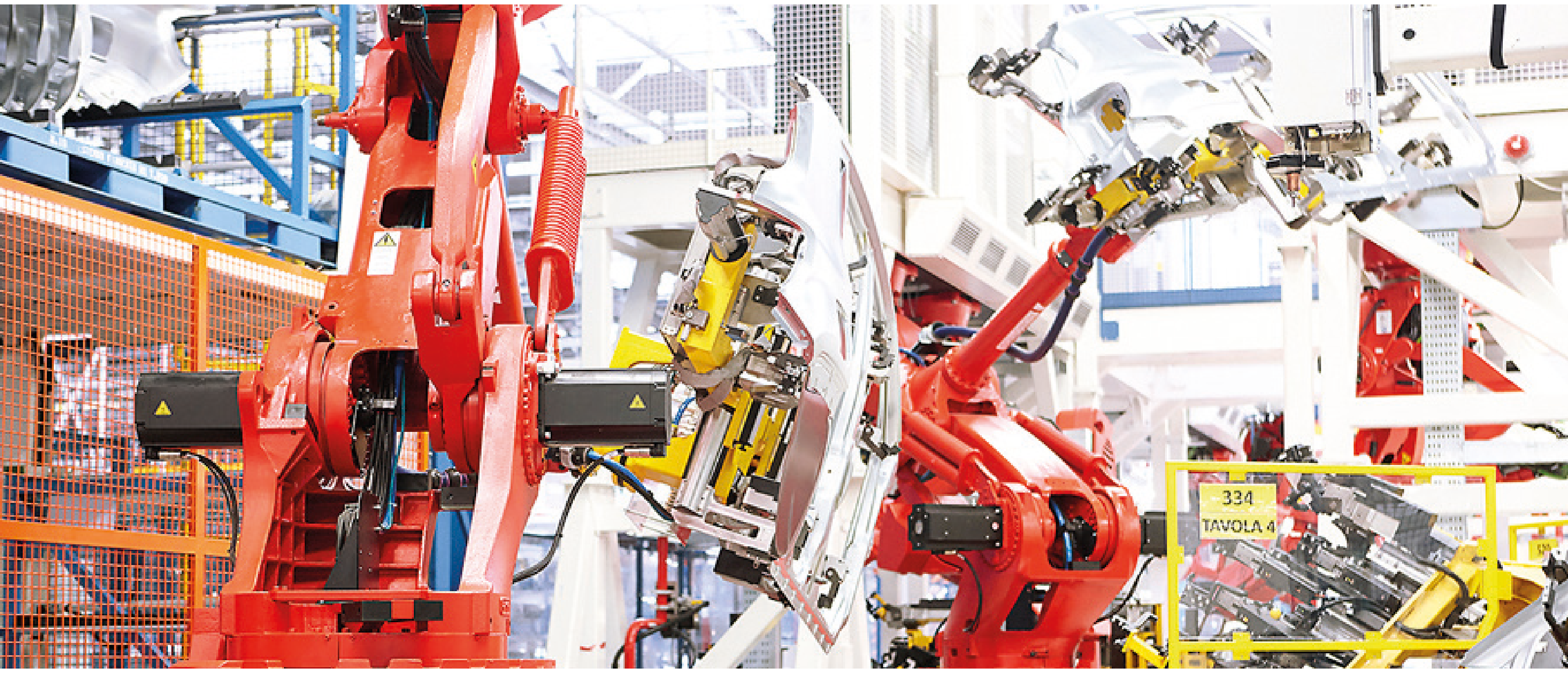
Optimization of an automotive manufacturing system design taking into account regional requirements



A new solution for Proposal Engineering design in COMAU

COMAU Spa, a subsidiary of Fiat Chrysler Automobiles, is a leading provider of advanced manufacturing systems: the company operates in 33 locations spread over 17 countries. The design of automotive manufacturing systems is a core competence of COMAU: who are the largest supplier of automotive assembly line systems in the world and its customers are all the major automotive OEMs. COMAU's challenges are those of every automaker: increased production volumes and line capacity demand, increased line efficiency, car mass reduction and usage of multiple materials and joining technologies in a single line, just to mention a few.

Designing a new automotive manufacturing system represents a complex task that relies heavily on knowledge and experience. COMAU is continuously improving its manufacturing systems design processes in order to reduce the system design lead times, shorten the time to market and increase the "first time right" designs.

The work presented in this article is grounded on a novel approach to the preliminary design of production systems (Proposal Engineering, see fig. 1). This is the crucial manufacturing system

Fig. 1 - Proposal Engineering is the first step of the manufacturing system design process (courtesy of COMAU)

design phase in which timing and evaluation of alternatives are very important. In fact, most of design costs committed during this initial phase will affect the whole project. Moreover this phase is crucial for COMAU projects acquisition and business success.
The traditional approach to Proposal Engineering starts from a Customer Request For Quotation (RFQ), that initiates a bidding phase. Different manufacturing system providers (COMAU and its competitors) will participate in the bid. A manual design approach for systems is traditionally adopted, based on specific competences and past experiences from one side, and customer requirements from the other. In response to the RFQ, COMAU provides the customer with a technical solution, complete with production line description, the envisioned 2D line layout and a cost estimation.
In recent years problems emerged with the traditional approach, such as the need for COMAU to manage global operations with a growing manufacturing systems demand from emerging markets. This has pushed COMAU to identify more integrated approaches capable of taking into account; engineering and throughput constraints, equipment and lifecycle costs, and including region-dependent requirements.

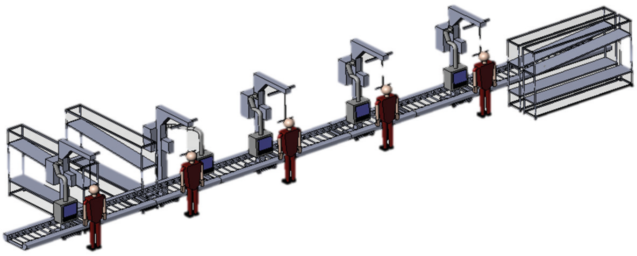


Fig. 2a - Exemplary models of a series of manual assembly workstations

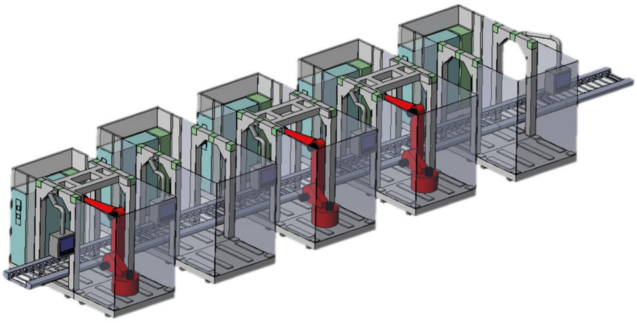


Fig. 2b - Exemplary models of a series of automatic assembly workstations

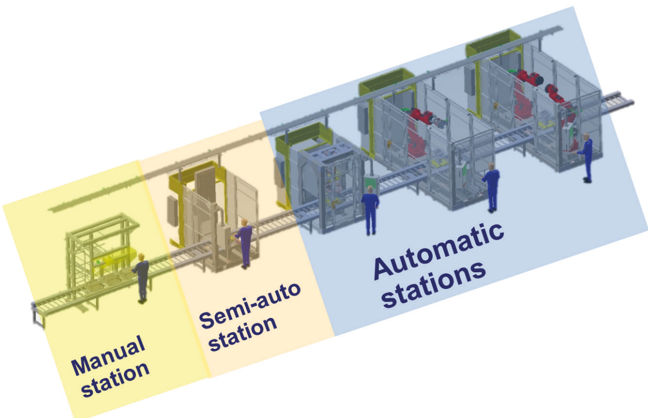


Fig. 2c - COMAU standard modules offer different levels of automation

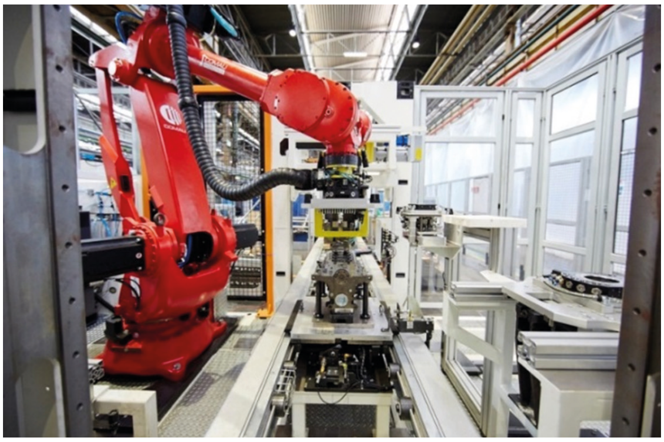


Fig.3 - Cylinder head assembly line (courtesy of COMAU)

Among the objectives of the new Proposal Engineering solution is the ability to re-use existing technical knowledge that has been previously captured and stored (via KBE – Knowledge Based Engineering techniques). Additionally, design input and requirements are considered, such as product information, manufacturing system design constraints, and the target KPIs (such as OEE, cycle time, etc.). Finally, region dependent parameters are considered, such as the desired automation level, local norms and regulations, and the local cost of energy and personnel of the country where the line will be put in operation.
A specific objective of the new solution is the ability to utilize standard COMAU manufacturing modules; in fact, this modular approach provides a direct answer to the growing manufacturing systems demand, and to the related higher volumes and production flexibility requirements. To enable this approach a manufacturing component and corresponding reliability database is connected to the new solution as the source of necessary data.

The Case Study: a car engine assembly production line

In order to develop, verify and validate the new Proposal Engineering design solution COMAU provided access to the expertise and data related to a traditional car engine assembly production system (e.g. cylinder head and cylinder head). This represents a relatively well-known product and process that can support different levels of automation: COMAU modular system architecture actually provides several automation level options for each assembly operation, going from manual stations, to semi-automated stations, to fully

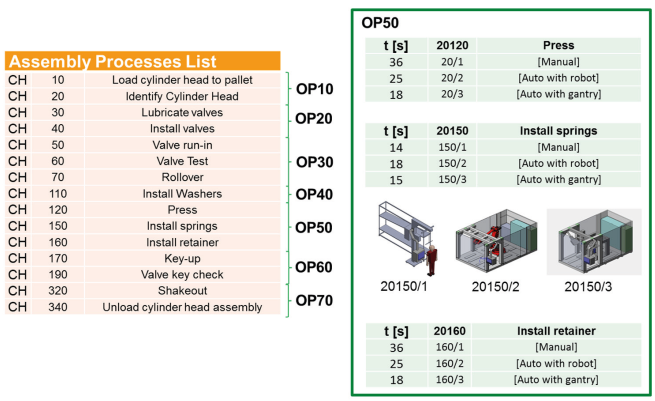


Fig. 4 - Manufacturing process / stations technological alternatives

automated stations with different automation technologies (see fig 2a, 2b, 2c).
A Cylinder Head Assembly case study has been developed: this manufacturing process includes the valve train assembly (fig. 3). This process was selected because it is very well defined and detailed information is available, and therefore it is ideal to be compared to existing design solutions and processes in order to derive further development ideas and suggestions.
The manufacturing process is composed of 16 operations, starting from "Load cylinder head to pallet" and ending with "Unload cylinder head assembly" (see fig. 4). Each operation can be assigned to a different station, but this assignment is subject to technological constraints: for example, it is necessary to lubricate the valve steams and insert them in the same station, in order to avoid lubricant spills.

Furthermore, each station can have a different level of automation, which entails different performance (cycle time, reliability, etc.), and, of course, different costs and flexibility levels. For example it is possible to design fully automated stations characterized by low cycle time, high cost and still retaining a high level of flexibility, but it is also possible to design fully automated stations with low cycle time, relatively high cost and lower flexibility (the so-called "hard automation" solutions). As previously said, different levels of manual and semi-automated stations are also possible.
The manufacturing system design problem is therefore characterized by different parameters, some of them region-dependent, such as:

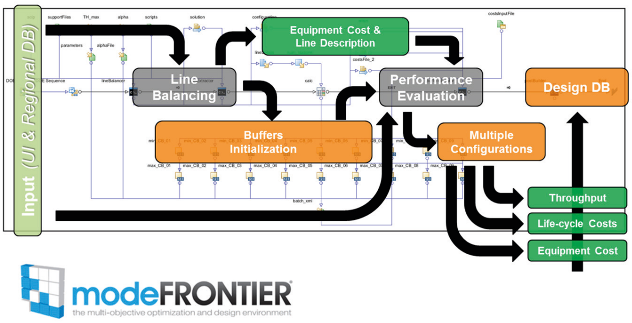


Fig. 5 - modeFRONTIER manufacturing system optimization workflow (courtesy of EnginSoft)

- A complex bill of process
- Technological constraints
- Equipment automation, costs, flexibility, reliability (expressed for example MTTR and MTBF values)
- Lifecycle costs, depending mostly on labour, maintenance (either corrective or preventive), and energy costs
- Other Customer requirements, such as the number of years the system will be in operation

A multi-objective optimization workflow for manufacturing systems design

In the described scenario, and moreover for complex processes, several manufacturing system designs are generally feasible, depending on the constraints that are chosen by the Customer or by COMAU engineers. Depending on the objectives targeted for maximization or minimization, and on the constraints, some of the feasible designs will also be optimal in the Pareto sense, as they represent different but equally optimal alternatives on which a decision can be made.

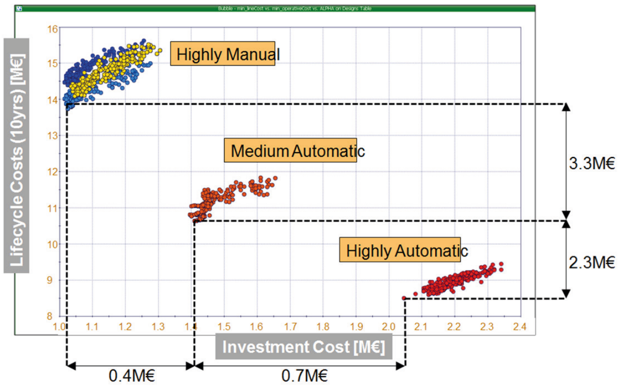


Fig. 6- EMEA region: production line Investment Vs Lifecycle costs

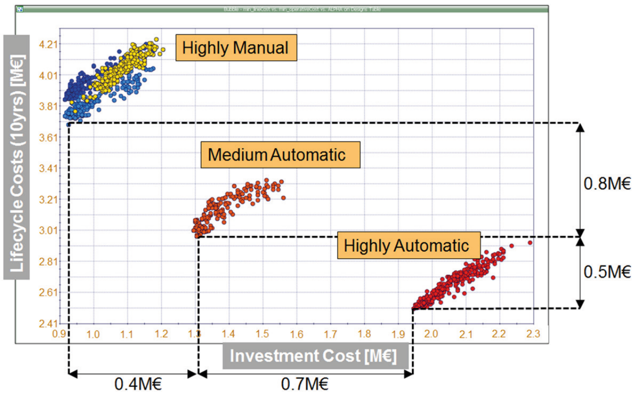


Fig. 7- APAC region: production line Investment Vs Lifecycle costs

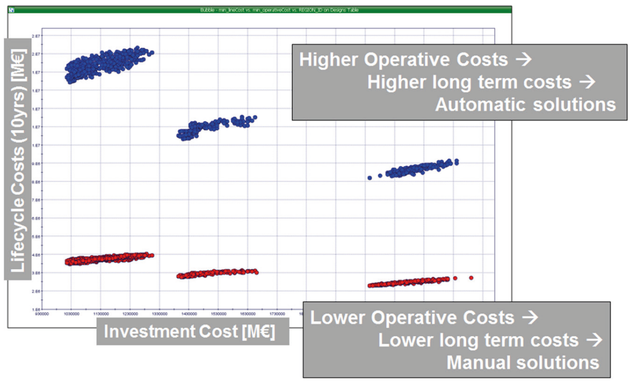


Fig. 8- EMEA Vs APAC production line designs.

It is self-evident that, especially when designing systems for complex processes, the traditional Proposal Engineering approach cannot take into account all the possible combinations and feasible designs. In order to automate the Proposal Engineering manufacturing system design, an optimization workflow has been created using modeFRONTIER (fig. 5).
The workflow receives as input the production bill of process, the manufacturing system technological alternatives and constraints, together with the cost, reliability and the other necessary data. The workflow integrates different solvers, capable to generate and evaluate manufacturing system designs alternatives. Among these solver we can identify the line balancing and the performance evaluation solvers.

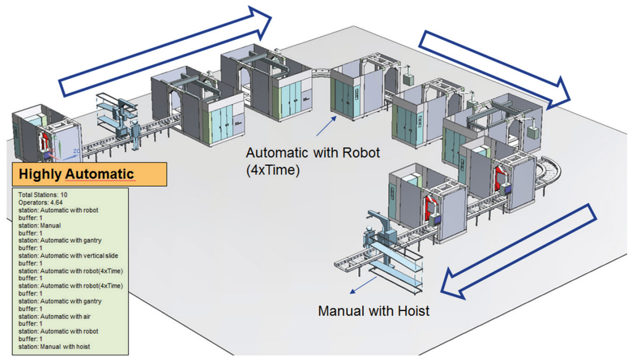


Fig. 9a - 3D visualization of the resulting highly automatic production line (courtesy of Politecnico di Milano)

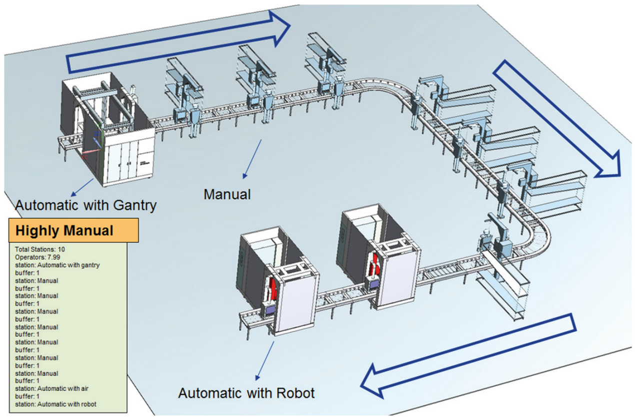


Fig. 9b - 3D visualization of the resulting highly manual production line (courtesy of Politecnico di Milano)

Overall, the workflow is capable of evaluating hundreds of different system designs in a few hours of computation. Each design that is generated by the modeFRONTIER workflow is characterized by its layout, type and number of stations, efficiency and throughput, equipment and lifecycle costs, etc. . Unfeasible designs, those that do not respect the given constraints (e.g. throughput or efficiency constraints), are automatically discarded. Feasible designs are collected and, as the optimization process continues, further refined.

Some results of the optimization process are presented in figures 6, 7 and 8. Each dot on the charts represents a different manufacturing system design. Fig. 6 presents the results for a manufacturing plant designed for a European country (EMEA region), when Investment costs for the desired production line are plotted against its Lifecycle costs computed over a 10 years period. These are competing objectives for the optimization.

It can be noticed that, in this example, the feasible results tend to group together into three main clusters, corresponding to Highly manual, Medium automatic and Highly automatic designs. This effect is due to the provided technological constraints for the system. A Pareto front is provided, composed by different designs belonging to the three clusters: these Pareto optimal designs represent the set of optimum designs among whose a decision should be made. The distance between some of these designs, in terms of costs, is plotted in the chart: referring to Fig. 6 (EMEA region) the investment (CapEx) on a Highly automatic production line will exceed that of a Highly

Manual by around 1.1 M€, but over 10 years it is expected that a Highly manual production line will cost 5.5 M€ more. Taking fig. 7 as a comparison, for the APAC region (e.g. China), the investment cost on a Highly automatic production line will also exceed that of a Highly Manual by around 1.1 M€, but over 10 years it is expected that an Highly manual production line will cost only 1.3 M€ more. Fig. 8 presents the cost analysis for a similar production plant for the two EMEA and APAC regions together on the same chart. While it can be inferred, in a simplistic way, that Highly Automatic solutions are to be preferred in EMEA (due to the higher operative costs) with respect to Highly Manual solutions in APAC (lower operative costs), this analysis can be further enhanced by considering different scenarios for the evolution of the cost parameters over time, etc., in order to carry out what-if analysis of the investment.

Figures 9a and 9b provide a 3D visual representation of two Highly Automatic and Highly Manual production system designs respectively.

Conclusions

The new Proposal Engineering system configuration design platform developed provides several advantages:

- Reduction of design time, that translates into the possibility of fast quoting in response to a Customer RFQ. This also reduces the time to market of a manufacturing system configuration.
- The knowledge based engineering and knowledge reuse, adopted to automatically extract the required data and constraints for the optimization, is capable to capture, store, and re-use existing technical knowledge. This, together with the automation of the manufacturing system design process increases first-time-right designs, improving the feasibility of the system design directly from the proposal engineering phase.
- Design of systems under region-dependent requirements: regional and Customer dependent requirements are automatically taken into account by the solution.
- The solution can be also easily integrated with visualization tools and tools for analytics and simulation for advanced Customer interaction.

Acknowledgment: this work has been carried out in the context of the European Union Programme H2020. The ProRegio – Customerdriven design of product-services and production networks to adapt to regional market requirements - project has received funding from the

European Union's Horizon 2020 research and innovation programme under grant agreement No 636966.

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