by deploying the new system through sequential phases, which requires a well-planned implementation that carefully considers the interdependencies and the priorities of the involved processes.

An important characteristic of this strategy is its recursive nature, meaning that one of the migration strategies can be selected for each phase. As an example, if a phased strategy is applied to migrate the entire factory, the migration of each production line can adopt the one-shot, parallel or phased strategy, and if this last one is selected, then again one of the migration strategies can be selected for each workstation.

Figure 15 illustrates the Petri nets model for the phased strategy. Once the strategy is selected during the design stage, one important note that needs to be taken in consideration is the number of phases and the associated strategy for each one. This information is associated to different variables used to regulate the flow of tokens along the Petri nets model: *b* represents the number of phases using the one-shot strategy and *p* represents those using the parallel strategy. The number of phased phases is calculated by *L-(p+b)*, where *L* is the total number of phases.

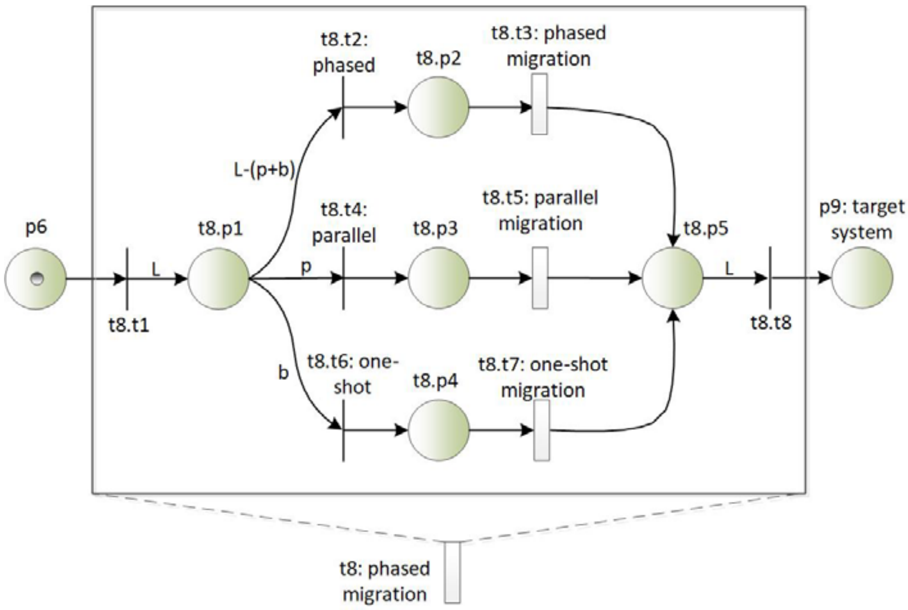


Figure 15 - Petri net model for the Phased migration strategy.

After selecting this migration strategy, each one of the migration phases is properly executed, considering the defined strategy for each one. A migration phase using the phased strategy will trigger the recursive application of the same Petri nets model, and migration phases using the one-shot and parallel strategies will invoke, respectively, the Petri nets models illustrated in Figure 11 and Figure 14.

The migration process is concluded when the defined *L* phases are all successfully implemented and the target system is commissioned.

5.5 Validation of the Petri nets Models

The designed Petri nets models for the implementation of the different migration strategies, for the transformation of traditional production systems into CPPS, were edited, analysed and validated by using the Petri nets Development toolKit (PnDK) [30]. In this deliverable, the validation is illustrated by performing a qualitative and quantitative analysis to the general migration process (see Figure 7).

5.5.1 Qualitative Analysis

The qualitative analysis is related to the structural and behavioural validation of the designed Petri nets models, and particularly the verification of the structural and behavioural characteristics of the model, obtaining information related to the existence of deadlocks, bounded capacity of resources, and conflicts within the system [31]. The analysis of the behavioural properties for the Petri nets model representing the general migration process is illustrated in Figure 16.

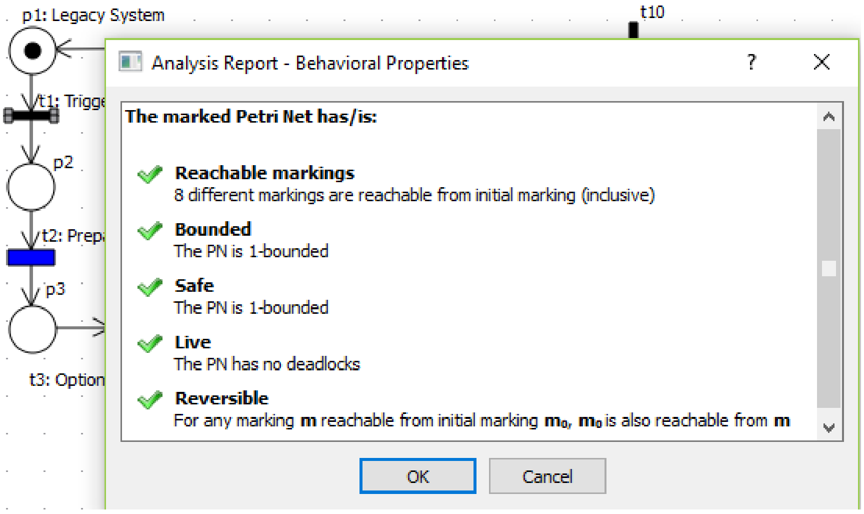


Figure 16 - Behavioural analysis of the Petri nets model.

This analysis allows to extract the following conclusions:

- *Safe and 1-Bounded*: the maximum number of tokens that can be in a place is one, which means that only one migration strategy can be selected for the overall migration process.
- *Reversible*: the initial marking is reachable from all reachable markings, which means that after concluding a migration process, a new one can be started if necessary.
- *Absence of deadlocks*: for each reachable marking there is at least one transition that can be triggered to reach another marking, which means that the migration process doesn't stop in any particular step.

Additional characteristics can be extracted through the analysis of the P- and T- invariants, as illustrated in Figure 17.

Minimal P-invariants:

Place	p1	p2	p3	p4	p5	p6	p7	p8	p9
x1	1	1	1	1	1	1	1	1	1

Minimal T-invariants:

Transition	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11
y1	1	1	1	1	1	0	0	1	0	0	1
y2	1	1	1	1	0	1	0	0	1	0	1
y3	1	1	1	1	0	0	1	0	0	1	1

Figure 17 - P- and T-invariants of the Petri nets model.

The analysis of the P-invariants allows the verification of mutual exclusion relationships among places, functions and resources involved in the structure and behaviour of the model. For the Petri nets model of the general migration process there are only one P- invariant, x1 = {p1, p2, p3, p4, p5, p6, p7, p8, p9} and, by its analysis, it is possible to confirm that only one place can be marked at any time, meaning the mutual exclusion among the several phases of the migration process.

The T-invariants represent the several sequences of operation, i.e. the work cycles, exhibited by the behaviour model. From the analysis of the T-invariants, it is possible to confirm the existence of 3 invariants and its physical meaning can be translated as follows:

- y1={t1, t2, t3, t4, t5, t8, t11} represents the execution of phased strategy.
- y2={t1, t2, t3, t4, t6, t9, t11} represents the execution of the parallel strategy.
- y3={t1, t2, t3, t4, t7, t10, t11} represents the execution of the one-shot strategy.

Since the model representing the general migration process comprises several timed transitions that are refined and exploded (see Figure 7), the complete analysis of this large model requires the analysis of all sub-Petri nets and the application of the theorems established by [32] and generalized by [33] about the preservation of boundedness and liveness properties in Petri nets obtained using the stepwise refinement. The Valette theorem [32] states that all properties of a large Petri net can be deduced from the behavioural analysis of the initial Petri net and each one of the sub Petri nets, performed independently.

For this purpose, all timed transitions from the large Petri net, and also the timed transitions included in the exploded sub Petri nets, were analysed using the same procedure as previously described. As an example, the validation of the sub-Petri nets model "develop system components" was performed, as illustrated in Figure 18, considering $k=6$, $f=2$ and $w=4$.

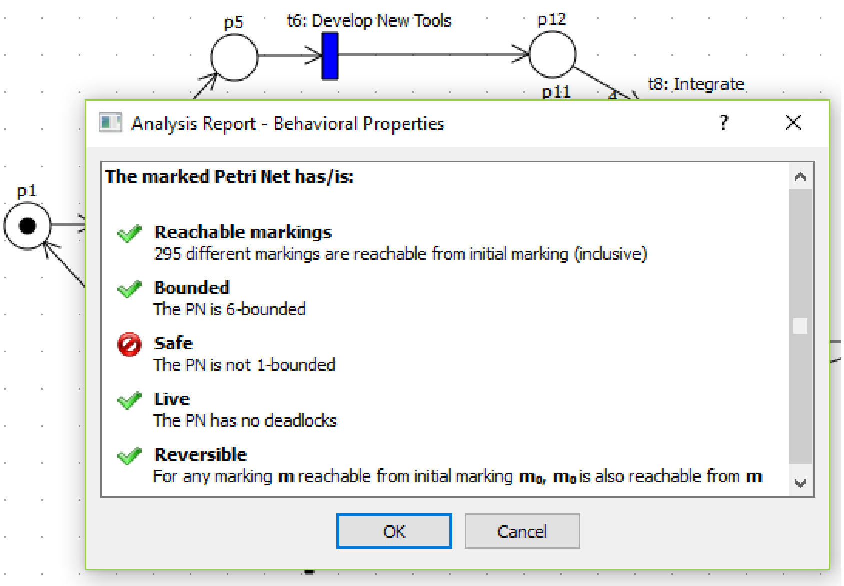


Figure 18 - Behavioural analysis of the "Develop system components" model.

This analysis allows to conclude that this model is reversible, absent of deadlocks and 6-bounded (a maximum of 6 tokens may be hosted in one place, representing the actions to develop 6 adaptors for the identified legacy systems).

Since all sub-Petri nets were validated, concluding that they are bounded and absent of deadlocks, it is possible to conclude that, according to the Vallete theorem [32], the large Petri nets model for the general migration process is also bounded and absent of deadlocks.

5.5.1 Quantitative Analysis

The quantitative analysis is related to the simulation of the temporized Petri nets models by performing the token-game, which requires the association of the time parameter to the transitions.

For this purpose, and considering the general Petri nets model representing the migration process, deterministic distribution times will be used as follows: transitions representing the logical conditions, i.e. *t1*, *t4*, *t5*, *t6* and *t10* have 1 time unit (t.u.), while the transitions related to preparations and options investigation, i.e. *t2 and t3* have 2 t.u. Additionally, the transitions representing the transformation and deployment phase, i.e. *t8*, *t9* and *t9* have 10 t.u.

The information of the time evolution in this Petri nets model can be summarized with a Gantt diagram. Figure 19 refers the temporal sequence of the migration process dynamics when the parallel migration strategy is selected. The analysis of the results allows to verify important characteristics, such as cyclic evolution and mutual exclusion activities.

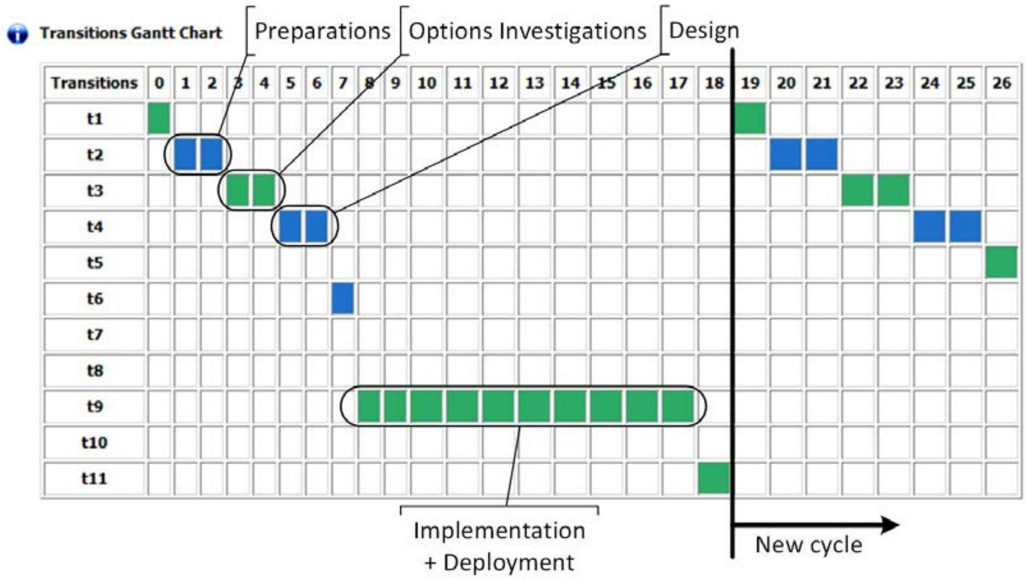


Figure 19 - Gantt diagram for the performance analysis.

The previous qualitative and quantitative analysis allowed to validate the correctness of the Petri nets model representing the designed migration process towards CPPS to be used within the PERFoRM ecosystem, as well as to understand and synthesize the process specifications. Based on the structural and performance analysis, optimized strategies, re-tuning of some parameters and also re-design of the migration process can be implemented and tested.

6. Methodology for the Implementation of the Migration Plan

This chapter intends to explain the methodology adopted to implemented the PERFoRM migration strategy and how the questionnaire is valuable tool to understand the needs and perspectives of the companies in order to achieve a successful migration.

6.1 Methodology

A methodology, defining a set of sequential steps as illustrated in Figure 20, is established to support the execution of the migration plan. It is a stepwise methodology in which every step is an important point of reflection and decision making.

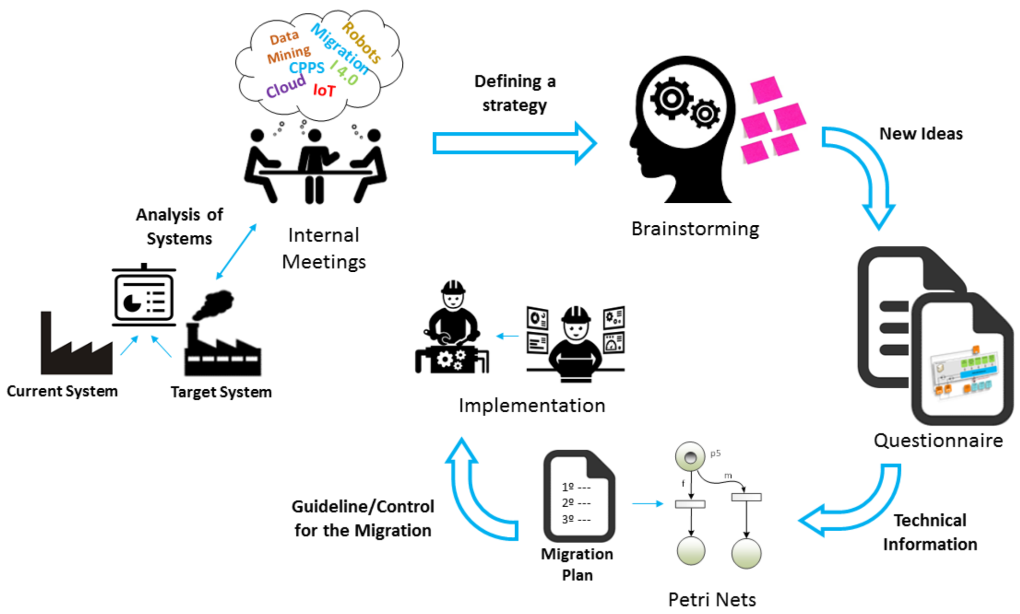


Figure 20 – Methodology for implementing the migration plan.

Initially, several internal meetings should be performed to allow the consolidation of ideas between the persons involved in the migration process. These meetings will be crucial for the analysis of the current and target systems. The results coming from this performed analysis will support the definition of a preliminary strategy for the action plan. At this stage, it is also important to implement brainstorming sessions in order to stimulate the raising of new/different ideas, e.g., what is necessary to improve in the target system.

After having a first idea about the current state and the vision for the target system, it is necessary to organize the ideas and strategies, previously discussed and defined, e.g., by using a questionnaire, to transform these ideas into well-founded technical information.

The technical information that can be extracted from this questionnaire will allow to establish a migration plan. This plan may be represented by using the Petri nets formalism, as proposed in the previous chapter, allowing a formal specification of the migration plan (modelling, analysis and validation). After the theoretical validation that can be performed by using the mathematical background associated to the Petri nets formalism, a migration plan is elaborated, providing guidelines and control of the migration process. This migration plan can be executed, transforming the current system into the desired target system.

6.2 Questionnaire Tool

The defined questionnaire template, presented in Annex B, is an important tool to support the collection of information from the use case (as much as possible to identify the current and target systems), allowing the enlightenment of what has been and needs to be made, to have a more complete migration plan.

This questionnaire was developed in a comprehensively way, taking into account several differentiating features that cover a wide spectrum of industrial aspects. With the filling out of the questionnaire, the second phase of the migration process, i.e. the Options Investigation phase, will have a way of collecting information from the use case without considering that these are different. The information within the questionnaire was organized by categories, being the collected information not only as simple as the type of tool that is going to be implemented, but also the way that this tool will interact with the rest of the system. This type of information is crucial in the development of the migration plan, since it strongly affects the way or disable or connect the tools.

The organization of the questionnaire was made by dividing it into five parts, each part having its own importance, but also exhibiting complementary information. The first part, Part I, is essentially related to the assessment of the current and target systems, and the definition of the migration scope. The second part, Part II, is related to the definition of the set of components belonging to the target system, in terms of software and hardware. The third part, Part III, is related to the definition of all manufacturing hardware for the target system. The fourth part, Part IV, is related to the assessment of the design of human training in the new environment, and finally, the fifth part, Part V, is related to the risk analysis and the plan of the contingencies.

An important issue is to get understanding of the matching between the information gathered in the questionnaire and the way that it can be useful in the migration process. Figure 21 presents the way the information collected in the different parts of the questionnaire are related to the established phases of the designed migration process.

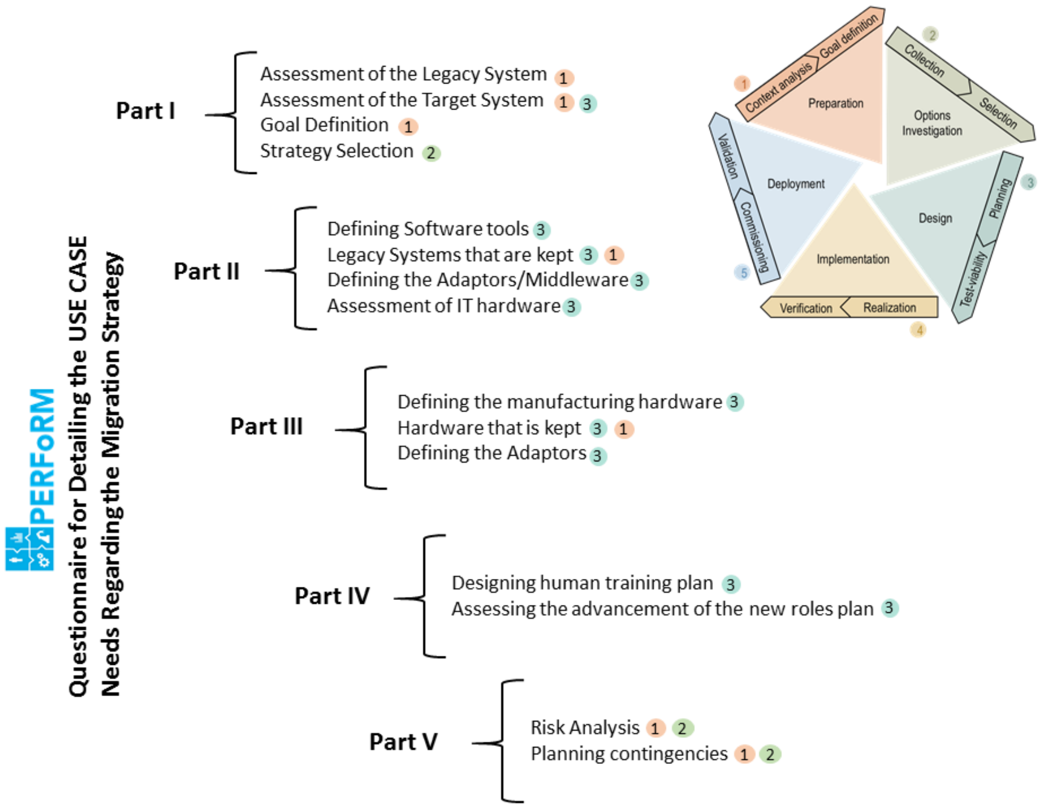


Figure 21 – Matching the questionnaire template according to the migration phases.

For this purpose, the questionnaire is divided in the five described parts, each one subdivided in several important topics. These topics are followed by coloured circles with a number, representing the phases of the migration process where the information is most helpful. As an example, the first part of the questionnaire comprises the assessment of the target system, which information is important for the Preparation and Design phases. The same line of thought is applied for the other topics.

7. Planning the Migration Strategy for Show Cases Within Testbeds

This chapter describes the instantiation of the generic migration strategy devised in the previous chapters for the Siemens use case.

7.1 Brief Description of the Siemens Use Case

The Siemens use case is related to the production of industrial compressors and gas separators. The main problems in the production of these products are the delays and costs in machines failures and breakdowns. These problems are introduced during the production of the components utilized. There are parts that display specific requirements, and thus can only be processed on certain production stations. Due to the characteristics of these stations/machines (costs, set up effort, etc.) they form a bottleneck in the manufacturing process, since the redundancy in terms of multiple capacities for the same purpose is very limited. With the expected production time ranging from days to weeks, several delays and costs in machines failures and breakdowns may occur. Today the maintenance activities are done by scheduling and by failure reporting, making hard for the maintenance to recognize late the problems that arise not being possible to schedule an intervention [34].

In this project, it is expected to integrate the separate existing systems, enhanced with additional data acquisition approaches, to allow a data based identification of machine health issues and to plan maintenance activities accordingly. In particular, machine breakdowns shall be avoided better then today, and the necessary actions should be planned jointly considering production, logistics and maintenance tasks. When the problems are early detected, it is expected three different scenarios:

- The machine is still capable to operate and future maintenance should be planned. The work does not need to be rescheduled.
- The machine cannot operate, meaning that immediate repair will be done. The work does not need to be rescheduled.
- The machine cannot operate and maintenance is needed but the necessary material and resources are not available. The work needs to be rescheduled to another machine [34].

In short, Siemens aims to improve the availability of machines present in the manufacturing environment in order to reduce delays times in product finalization due to machines failures and breakdowns.

7.2 Analysis of the migration questionnaire for the Siemens Use case

This section intends to instantiate the Petri nets models related to the migration process according to the Siemens use case while performing an analysis of the Siemens migration questionnaire. Note that the analysis described here was applied to the other use cases as well, namely the GKN, Whirlpool and E-district use cases, and the corresponding questionnaires can be consulted in the Annex D, E and F, respectively.

The next subsections present each phase of the migration process complemented with the information obtained from the analysis of the questionnaire, which supports the planning of the migration strategy. Thus, recalling the PERFoRM smooth migration process (see Figure 7), when the need to migration arises, the transition *t1* is triggered and the migration process is initiated.

7.2.1 Preparation phase

In this phase the legacy and target systems were assessed, aiming to understand the existing problems in the current situation and how these problems can be solved in the target system.

In order to define the direction of the migration for this use case, first the business long-term vision (transition *t2.t2*) of the company for the considered plant has been discussed. Within the context of the PERFoRM project, which aims at flexible and reconfigurable production system, the Siemens use case identified as long-term goal the improvement of availability and reliability of production machinery in order to increase the production flexibility at the compressor plant of the company [see Deliverable 7.1 [35]].

Based on this information, the current system and the migration opportunities have been assessed accordingly to the defined business long-term vision.

Through questionnaires and workshops [see Deliverable 1.1 [36] and Deliverable 1.2 [37]] the current situation of the system has been analysed (transition *t2.t3*), resulting in the identification of what legacy systems need to be taken into account:

- Machines
- Production data acquisition system
- Production scheduling system
- Oracle database (for production data and manufacturing schedules)
- Microsoft-Structured Query Language (MS-SQL) database (for maintenance data)
- Maintenance ticketing terminal(s)

Briefly, machines' maintenance tasks are defined by the machine supplier and stored in a MS-SQL database. These tasks are manually integrated with the production tasks in the production scheduling system, generating manufacturing schedules that are stored in an Oracle database. This database receives the machines' production data via a production data acquisition system. The systems are connected via a TCP/IP (Transmission Control Protocol/ Internet Protocol) Network, which is not connected to the Manufacturing Network.

The analysis of the current situation in Siemens use case is described in Deliverable 5.1 [38].

Contemporarily, an assessment of the migration opportunities (transition *t2.t4*), i.e. the available technologies within Industry 4.0 vision that can support the change towards the long-term vision, has been conducted during the activity of Task 1.3 [see Deliverable 1.3 [39]]. From this analysis emerged that new manufacturing computerized system technologies will improve the current production scheduling, together with the introduction of machine breakdown prediction technologies, human-machine interaction technologies and system communication protocols and interfaces.

The assessment of legacy systems and migration opportunities lead to the definition of a desired condition of the use case in the short-medium run (transition *t2.t5*). The Siemens use case target condition concerns the ability to prevent machine breakdowns and downtimes through improved production monitoring systems, i.e. predictive maintenance and system scheduling and planning technologies supported by new simulation tools. Moreover, in order to start moving in the direction of flexible and reconfigurable production system according to the Industry 4.0 and Digital Factory paradigms, information and communication technologies are required to enable the integration of different systems and applications. This will require the decentralization of the control automation architecture by implementing a common middleware, communication protocols and standard interfaces. In fact, the intention for the target system is to maintain some of the legacy components in place which will be connected to the new components.

Of course, some risks and constraints need to be taken into account before start defining the specific technologies and application to be implemented. To this end, a very preliminary risks and impact analysis (transition *t2.t6*) has been performed based on the requirements derived from the questionnaire developed in Task 1.2 [see Deliverable 1.2 [37]]. In particular, the identified obstacles and limitations are related to the insufficient acquisition of physical data, due to unavailable specific sensors, and the need of higher skilled operators.

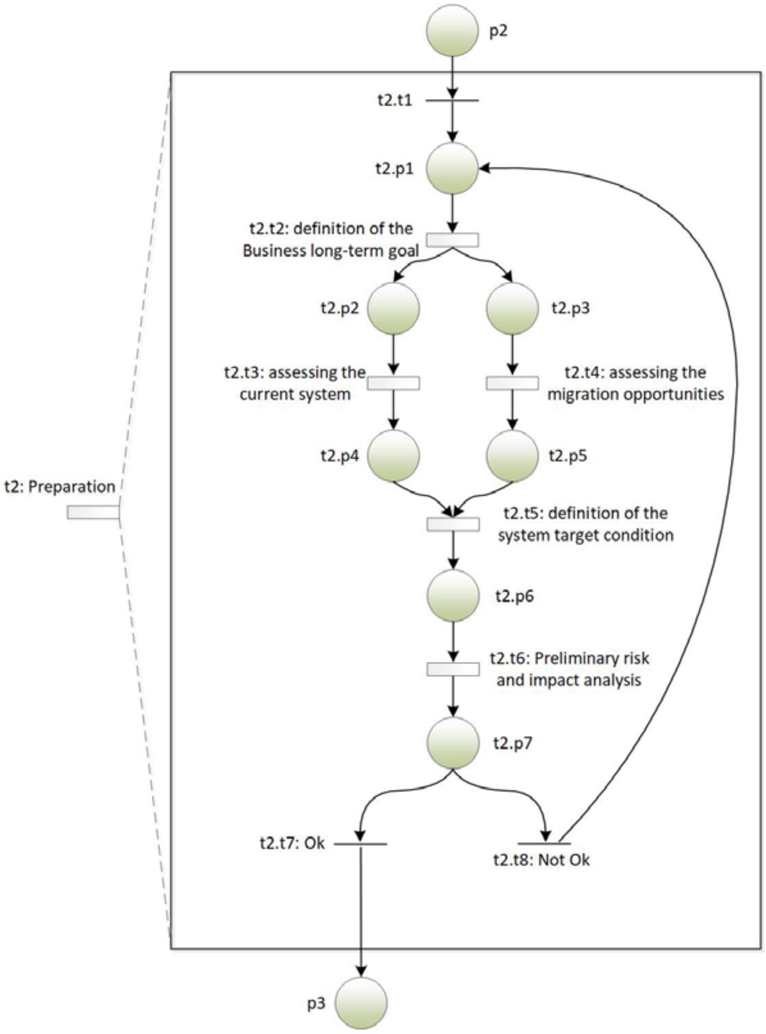


Figure 22 -Petri nets model for the preparation phase for the Siemens use case.

The preparation phase for the Siemens use case was extended for, approximately, 6-8 weeks within the first 6 months of the project.

Once the preparation phase is completed, the options investigation phase is initiated.

7.2.2 Options Investigation phase

The Options Investigation starts with the collection of information (transition t3.t2) regarding the possible systems and components that can be implemented and integrated with the legacy systems to achieve the target condition defined in the previous phase. Since the goal for the Siemens use case is to improve the maintenance and production planning of machines, possible Data Analytics, Maintenance Task Editor, Scheduling, and Simulation tools have been investigated. Moreover, a middleware is required to enable the integration and communication between the new tools and legacy systems. In particular, Data Analytics application will be able to gather data from databases and machines to analyse machine alarms and production data trends. To this end, standard interfaces and wrappers are mandatory to translate system data in a common language and enable data exchange. Figure 23 shows a general view of the possible target system defined at this stage.

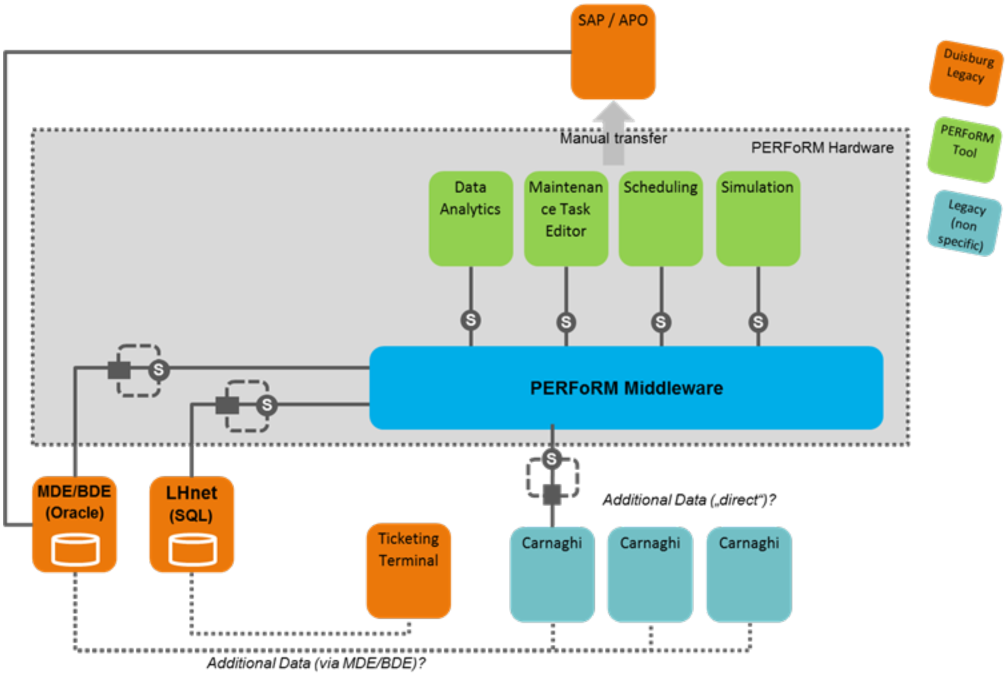


Figure 23 - Initial implementation solution.

The consortium proposed different solution within the project and the systems applicable to the Siemens use case have been evaluated during several meetings and workshops (transition *t3.t3*). This activity results in the identification of the suitable tools and systems to be implemented in the current production plant, enabling the transformation towards the system target condition defined in *t2.t5*. At the end, the target technology system (transition *t3.t6*) for the Siemens use case is defined. Figure 24 depicts an overview of the target architecture, which is also described in detail in Deliverable 5.1 [38].

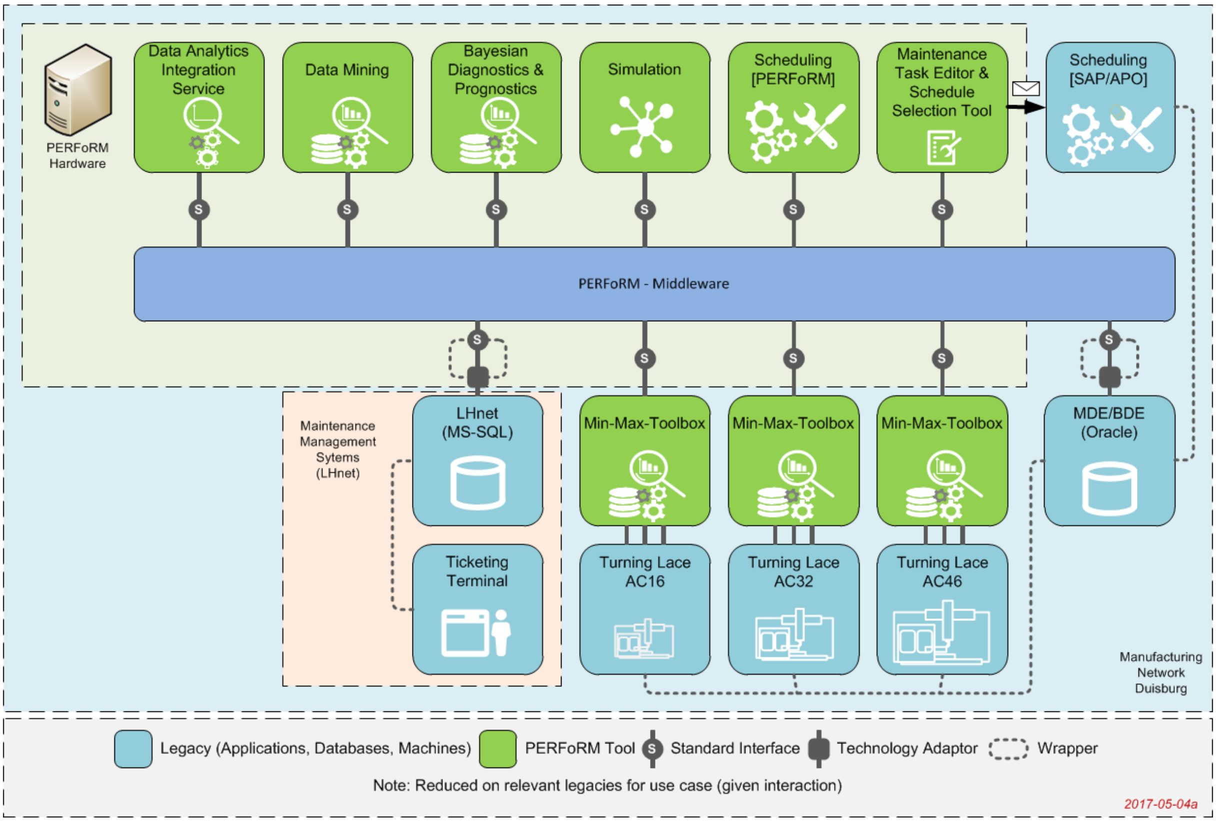


Figure 24 - Hierarchical organization of the PERFoRM target system for the Siemens use case.

At this point, the critical interdependencies need to be analysed (transition *t3.t7*) and verified (transition *t3.t8*) taking into account the preliminary risks and impact analysis of the previous phase in *t2.t6*. In fact, from the analysis of the hierarchical organization is possible to observe that several legacy components, such as data bases, machines and applications, are kept in place and will interact with new components. The PERFoRM tools will have, by default, read access to the legacy components. If there is the need to write in the legacy systems, the "write access" will be conceded manually.

Furthermore, regarding the hardware tools, a separate Professional Computer (PC) will be installed to host the new tools and the middleware, and the three machines represented in Figure 24 will be equipped with additional sensing and data processing devices. The PC previously mentioned will also host several tools, such as Data Analytics, Scheduling and User Interaction.

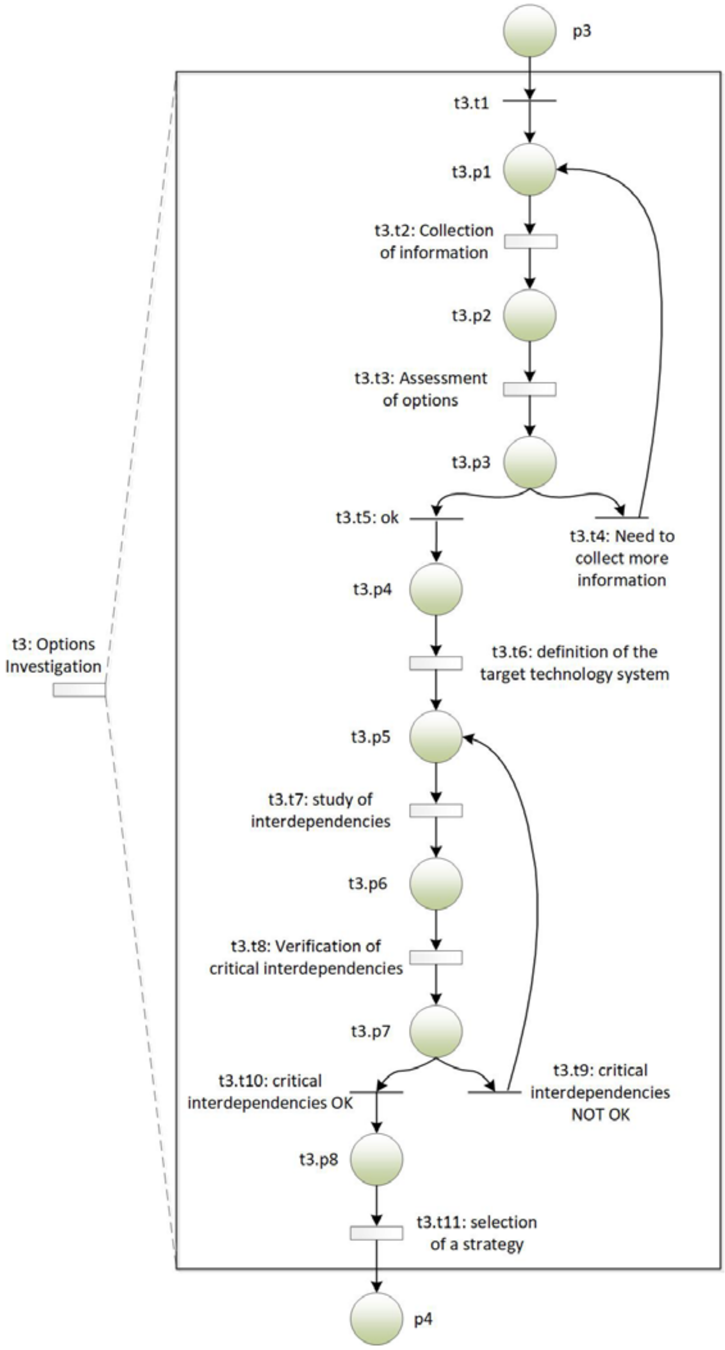


Figure 25 - Petri nets model for the options investigation phase for the Siemens use case.

Regarding the migration strategy, Siemens considers that the most suitable strategy to migrate its systems is the One-Shot migration strategy and the main focus is the migration of software.

With both previous phases completed the design phase takes place. This is a very important phase considering that here all system components are projected. The options investigation phase for the Siemens use case was extended for, approximately, 10 months within the first two years of the project.

7.2.3 Design phase

Figure 26 represents the design phase, here the variables are now defined considering the information extracted from the questionnaire.

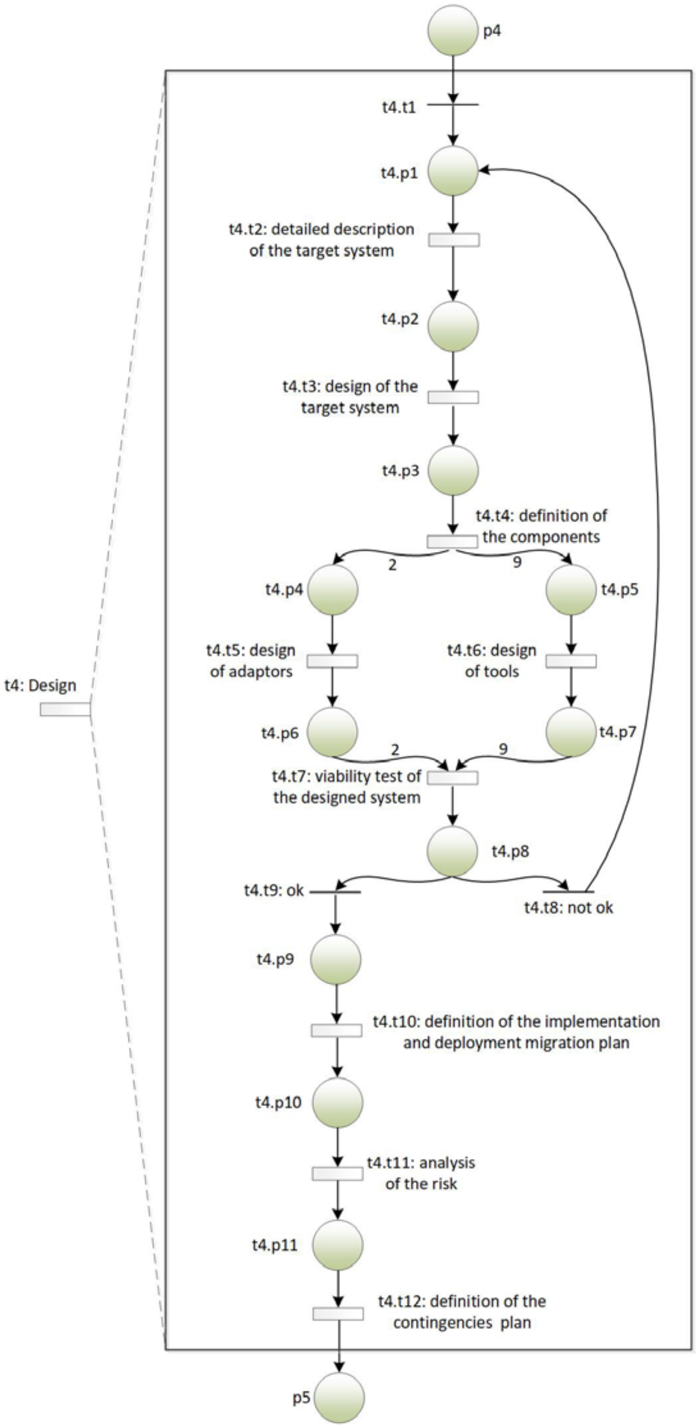


Figure 26 - Petri nets model for the design phase for the Siemens use case.

The design phase starts with the definition and design of the target system. Thus, the detailed interactions between the components (new tools, middleware, legacy software and machines) can be consulted in Figure 27, where the legacy systems are depicted in light blue while the systems developed within PERFoRM are represented in green and the other new components in dark green.

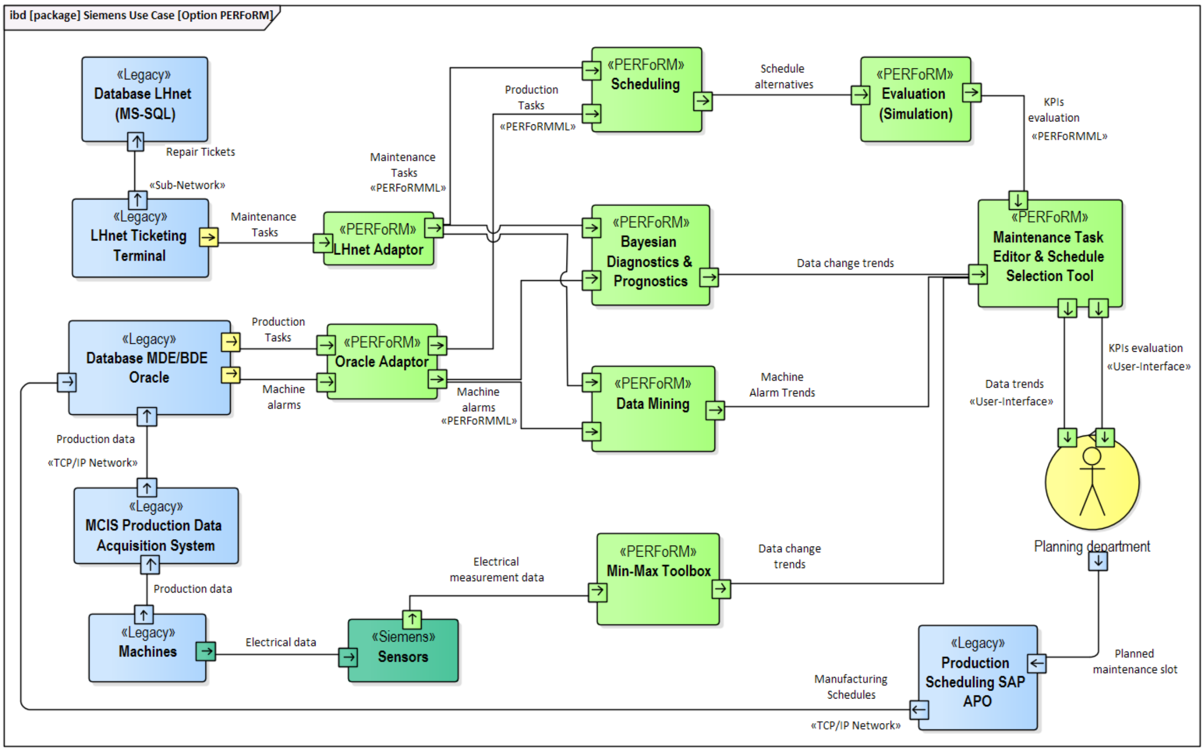


Figure 27 - Target System of the PERFoRM use case.

As described in Deliverable 5.1 [38], the target system for the Siemens use case demonstrator integrates applications developed within PERFoRM and legacy systems through technology adaptors. In particular, the Data Analytics will be performed by three different tools, namely Bayesian Diagnostic & Prognostics, Data Mining, and Min-Max Toolbox, which collect data regarding maintenance tasks, production tasks, machine alarms and machine data from the databases via databases adaptors and directly from the machine via specific sensors. These tools generate some data change and machine alarm trends that will be send to the Maintenance Task Editor and Selection Scheduling Tool that has a human-machine interface. Through this tool the human operator from the Planning Department will be able to change maintenance tasks and select the best scheduling based on the data trends and the KPIs evaluation displayed in the interface. The KPIs are evaluated by a Simulation tool based on the schedules generated by the Scheduling tool, which receives both maintenance and production tasks from the databases through the adaptors.

In short, it is planned to have three data-analytics services, one scheduling service, one simulation service, one user interaction service (Graphical User Interface (GUI) Application), possibly 1 Data-Analytics-Results-Integration-Service (3 Services calculate results, have to be one result for user to work with), 2 Connectors (to existing SQL-based Databases), additionally, measurement devices ("Min-Max-Datamining-Toolbox" might be applied permanently. As referred previously, all applications will run on a single PC which shall be connected to the existing manufacturing network.

In order to allow the connection between the legacy system and the target system it is necessary to develop two database adaptors. Furthermore, one middleware is also required.

Finally, an assessment of the risks has been performed and the following obstacles have been identified: i) compatibility, data adaptors may not be working properly; ii) Human interference, system usability may not be good enough (UI); iii) Implementation, solutions provided may not be working partially or entirely and quality of predictions may be too low; iv) others, problems related to licence and system maintenance issues. Concerning the human interference, training of the operators is required however a training plan has not been developed.

Even though a risk analysis has been performed, a contingencies plan, to be applied in case of failure of the migration process, has not been developed.

The design phase for the Siemens use case was extended for, approximately, 10-12 weeks within the second year of the project.

7.2.4 Implementation and deployment phases

Once the design phase is completed one of the three transitions, namely transition *t5*, *t6* and *t7*, has to be triggered. For this specific use case the priority is to transition *t7*. As referred previously, the questionnaire indicated that the migration of the Siemens systems will be realized by the One-Shot migration strategy.

Figure 28 depicts the migration process for the Siemens use case.

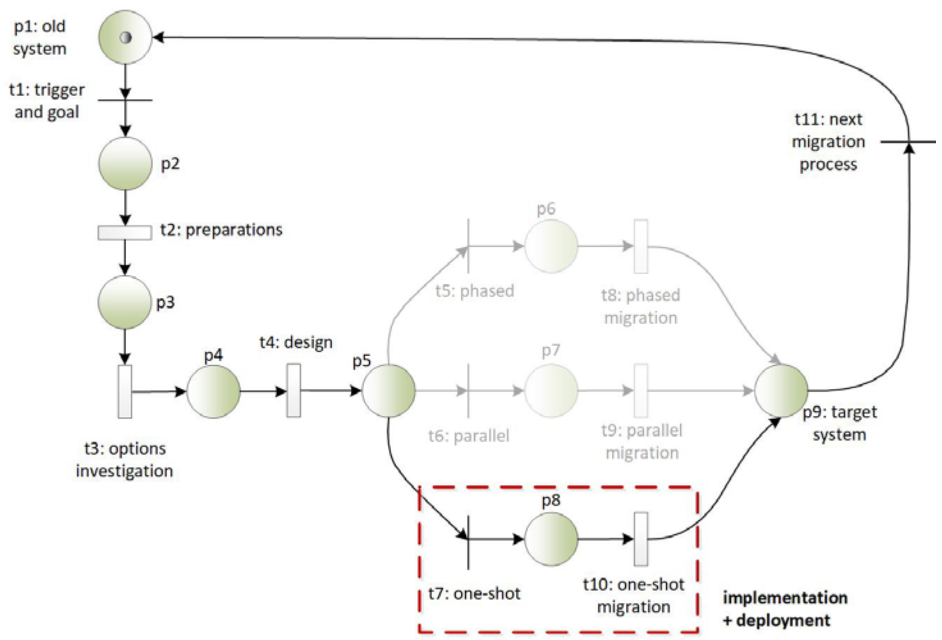


Figure 28 - Migration process for the Siemens Use Case.

The trigger of transition *t7* is followed by the implementation and deployment of the target system according to the One-Shot migration strategy, represented in Figure 29.

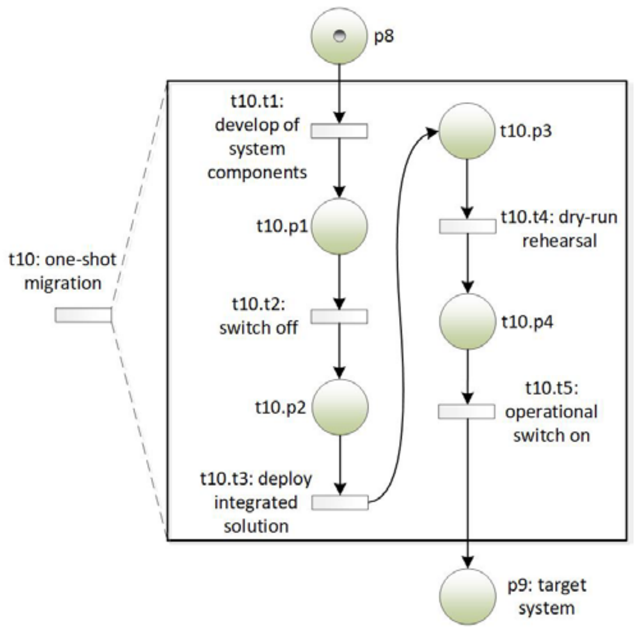


Figure 29 - Petri nets model for the One-Shot migration strategy for the Siemens use case.

The One-Shot migration strategy starts with the development of the system components (transition *t10.t1*), which were designed in the design phase. The transition *t10.t1* explodes to introduce the sub-Petri net that controls the development of the system components, represented in Figure 30.

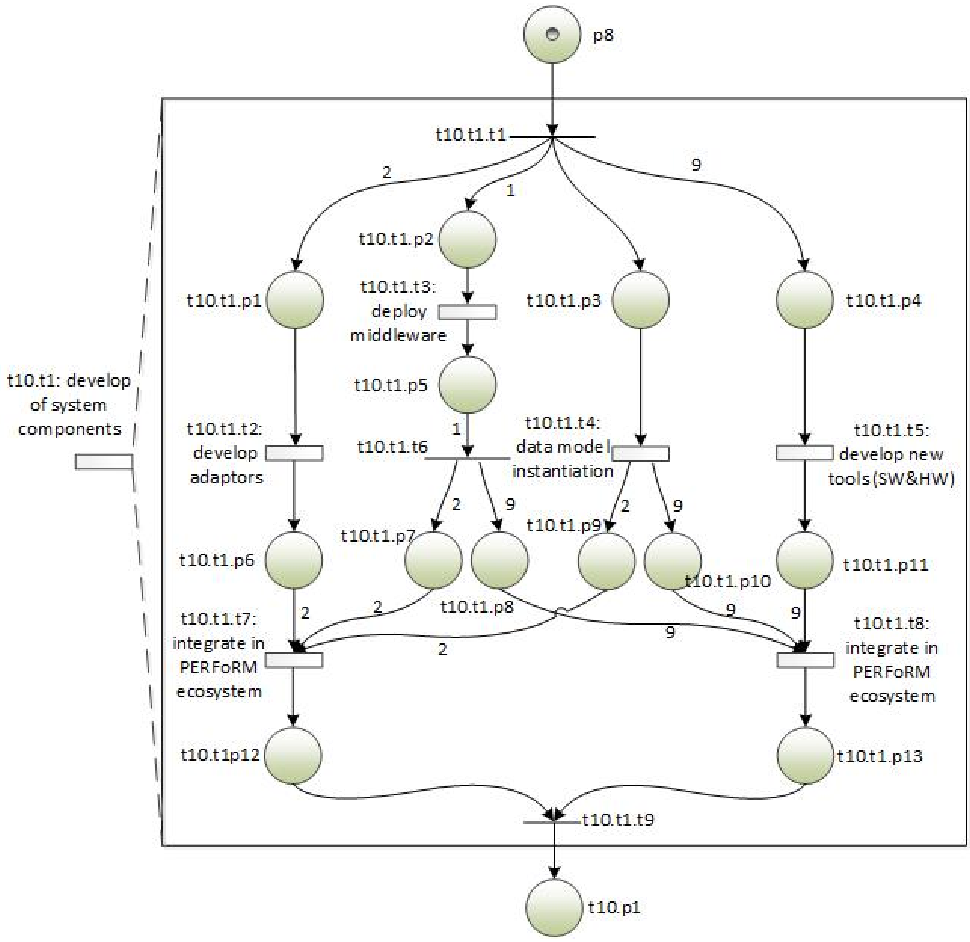


Figure 30 - Petri nets model for the "develop system components" transition for the Siemens use case.

The *k*, *f* and *w* variables were defined in accordance with the variables defined in the design phase Petri nets model, and in this case are equal to 2, 1 and 9 respectively.

Once all components are developed some of the legacy system components are switched off (transition t*10.t2*) and the integrated solution is deployed in the factory (transition *t10.t3*). Task that follows is a dry-run rehearsal (transition *t10.t4*) which is detailed in Figure 31.

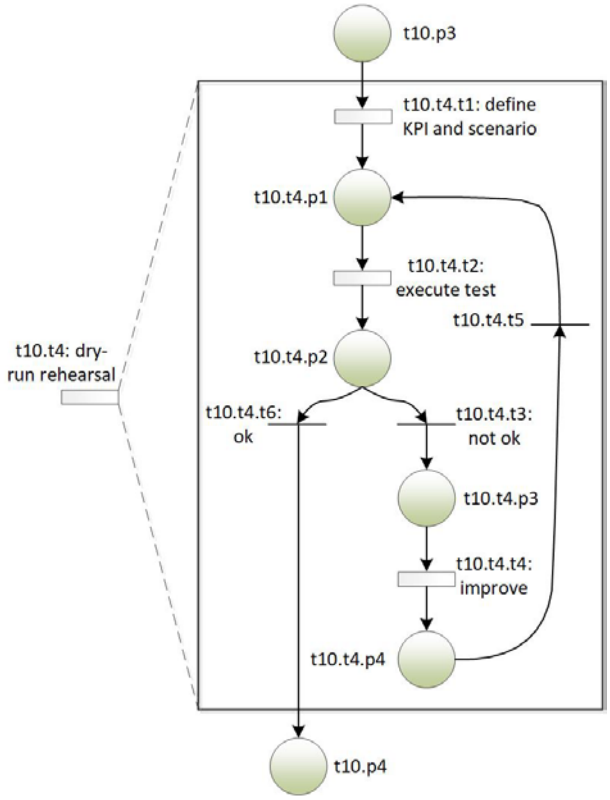


Figure 31 - Petri nets model for the "dry-run rehearsal" transition for the Siemens use case.

Once the dry-run rehearsal proves that the target system is ready to run an operational switch on is performed. The following tasks are the commissioning and validation of the target system, once these task are completed, place *p9* has been achieved and a new migration process can be initiated if necessary.

7.3 Testing the Migration Process

For the testing of the migration process for the Siemens use case, the PnDK software was used [30]. All Petri nets models were modelled in the PnDK software considering the variables defined in section 7.2. The sub-Petri nets models were validated according to the Valette theorem [32]. All screenshots related to the validation of the Petri nets model can be consulted in Annex G.

Given the fact that the migration strategy chosen for the Siemens use case is the One-Shot strategy, the logic value 1 (true) is attributed to transition *t7* and the logic value 0 (false) is attributed to transitions *t5* and *t6*. By attributing logic values to the transitions is possible to control which branches will be executed.

Figure 32 represents the migration process for the Siemens use case.

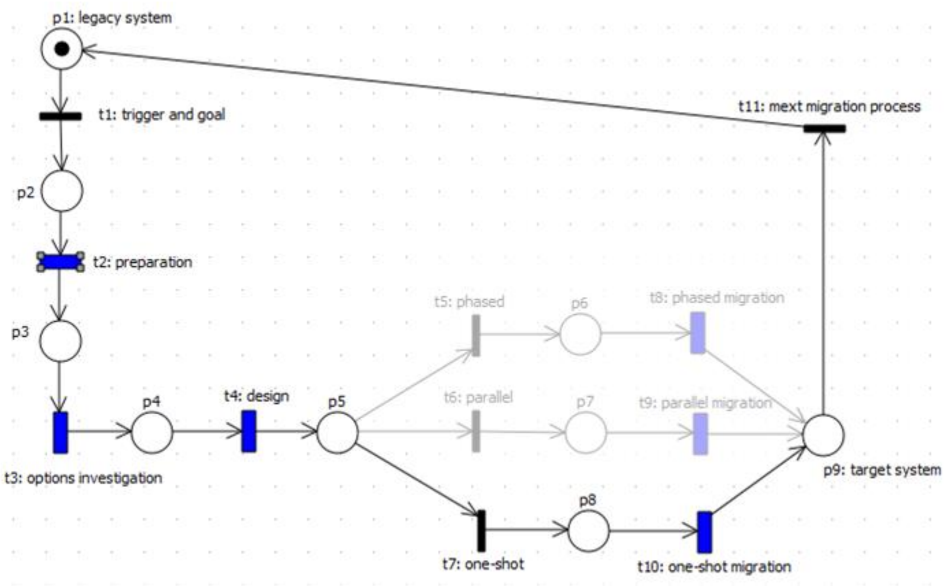


Figure 32 - Migration process for the Siemens Use Case.

By attributing the logic value 1 (true) to transition *t7* the branch that implements and deploys the target system with the One-Shot strategy is the only branch executable, while the others, parallel and phased strategies, are deactivated.

8. Conclusions

The smooth migration, from existing production systems towards the new and more effective CPPS, is a critical issue for the success of the so-called fourth industrial revolution.

This document describes the PERFoRM migration strategy, which comprises Preparation, Options of Investigation, Design, Transformation and Deployment. The modelling of this migration strategy, and particularly each one of these phases, use of the Petri nets formalism to design, verify, simulate and validate the migration process, taking advantage of the graphical and mathematical foundation.

For this purpose, the several phases were modelled using Petri nets, being the modelling process refined by successively explode the timed transitions to include more details (e.g., illustrated by modelling the three migration strategies, namely One-Shot, Parallel and Phased, that can be used to implement the transformation and deployment phases). The designed Petri nets models were analysed, simulated and validated by conducting a qualitative and quantitative analysis. From this analysis it is possible to state that the proposed migration process is structurally and behaviourally validated, as well as properly simulated.

The designed migration strategy was then instantiated for the Siemens use case, based on a questionnaire that compiled the most important information related to the migration path and the instantiation of the Petri nets model for the particularities of this use case. Also the testing of the migration strategy for this use case was performed to verify its correctness.

This deliverable is the 1st release of the PERFoRM migration strategy, being the 2nd release planned to the M36. At the moment, it is already identified two topics that address some attention to be included in this 2nd release: i) exploration of the use of coloured Petri nets to mitigate some problems of the ordinary Petri nets when facing the system scalability, and ii) consider the planning of the migration path for the other 3 industrial use cases.

References

[1] E. A. Lee, "Cyber Physical Systems : Design Challenges," in *11th IEEE Symposium on Object Oriented Real-Time Distributed Computing (ISORC)*, 2008, pp. 363–369.

[2] L. Wang, M. TÃ¶rngren, and M. Onori, "Current status and advancement of cyber-physical systems in manufacturing," *J. Manuf. Syst.*, vol. 37, no. May, pp. 517–527, 2015.

[3] A. Calà *et al.*, "Migration from Traditional towards Cyber-Physical Production Systems," *2017 IEEE 15th Int. Conf. Ind. Informatics*, 2017.

[4] A. Cachada, F. Pires, J. Barbosa, and P. Leitão, "Petri nets Approach for Designing the Migration Process Towards Industrial Cyber-Physical Production Systems," *IECON 2017 - 43rd Annu. Conf. IEEE Ind. Electron. Soc.*, p. (Acepted to), 2017.

[5] Transvive, *Migration Strategies & Methodologies [White Paper]*. 2011.

[6] J. A. Estefan, "Survey of Model-Based Systems Engineering (MBSE) Methodologies," *Jet Propuls.*, vol. 25, pp. 1–70, 2008.

[7] ARC Advisory Group, *Siemens Process Automation System Migration and Modernization Strategies [White Paper]*. 2007.

[8] J. Delsing, F. Rosenqvist, O. Carlsson, A. W. Colombo, and T. Bangemann, "Migration of industrial process control systems into service oriented architecture," *IECON 2012 - 38th Annu. Conf. IEEE Ind. Electron. Soc.*, pp. 5786–5792, 2012.

[9] C. Zillmann *et al.*, "The SOAMIG Process Model in Industrial Applications," *2011 15th Eur. Conf. Softw. Maint. Reengineering*, no. March, pp. 339–342, 2011.

[10] G. Lewis, E. Morris, D. Smith, and L. O'Brien, "Service-oriented migration and reuse technique (SMART)," in *Proceedings - 13th IEEE International Workshop on Software Technology and Engineering Practice, STEP 2005*, 2005, vol. 2005, pp. 222–229.

[11] G. A. Lewis, E. J. Morris, D. Smith, and S. Simanta, "SMART: Analyzing the Reuse Potential of Legacy Systems in Service- Oriented Architecture (SOA) Environments," *Tech. Rep. C. Softw. Eng. Institute, Carnegie Mellon Univ. Pittsburgh, PA*, vol. 8, no. June, 2008.

[12] S. Cetin, N. I. Altintas, H. Oguztuzun, A. H. Dogru, O. Tufekci, and S. Suloglu, "A mashup-based strategy for migration to Service-Oriented Computing," in *2007 IEEE International Conference on Pervasive Services, ICPS*, 2007, pp. 169–172.

[13] P. V. Beserra, A. Camara, R. Ximenes, A. B. Albuquerque, and N. C. Mendonça, "Cloudstep: A step-by-step decision process to support legacy application migration to the cloud," in *2012 IEEE 6th International Workshop on the Maintenance and Evolution of Service-Oriented and Cloud-Based Systems, MESOCA 2012*, 2012, pp. 7–16.

[14] R. Fuentes-Fernández, J. Pavón, and F. Garijo, "A model-driven process for the modernization of component-based systems," in *Science of Computer Programming*, 2012, vol. 77, no. 3, pp. 247–269.

[15] Critical Manufacturing, *MES Migration Strategies*. 2015.

[16] P. Madkan, "Empirical Study of ERP Implementation Strategies-Filling Gaps between the Success and Failure of ERP," *Int. J. Inf. Comput. Technol.*, vol. 4, no. 6, pp. 633–642, 2014.

[17] HSO, "Choosing the right ERP implementation strategy for your company ERP," *[White Pap.*, 2016.

[18] Open Text, *Top 10 Best Practices in Content Migration*. 2009.

[19] W. M. P. Van Der Aalst, "Making Work Flow: On the Application of Petri nets to Business Process Management," *Appl. Theory Petri Nets 2002 23rd Int. Conf. ICATPN 2002, Adelaide, Aust. June 24-30.*, pp. 1–22, 2002.

[20] H. Mili, G. Tremblay, G. B. Jaoude, É. Lefebvre, L. Elabed, and G. El Boussaidi, "Business process modeling languages," *ACM Comput. Surv.*, vol. 43, no. 1, pp. 1–56, 2010.

[21] G. B. Davis, "Strategies for information requirements determination," *IBM Syst. J.*, vol. 21, no. I, pp. 4–30, 1982.

[22] F. Ahmed, S. Robinson, and A. A. Tako, "Using the structred analysis and design technique (SADT) in simulation conceptual modeling," *Proc. - Winter Simul. Conf.*, vol. 2015–Janua, pp. 1038–1049, 2015.

[23] G. M. Giaglis, "A TAXONOMY OF BUSINESS PROCESS MODELLING AND INFORMATION SYSTEMS MODELLING TECHNIQUES," *Int. J. Flex. Manuf. Syst.*, 2001.

[24] W. M. P. van der Aalst, "Three Good reasons for Using a Petri-net-based Workflow Management System," *Inf. Process Integr. Enterp. Rethink. Doc.*, pp. 161–182, 1998.

[25] W. M. P. van der Aalst and K. M. van Hee, "Business process redesign: A Petri-net-based approach," *Comput. Ind.*, vol. 29, no. 1–2, pp. 15–26, 1996.

[26] T. Murata, "Petri Nets: Properties, Analysis and Applications," *Proc. IEEE*, vol. 77, no. 4, pp. 541–580, 1989.

[27] A. Colombo and R. Carelli, "Petri Nets for Designing Manufacturing Systems," in *Computer-Assisted Management and Control of Manufacturing Systems*, Spyros Tzafestas, chapter 11, Springer-Verlag, 1997.

[28] A. Desrochers and R. Al-Jaar, *Applications of Petri Nets in Manufacturing Systems-Modeling, Control and Performance Analysis*. IEEE Press, 1995.

[29] A. W. Colombo, R. Carelli, and B. Kuchen, "A Temporised Petri Net Approach for Design, Modelling and Analysis of Flexible Production Systems," *Int. J. Adv. Manuf. Technol.*, vol. 13, no. 3, pp. 214–226, 1997.

[30] J. M. Mendes, A. Bepperling, J. Pinto, P. Leitão, F. Restivo, and A. W. Colombo, "Software methodologies for the engineering of service-oriented industrial automation: The continuum project," in *Proceedings - International Computer Software and Applications Conference*, 2009, vol. 1, pp. 452–459.

[31] K. Feldmann, C. Schnur, and W. Colombo, "Modularised, distributed real-time control of flexible production cells, using Petri nets," *Control Eng. Pract.*, vol. 4, no. 8, pp. 1067–1078, 1996.

[32] R. Valette, "Analysis of petri nets by stepwise refinements," *J. Comput. Syst. Sci.*, vol. 18, no. 1, pp. 35–46, 1979.

[33] I. Suzuki and T. Murata, "A method for stepwise refinement and abstraction of Petri nets," *J. Comput. Syst. Sci.*, vol. 27, no. 1, pp. 51–76, 1983.

[34] Deliverable 2.2, *Definition of the System Architecture*. PERFoRM project, 28th September 2016.

[35] Deliverable 7.1, *Siemens description and requirements of architectures for retrofitting production equipment*. PERFoRM project, 18th March 2016.

[36] Deliverable 1.1, *Report on decentralized control & Distributed Manufacturing Operation*

Systems for Flexible and Reconfigurable production environments. PERFoRM project, 30th March 2016.

[37] Deliverable 1.2, *Requirements for Innovative Production System Functional requirement analysis and definition of strategic objectives and KPIs*. PERFoRM project, 29th March 2016.

[38] Deliverable 5.1, *The PERFoRM Integration Approach*. PERFoRM project, 19th September 2017.

[39] Deliverable 1.3, *Requirements Review, evaluation and selection of best available Technologies and Tools*. PERFoRM project, 31st March 2016.

Annex A: Acronyms

Abbreviation	Explanation
BPML	Business Process Modeling Language
CPPS	Cyber-Physical Production Systems
CPS	Cyber-Physical Systems
DFD	Data Flow Diagram
GUI	Graphical User Interface
IDEF	Integrated DEFinition Methods
IDEF0	Function Modelling
IDEF1x	Data Modelling
IDEF3	Process Description Capture
IMC-AESOP	ArchitecturE for Service-Oriented Process - Monitoring and Control
ISAC	Information Systems Work and Analysis of Changes
IT	Information Technology
KPIs	Key Performance Indicators
MASHUP	MigrAtion to Service Harmonization compUting Platform
MOMOCS	MOdel driven MOdernisation of Complex Systems
MS-SQL	Microsoft-Structured Query Language
PC	Professional Computer
PERFoRM	Production harmonizEd Reconfiguration of Flexible Robots and Machinery
PnDK	Petri nets Development toolKit
SADT	Structured Analysis Design Technique
SMART	Service-Oriented Migration and Reuse Technique
SOA	Service Oriented Architecture
SOAMIG	Migration of legacy software into service-oriented architectures
T	Task
TCP/IP	Transmission Control Protocol/ Internet Protocol
WP	Work Package
XIRUP	eXtreme end-User dRiven Process
XML	eXtensible Markup Language

Annex B: Questionnaire Template

This appendix describes the questionnaire template used to gather the information regarding the planning and deployment of the strategic migration for the different use cases, as well as the questionnaire fulfilled for the several testbeds.

Questionnaire for Detailing the USE CASE Needs Regarding the Migration Strategy

Date: Click here to enter a date.

Use Case: Click here to enter text.

……………………………………………………………………………………………...

This questionnaire will allow to better understand the legacy system and the parameters and steps required to be performed during the migration process to the PERFoRM demonstrator system. Please note that the PERFoRM demonstrator here is considered as a first migration step towards your long-term vision of the architecture that you want to achieve in the long run (after PERFoRM).

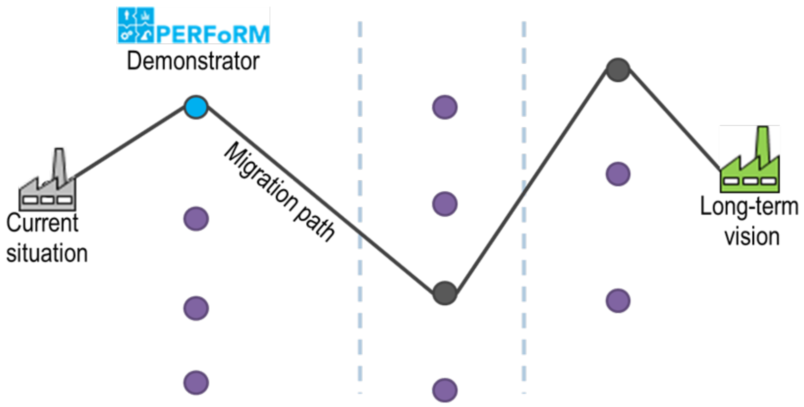


Figure 33 - Migration path.

Some additional Information: There are three main strategies for the migration implementation:

- **One-shot strategy:** characterized by making all the necessary preparations and testing so that, on a single moment, the old system is switched off and the new system is switched on.
- **Parallel strategy:** both old and new systems run in parallel for a while. During this period, the old system is designated as Master and the new system as Slave. After several tests and improvements, the new system can become Master and the old system becomes Slave or is switched off.

- **Phased strategy:** the migration is executed through a gradual transition, introducing parts of the new system in a well-planned sequence. Since this process is executed by replacing small units, it is possible to get feedback between each phase and improve the process.

The next table compares, very generally, the characteristics of the three migration strategies.

Table 2 - Comparison of migration strategies.

	ONE-SHOT	PARALLEL	PHASED
RISK	HIGH	LOW	MEDIUM
MIGRATION DESIGN TIME	HIGH	LOW	MEDIUM (?)
MIGRATION EXECUTION TIME	LOW	MEDIUM	HIGH
DOWN TIME	HIGH	LOW	MEDIUM
COST (EFFORT)	LOW	HIGH	MEDIUM
AREAS OF APPLICATION	Software, product redesign, small productions lines	Software, production lines	Software, production lines

Part I – Assessing the current environment to be migrated and defining the scope of the migration

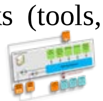
1. What is the main goal of the migration in your case?

A: Click here to enter text.

Description of the Legacy System:

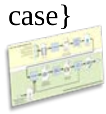
a. **Hierarchical organization of the legacy system**

   i. **Picture** {Include a scheme that refers the existing building blocks (tools, robots, DBs, etc.) and their interconnections}



b. **"User-Story-Flow" of the current use case**

   i. **Picture** {Include a scheme that refers the existing workflow of the use case}

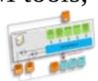


   ii. **Description** {add a description for each block including function, input/output and human interaction}

2. **Description of the Target System within PERFoRM:**

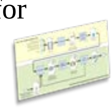
a. **Hierarchical organization of the PERFoRM Target System**

   i. **Picture** {Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors and interconnection using the PERFoRM middleware}



b. **"User-Story-Flow" of the current use case**

i. **Picture** {Include a scheme that refers the workflow of the use case for PERFoRM Demonstrator}



ii. **Description** {add a description for each block including function, input/output and human interaction}

3. **Hierarchical organization of the system (Future Target System):**

   a. **Picture** {Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors, interconnection using the PERFoRM middleware, considering future developments after PERFoRM and other tools}

4. Taking into account the definition of the 3 migration strategies (see previous page), which one do you think it will be the most suitable for your case to achieve the PERFoRM Target System?

   One-shot ☐ Parallel ☐ Phased ☐

5. What is the main focus of the migration process?

   Software ☐ Hardware ☐ Both ☐

   A: Click here to enter text.

Part II – Architecting a new environment (Software and IT Hardware Scope)

1. Has a transition plan been already developed?

   Yes ☐ No ☐

2. Are PERFoRM tools going to be installed? Yes ☐ No ☐

   If the answer is **Yes**, then:

   a) How many tools are going to be developed?

      A: Click here to enter text.

   b) Of what kind(s) are those tools?

      Scheduling ☐ Planning ☐ Simulation ☐

      Re-configuration ☐ Monitoring ☐ Maintenance ☐

      Other(s): Click here to enter text.

   c) Which are the inputs, outputs and flow schema for these tools? Note: Probably the tools characteristics below have already been prepared for the WP4-WP5-Workshop and can be reissued here.

Tool name	Inputs:	Outputs:
Click here to	Click here to enter text.	

enter text.		
	Flow schema: (Picture) Click here to enter text.	

{repeat for all the tools}

3. Are there / Do you know of restrictions in terms of incompatibilities between the different types of tools that are/going to be installed?

   Yes ☐ No ☐

   If the answer is **Yes**, then what are those restrictions?

   A: Click here to enter text.

4. Are you going to maintain legacy systems? Yes ☐ No ☐

   If the answer is **Yes**, then:

   a) How many legacy systems are going to be maintained?
   A: Click here to enter text.

   b) Of what kind(s) are the legacy systems?

Scheduling	☐	Planning	☐	Simulation	☐
Re-configuration	☐	Maintenance	☐	Monitoring	☐
Database	☐	PLCs	☐	Production equipm.	☐

   Other(s): Click here to enter text.

   c) Which are the inputs, outputs and flow schema of legacy systems?

Legacy System name: Click here to enter text.	Inputs: Click here to enter text.	Outputs: Click here to enter text.
	Flow schema: (Picture) Click here to enter text.	

{repeat for all the legacy systems}

5. Do you have access to the legacy systems? Please motivate your answer.

Yes ☐ No ☐

A: Click here to enter text.

6. Taking into account the components above, it will be necessary the development of adaptors?

Yes ☐ No ☐

We are currently exploring two alternatives one with adaptor needed and one without adaptors

If the answer is **Yes**, then:

a) How many adaptors are going to be developed?

A: Click here to enter text.

b) Of what kind(s) are the adaptors needed?

A: Click here to enter text.

c) Which are the inputs, outputs and flow schema of the adaptors?

<table>
<tr><td rowspan="2">Adaptor name:
Click here to enter text.</td><td>Inputs:
Click here to enter text.</td><td>Outputs:
Click here to enter text.</td></tr>
<tr><td colspan="2">Flow schema:
(Picture)
Click here to enter text.</td></tr>
</table>

{repeat for all the adaptors}

7. Is there already a “Middleware” installed (e.g., GKN Factory Middleware BizTalk)?

Yes ☐ No ☐

If the answer is **Yes** then,

a) How many Middlewares are already installed?

A: Click here to enter text.

b) What is the Middleware used?

A: Click here to enter text.

c) Is necessary to maintain the installation of the existing Middleware?

Yes ☐ No ☐

8. How many Middlewares are going to be installed?

A: middleware will be replaced by the equipment integrator of Xetics

9. The existing **IT hardware** has the capacity of supporting the software that is going to be installed?

    a) Yes ☐ No

    b) If the answer is No, which are the problems associated with the hardware:

Type of Problem	Yes
Low Storage	☐
Low Processing Speed	☐
Low Bandwidth	☐
….	☐
Other(s):	

    c) If you consider to purchase new hardware, please indicate:

Equipment	Model	Storage	Processor	Other(s)

    d) Are there restrictions in terms of incompatibilities between the different types of equipment that are/going to be installed?

    Yes ☐ No ☐

    If the answer is **Yes**, then:

    a) Which are the equipment?

    A: Click here to enter text.

    b) What are those restrictions?

    A: Click here to enter text.

Part III - Architecting a new environment (Manufacturing Hardware Scope), e. g. change a robot; add a new PLC, etc.

1. What is the goal in the change of the hardware:

Change in Hardware	Yes
Product Redesign	☐
Process Redesign	☐
New system functionalities	☐
Improve resources capabilities	☐
Other(s): Click here to enter text.	

2. Is going to be necessary to maintain existing hardware?

   Yes ☐ No ☐

   If the answer is **Yes**, then:

   a) How many adaptors are going to be developed?

      A: Click here to enter text.

   b) Of what kind(s) are the adaptors needed?

      A: Click here to enter text.

   c) Which are the inputs, outputs and flow schema of the adaptors?

Adaptor name: Click here to enter text.	Inputs: Click here to enter text.	Outputs: Click here to enter text.
	Flow schema: (Picture) Click here to enter text.	

{repeat for all the legacy systems}

Part IV - Designing a human training/new roles plan for the new environment

1. Is there a qualified personnel in the new technologies that is going to be installed for realization of the migration process?

   Yes ☐ No ☐

   A: Click here to enter text.

2. Has already been developed a training plan for the new implementations for the operators?

   Yes ☐ No ☐

   A: Click here to enter text.

3. Is it possible to give training to the operators before the installation of the new system?

   Yes ☐ No ☐

   A: Click here to enter text.

4. Is it necessary to have the new implementations installed to give training to the operators?

   Yes ☐ No ☐

A: Click here to enter text.

Part V – Understanding the risks and planning contingencies

1. Has already been done a risks identification/estimation/assessment to the business and to the project?

   Yes ☐ No ☐

2. What are the possible risks and obstacles for the implementation of the new architecture?

   a. Production → {list risks related to your production line}

   A:

   b. Technology → {list risks related to the technological choice}

   A:

   c. Compatibility → {list risks related to compatibility with legacy systems}

   A:

   d. Humans → {list risks related to the organizational impact}

   A:

   e. Implementation → {list risks related to implementation of the new technology}

   A:

   f. Others → {list other risks that should be considered for your use case}

   A:

3. In case of failure of some part of the migration has been created a contingency plan?

   Yes ☐ No ☐

   A:

Annex C: Questionnaire Results for the Siemens Use Case

The questionnaire fulfilled by Siemens and used as input for planning and deployment its migration strategy, is illustrated as follows.

Part I – Assessing the current environment to be migrated and defining the scope of the migration

1. What is the main goal of the migration in your case?

A: Better availability of machines and less delays in product finalization times/dates; shall be achieved by improved planning of maintenance actions (better fitting schedule of production and maintenance tasks) and better prevention of breakdowns (predictive maintenance approach) [Note: Details see Deliverable 7.1 and M18 Reports for minor revisions / clarifications]

Description of the Legacy System:

a. Hierarchical organization of the legacy system

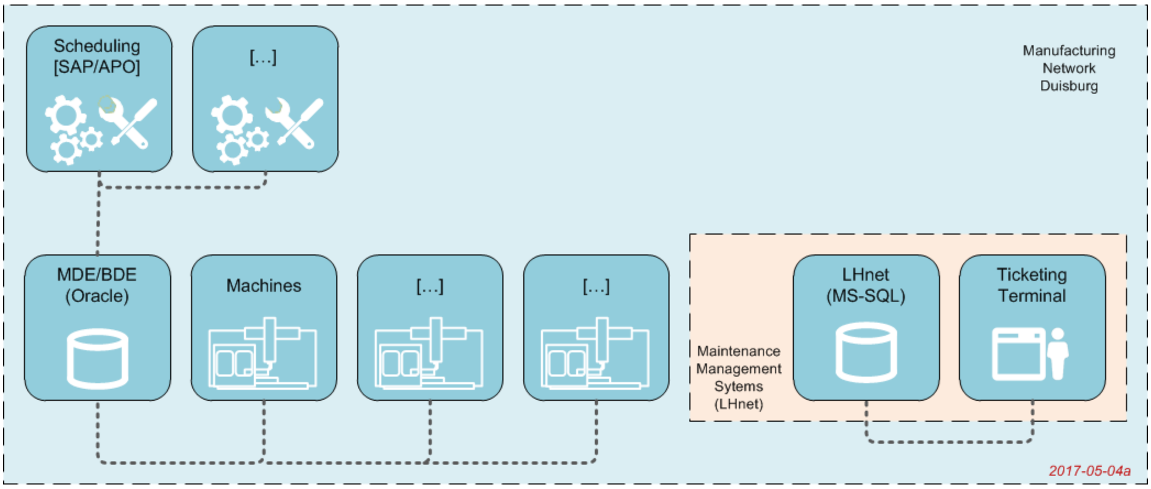


Figure 34 - System Architecture of current production data acquisition and maintenance management system [Visualization of legacy system reduced to components relevant for the demonstrator use case].

- [Note: Scope reduced on relevant subsystems for Demonstrator]
- All Machines in the production area are connected via the Siemens MCIS Manufacturing/Production Data acquisition system. Data collected consists of occupancy state of the machine (productive, non-productive with cause (technical, organizational break)) and the alarms thrown by the machines controls. Collected data is stored in an Oracle Database. In the same Database, the Manufacturing Schedules per Machine and thus overall are stored. The systems are connected via a TCP/IP Network, which is not connected to the outside world (Manufacturing Network).
- As a sub-network, the maintenance ticketing system LHnet is run, consisting of Terminals with webbrowsers to open maintenance tickets and transfer them to a (proprietory by the supplier; MS Sql) Database. Further Applications for Maintenance Management read and display data from that database.

b. "User-Story-Flow" of the current use case

i. Picture

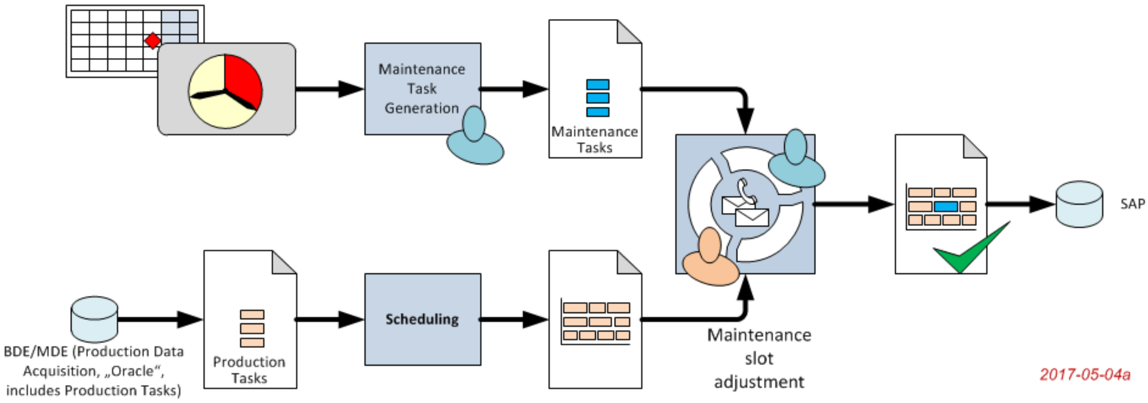


Figure 35 - User Story of time-based maintenance in the legacy system.

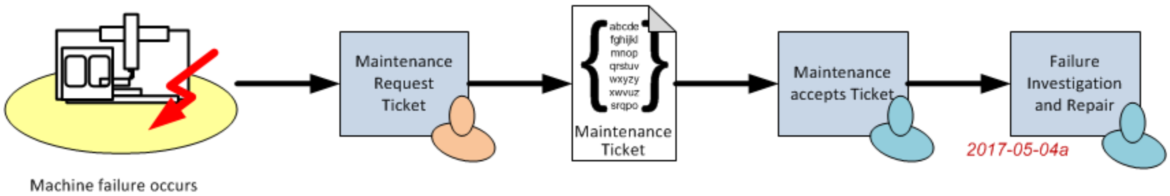
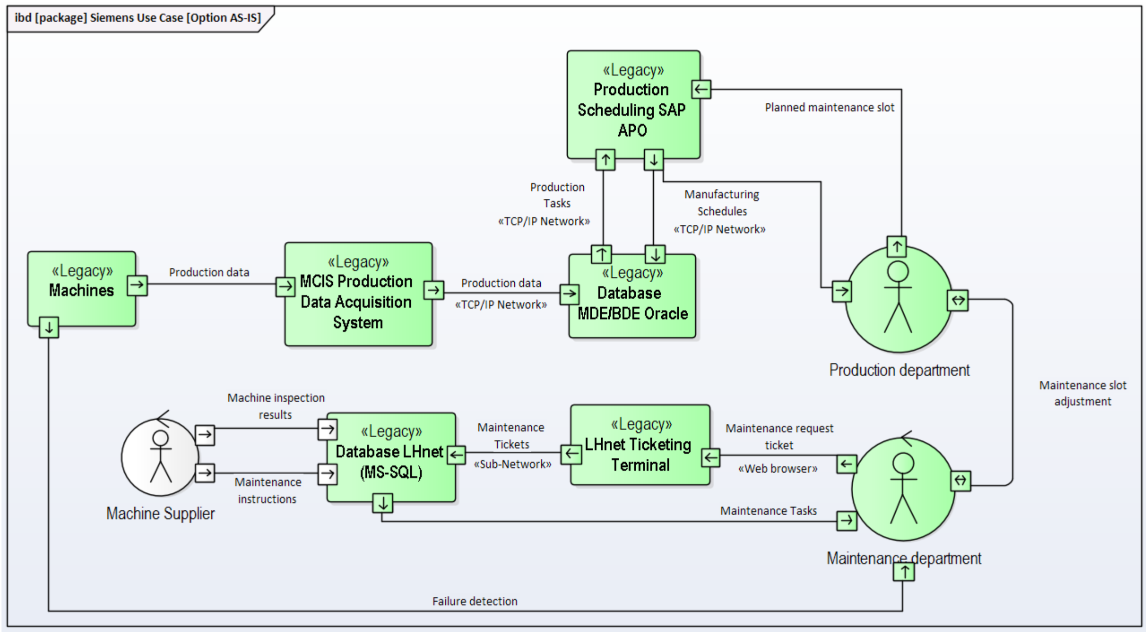
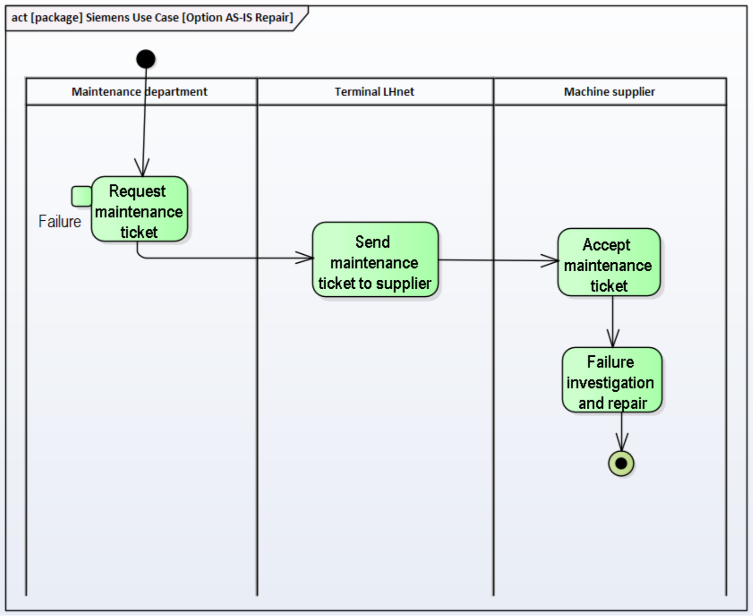
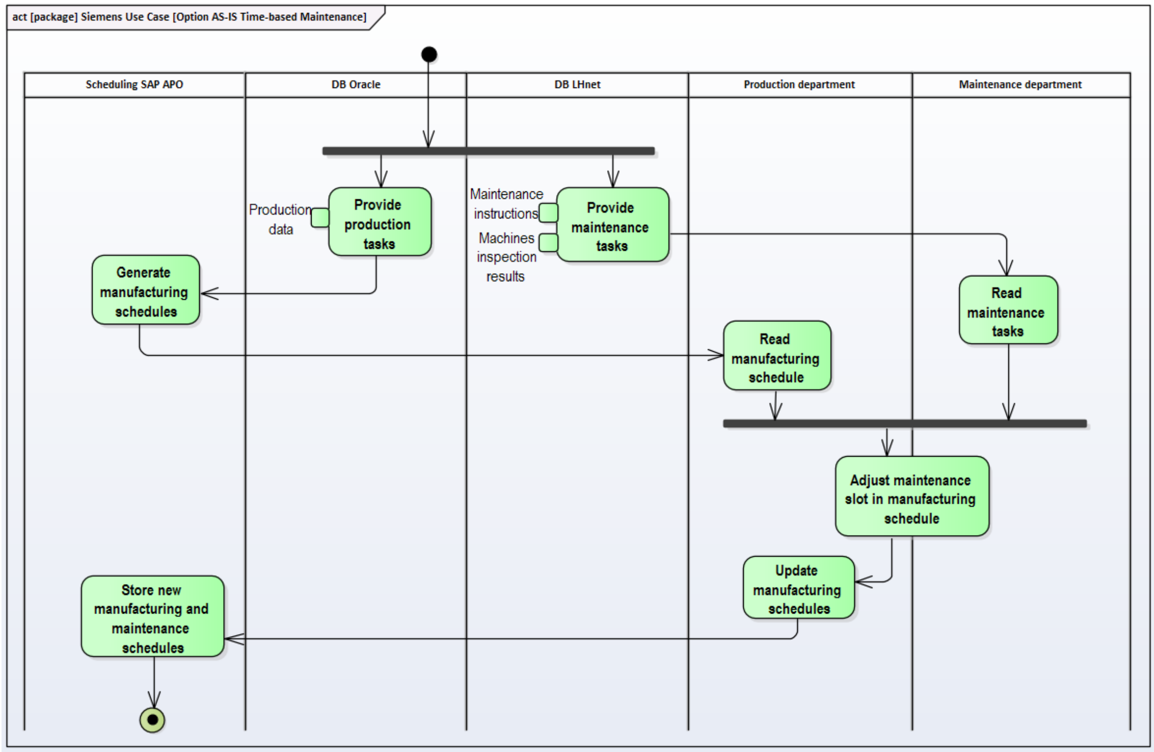


Figure 36 - User Story of repair in the legacy system.







ii. Description

- Currently maintenance and repair is not fully integrated
- maintenance (inspection + maintenance, Figure 35) is done time based (e.g. once per year) within a dedicated slot (e.g. 3 days of inspection and maintenance within a two week slot defined before). Maintenance actions are then defined based on inspection results (or based on maintenance instructions by machine manufacturer)

  - o Maintenance slot and exact execution is negotiated between between involved departments (normally production and maintenance) manually
  - o Planned maintenance slots are considered in the planning/scheduling by lowering the machine availability for the time slot
- Repair (Figure 36) is done following an Case-based approach (Failures, Breakdowns) which are reported through a ticketing system to the maintenance department. Maintenance actions are defined based on these tickets (descriptions in ticket) or on a following problem inspection of the machine.
- In both cases, new defined maintenance actions are done immediately, if possible (e.g. spare parts and resources available)
- If no immediate handling is possible, time for maintenance is negotiated between involved departments (normally production and maintenance) manually. Work flow representation is similar to inspection + maintenance, Figure 35 now.
- In general, if production resources are not fully occupied by production tasks, maintenance (inspection + maintenance) might be moved up.

2. Description of the Target System within PERFoRM:

a. Hierarchical organization of the PERFoRM Target System

i. Picture

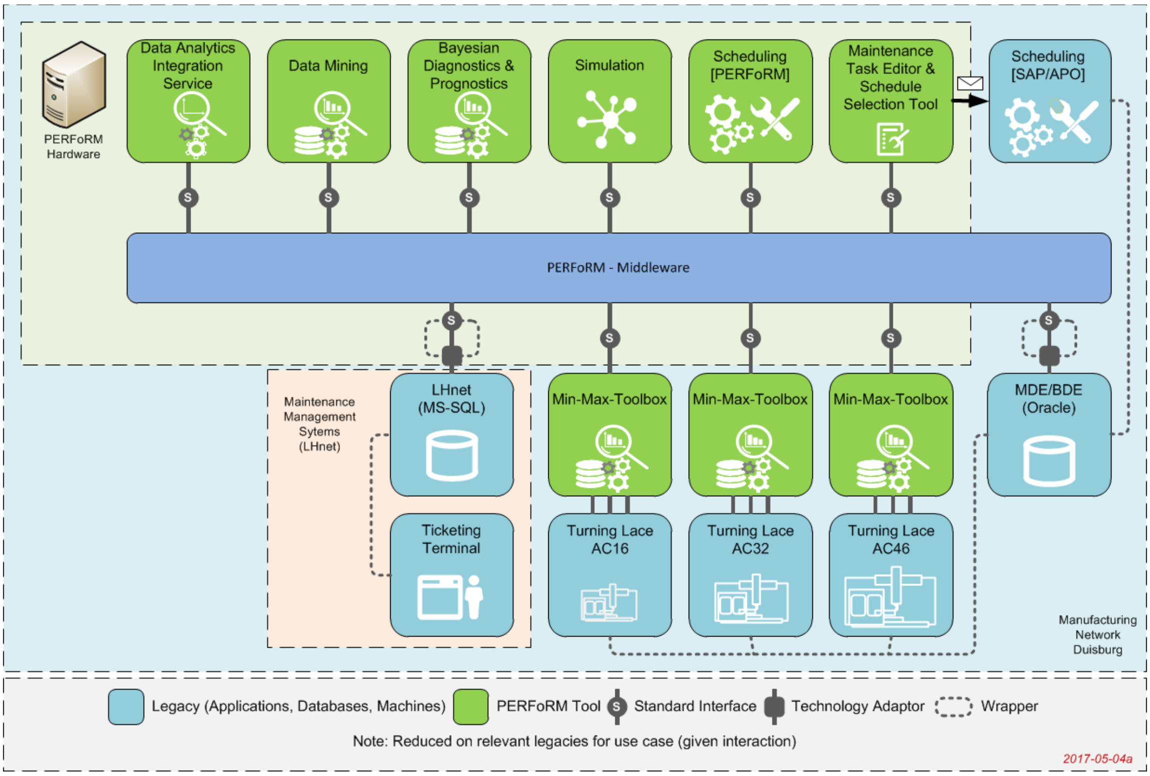
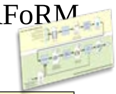


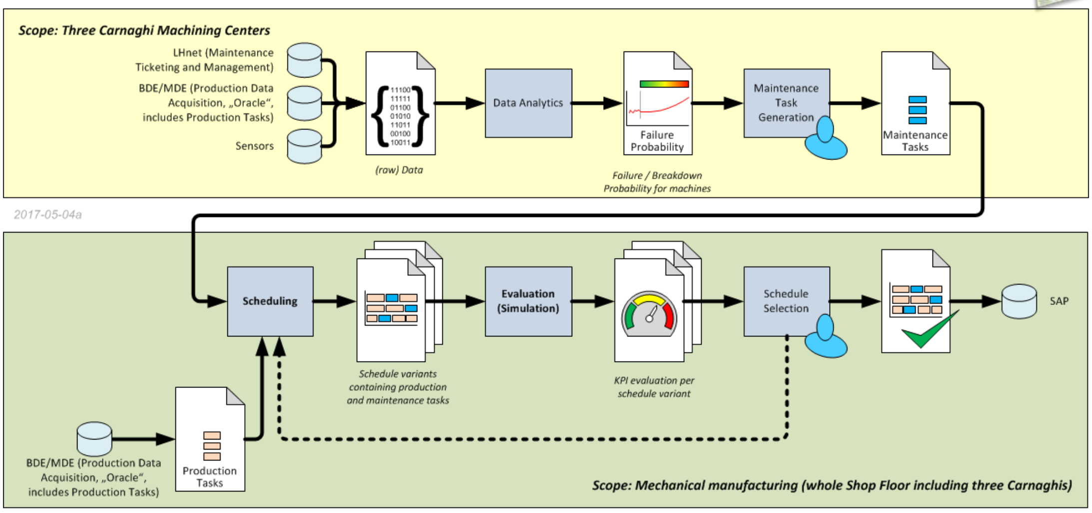
Figure 37 - Targeted Architecture of the PERFoRM Demonstrator Implementation.

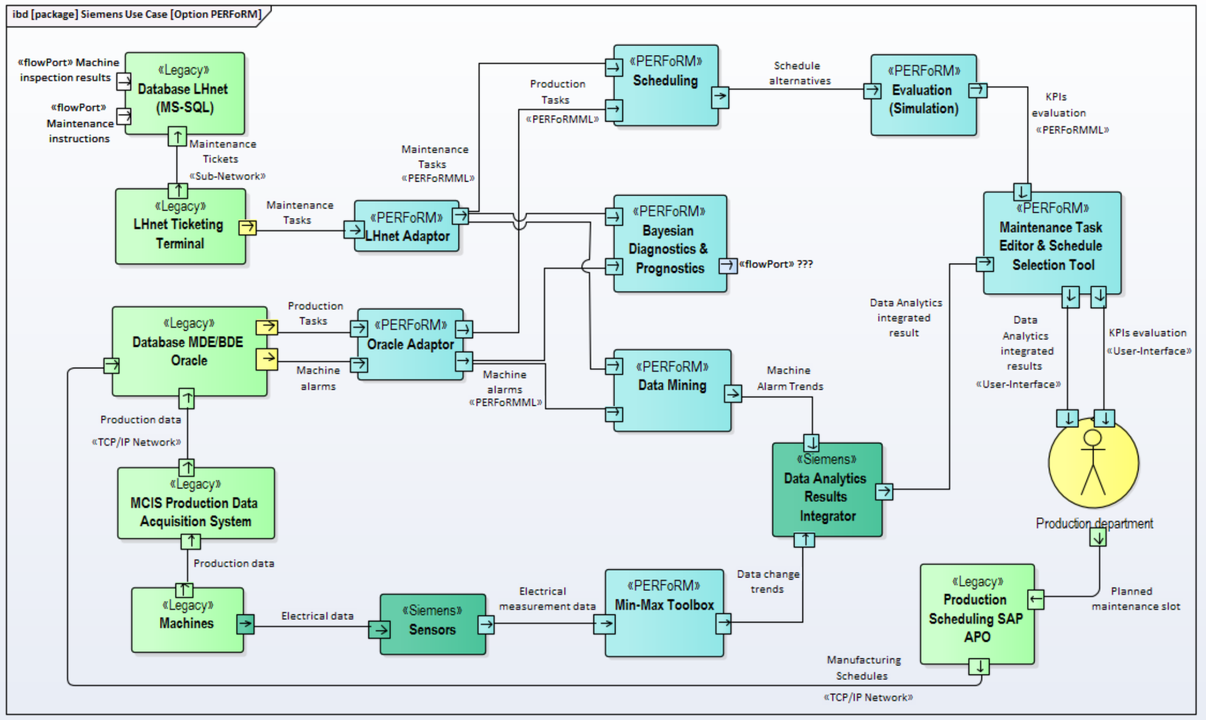
- Legacy tools are kept in place as today, PERFoRM Additions will only read from existing systems, “write access” will be done manually (feeding defined maintenance slots to existing Scheduling system)
- All PERFoRM-Enhancements to the legacy system will be run on a separate PC, hosting the middleware and tools (if necessary, further PC’s for e.g. hosting tools are possible)
- Three machines will be equipped with additional sensing and data processing devices for electricity-based condition monitoring; these will be connected to the network and thus to the perform middleware
- Services for Data Analytics, Scheduling and User Interaction will be hosted on additional hardware (PC, as mentioned above)
  - o Architechture still undergoing changes, since adjustments with tool providers still going on (e.g. if User Interaction Tool is a Web-Application or a classic Windows Application, etc.). Principle should be final.

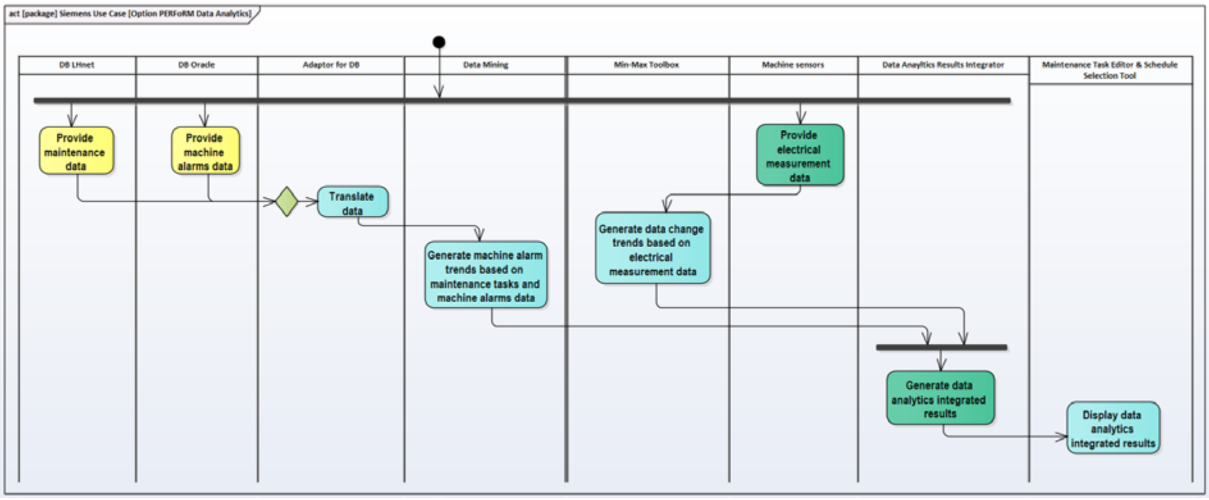
b. “User-Story-Flow” of the current use case

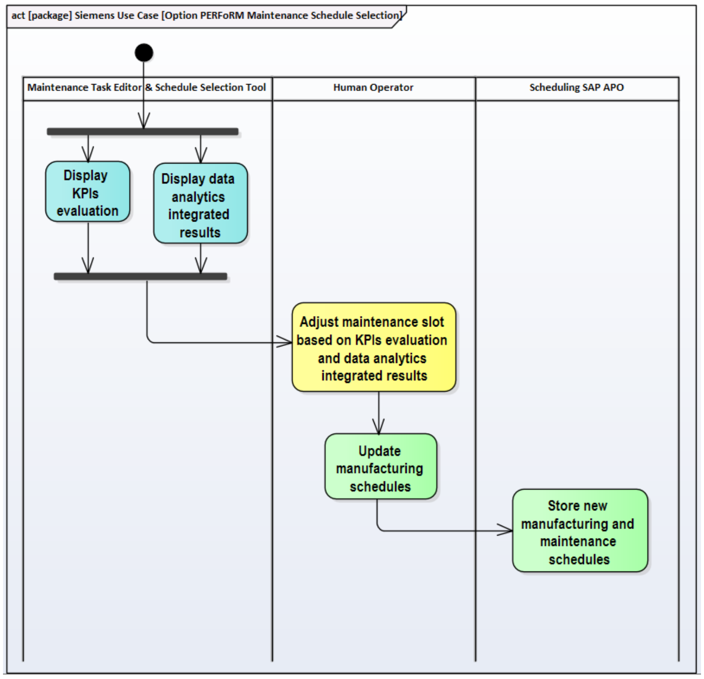
i. Picture{Include a scheme that refers the workflow of the use case for PERFoRM Demonstrator}

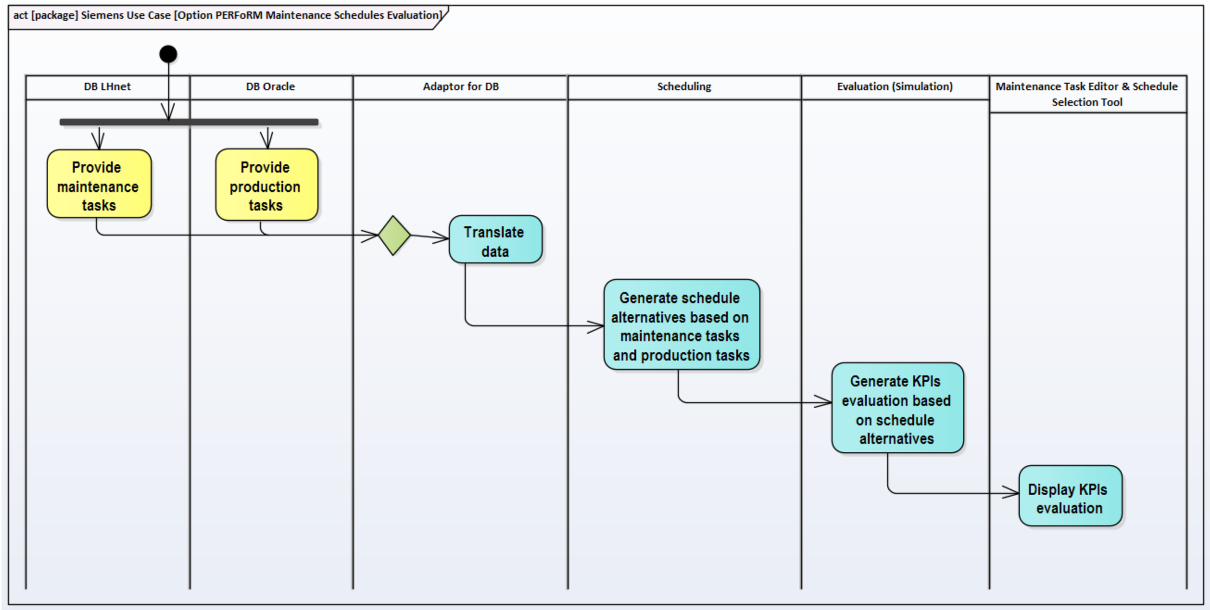





ibd [package] Siemens Use Case [Option PERFoRM]
«flowPort» Machine inspection results
«flowPort» Maintenance instructions
«Legacy» Database LHnet (MS-SQL)
Maintenance Tickets
«Sub-Network»
«Legacy» LHnet Ticketing Terminal
Maintenance Tasks
«PERFoRM» LHnet Adaptor
Maintenance Tasks
«PERFoRMML»
Production Tasks
«PERFoRMML»
«PERFoRM» Scheduling
Schedule alternatives
«PERFoRM» Evaluation (Simulation)
KPIs evaluation
«PERFoRMML»
«PERFoRM» Bayesian Diagnostics & Prognostics
«flowPort» ???
«PERFoRM» Maintenance Task Editor & Schedule Selection Tool
Data Analytics integrated result
Data Analytics integrated results
«User-Interface»
KPIs evaluation
«User-Interface»
«Legacy» Database MDE/BDE Oracle
Production Tasks
«PERFoRM» Oracle Adaptor
Machine alarms
Machine alarms
«PERFoRMML»
«PERFoRM» Data Mining
Machine Alarm Trends
Production data
«TCP/IP Network»
«Siemens» Data Analytics Results Integrator
Production department
«Legacy» MCIS Production Data Acquisition System
Production data
«Legacy» Machines
Electrical data
«Siemens» Sensors
Electrical measurement data
«PERFoRM» Min-Max Toolbox
Data change trends
«Legacy» Production Scheduling SAP APO
Planned maintenance slot
Manufacturing Schedules
«TCP/IP Network»


act [package] Siemens Use Case [Option PERFoRM Data Analytics]
DB LHnet
DB Oracle
Adaptor for DB
Data Mining
Min-Max Toolbox
Machine sensors
Data Anayltics Results Integrator
Maintenance Task Editor & Schedule Selection Tool
Provide maintenance data
Provide machine alarms data
Translate data
Provide electrical measurement data
Generate machine alarm trends based on maintenance tasks and machine alarms data
Generate data change trends based on electrical measurement data
Generate data analytics integrated results
Display data analytics integrated results



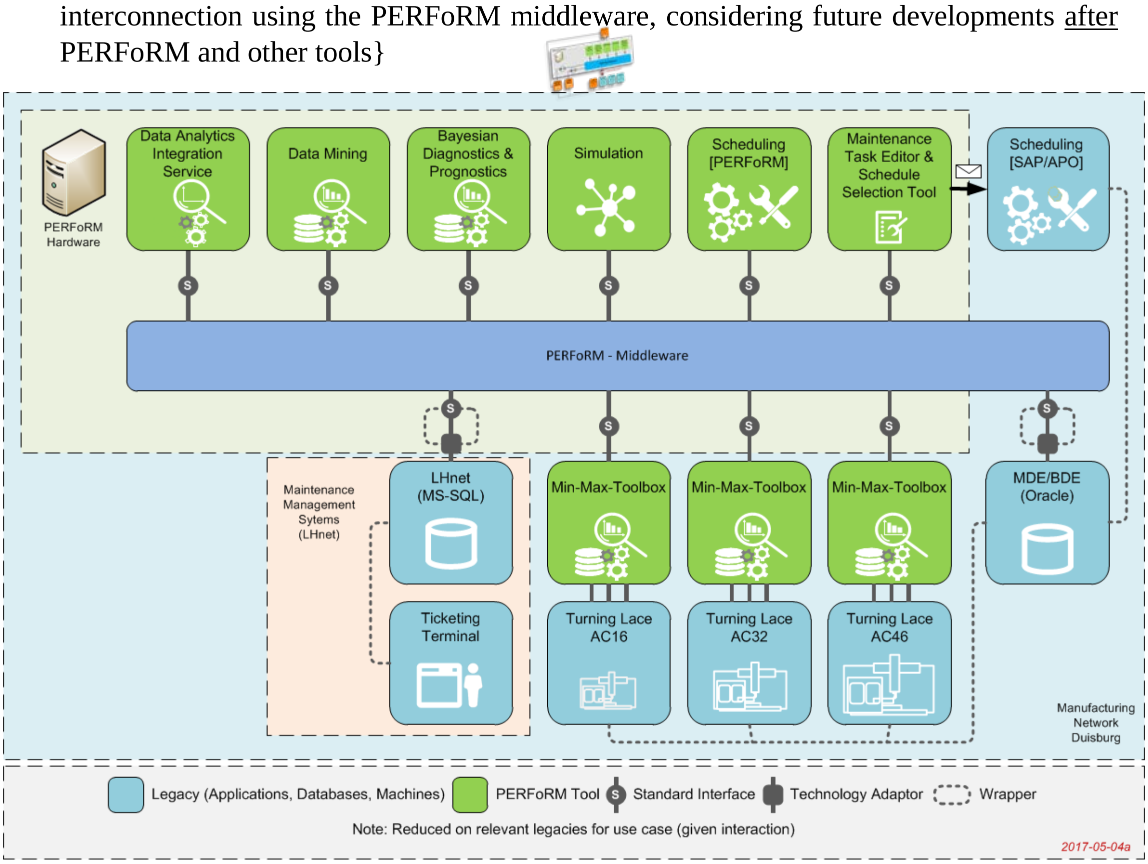


ii. **Description** {add a description for each block including function, input/output and human interaction}

- Data Analytics:
  - Three different Data Analytics Services, providing information on trends in machine health conditions (e.g. frequency of failure patterns occurring, changes in electrical consumption of single components)
- “Maintenance Task Generation” and “Schedule Selection”:

- o "User-Interface-Application" for providing output of the three Data Analytics Services in one Tool, allowing the User to define Maintenance Tasks and transfer them to the Scheduling Service.
  - o Presenting the Results from the simulation-based schedule evaluation to the user and let him select a schedule to be (manually) transferred to the legacy Scheduling System (SAP APO)
- Scheduling:
  - o Scheduling Service which generates suitable schedules following alternative goals (e.g. minimal throughput time, earliest completion possible, earliest maintenance)
- Evaluation (Simulation):
  - o Service will run several simulation experiments on each schedule, varying e.g. Failures, Downtimes, Delays etc. for calculating Indicators defining the quality of the schedule. (Indicators are used in schedule selection to allow the user to distinguish between different schedules and select the best fitting one)

3. **Hierarchical organization of the system (Future Target System):**
   a. **Picture** {Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors, interconnection using the PERFoRM middleware, considering future developments after PERFoRM and other tools}



4. Taking into account the definition of the 3 migration strategies (see previous page), which one do you think it will be the most suitable for your case to achieve the PERFoRM Target System?

   One-shot X Parallel ☐ Phased ☐

   Since we intend to put all software on a computer (also the MW), and at one point connect that pc to the manufacturing network, I would consider it one shot. However, there are several iterations, we are for example already experimenting with measurement devices in the considered machine's cabinets.

5. What is the main focus of the migration process?

   Software X Hardware ☐ Both ?

   Mainly software; but with the min-max datamining, there might be some hardware involved.

   A: System is consisting mainly of software services, although hardware is involved. The modular design is dedicatedly chosen to allow a one-time set up of the system at the plant.

Part II – Architecting a new environment (Software and IT Hardware Scope)

1. Has a transition plan been already developed?

   Yes X No ☐

2. Are PERFoRM tools going to be installed? Yes X No ☐

   If the answer is **Yes**, then:

   d) How many tools are going to be developed?
   A: Currently, it is planned to have 3 Data-Analytics-Services, 1 Scheduling Service, 1 Simulation Service, 1 (or 2) User Interaction Service (GUI-Application), possibly 1 Data-Analytics-Results-Integration-Service (3 Services calculate results, have to be one result for user to work with), 2 Connectors (to existing SQL-based Databases); will all run on one PC which shall be connected to the existing manufacturing network, no internet connection; possible: additionally, measurement devices ("Min-Max-Datamining-Toolbox" might be applied permanently); AND: Middleware (is that considered a Tool?)

   e) Of what kind(s) are those tools?
   Scheduling X Planning ☐
   Simulation X Re-configuration ☐
   Monitoring X Maintenance X
   Other(s): GUI-Application for User Interaction, Data-Adapters

   f) Which are the inputs, outputs and flow schema for these tools?
   Note: Probably the tools characteristics below have already been prepared for the WP4-WP5-Workshop and can be reissued here.

This is still not finalized yet, we are still adjusting.

Tool name Data Analytics: Min-Max-Datamining-Toolbox	Inputs: Electrical Measurement Data	Outputs: Data Change Trends
	Flow schema: (Picture) For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.	

Tool name Data Mining "Machine Alarm Trend Analysis"	Inputs: BDE/MDE Data (Machine Alarms); LHnet Data	Outputs: Data Change Trends (Alarm Patterns)
	Flow schema: (Picture) For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.	

Tool name Bayesian Diagnostics & Prognostics	Inputs: BDE/MDE Data (Machine Alarms); LHnet Data	Outputs: Click here to enter text.
	Flow schema: (Picture) For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.	

Tool name Data Analytics Results Integrator	Inputs: Results from the three Data Analytics Services	Outputs: Combined Result per Machine
	Flow schema: (Picture) Note: This is new from our (Siemens) proceedings on the overall use case, has to be discussed with the partners	

Tool name Scheduling	Inputs: Manufacturing Tasks, Maintenance Tasks	Outputs: Schedule Alternatives
	Flow schema: (Picture) For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.	

Tool name Simulation	Inputs: Schedules from Scheduling tool	Outputs: KPI(s) per schedule
	Flow schema: (Picture) For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.	

3. Are there / Do you know of restrictions in terms of incompatibilities between the different types of tools that are/going to be installed?

Yes X   No ☐

If the answer is **Yes**, then what are those restrictions?

A: According to the current discussions on the integration of all tools as one system, there still seem to be adjustments necessary e.g. for data formats, triggers, etc.

4. Are you going to maintain legacy systems? Yes X No ☐

If the answer is **Yes**, then:

d) How many legacy systems are going to be maintained?
A: Can not say, all of them; Systems within Scope of Use Case would be ~4 (SAP APO Scheduling, LHnet Maintenance Ticketing, 2 Databases); + Prod. Equipment

e) Of what kind(s) are the legacy systems?

Scheduling X Planning ☐ Simulation ☐

Re-configuration ☐ Maintenance X Monitoring X

Database X PLCs X Production equipm.X

Other(s): n/a

f) Which are the inputs, outputs and flow schema of legacy systems?

Legacy System name: BDE/MDE	Inputs: Machine Alarms, Product ID	Outputs: [none in this context]
	Flow schema: (Picture) For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.	

Legacy System name: LHnet	Inputs: Maintenance requests (manual tickets)	Outputs: [none in this context]
	Flow schema: (Picture) For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.	

5. Do you have access to the legacy systems? Please motivate your answer.

Yes X No ☐

A: We will have read access to the Databases of the legacy systems; which allows to read all relevant data (Production task, schedules, Machine alarms and failures, etc.; at the same time no problems in case of PERFoRM-System-Failures can be passed on to existing systems.

6. Taking into account the components above, it will be necessary the development of adaptors?

Yes X No ☐

If the answer is **Yes**, then:

d) How many adaptors are going to be developed?
A: 2
e) Of what kind(s) are the adaptors needed?
A: Database-to-Middleware
f) Which are the inputs, outputs and flow schema of the adaptors?

<table>
<tr><td rowspan="2">Adaptor name: Production-Data-Acquisition-System-Connector (Oracle-DB)</td><td>Inputs:
Data Request from Services through the middleware</td><td>Outputs:
Requested Data as PERFoRM-ML-Response</td></tr>
<tr><td colspan="2">Flow schema: (Picture)
For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.</td></tr>
</table>

{repeat for all the legacy systems}

<table>
<tr><td rowspan="2">Adaptor name: Maintenance-Ticketing-System-Connector (MSSQL-DB)</td><td>Inputs:
Data Request from Services through the middleware</td><td>Outputs:
Requested Data as PERFoRM-ML-Response</td></tr>
<tr><td colspan="2">Flow schema: (Picture)
For overall flow see pictures above (Part I), for internal flow of tool refer to respective deliverables.</td></tr>
</table>

7. Is there already a “Middleware” installed (e.g., GKN Factory Middleware BizTalk) ?

Yes ☐ No X

If the answer is **Yes** then,

d) How many Middlewares are already installed?
A: Click here to enter text.
e) What is the Middleware used?
A: Click here to enter text.
f) Is necessary to maintain the installation of the existing Middleware?

Yes ☐ No ☐

8. How many Middlewares are going to be installed?
A: 1

9. The existing **IT hardware** has the capacity of supporting the software that is going to be installed?

e) Yes ☐ No X

f) If the answer is No, which are the problems associated with the hardware:

Type of Problem	Yes
Low Storage	☐
Low Processing Speed	☐
Low Bandwidth	☐
….	☐
Other(s): Modular concept of additional system would not be maintained if existing hardware was used	

g) If you consider to purchase new hardware, please indicate:

Equipment	Model	Storage	Processor	Other(s)
Standard PC	tbd	tbd	tbd	

Currently, we intend „one“, but we assume that it would be possible without much effort to have e.g. one PC for hosting the Middleware and one for running some Services

h) Are there restrictions in terms of incompatibilities between the different types of equipment that are/going to be installed?

Yes ☐ No X

At least by now we don't know any.

If the answer is **Yes**, then:

c) Which are the equipments?
A: Click here to enter text.

d) What are those restrictions?
A: Click here to enter text.

Part III - Architecting a new environment (Manufacturing Hardware Scope), e. g. change a robot; add a new PLC, etc.

1. What is the goal in the change of the hardware:

Change in Hardware	Yes
Product Redesign	☐
Process Redesign	☐
New system functionalities	X

Improve resources capabilities	X
Other(s): Possible: Apply Sensors	

2. Is going to be necessary to maintain existing hardware?

   Yes X No ☐

   If the answer is **Yes**, then:

   d) How many adaptors are going to be developed?
      A: 0
      There are no Hardware adaptors, since all is covered through the database adaptors mentioned above.
   e) Of what kind(s) are the adaptors needed?
      A: Click here to enter text.
   f) Which are the inputs, outputs and flow schema of the adaptors?

Adaptor name: Click here to enter text.	Inputs: Click here to enter text.	Outputs: Click here to enter text.
	Flow schema: (Picture) Click here to enter text.	

Part IV - Designing a human training/new roles plan for the new environment

1. Is there a qualified personnel in the new technologies that is going to be installed for realization of the migration process?

   Yes ☐ No X

   A: Unless we count "us" as the ones involved in the project…

2. Has already been developed a training plan for the new implementations for the operators?

   Yes ☐ No X

   A: Click here to enter text.

3. Is it possible to give training to the operators before the installation of the new system?

   Yes X No ☐

   A: Click here to enter text.

4. Is it necessary to have the new implementations installed to give training to the operators?

   Yes X No ☐

   A: Training will essentially be to introduce the new system, therefore it will have to be installed before

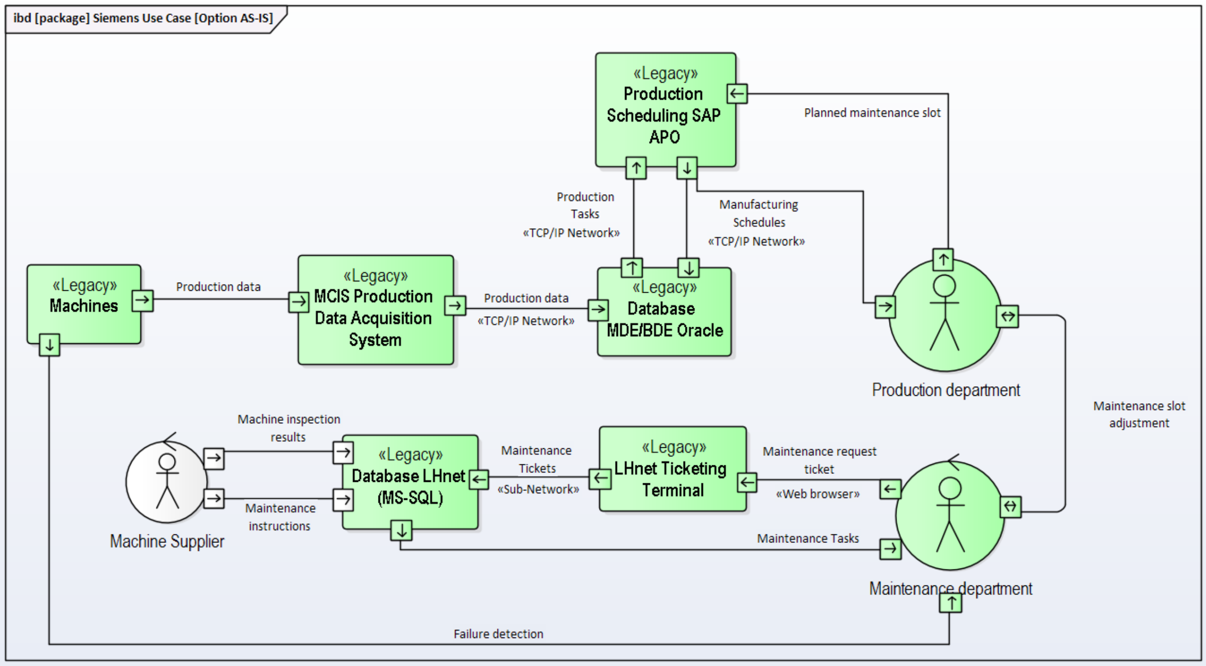
Part V – Understanding the risks and planning contingencies

1. Has already been done a risks identification/estimation/assessment to the business and to the project?

   Yes X No ☐

2. What are the possible risks and obstacles for the implementation of the new architecture?
   a. Production → {list risks related to your production line}
   A: n/a [Production is not endangered due to modular design]

   b. Technology → {list risks related to the technological choice}
   A: Middleware not running



   c. Compatibility → {list risks related to compatibility with legacy systems}
   A: Data adapters not working properly

   d. Humans → {list risks related to the organizational impact}
   A: System usability not good enough (UI), to complex to evaluate results

   e. Implementation → {list risks related to implementation of the new technology}
   A: Solutions provided not working partially or entirely; quality of predictions to low

   f. Others → {list other risks that should be considered for your use case}
   A: License, System-Maintenance Issues

3. In case of failure of some part of the migration has been created a contingency plan?

Yes ☐ No X

A: not yet

Annex D: Questionnaire Results for the GKN Use Case

The questionnaire fulfilled by GKN and used as input for planning and deployment its migration strategy, is illustrated as follows.

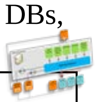
Part I – Assessing the current environment to be migrated and defining the scope of the migration

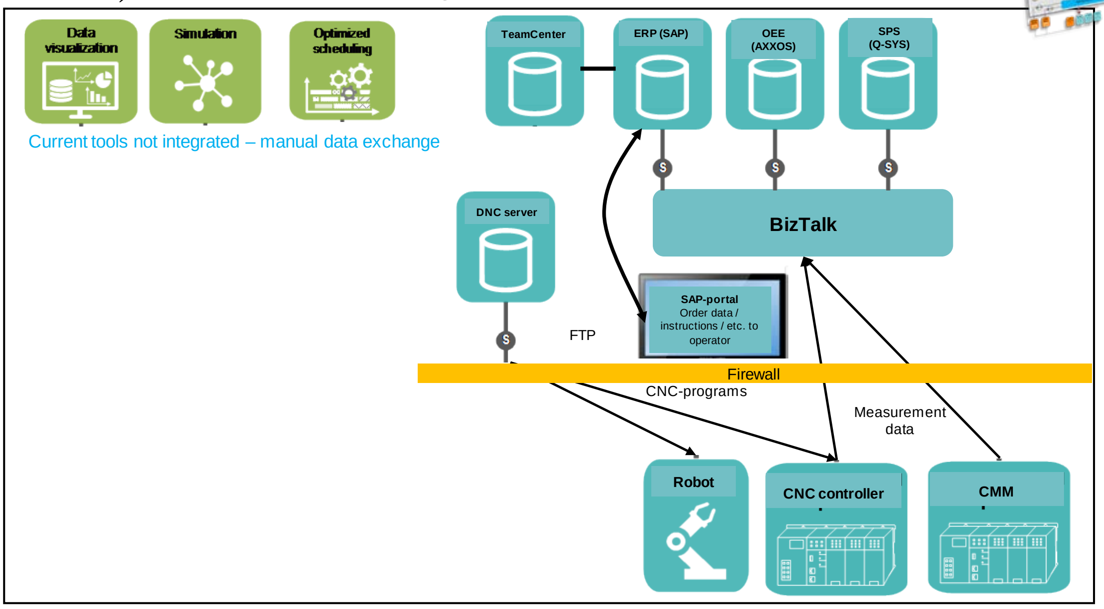
1. What is the main goal of the migration in your case?

A: *Primary goal is to build an industrial solution for higher degree of flexibility and reconfigurability of automated or semi-automated discrete manufacturing cells. The cell system should be a platform solution that can have different configuration of production processes. The processes can work individually or in a operation sequence – the "micro-flow cell" concept. The cell scheduling and control, integration and reconfiguration in a hetrogenous system is the key functions/tools ("Cell middleware"). The secondary goal is the vertical integration with the business level systems to automate data/information management for the production execution and reporting results ("Factory middleware".*

Description of the Legacy System:

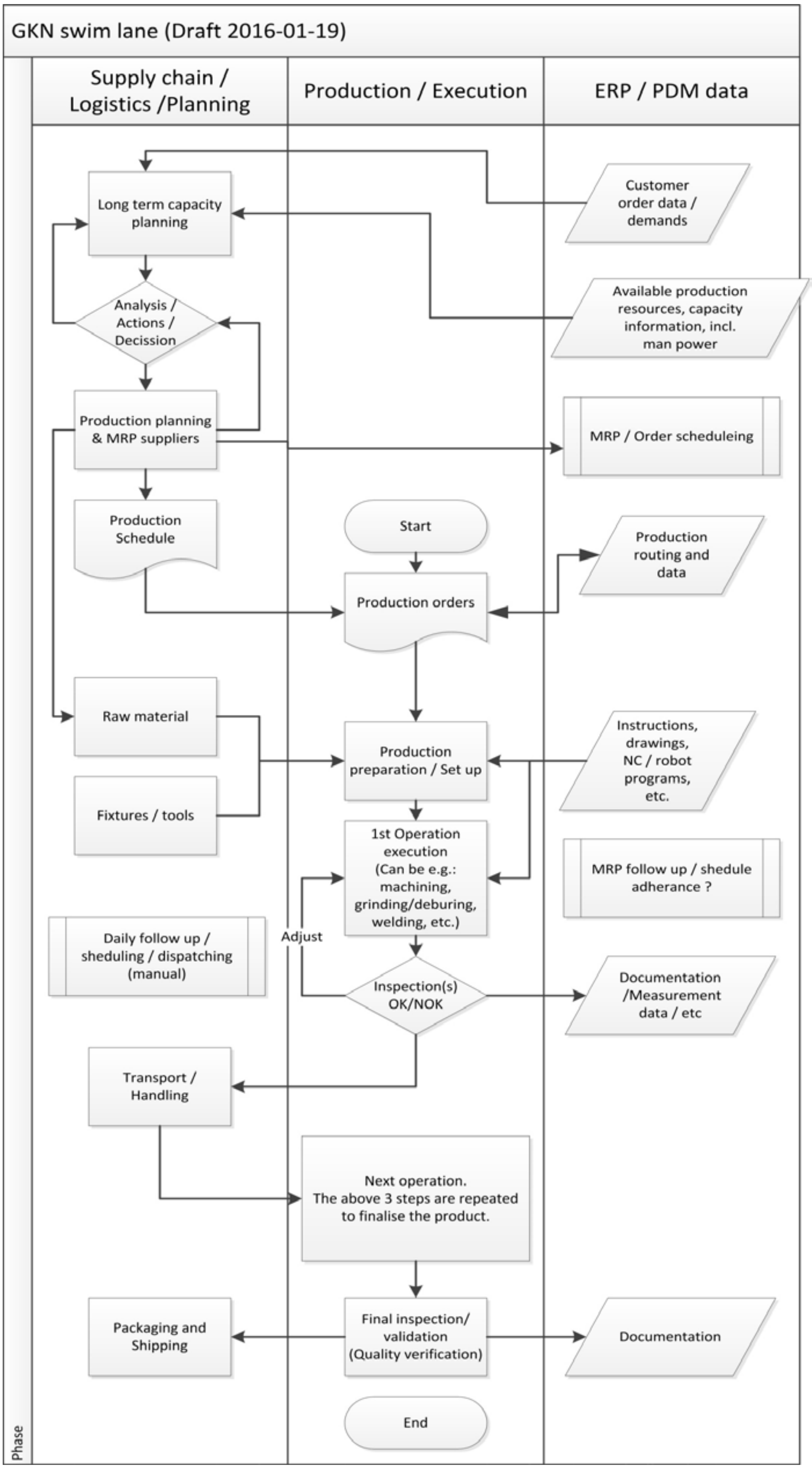
a. **Hierarchical organization of the legacy system**
   i. **Picture**{Include a scheme that refers the existing building blocks (tools, robots, DBs, etc.) and their interconnections}





b. **"User-Story-Flow" of the current use case**
   i. **Picture** {Include a scheme that refers the existing workflow of the use case}
   Sorry, don't have that available in a nice picture but these things have been described at different times as inputs to WP1 & WP2.

E.g Swimlane

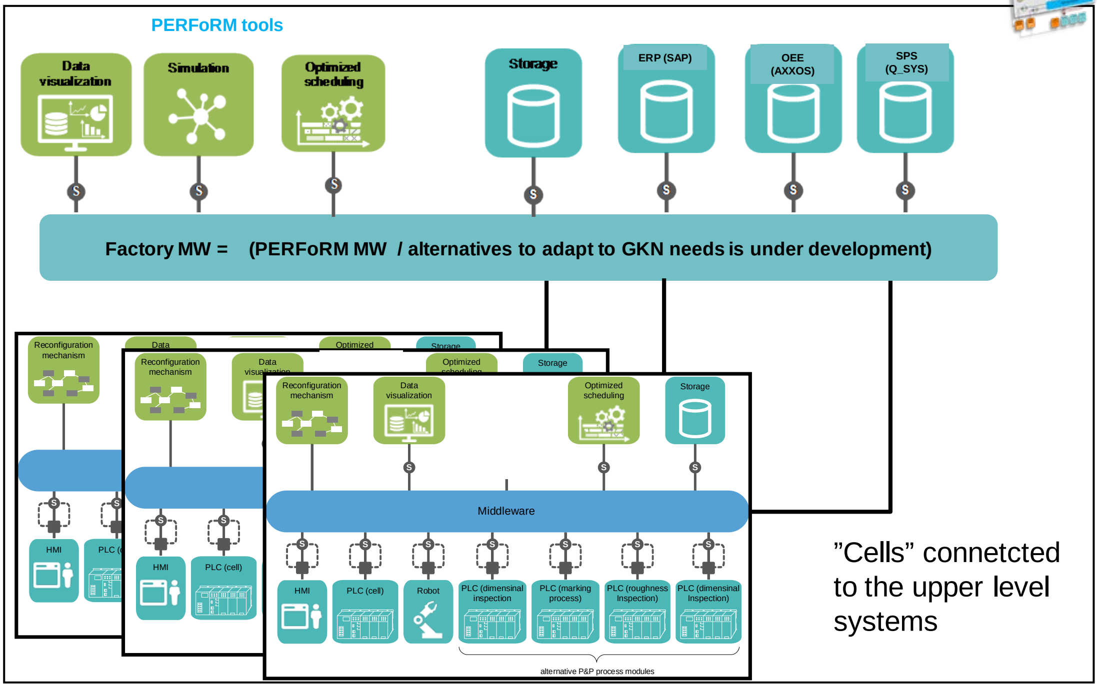

GKN swim lane (Draft 2016-01-19)
Supply chain / Logistics /Planning
Production / Execution
ERP / PDM data
Long term capacity planning
Customer order data / demands
Analysis / Actions / Decission
Available production resources, capacity information, incl. man power
Production planning & MRP suppliers
MRP / Order scheduleing
Production Schedule
Start
Production routing and data
Production orders
Raw material
Production preparation / Set up
Instructions, drawings, NC / robot programs, etc.
Fixtures / tools
1st Operation execution (Can be e.g.: machining, grinding/deburing, welding, etc.)
MRP follow up / shedule adherance ?
Daily follow up / sheduling / dispatching (manual)
Adjust
Inspection(s) OK/NOK
Documentation /Measurement data / etc
Transport / Handling
Next operation. The above 3 steps are repeated to finalise the product.
Packaging and Shipping
Final inspection/ validation (Quality verification)
Documentation
End
Phase

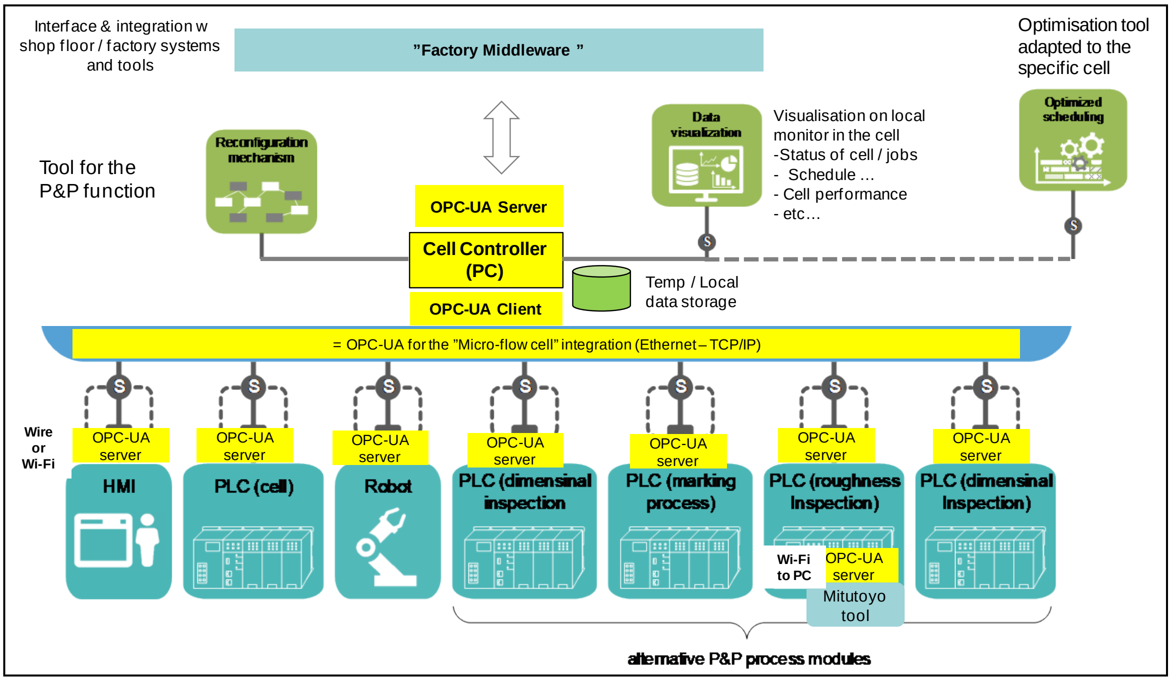
ii. **Description**{add a description for each block including function, input/output and human interaction}

2. Description of the Target System within PERFoRM:

a. Hierarchical organization of the PERFoRM Target System

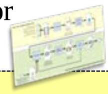
i. **Picture**{Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors and interconnection using the PERFoRM middleware}

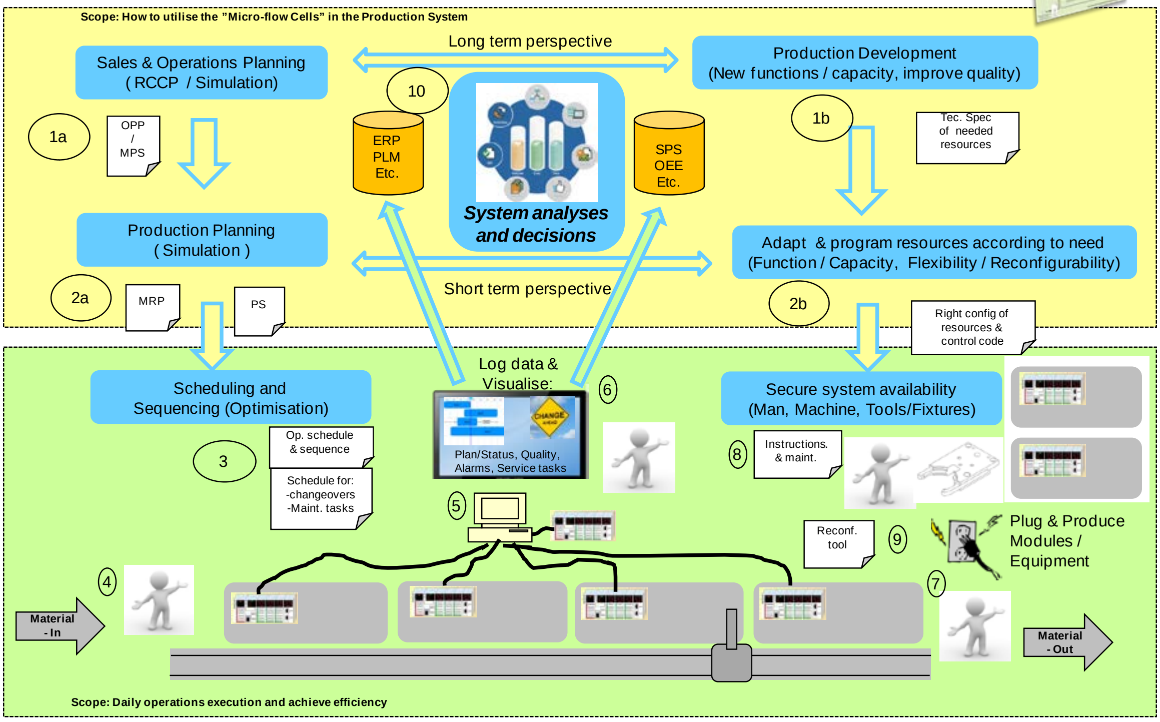




b. “User-Story-Flow” of the current use case

i. Picture{Include a scheme that refers the workflow of the use case for PERFoRM Demonstrator}





ii. Description {add a description for each block including function, input/output and human interaction}

1a) The long term analysis of sales/demands gives answers to the need of capacity (and which kind of capacity) using Rough Cut Capacity Planning (RCCP). Different scenarios can be simulated/analysed (based on available/wish for resources.) The result is a "Operation & Production Plan" (OPP) or "Master Production Schedule" (MPS).

1b) With input from the Sales & Operations Planning, there may be needs to adapt the functions/capability or capacity of the production system and its resources. This also include the need of and advantages from having flexible and reconfigurable equipment/resources. The decision can be to acquire more resources, i.e. some long term technology development and investments, etc. as well as competence and skills of the work force. It can also be an option of using/specifying need of flexibility and re-use/reconfigure equipments or parts of the production system. The result is technical requirements/specifications of the required production resources and plan to implement.

2a) The MPS and definition of available resources is input to make a more refined and detailed plan, This can be supported by simulation , but we don't use that at GKN today. The result is an MRP for material supply and Production Scheduling (PS) for the value streams.

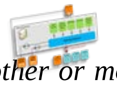
2b) The production resources need to be prepared and set up to do the right things

and can, depending on level of flexibility etc., be adapted and prepared to be used according to the Production Plan. This can include re-build a cell, re-build / get new tools, and re-programming etc. The result is right configuration of instructions, programs, and HW equipment etc.
3) With input from the "Production Schedule", the daily scheduling and sequencing of jobs at "cell-level" should be as optimal as possible – i.e. using the PERFoRM tool to be developed. (or GKN SOLV?). The result is an optimized schedule and sequence for the next shift or "X" hours. This plan also can create the slots and plan for when to make the changeovers, i.e. when to change from one process module to another, as well as take into account the need for maintenance and create slots for that on the schedule

4) *The jobs are triggered by the system/schedule. However its not done 100% automatically, as the operators first need to load/feed required material into the cell, and start the different orders. The operator also may have different tasks, as a shared resource, and perform tasks from different schedules.*
5) *The cell controller executes the automated activities of the production schedule, when the jobs are released by the operator.*
6) *The operators are supported by supervision and visualisation from the system, to show status of jobs/orders, equipment, etc. and display on Monitor or HMI. (Local Real time and History database). This data (or part of that data) is also sent to or upper level systems / data base(es) for further use, e.g. the PERFoRM "tools".*
7) *The operators un-load parts from the cell, and after any required inspection is done and confirmed, the operator finalize each job to report the completion.*
8) *Depending on type and level of designed and available flexibility, there are additional tools, fixtures and process modules for change overs in the cell – i.e. "Plug & Produce" equipment "ready-to-use" ! This requires routines, plans and instructions for e.g. maintenance, standard work etc. to use the production resources.*
9) *To execute the "Plug and Produce", a "Reconfiguration Tool" in the cell control system is required to manage the change over process.*

The data made available from the production cell/system provides the source to visualisation of KPIs, to be used in different "tools", analyses and decision support for improvements and the planning, scheduling etc.

3. **Hierarchical organization of the system (Future Target System):**
   a. **Picture**{Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors, interconnection using the PERFoRM middleware, considering future developments <u>after</u> PERFoRM and other tools}



At the moment we don't have any other or more advanced/developed organization of future target system, than the one above. It is however a good vision and representative for how horizontal / vertical integration can be done.

4. Taking into account the definition of the 3 migration strategies (see previous page), which one do you think it will be the most suitable for your case to achieve the PERFoRM Target System?

   One-shot ☐ Parallel ☐ Phased X

5. What is the main focus of the migration process?

   Software ☐ Hardware ☐ Both X

   A: Click here to enter text.

Part II – Architecting a new environment (Software and IT Hardware Scope)

1. Has a transition plan been already developed?

   Yes ☐ No X

2. Are PERFoRM tools going to be installed? Yes X No ☐

   If the answer is **Yes**, then:

   g) How many tools are going to be developed?
   A: 3

   h) Of what kind(s) are those tools?
   Scheduling X Planning ☐
   Simulation ☐ Re-configuration X
   Monitoring X Maintenance ☐
   Other(s): Click here to enter text.

   i) Which are the inputs, outputs and flow schema for these tools? Note: Probably the tools characteristics below have already been prepared for the WP4-WP5-Workshop and can be reissued here.

<table>
<tr><td rowspan="2">Tool name
Click here to enter text.</td><td>Inputs:
Click here to enter text.</td><td>Outputs:
Click here to enter text.</td></tr>
<tr><td colspan="2">Flow schema: (Picture)
Click here to enter text.</td></tr>
</table>

{repeat for all the tools}

3. Are there / Do you know of restrictions in terms of incompatibilities between the different types of tools that are/going to be installed?

Yes ☐ No X

If the answer is **Yes**, then what are those restrictions?

A: Click here to enter text.

4. Are you going to maintain legacy systems? Yes X No ☐

If the answer is **Yes**, then:

g) How many legacy systems are going to be maintained?
A: Click here to enter text.
h) Of what kind(s) are the legacy systems?

Scheduling ☐ Planning X Simulation ☐

Re-configuration ☐ Maintenance ? Monitoring ?

Database ☐ PLCs X Production equipm.X

Other(s): SPS/Quality system

i) Which are the inputs, outputs and flow schema of legacy systems?

Legacy System name: Click here to enter text.	Inputs: Click here to enter text.	Outputs: Click here to enter text.
	Flow schema: (Picture) Click here to enter text.	

{repeat for all the legacy systems}

5. Do you have access to the legacy systems? Please motivate your answer.

Yes X No ☐

A: (As far as known at the moment, and at least

6. Taking into account the components above, it will be necessary the development of adaptors?

Yes X No ☐

If the answer is **Yes**, then:

g) How many adaptors are going to be developed?
A: Click here to enter text.

h) Of what kind(s) are the adaptors needed?
A: Click here to enter text.

i) Which are the inputs, outputs and flow schema of the adaptors?

<table>
<tr><td rowspan="2">Adaptor name:
Click here to enter text.</td><td>Inputs:
Click here to enter text.</td><td>Outputs:
Click here to enter text.</td></tr>
<tr><td colspan="2">Flow schema:
(Picture)
Click here to enter text.</td></tr>
</table>

{repeat for all the Adaptors}

7. Is there already a “Middleware” installed (e.g., GKN Factory Middleware BizTalk) ?

Yes X No ☐

If the answer is **Yes** then,

g) How many Middlewares are already installed?
A: 1

h) What is the Middleware used?
A: *Biztalk – message broker/adaptor*

i) Is necessary to maintain the installation of the existing Middleware?

Yes X No ☐

8. How many Middlewares are going to be installed?
A: *To be defined – do not know yet how to make the connection from cell level (OPC-UA? Or xxx?) to Biztalk, but it is a priority requirement from GKN IT department to continue using this for integration at the Business System level.*

9. The existing **IT hardware** has the capacity of supporting the software that is going to be installed?

i) Yes X No ☐

j) If the answer is No, which are the problems associated with the hardware:

Type of Problem	**Yes**
Low Storage	☐
Low Processing Speed	☐
Low Bandwidth	☐
….	☐
Other(s): Click here to enter text.	

k) If you consider to purchase new hardware, please indicate:

Equipment	Model	Storage	Processor	Other(s)

l) Are there restrictions in terms of incompatibilities between the different types of equipment that are/going to be installed?

Yes ☐ No ☐

If the answer is **Yes**, then:

e) Which are the equipments?
A: *Don't know of any at the moment*

f) What are those restrictions?
A: *Don't know of any at the moment*

Part III - Architecting a new environment (Manufacturing Hardware Scope), e. g. change a robot; add a new PLC, etc.

1. What is the goal in the change of the hardware:

Change in Hardware	**Yes**
Product Redesign	☐
Process Redesign	☐
New system functionalities	X
Improve resources capabilities	☐
Other(s): Click here to enter text.	

2. Is going to be necessary to maintain existing hardware?

Yes X No ☐

If the answer is **Yes**, then:

g) How many adaptors are going to be developed?
A: 1 (or 2?)

h) Of what kind(s) are the adaptors needed?
A: *1- The adaptor for the surface measurement devise. WiFi communication with OPC-UA (Loccioni) (2:nd one could be an adaptor for legacy PLCs -> OPC-UA)*

i) Which are the inputs, outputs and flow schema of the adaptors?

Adaptor name:	Inputs: Click here to enter text.	Outputs: Click here to enter text.

Sensor adaptor		
	Flow schema: *The functions/flow of information of the adaptor is defined in Deliverable 3.1, section 7.4.*	

{repeat for all the legacy systems}

Part IV - Designing a human training/new roles plan for the new environment

1. Is there a qualified personnel in the new technologies that is going to be installed for realization of the migration process?

   Yes X No ☐

   A: Click here to enter text.

2. Has already been developed a training plan for the new implementations for the operators?

   Yes ☐ No X

   A: *First we need to develop the solution in more detail to better identify the specific knowledge and skills needed. Possibly this can be defined in the final report for the demonstrator. In any case of industrialization at a production site, the demonstrator cell can be used for training.*

3. Is it possible to give training to the operators before the installation of the new system?

   Yes X No ☐

   A: *Yes, see above*

4. Is it necessary to have the new implementations installed to give training to the operators?

   Yes ☐ No X

   A: *Some training is more theoretical and to understand the technology used in the system, and some can be done with virtual tools.*

Part V – Understanding the risks and planning contingencies

1. Has already been done a risks identification/estimation/assessment to the business and to the project?

   Yes ☐ No X

2. What are the possible risks and obstacles for the implementation of the new architecture?

a. Production → {list risks related to your production line}
A: *Reliability and availability. We are dependent on connection to business systems to get / report production order information – production/delivery delays as well as incomplete documentation and traceability.*

b. Technology → {list risks related to the technological choice}
A: *Reliability and availability of e.g. adaptors and "plug-and-play" functions and cell middleware (UPC-UA and the implementation of data structure/model*

c. Compatibility → {list risks related to compatibility with legacy systems}
***A**: Adaptors + possible gateway to factory/business systems (e.g communication through Biztalk).*

d. Humans → {list risks related to the organizational impact}
A: *Skills/Competence in how the new technology work. Operators as well as technicians/maintenance.*

e. Implementation → {list risks related to implementation of the new technology}
A: *Complexity and skills … may take longer than expected*

f. Others → {list other risks that should be considered for your use case}
A: Click here to enter text.

3. In case of failure of some part of the migration has been created a contingency plan?

Yes ☐ No X

A: *Not yet*

Annex E: Questionnaire Results for the Whirlpool Use Case

The questionnaire fulfilled by Whirlpool and used as input for planning and deployment its migration strategy, is illustrated as follows.

Part I – Assessing the current environment to be migrated and defining the scope of the migration

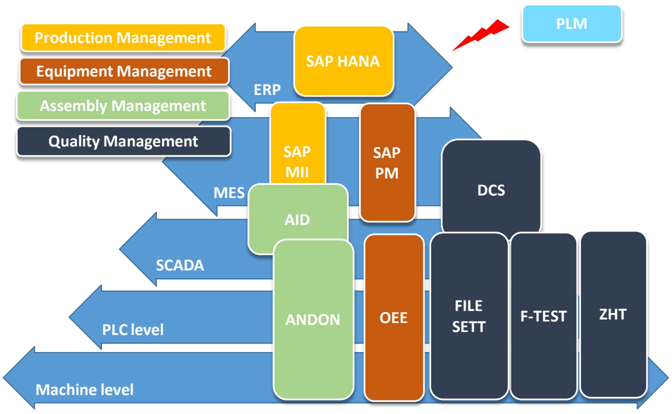
1. What is the main goal of the migration in your case?

A: The main goal of the migration is to flatten the present automation architecture with a middleware based approach and allow a novel simulation system to get connected with real data coming from field through a factory DB. This new approach should enable more robust and solid reconfiguration of factories KBF.

Description of the Legacy System:

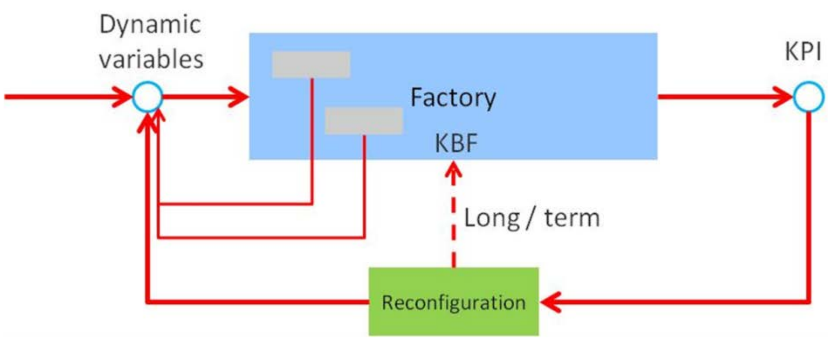
a. Hierarchical organization of the legacy system

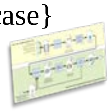
i. **Picture**



b. "User-Story-Flow" of the current use case

i. Picture {Include a scheme that refers the existing workflow of the use case}





ii. **Description**{add a description for each block including function, input/output and human interaction}

Factory KPIs are the sum of all the outputs coming from the legacy systems.

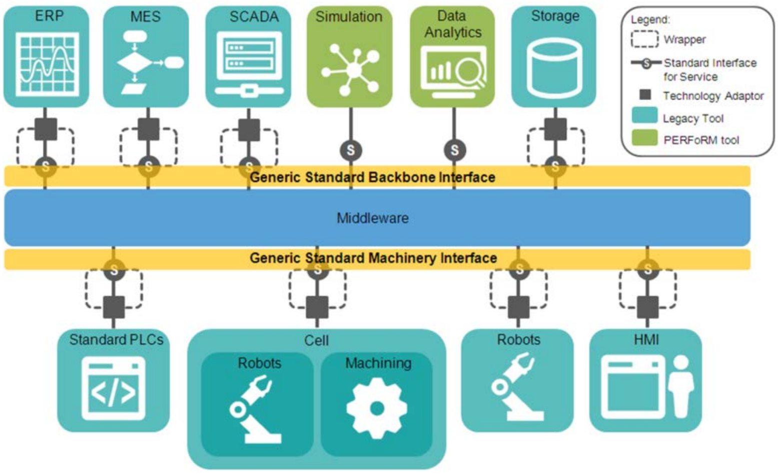
The reconfiguration activity is carried out by industrial engineers, who are in charge of reconfiguring the factory's set-up in response to specific events such as factory masterplan, profit plan, new product introduction, etc.

It is important to note that the visibility of the potential correlation between internal KPIs and the factory's configuration is mediated by time factors (i.e. the visibility is not real time), and that there is no direct correlation among the KPIs.

2. **Description of the Target System within PERFoRM:**

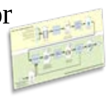
a. **Hierarchical organization of the PERFoRM Target System**

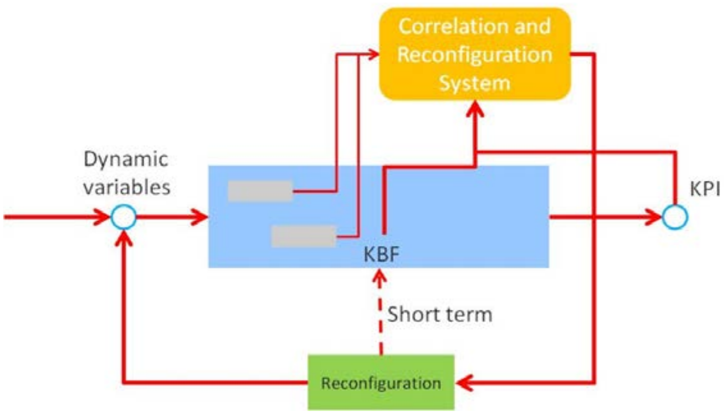
i. **Picture**{Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors and interconnection using the PERFoRM middleware}



b. **"User-Story-Flow" of the current use case**

i. **Picture**{Include a scheme that refers the workflow of the use case for PERFoRM Demonstrator}

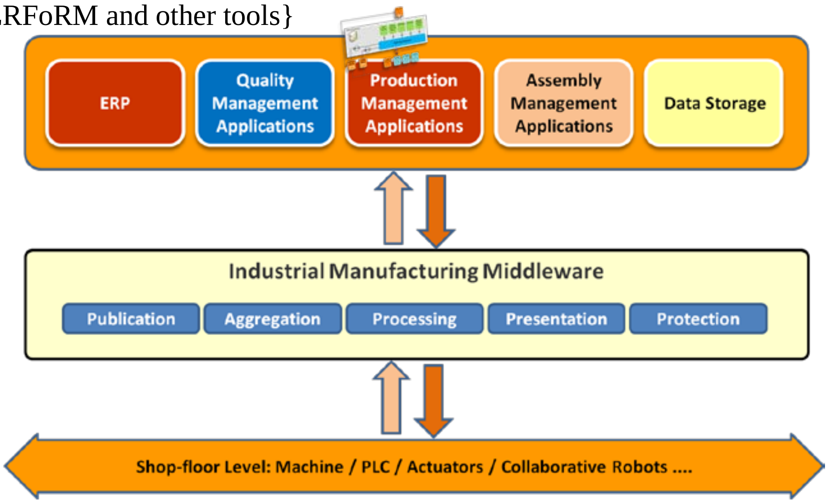




ii. **Description** {add a description for each block including function, input/output and human interaction}

In contrast to the AS-IS situation, in the TO-BE scenario there will be direct and real-time visibility on the potential correlation between internal KPIs and the factory's configuration. The employees in charge of the factory reconfiguration have direct visibility on the KPIs, and have available a system able to perform simulations, with a greater amount of data, and able to generate projections.

3. **Hierarchical organization of the system (Future Target System):**
   a. **Picture**{Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors, interconnection using the PERFoRM middleware, considering future developments after PERFoRM and other tools}



4. Taking into account the definition of the 3 migration strategies (see previous page), which one do you think it will be the most suitable for your case to achieve the PERFoRM Target System?

   One-shot ☐ Parallel ☐ Phased V

5. What is the main focus of the migration process?

   Software V Hardware ☐ Both ☐

   A: the migration process for WHR is focused on software implementation at three level: a middleware to connect existing and new applications and data storage; adapters for robot connection to middleware and a new simulation and data KPI visualization to help Value Stream reconfiguration.

Part II – Architecting a new environment (Software and IT Hardware Scope)

1. Has a transition plan been already developed?

   Yes ☐ No V

2. Are PERFoRM tools going to be installed? Yes V No ☐

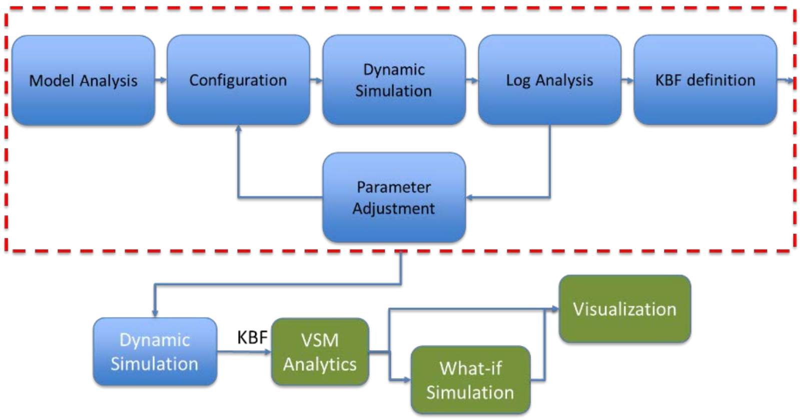
If the answer is **Yes**, then:

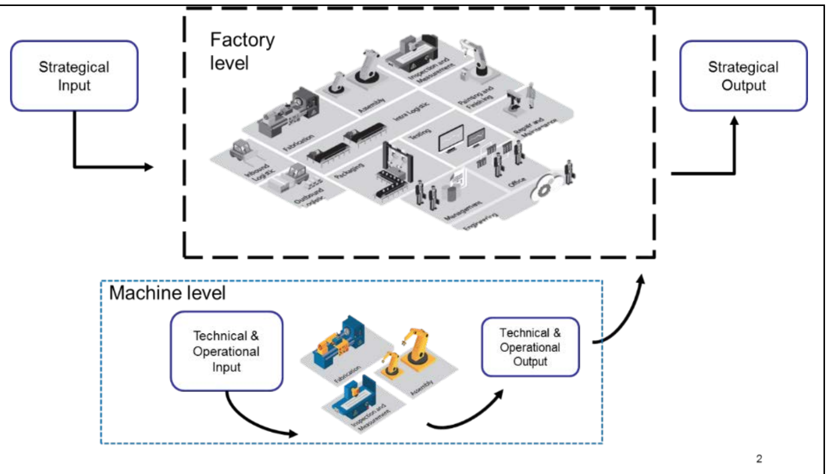
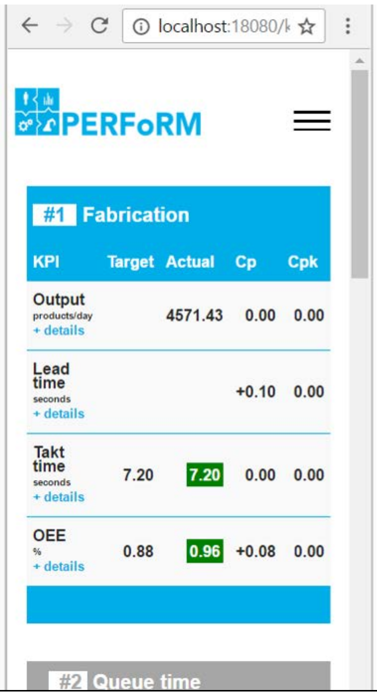
j) How many tools are going to be developed?
A: Simulation Tool, What-if tool, KPI visualization, Robot Reconfiguration

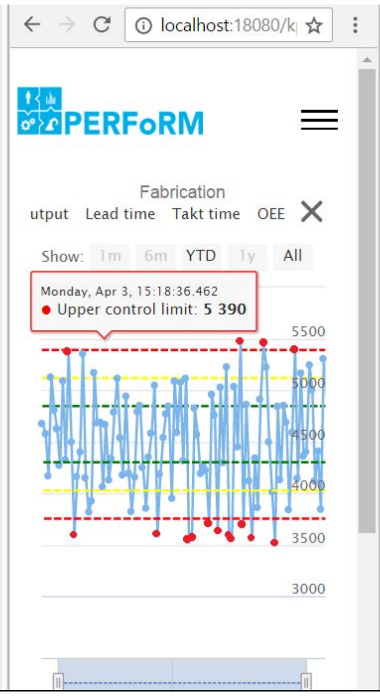
k) Of what kind(s) are those tools?

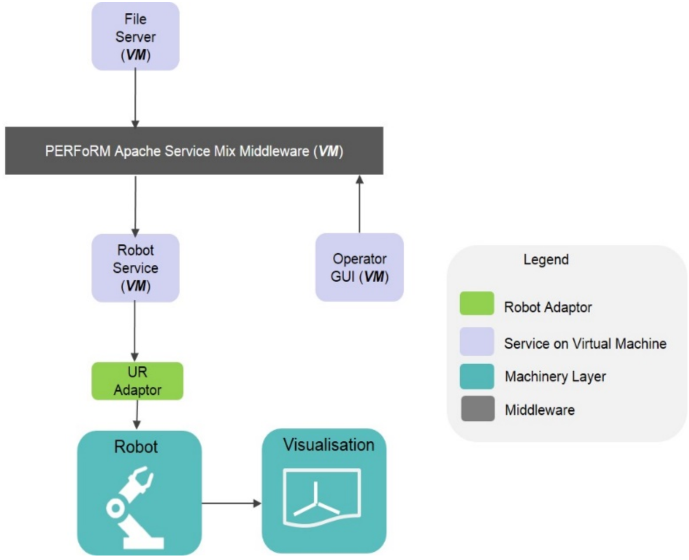
Scheduling ☐ Planning ☐
Simulation V Re-configuration V
Monitoring V Maintenance ☐
Other(s): Click here to enter text.

l) Which are the inputs, outputs and flow schema for these tools? Note: Probably the tools characteristics below have already been prepared for the WP4-WP5-Workshop and can be reissued here.

Tool name **Simulation Tool**	Inputs: Key Business Factors - KBF	Outputs: Key Performance Indicators- KPI
	Flow schema:  Click here to enter text.	
	Inputs: KBF – Factory Level KBF – Machine Level	Outputs: KPI Visualization
	Flow schema:	

<table>
<tr><td></td><td colspan="2">
</td></tr>
<tr><td></td><td>Inputs:
KBF</td><td>Outputs:
KPI Monitoring
What-if Analysis</td></tr>
<tr><td></td><td colspan="2">Flow schema:



</td></tr>
</table>

<table>
<tr><td rowspan="3"></td><td colspan="2">
</td></tr>
<tr><td>Inputs:
Path drawing</td><td>Outputs:
Robot commands</td></tr>
<tr><td colspan="2">Flow schema:

</td></tr>
</table>

3. Are there / Do you know of restrictions in terms of incompatibilities between the different types of tools that are/going to be installed?

Yes ☐ No V

If the answer is **Yes**, then what are those restrictions?

A: Click here to enter text.

4. Are you going to maintain legacy systems? Yes V No ☐

If the answer is **Yes**, then:

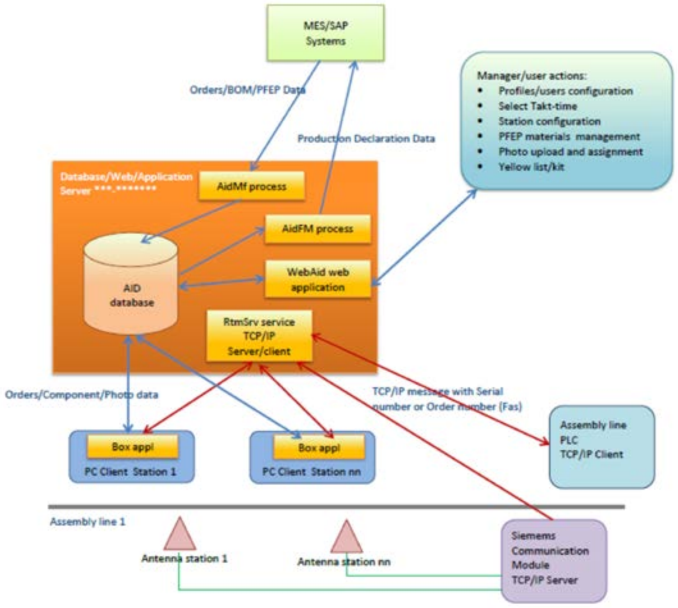
j) How many legacy systems are going to be maintained?
A: All MES tools, existing SCADA, ERP and MII

k) Of what kind(s) are the legacy systems?

Scheduling V	Planning V	Simulation ☐
Re-configuration ☐	Maintenance V	Monitoring V
Database V	PLCs V	Production equipm.V

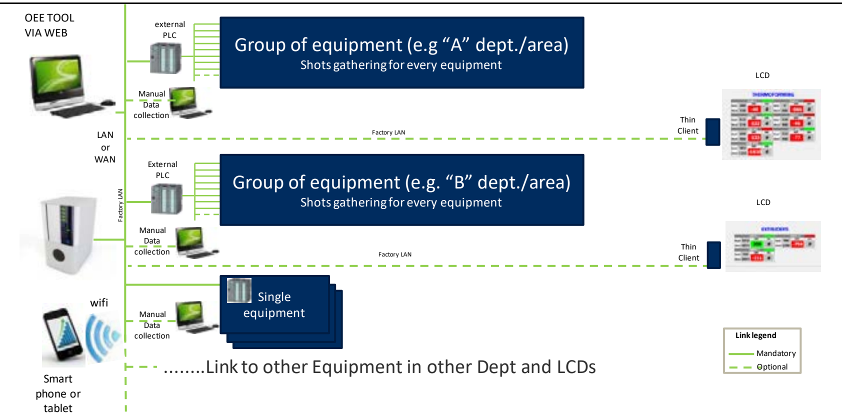
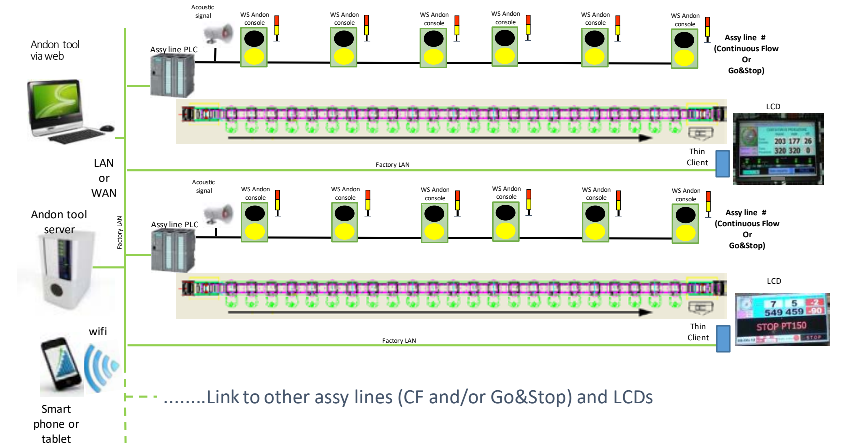
Other(s): Click here to enter text.

l) Which are the inputs, outputs and flow schema of legacy systems?

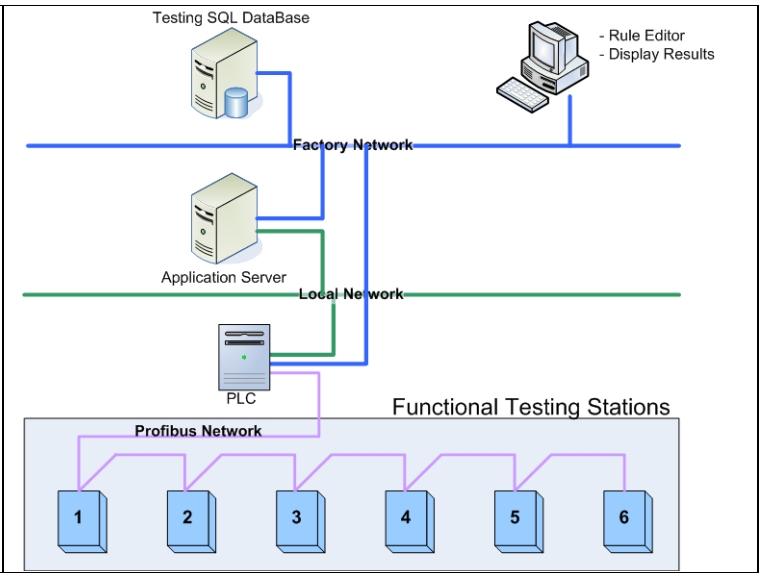
<table>
<tr><td rowspan="2">Legacy System name:
AID</td><td>Inputs:
SCADA Messages</td><td>Outputs:
Database transactions</td></tr>
<tr><td colspan="2">Flow schema: (Picture)

</td></tr>
</table>

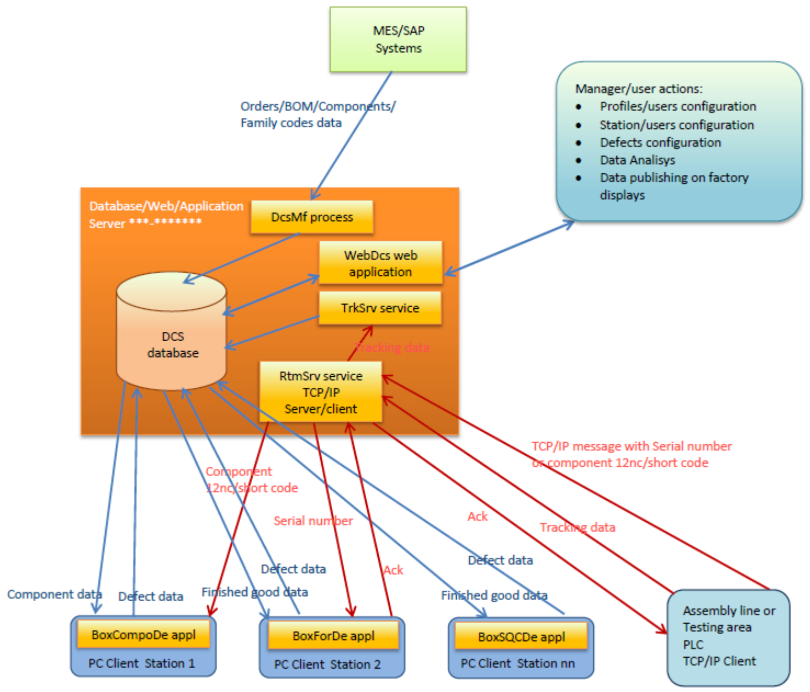
{repeat for all the legacy systems}

<table>
<tr><td rowspan="2">Legacy System name:
OEE</td><td>Inputs:
SCADA Messages</td><td>Outputs:
DB Transactions
KPI Visualization</td></tr>
<tr><td colspan="2">Flow schema: (Picture)</td></tr>
</table>

		
	Inputs: SCADA messages	Outputs: DB Transaction KPI Visualization
	Flow schema: (Picture) 	

Legacy System name: FTEST	Inputs: SCADA messages	Outputs: DB transactions KPI visualization
	Flow schema: (Picture)	

Legacy System name: DCS	Inputs: SCADA messages	Outputs: DB Transaction KPI Visualization
	Flow schema: (Picture) 	

5. Do you have access to the legacy systems? Please motivate your answer.

Yes V No ☐

A: All the legacy systems are developed and maintained through Operations Excellence department.

6. Taking into account the components above, it will be necessary the development of adaptors?

   Yes No V

   If the answer is **Yes**, then:

   j) How many adaptors are going to be developed?
      A:
   k) Of what kind(s) are the adaptors needed?
      A: Click here to enter text.
   l) Which are the inputs, outputs and flow schema of the adaptors?

<table>
<tr><td rowspan="2">Adaptor name:
Click here to enter text.</td><td>Inputs:
Click here to enter text.</td><td>Outputs:
Click here to enter text.</td></tr>
<tr><td colspan="2">Flow schema:
(Picture)
Click here to enter text.</td></tr>
</table>

{repeat for all the legacy systems}

7. Is there already a “Middleware” installed (e.g., GKN Factory Middleware BizTalk) ?

   Yes V No ☐

   If the answer is **Yes** then,

   j) How many Middlewares are already installed?
      A: 1
   k) What is the Middleware used?
      A: SAP MII
   l) Is necessary to maintain the installation of the existing Middleware?

      Yes V No ☐

8. How many Middlewares are going to be installed?
   A: 1

9. The existing **IT hardware** has the capacity of supporting the software that is going to be installed?
   m) Yes V No ☐
   n) If the answer is No, which are the problems associated with the hardware:

Type of Problem	Yes
Low Storage	☐
Low Processing Speed	☐
Low Bandwidth	☐

….	☐
Other(s): Click here to enter text.	

o) If you consider to purchase new hardware, please indicate:

Equipment	Model	Storage	Processor	Other(s)

p) Are there restrictions in terms of incompatibilities between the different types of equipment that are/going to be installed?

Yes ☐ No V

If the answer is **Yes**, then:

g) Which are the equipments?
A: Click here to enter text.

h) What are those restrictions?
A: Click here to enter text.

Part III - Architecting a new environment (Manufacturing Hardware Scope), e. g. change a robot; add a new PLC, etc.

1. What is the goal in the change of the hardware:

Change in Hardware	Yes
Product Redesign	V
Process Redesign	V
New system functionalities	V
Improve resources capabilities	V
Other(s): Click here to enter text.	

2. Is going to be necessary to maintain existing hardware?

Yes ☐ No V

If the answer is **Yes**, then:

j) How many adaptors are going to be developed?
A: Click here to enter text.

k) Of what kind(s) are the adaptors needed?
A: Click here to enter text.

l) Which are the inputs, outputs and flow schema of the adaptors?

Adaptor name: Click here to enter text.	Inputs: Click here to enter text.	Outputs: Click here to enter text.
	Flow schema: (Picture) Click here to enter text.	

{repeat for all the Adaptors}

Part IV - Designing a human training/new roles plan for the new environment

1. Is there a qualified personnel in the new technologies that is going to be installed for realization of the migration process?

   Yes V No ☐

   A: Click here to enter text.

2. Has already been developed a training plan for the new implementations for the operators?

   Yes ☐ No V

   A: Click here to enter text.

3. Is it possible to give training to the operators before the installation of the new system?

   Yes V No ☐

   A: Click here to enter text.

4. Is it necessary to have the new implementations installed to give training to the operators?

   Yes ☐ No V

   A: Click here to enter text.

Part V – Understanding the risks and planning contingencies

1. Has already been done a risks identification/estimation/assessment to the business and to the project?

   Yes ☐ No V

2. What are the possible risks and obstacles for the implementation of the new architecture?
   a. Production → {list risks related to your production line}
   A: Reliability of new architecture. Availability should be close to 99%.

b. Technology → {list risks related to the technological choice}
A: Performance: real time application must provide 100msec response time.

c. Compatibility → {list risks related to compatibility with legacy systems}
A: Solution must be compatible with legacy system and accepted at global level from IT organization

d. Humans → {list risks related to the organizational impact}
A: no risk

e. Implementation → {list risks related to implementation of the new technology}
A: Synchronization with existing transformation plans in factories and at Corporate level.

f. Others → {list other risks that should be considered for your use case}
A: Click here to enter text.

3. In case of failure of some part of the migration has been created a contingency plan?

Yes ☐ No V

A: Click here to enter text.

Annex F: Questionnaire Results for the E-district Use Case

The questionnaire fulfilled by E-District and used as input for planning and deployment its migration strategy, is illustrated as follows.

Part I – Assessing the current environment to be migrated and defining the scope of the migration

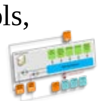
1. What is the main goal of the migration in your case?

A: Through PERFoRM I-FEVS and Polimodel aim at making available low cost automated turnkey flexible assembly lines to rapidly start the manufacturing of safe, ergonomic, clean and efficient vehicles adapted to local needs. The proposed experimental assembly line **has been originally conceived for 50 vehicles a day over two shifts.**

Description of the Legacy System:

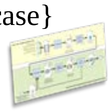
a. Hierarchical organization of the legacy system

i. Picture{Include a scheme that refers the existing building blocks (tools, robots, DBs, etc.) and their interconnections}
No legacy systems



b. "User-Story-Flow" of the current use case

i. Picture {Include a scheme that refers the existing workflow of the use case}
A complete manual assembling line.

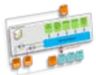


ii. Description{add a description for each block including function, input/output and human interaction}
A complete manual assembling line.

2. **Description of the Target System within PERFoRM:**

a. Hierarchical organization of the PERFoRM Target System

i. Picture{Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors and interconnection using the PERFoRM middleware}



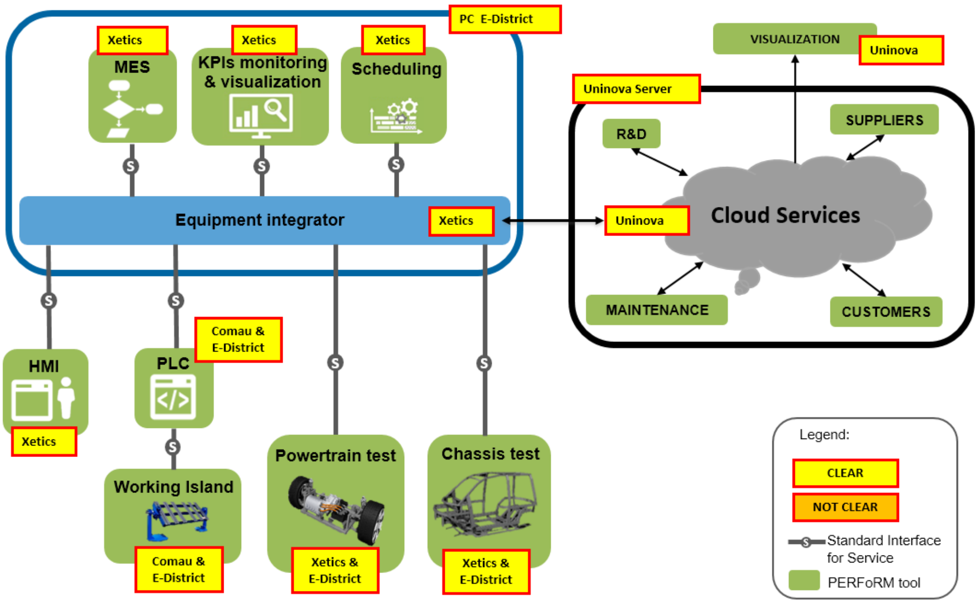
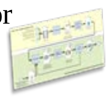


Figure 38 - Targeted Architecture of the PERFoRM Demonstrator Implementation.

- PERFoRM MES will run on a dedicated PC hosting also the scheduler and KPI monitoring and visualization developed by Xetics
- A complete working island will be implemented hosting part presence sensors, plc.
- The HMI will be developed by Xetics and will run on a android based portable device.
    - o Architecture still undergoing changes, since adjustments with tool providers still going on. Principle should be final.

b. "User-Story-Flow" of the current use case

i. Picture{Include a scheme that refers the workflow of the use case for PERFoRM Demonstrator}



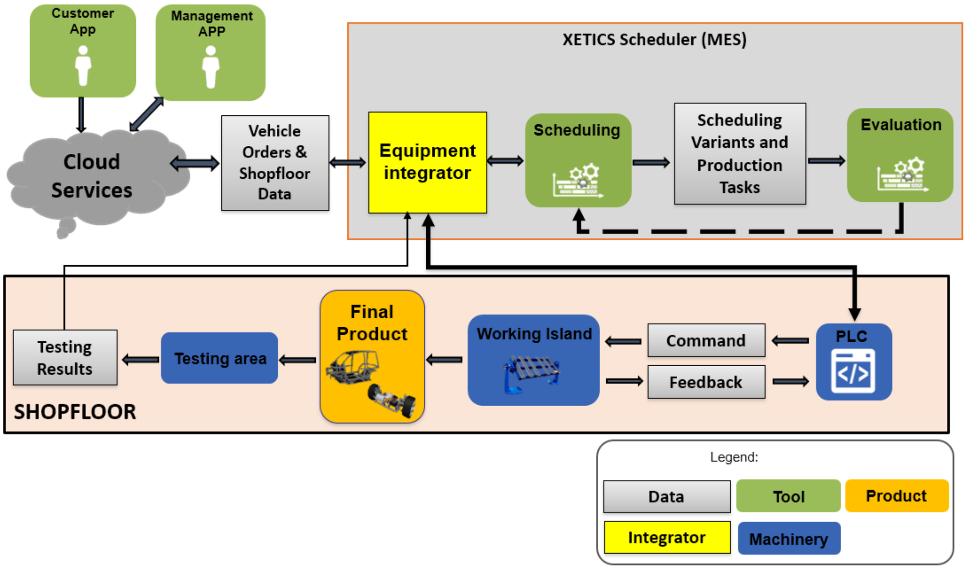
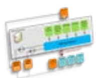


Figure 39 - Targeted Workflow of the PERFoRM Demonstrator Implementation.

ii. **Description** {add a description for each block including function, input/output and human interaction}

- MES:
  - Accepts orders inserted manually or from the cloud
  - Monitoring and visualization of the KPIs
- Scheduling:
  - Scheduling Service which generates suitable schedules following alternative goals
- Working island:
  - Sensorized working island including PLC and HMI
- Testing area:
  - The test results are stored within the MES.

3. **Hierarchical organization of the system (Future Target System):**
   a. **Picture**{Include a scheme that refers the legacy tools, the PERFoRM tools, adaptors, interconnection using the PERFoRM middleware, considering future developments <u>after</u> PERFoRM and other tools}



Not developed yet.

4. Taking into account the definition of the 3 migration strategies (see previous page), which one do you think it will be the most suitable for your case to achieve the PERFoRM Target System?

One-shot x Parallel ☐ Phased ☐

5. What is the main focus of the migration process?

Software ☐ Hardware ☐ Both x

A: Click here to enter text.

Part II – Architecting a new environment (Software and IT Hardware Scope)

1. Has a transition plan been already developed?

   Yes ☐ No x

2. Are PERFoRM tools going to be installed? Yes x No ☐

   If the answer is **Yes**, then:

   m) How many tools are going to be developed?
   A: Click here to enter text.

   n) Of what kind(s) are those tools?
   Scheduling x Planning x
   Simulation ☐ Re-configuration ☐
   Monitoring x Maintenance ☐
   Other(s): Click here to enter text.

   o) Which are the inputs, outputs and flow schema for these tools? Note: Probably the tools characteristics below have already been prepared for the WP4-WP5-Workshop and can be reissued here.

Tool name Scheduling	Inputs: Manufacturing Tasks	Outputs: Schedule Alternatives
	Flow schema: (Picture) Click here to enter text.	

Tool name KPI monitoring & visualization	Inputs: Shopfloor data	Outputs: KPI
	Flow schema: (Picture) Click here to enter text.	

Tool name MES	Inputs: Vehicle Orders	Outputs: Production tasks
	Flow schema: (Picture) Click here to enter text.	

3. Are there / Do you know of restrictions in terms of incompatibilities between the different types of tools that are/going to be installed?

Yes ☐ No x

If the answer is **Yes**, then what are those restrictions?

A: Click here to enter text.

4. Are you going to maintain legacy systems? Yes ☐ No x

If the answer is **Yes**, then:

m) How many legacy systems are going to be maintained?
A: Click here to enter text.
n) Of what kind(s) are the legacy systems?

Scheduling ☐	Planning ☐	Simulation ☐
Re-configuration ☐	Maintenance ☐	Monitoring ☐
Database ☐	PLCs ☐	Production equipm.☐

Other(s): Click here to enter text.

o) Which are the inputs, outputs and flow schema of legacy systems?

Legacy System name: Click here to enter text.	Inputs: Click here to enter text.	Outputs: Click here to enter text.
	Flow schema: (Picture) Click here to enter text.	

{repeat for all the legacy systems}

5. Do you have access to the legacy systems? Please motivate your answer.

Yes ☐ No ☐

A: Click here to enter text.

6. Taking into account the components above, it will be necessary the development of adaptors?

Yes ☐ No x

We are currently exploring two alternatives one with adaptor needed and one without adaptors

If the answer is **Yes**, then:

m) How many adaptors are going to be developed?
A: Click here to enter text.

n) Of what kind(s) are the adaptors needed?
A: Click here to enter text.

o) Which are the inputs, outputs and flow schema of the adaptors?

Adaptor name: Click here to enter text.	Inputs: Click here to enter text.	Outputs: Click here to enter text.
	Flow schema: (Picture) Click here to enter text.	

{repeat for all the legacy systems}

7. Is there already a “Middleware” installed (e.g., GKN Factory Middleware BizTalk) ?

Yes ☐ No x

If the answer is **Yes** then,

m) How many Middlewares are already installed?
A: Click here to enter text.

n) What is the Middleware used?
A: Click here to enter text.

o) Is necessary to maintain the installation of the existing Middleware?

Yes ☐ No ☐

8. How many Middlewares are going to be installed?
A: middleware will be replaced by the equipment integrator of Xetics

9. The existing **IT hardware** has the capacity of supporting the software that is going to be installed?

q) Yes x No

r) If the answer is No, which are the problems associated with the hardware:

Type of Problem	Yes
Low Storage	☐
Low Processing Speed	☐
Low Bandwidth	☐
….	☐
Other(s):	

s) If you consider to purchase new hardware, please indicate:

Equipment	Model	Storage	Processor	Other(s)
PLC				

Portable device	Android based			

t) Are there restrictions in terms of incompatibilities between the different types of equipment that are/going to be installed?

Yes ☐ No x

If the answer is **Yes**, then:

i) Which are the equipments?
A: Click here to enter text.

j) What are those restrictions?
A: Click here to enter text.

Part III - Architecting a new environment (Manufacturing Hardware Scope), e. g. change a robot; add a new PLC, etc.

1. What is the goal in the change of the hardware:

Change in Hardware	**Yes**
Product Redesign	x
Process Redesign	x
New system functionalities	x
Improve resources capabilities	x
Other(s): Click here to enter text.	

2. Is going to be necessary to maintain existing hardware?

Yes ☐ No x

If the answer is **Yes**, then:

m) How many adaptors are going to be developed?
A: Click here to enter text.

n) Of what kind(s) are the adaptors needed?
A: Click here to enter text.

o) Which are the inputs, outputs and flow schema of the adaptors?

Adaptor name: Click here to enter text.	Inputs: Click here to enter text.	Outputs: Click here to enter text.
	Flow schema: (Picture) Click here to enter text.	

{repeat for all the legacy systems}

Part IV - Designing a human training/new roles plan for the new environment

1. Is there a qualified personnel in the new technologies that is going to be installed for realization of the migration process?

   Yes ☐ No x

   A: Click here to enter text.

2. Has already been developed a training plan for the new implementations for the operators?

   Yes ☐ No x

   A: Click here to enter text.

3. Is it possible to give training to the operators before the installation of the new system?

   Yes x No ☐

   A: Click here to enter text.

4. Is it necessary to have the new implementations installed to give training to the operators?

   Yes ☐ No x

   A: Click here to enter text.

Part V – Understanding the risks and planning contingencies

1. Has already been done a risks identification/estimation/assessment to the business and to the project?

   Yes ☐ No x

   The new approach based on microfactory concept developed by I-FEVS is under deep elaboration to reduce all associated risks. The first analysis shows that the risk is very limited. In fact, the upfront investments are very low.

2. What are the possible risks and obstacles for the implementation of the new architecture?
   - **a.** Production → {list risks related to your production line}
     A: Production is not endangered due to modular design
   - **b.** Technology → {list risks related to the technological choice}
     A: MES not running
   - **c.** Compatibility → {list risks related to compatibility with legacy systems}
     A: No legacy systems

d. Humans → {list risks related to the organizational impact}
A: System usability not good enough (UI), too complex to evaluate results

e. Implementation → {list risks related to implementation of the new technology}
A: Solutions provided not working partially or entirely

f. Others → {list other risks that should be considered for your use case}
A: System-Maintenance Issues

3. In case of failure of some part of the migration has been created a contingency plan?

Yes ☐ No x

A: not yet

Annex G: Petri nets models validation for the Siemens Use Case

This annex summarises the formal analysis and validation of the Petri nets models of the migration process for the Siemens use case. The following figures are related to the validation process of all Petri nets models involved in the Siemens use case migration process.

General migration process

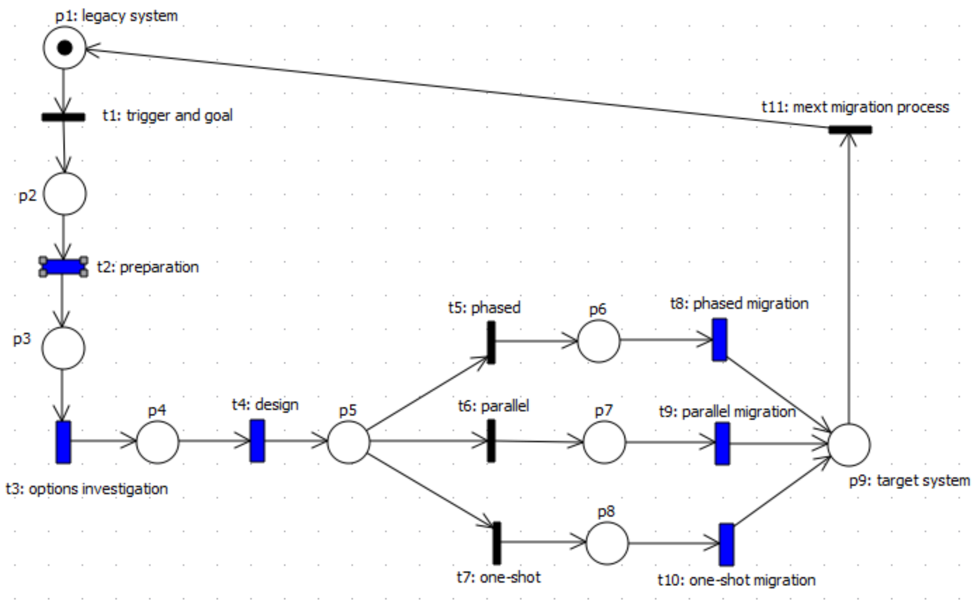


Figure 40 – Validation of the Petri nets Model for the PERFoRM Smooth Migration.

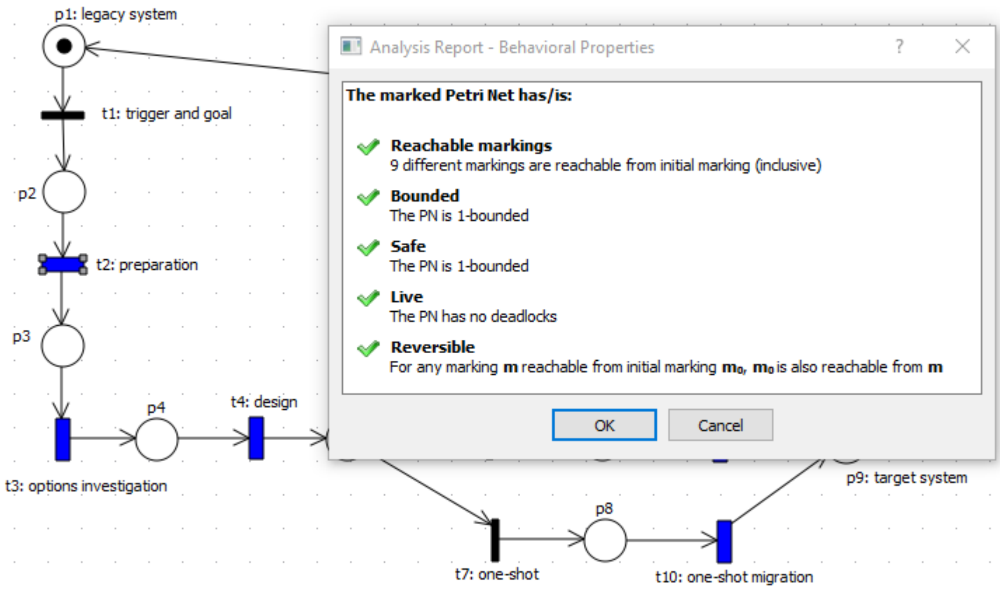


Figure 41 – Properties of the Petri nets Model for the PERFoRM Smooth Migration.

Minimal P-invariants:

Place	p1	p2	p3	p4	p5	p6	p7	p8	p9
x1	1	1	1	1	1	1	1	1	1

Minimal T-invariants:

Transition	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11
y1	1	1	1	1	1	0	0	1	0	0	1
y2	1	1	1	1	0	1	0	0	1	0	1
y3	1	1	1	1	0	0	1	0	0	1	1

Figure 42 – P and T invariants of the Petri nets Model for the PERFoRM Smooth Migration.

Preparation phase

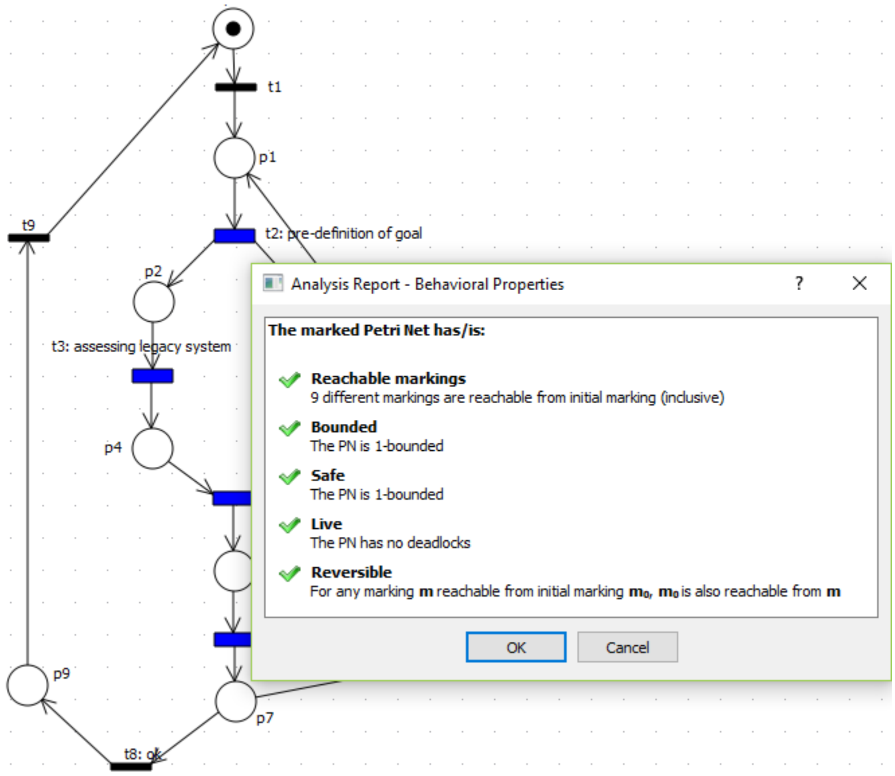


Figure 43 - Properties of the Petri nets Model for the Preparation phase.

Minimal P-invariants:

Place	p1	p2	p3	p4	p5	p6	p7	p8	p9
x1	1	1	0	1	0	1	1	1	1
x2	1	0	1	0	1	1	1	1	1

Minimal T-invariants:

Transition	t1	t2	t3	t4	t5	t6	t7	t8	t9
y1	0	1	1	1	1	1	1	0	0
y2	1	1	1	1	1	1	0	1	1

Figure 44 – P and T invariants of the Petri nets Model for the Preparation phase.

Options Investigation phase

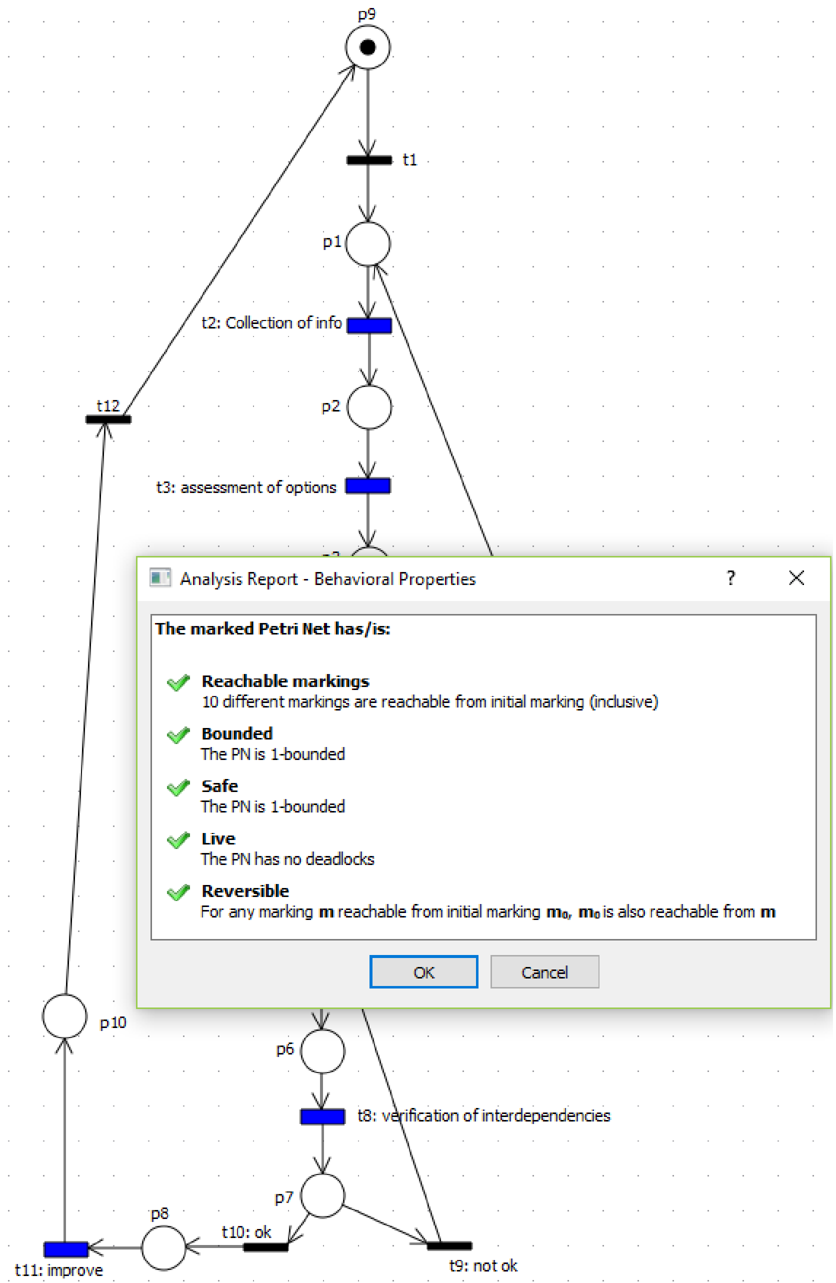


Figure 45 - Properties of the Petri nets Model for the Options Investigation phase.

Minimal P-invariants:

Place	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10
x1	1	1	1	1	1	1	1	1	1	1

Minimal T-invariants:

Transition	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12
y1	0	1	1	1	0	0	0	0	0	0	0	0
y2	0	0	0	0	0	0	1	1	1	0	0	0
y3	1	1	1	0	1	1	1	1	0	1	1	1

Figure 46 – P and T invariants of the Petri nets Model for the Options Investigation phase.

Design phase

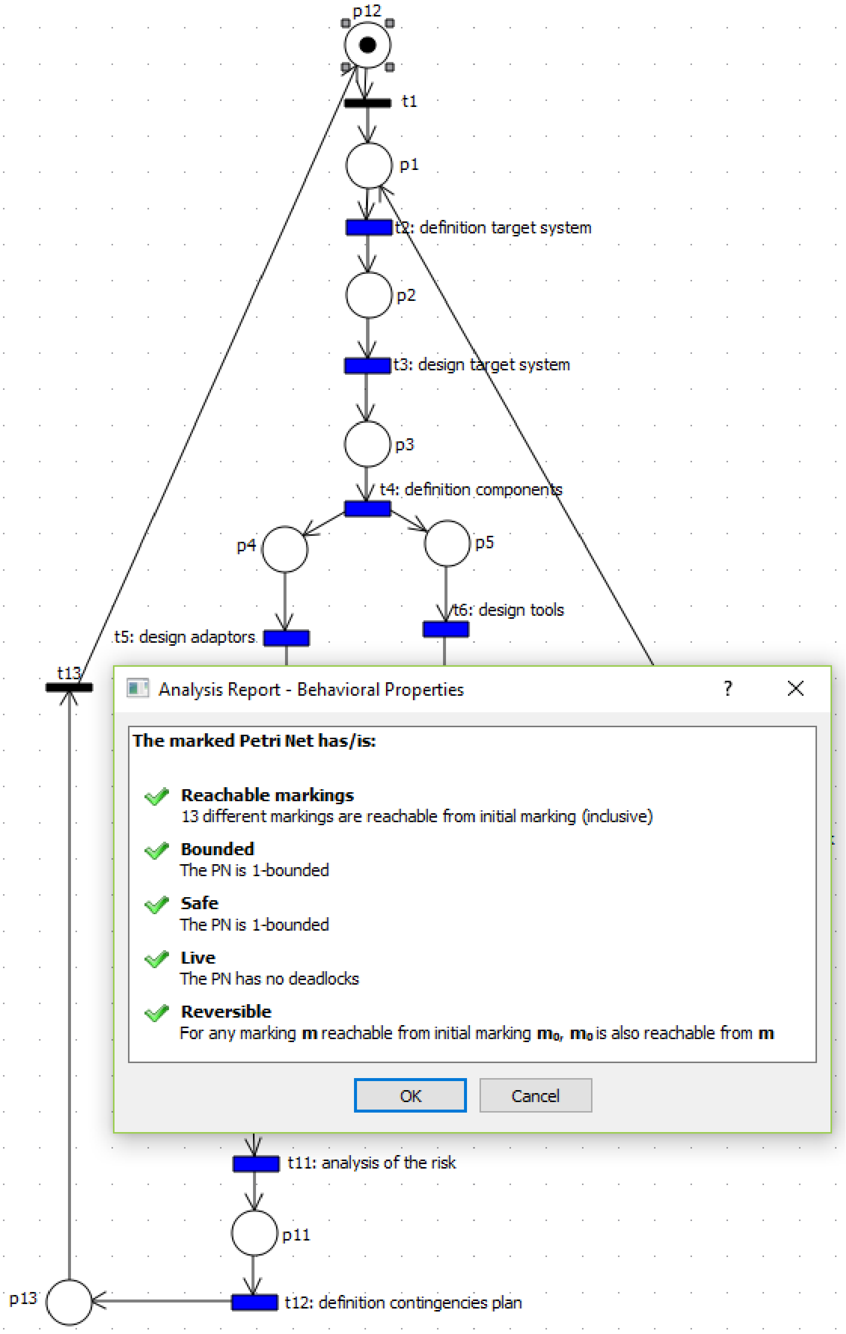


Figure 47 - Properties of the Petri nets Model for the Design phase.

Minimal P-invariants:

Place	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	p13
x1	1	1	1	1	0	1	0	1	1	1	1	1	1
x2	1	1	1	0	1	0	1	1	1	1	1	1	1

Minimal T-invariants:

Transition	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13
y1	0	1	1	1	1	1	1	1	0	0	0	0	0
y2	1	1	1	1	1	1	1	0	1	1	1	1	1

Figure 48 – P and T invariants of the Petri nets Model for the Design phase.

Implementation and deployment phases

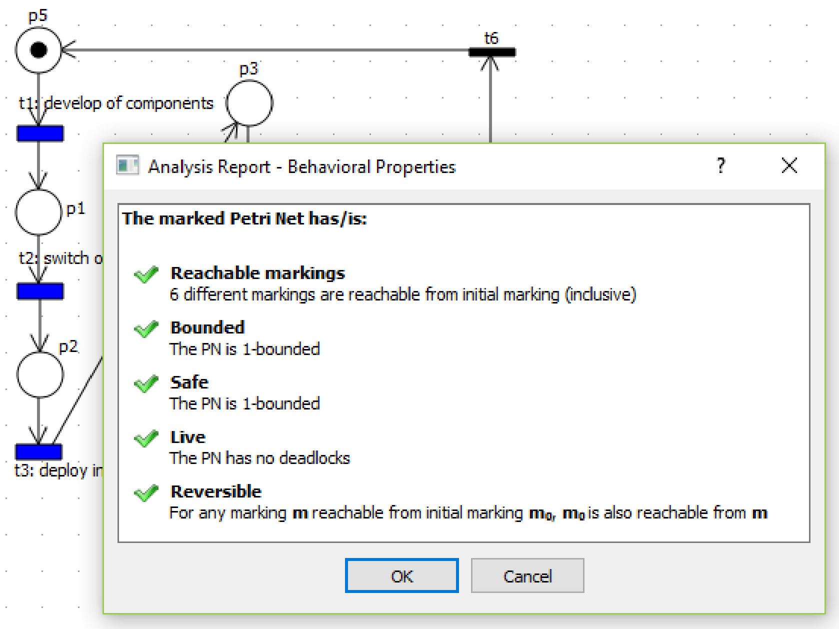


Figure 49 - Properties of the Petri nets Model for the One-Shot migration strategy.

Minimal P-invariants:

Place	p1	p2	p3	p4	p5	p6
x1	1	1	1	1	1	1

Minimal T-invariants:

Transition	t1	t2	t3	t4	t5	t6
y1	1	1	1	1	1	1

Figure 50 – P and T invariants of the Petri nets Model for the One-Shot migration strategy.

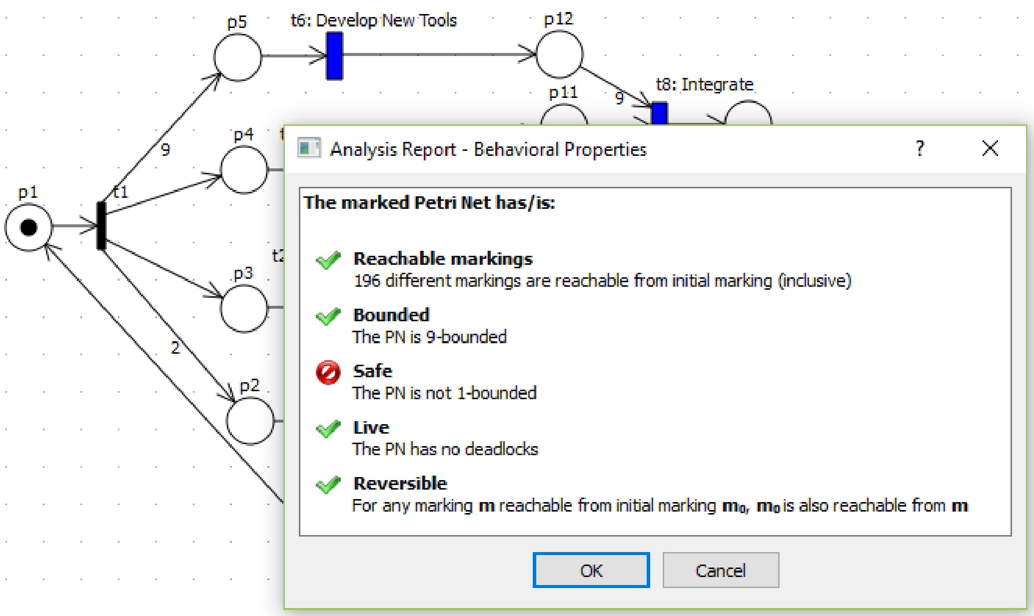


Figure 51 - Properties of the “develop of system components” Petri nets Model.

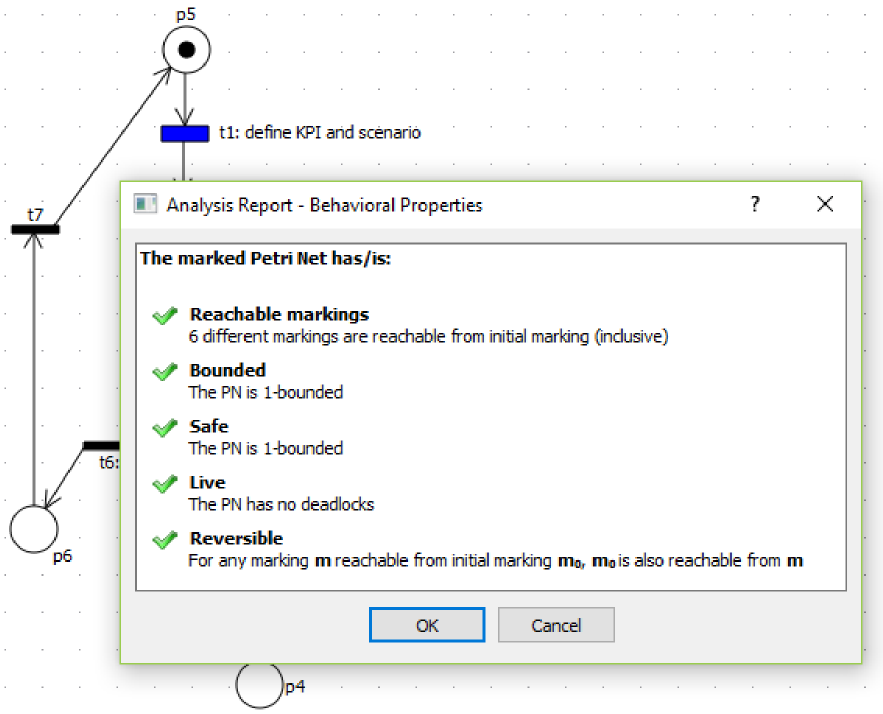


Figure 52 - Properties of the "dry-run rehearsal" Petri nets Model.

Minimal P-invariants:

Place	p1	p2	p3	p4	p5	p6
x1	1	1	1	1	1	1

Minimal T-invariants:

Transition	t1	t2	t3	t4	t5	t6	t7
y1	0	1	1	1	1	0	0
y2	1	1	0	0	0	1	1
y3	1	2	1	1	1	1	1

Figure 53 – P and T invariants of the "dry-run rehearsal" Petri nets Model.