UML based reconfiguration rate analysis of assembly line depending on robot integration

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Abstract: Factories with a high production throughput and a low product variety traditionally choose a flow layout for mass production. The future market profile however will be volatile, customers expecting a larger choice in product diversity. Such a variable demand calls a new, flexible and reconfigurable production system, able to reconfigure in order to follow the market. This paper aims to present a method to modelize the production system permitting to identify the ways of improving the facilities on the reconfigurability criterion. Several reconfigurable assembly systems are proposed, targeting full load of the facilities. The specificity of the study consists in the consideration of both multiproduct and volume flexibility.

Keywords: Reconfigurable Manufacturing Systems (RMS), Reconfigurable Assembly System (RAS), Flexibility, Modularity, Production System Modelization, UML

1. INTRODUCTION

Over the last decades, Reconfigurable Manufacturing/ Assembly Systems (RMS/RAS) have been a main focus for researchers in production engineering. Today manufacturing systems have to face quick changes and a growing product customization to client wishes, without degrading the lead time (Jina *et al.*, 1997). In parallel, enterprises have now new mature technologies that they can integrate to their production system: human-robot cooperation, Automated Guided Vehicles (AGVs), Big Data. Flexible software programs have been a first solution to manage diversity, but reach their limits when the needed variety is too wide.

The ideal production system would be used to its maximal capacity during the whole production system lifecycle, including ramp-up, producing the desired product mix ratio and being able to change rapidly product ratio or throughput. In this paper, volume and multiproduct reconfigurability in assembly systems is considered. Product design, multiproduct ratio and volume are inputs of the assembly system.

(Koren, 2005) identified five changeability enablers: modularity, integrability, diagnosability, scalability and convertibility. Based on the identification of these enablers, (Francalanza *et al.*, 2014) and (Andersen *et al.*, 2017) proposed a methodology for RMS design. After enabler identification, a new layout can be designed and simulated to assess its reconfigurability ability and productivity.

In order to assess several solutions for RAS design, a modelization able to support the manufacturing systems design elements: layout, machine, material handling and services, is needed (Francalanza *et al.* 2014). This paper proposes a formalism and a modelization seeking analysis of assembly layouts regarding reconfigurability. For this study, performance indicator for reconfigurability is restricted to the time needed to change from one assembly system configuration to another with a different product mix ratio or volume.

2. PROBLEM DESCRIPTION

2.1 Use Case, problematic and objective

The industrial use case is engine assembly in automotive industry. This work is realized after crankcase and cylinder head milling. Both parts are first assembled with their components on separated lines, which merge to join the engine crankcase and cylinder head together. Then, on a final manual assembly line, the last components are added to the engine. While main components, such as crankcase, cylinder head, crankshaft, camshaft, are manufactured in the plant, the majority of the small components are manufactured by suppliers.

The assembly sequence faces a strong diversity, due to the different cylinder volumes, European norms which have impact on components, engine types (diesel, gasoline, with or without turbocharger…). This diversity is partially managed through logistics. Indeed, in order to reduce the size of the line-side delivery areas and to relieve worker's mental load, kitting areas have been installed in the production plant. On dedicated logistic areas, kits of manufactured items are composed, each corresponding to a future engine. Kits are then taken to the assembly lines and put on the conveyor besides the engine they belong to. During assembly tasks,

elements are directly taken from the kit and joined on the engine. This enables to manage a part of product diversity, when the diversity only consists in variety among components. However, for strong variety management in a same production line, as changes in the number of cylinders, kitting is not sufficient. This is why automotive industry faces a need in reconfigurable systems.

With production rates in the range of 200.000 to 640.000 products per year on a line, and a target variety of 16 variants for two product families, the use case is classified as high volume with medium variability according to the classification found in the literature (Fig. 1) (Jina *et al.*, 1997).
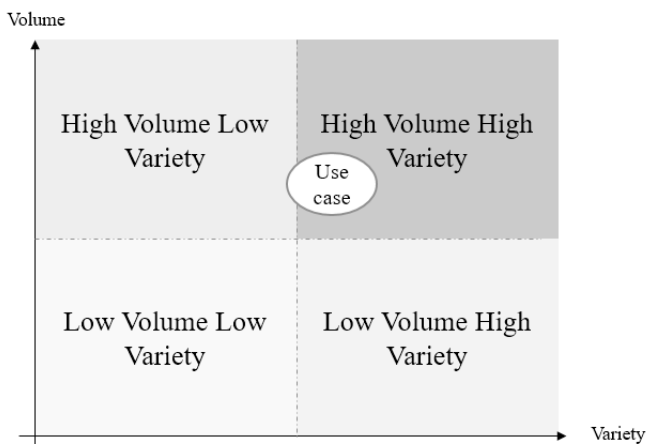

Fig. 1. Volume-Variety Diagram, adapted from (Jina *et al.*, 1997)

Considering the three factory levels: strategic, tactical, and operational, the considered reconfiguration rate is positioned on tactical and operational levels, the strategic level being related to agility (Wiendahl and Heger, 2004). Indeed, with a time horizon of months, weeks, days or even minutes, reconfigurable changes aim to resize or reschedule the system.

2.2 State of the Art

In literature, "Reconfigurability" is defined as the capacity of a system of being divided into several modules, which can be redisposed or replaced in response to market changes or for scheduled changes (Mehrabi *et al.*, 2000), (ElMaraghy, 2016). According to (Zäh *et al.*, 2005), a key component of a reconfigurable system is the standardization of units. Rapidity and easiness of reconfiguration is a characteristic common to all definitions found in the literature.

For the following work, the adopted definition is: a reconfigurable system is composed of maximum standardized sub-assemblies, enabling rapid volume or product change through production structure modification.

On the other side, "Flexibility" refers to a system equipped with fixed hardware and flexible programming according to (Mehrabi *et al.*, 2000), and which is able to adapt to rapid context changes, within delimited boundaries, defined before the launch of the system (Zäh *et al.*, 2005).

Flexibility and Reconfigurability are represented Fig. 2, as a need in changing capacity function of the economic environment (Reinhart, 2000). Flexibility is relevant in a well-forecasted economic environment, while Reconfigurability is used in a turbulent market.

So far, in factories comparable to the use case, Flexible Manufacturing Systems are implemented, which means, that the changeability of the market is forecasted. This strategy manages systems with high volume and some variety and the production system, by means of automatic tool change within CNC-machines or robotic systems and flexible programming, is fully able to manufacture the planned product variants. The aim of this paper is being able to consider turbulent variations too (cf. Fig. 2).
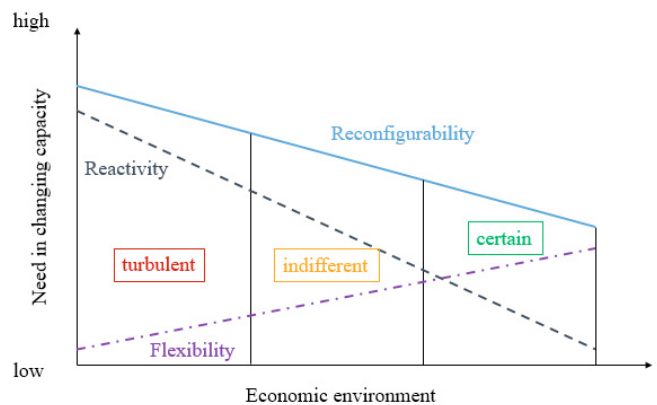

Fig. 2. Link between Reconfigurability, Reactivity and Flexibility, adapted from (Reinhart, 2000)

3. SYSTEM MODELLING

3.1 Formalism

The system representation of a RMS/RAS should include manufacturing facilities, all kinds of resources and production data. Links between instances need to be underlined.
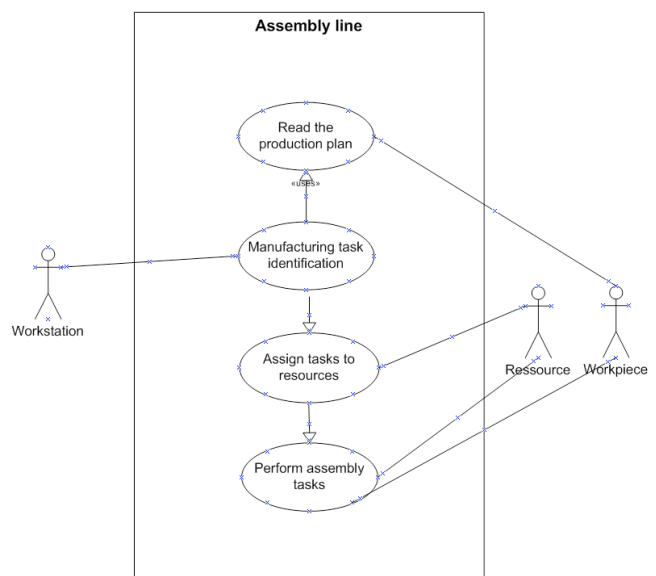

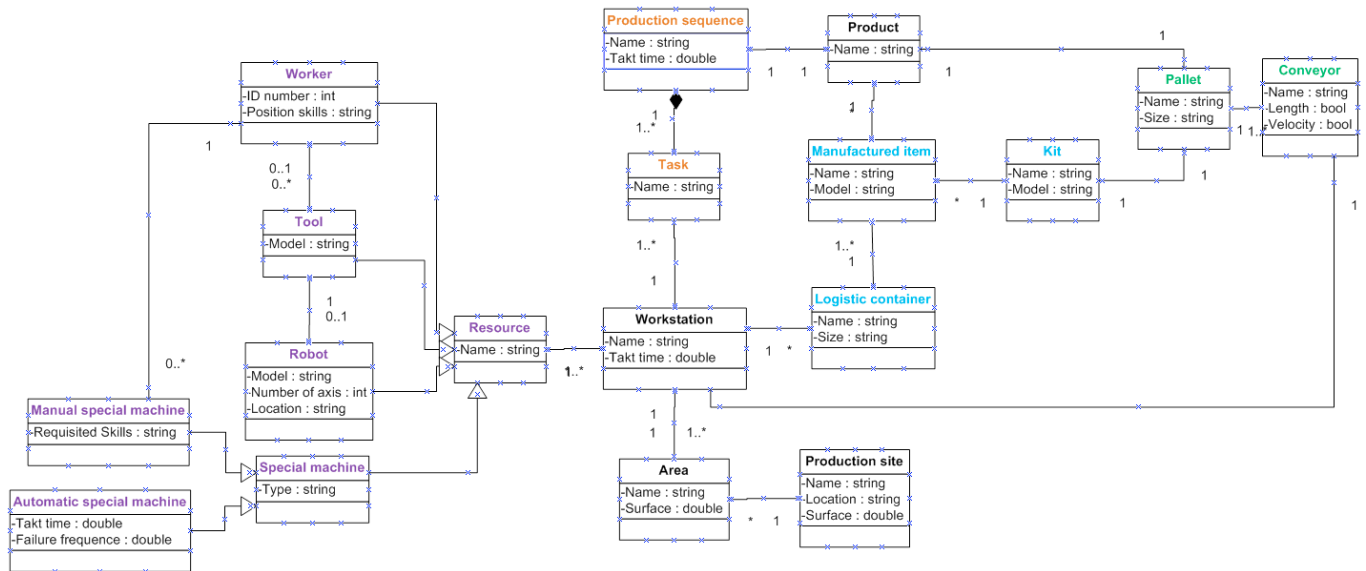Fig. 3. Use case of the current assembly system

Fig. 4. UML class diagram of the current production system

UML class diagram has been chosen for the representation of the static production system with its hardware components, from production cell to production plant scale. This view also enables to outline information content, in form of tasks and production plan. UML representation allows highlighting associations and dependencies with generalisations, compositions, and to precise the multiplicity between elements, in order to have a modelization as close as possible to the real system.

Many articles use UML class diagram for production system representation, in order to represent the link between product, operation resources and information system (Batchkova *et al.*, 2004), (Benkamoun *et al.*, 2014), (Bruno, 2016).

3.2 Current Situation

Currently, production lines in the use case factory are composed of a succession of workstations, building a flow shop layout. Production volume is high, transported between workstations by means of a conveyor.

The mode of operation of the system is the following one: when the pallet with the product and its kit enters a workstation, the cell reads the product's ID. This gives information about the related production plan and the tasks which have to be performed on the cell, with the necessary resources. This procedure is presented Fig. 3.

Each workstation is dedicated to a sequence of tasks and to a range of product variants. The range of products, the tasks performed on the workstations and the allocated resources are fixed before the launch of the line. If the system manages changes, it handles of flexibility, as presented in Fig. 2. The UML class diagram is centred on the workstation, building the node of the model.

Workstations are characterized by resources, related operating tasks and localization (Fig. 4). Within resources,

workers, tools, robots and special machines are distinguished and are inheritances of class "Resource". A robot uses an assembly tool. Besides, the operator working on the station fulfils a task only using his hands, or a tool like for example a screwdriver, or a special machine, which can be manually or automatically actuated. A single workstation can include between 0, 1 or more of each resource type. The main point is that, in the current system, resources are fixed.

One or more tasks from a production sequence, linked to a final product type, are performed on the workstation. The product itself is composed by the main part, machined by the car manufacturer – engine crankcase or cylinder bloc in the presented use case, and of items, manufactured by the company itself or by a supplier. As seen in paragraph 2.1, the logistic related to the manufactured items for assembly is divided into two techniques: kitting and line-side supply. Supply containers are related to a workstation and its localisation in the production plant.

The product and its kit are placed on a pallet, which is on the conveyor, distributing a row of workstations.

3.3 Identification of the Amelioration Potential

On the base of this model, the identified ways of improvement to reach a higher reconfigurability are the following:

- Changing one of the classes is a solution for reconfiguration. The most evident is to enable tool change at the end of the handling arm or to propose to the worker several tools.

- The fact that the tool is dedicated either to the worker or to the robot is an obstacle. A potential solution is a common user-tool interface, so that both workers and robots can use the same tools.

- On a larger scale, the dedication of resources to a fixed workstation implies losses if the throughput is not the maximal one of the line. Indeed, resources cannot be used elsewhere. If workers reallocation is not complex, displacing fixed facilities is arduous. Interface between resources and workstations needs to be rethought in order to have a more "Plug and Play" solution.

- Workstations are limited to their area and surface in the factory plant, which is linked to the fixed property of current resources. This means that, if the task needs more surface or to be elsewhere in the factory, the production system is not able to react rapidly.

- Line-side logistic containers fill a lot of space. In the use case factory, one of the workstations takes about 150 m² in order to place six workpieces which dimensions are a few centimetres, because the workstation has a huge buffer to have all sizes available.

- Conveyors restrict the production sequence, as the sequence of the consecutive cells is fixed by the layout of conveyors. There is consequently a need for a revision of the concept of a fixed conveyor, crossing a row of workstations. Strategies can consist in reviewing the conveyor type in order to render it more configurable, or use another concept to transport products within the assembly line.

4. RMS CONFIGURATIONS

This section presents a selection of layouts, arising from previous identified improvement possibilities.

Only extracts of UML diagrams are represented Fig. 5 to 8. The rest of the diagrams, not represented, are similar to the current system displayed Fig. 4. It is also possible to combine the presented solutions.

A main idea between those propositions is to reduce the specific dependencies between components of the system, and spatial dependencies, driven by the Reconfigurable Manufacturing System principles described by (Koren, 2005): modularity, integrability, diagnosability, scalability, and convertibility.

4.1 Solution with movable robots

If a handling robot is allowed to be mobile, by coupling it to a platform movable by an operator, it is possible to relocate the resource up to several times a day, as represented by Fig. 5. This reconfiguration may be planned each week and can be adjusted the day before. Adding a movable robot on the assembly line enables resource adjustment, which is not possible with the current layout, where robots are fixed on workstations and moving them would cost in average between one and three weeks of time. This time interval is explained by the laborious transport of the hardware, calibration, security checks and ramp up.

Considering a lightweight collaborative movable robot, this time-lapse may be reduced up to less than one hour. The flexibility of the end-tool has consequences on the easiness of the reconfiguration and the number of workstations on which it can be used. In the other case, tool change can be considered. With a shorter relocation time of the robot, the reconfigurability rate of the assembly system is improved.

This layout is a solution, which answers partially to the scalability paradigm. Indeed, by adding more resources on a workstation, Takt time is reduced. If production demand is reducing on the line, the movable robot can be placed on another line.
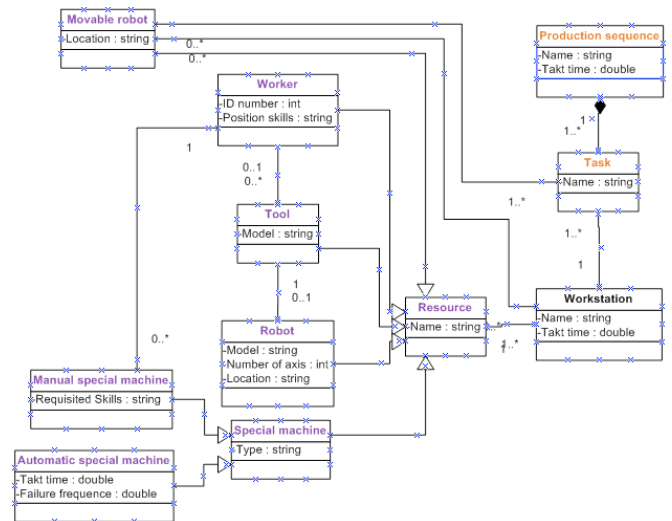

Fig. 5. Layout with movable robots (UML extract)
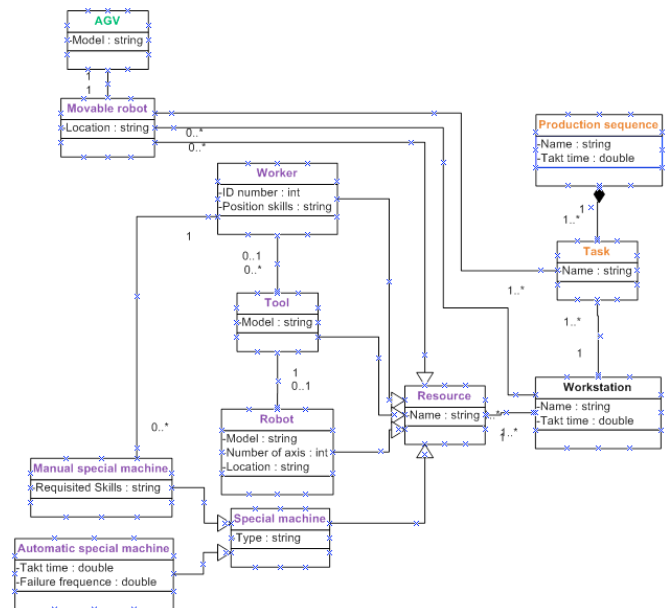
4.2 Solution with dynamically mobile robots

Fig. 6. Layout with dynamically movable robots

Fig. 6 presents the further step, consisting in adding to the resources an AGV, in order to have an autonomous mobile robot.

There are mainly two solutions for the control and planning of the system. Movements of the AGV can either be planned for a production period, as a week or a day. Other strategy is to recalculate regularly the best allocation for the robot. This layout necessitates high-level data connection, and an energy-autonomous robot able to reload on each workstation to avoid time losses on dedicated battery loading stations.

The mobile robot is efficient and viable only if it is not permanently moving. Indeed, it is better to have a fixed or only a movable robot as described in paragraph 4.1 upon a limit. The threshold value depends mainly on the cost of the AGV and of the control system software.

4.3 Logistics by AGVs

In place of the conveyor, AGVs are used to transport products, instead of being only used to move robotic resources. In this layout proposition, the line can be organized as a flow shop, including sections with conveyors and sections with AGVs for pallet transport.

Unlike the conveyor, which path is fixed, the AGV carrying a product can adapt its path to the product type and assembly operations needed. Work content which is common to several product families can be achieved on a conveyor section, and specific tasks on single isolated workstations, between which the AGV flow is free.

This solution has to be assessed regarding costs indicators because of the high price of autonomous mobile robots. With a throughput of several hundreds of thousands of products per year, it is not feasible to have all products on AGVs on full-time.
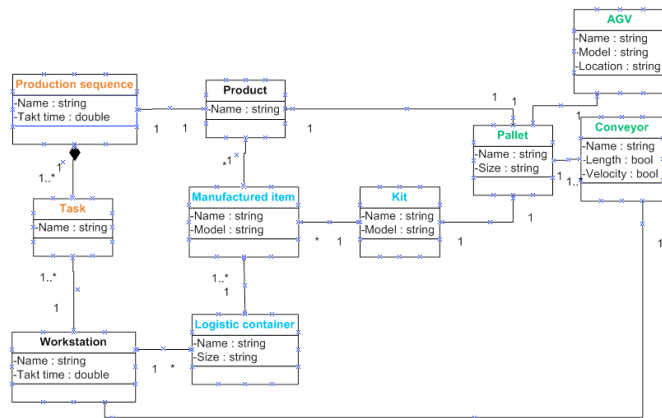

Fig. 7. Transport by AGVs

4.4 Job shop

One step further is the job shop (Fig. 8), having products transferring only on AGVs. Each workstation disposes of fixed resources. The production field has a matrix structure, where each node is a workstation. Those are independent and can be readjust during production. Supply is completely done through kitting in order to avoid logistic containers on the production line.

In this vision, optimization consists in attribution of the tasks to the workstations. Depending on the assembly sequence, the layout minimizing displacements is chosen. Reconfigurability potential consists in two aspects: reaffectation of cells and adding of workstations, as long as the area enables matrix growth. Reaffectation of cells supports changes in product types, or in production volume for a specific product, while another is decreasing.
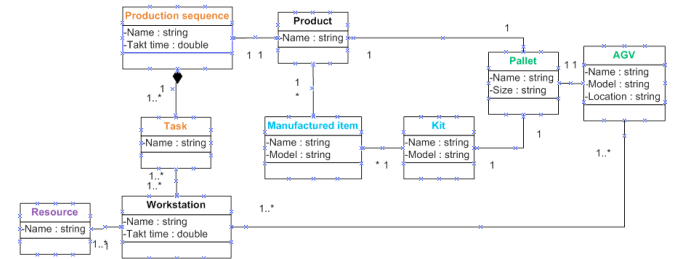

Fig. 8. Job shop layout with AGV transport

4.5 Solution with modular entities

A production system composed of modular blocks is proposed Fig. 9. The RMS is divided into modules of small size, easy to move. The production line is a succession of blocks, including resources, and a section of conveyor (Fig. 9). Several blocks are assembled the one after the other, building a continuous conveyor, transporting workpieces between stations. Reconfiguration of the system consists in the rearrangement of the blocks or/and of the tools within the blocks.

However, considering engine assembly, the size of the manufactured products implies cumbersome blocks. Therefore, this solution does not enable real-time reconfiguration.

5. CONCLUSIONS AND FURTHER WORK

This modelization is a base for a comparison of the several layouts and may help to develop further ones and justify reconfigurability concepts. During the project, the proposed layouts and configurations will have to be justified, using operational research.

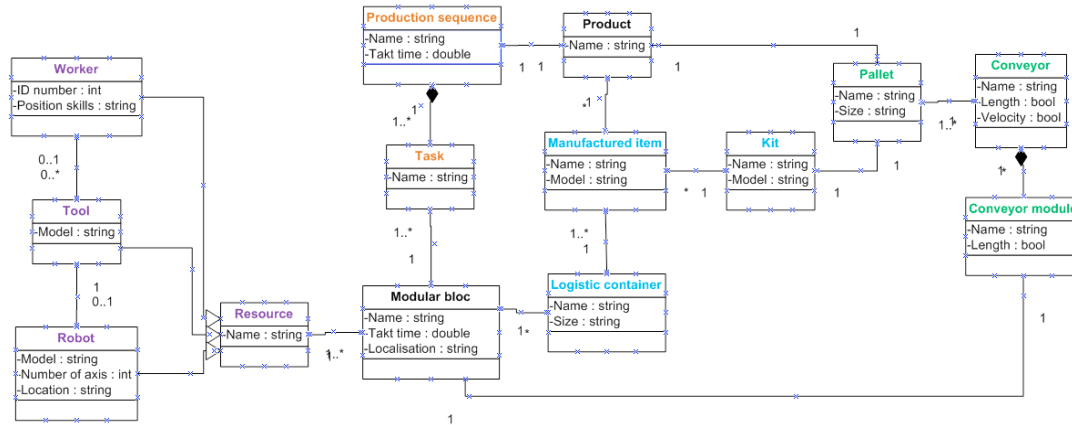Based on this modelization, Table 1 compares the six proposed layouts.

Fig. 9. UML class diagram of the modular blocks layout

Table 1. Comparison of the proposed layouts

Layout	Product Flex.	Vol. Flex.	Product Reconf.	Vol. Reconf.
Current layout	Variant Flex.	No	No	No
Mov. robot	Yes	Yes	Limited by nb of robots	Limited by nb of robots
Dyn. robot	Yes	Yes	Limited by nb of robots	Limited by nb of robots
AGV logistic	Yes	Yes	Yes	Limited by resources
Job shop	Yes	Yes	Yes	Yes
Modular layout	Yes	Yes	Yes	Limited

Thanks to the proposed modelization, it was possible to identify limits and opportunities regarding flexibility, reconfigurability and scalability of a production system, considering the use case of diesel and gasoline engine assembly. This modelization aims to be a tool for the identification of the modular mesh in order to design a reconfigurable system. Several proposals for a reconfigurable system considering product and volume variety have been modeled, based on the current layout of the case study factory.

Among the presented layouts, the best ones for the use case will be selected. A qualitative analysis will be carried out, based on the experience of decision-makers. On the experimental side, layouts will be implemented and scenarios will be modeled and simulated using Discrete Event Simulation, enabling assembly system assessment regarding performance indicators for reconfigurability. In addition, operation research algorithms will serve the choice of the best appropriate production schedule and resource allocation.

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