A software platform for the multi-objective early-stage design of automotive assembly lines

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Abstract: The early-stage design of automotive assembly lines is a critical, multi-objective task. This design process is typically carried out in industry by continuous interactions between the process design and the simulation and systems engineering departments, resulting in a time consuming and cost-ineffective procedure. This paper presents a novel approach and a software platform to support the early stage design of hybrid assembly lines including multiple assembly technologies, such as Resistance Spot Welding (RSW) and Remote Laser Welding (RLW). This platform relies on the integration of an Assembly Layout and Process Estimator and a Configuration Optimization, based on analytical performance evaluation models. With the platform, it is possible to reduce drastically the overall cost and time required by the design procedure. A real door assembly line in the automotive industry shows the effectiveness of the proposed approach in industrial settings, analyzed within the EU FP7 funded project RLW Navigator.

Keywords: **Assembly, Automotive, Remote Laser Welding, System design, Optimization**

1. INTRODUCTION

The early-stage design of automotive assembly lines is a challenging task, typically involving a selection of the proper manufacturing resources, a definition of the assembly tasks, the task assignment to different stations, the definition of material flow and the verification of system performance against multiple design requirements, such as throughput, cost, floor-space, and energy. In the industrial practice, this task usually requires multiple iterations between the design and simulation departments. The first selects all the resources involved as well as a proper assembly sequence, while the second optimizes the configuration and verifies the performance by discrete event simulation models, considering also machine reliability parameters (Genikomsakis and Tourassis, 2008). However, this iterative design methodology leads to a time-consuming procedure that usually requires between 30 and 60 days for converging. Due to a shorter design time required by the customers in this highly dynamic industry, this duration is a bottleneck to the whole assembly line delivery process. Moreover, the lack of specific software platforms to support this phase of design process inhibits a proper reuse for future problems of the knowledge generated during the design activity (Hu et al., 2011). In fact, this important phase is still based on human driven, trial and error approaches that seriously hinder the ability of delivering first-time-right designs, thus ending up in expensive design adjustments and modifications during the system commissioning phase.

These limitations are even more evident when designing automotive assembly lines that integrate multiple assembly technologies, namely hybrid assembly lines. For example, Remote Laser Welding (RLW) is an emerging technology in automotive applications enabling five times shorter processing times, 30% reduction in energy consumption and higher flexibility with respect to the traditional Resistance Spot Welding (RSW) technology (Michalos et al., 2010). However, RLW requires a tight part-to-part gap control, usually included between 0.05 mm and 0.3 mm. For this reason, such technology cannot be applied to any type of weld, but only specific assembly tasks. Therefore, RLW-enabled assembly lines are usually hybrid in the sense that they integrate both RSW and RLW technologies. These features make the design of the assembly line more complex, requiring the evaluation of a larger number of technically feasible line options along the system configuration optimization.

This paper presents a new methodology implemented in a software platform to support the design of hybrid assembly lines in the automotive industry, developed within the EU funded project "RLW Navigator". The platform relies on the integration of two modules, namely *Assembly Layout and Process Estimator* and *Configuration Optimization*. With the first module, the user can quickly populate the assembly line with technological contents, selecting the resources from a component database, and defining a complete assembly task sequence. The *Configuration Optimization* tests several alternative system configurations before implementation, by exploiting the features of a fast performance evaluation module, based on approximate analytical methods. The same module can be used to perform robustness and sensitivity analysis on the resulting candidate configurations. An application to a real door assembly in Jaguar Land Rover shows the main advantages of the proposed methodology.

The reminder of the paper is organized as follows. In Section 2, the methodology is outlined with respect to the main phases of the proposed approach. In Section 3, all specific methods and tools included in the platform are explained in details.

Section 4 shows the results obtained by the application of the approach to the industrial reference case. Conclusions and future research directions are discussed in Section 5.

2. OUTLINE OF THE APPROACH

The phases of the developed design approach are shown in the diagram in Figure 1. As already mentioned, the platform consists in two interlaced modules:

- *Assembly Layout and Process Estimator*. In this layer, the designer can interact with the software platform through a customized graphical interface to populate the system with all production resources, selected from a pre-defined component database, thus generating an initial assembly line configuration and layout. In the same interface, the user can define an initial task sequencing. It is possible to cluster all resources performing homogeneous set of operations into stations. The interface calculates and reports to the user some basic system Key Performance Indicator (KPI), i.e. configuration costs, system cycle time, etc. Once the initial configuration has been generated, all the related reliability data are automatically retrieved from a reliability database. The station model, as well as the system topology to be optimized, are provided as input to the second layer of the platform, by means of the so-called *transfer functions.*
- *Configuration Optimization*. In this layer, an optimization algorithm automatically generates a set of different alternative system configurations, starting from the input configuration. This set of configurations is then analyzed by means of the analytical performance evaluation model. Upon convergence of the selected optimization algorithm, the set of candidate Pareto-optimal configurations are visualized to the designer via GUI. In addition, it is possible to further post-processing activities on candidate solutions, such as robustness analysis and discrete event simulation. The designer can further refine the optimal solution and run a new optimization by using the ability of continuously interacting with the software platform.

The developed platform features relevant innovations with respect to scientific state-of-the-art approaches, integrating in the same unique framework design and evaluation techniques. For example, in Michalos et al., 2012 the authors present a method for assembly line design, based on the automatic generation of system design options and on simulation-based optimization. In our approach, the first phase is expert-driven, while the second phase relies on fast analytic optimization procedures. Overall, this approach provides the designer the ability to control and manage the process in each design phase, thus avoiding the generation of black-box solutions, which are usually not accepted by industrial users. The goal is to give the designers the capability of testing and visualizing an assembly system, during the early phases of system design. In the following, the methods and tools adopted in each phase of the approach are presented in details.

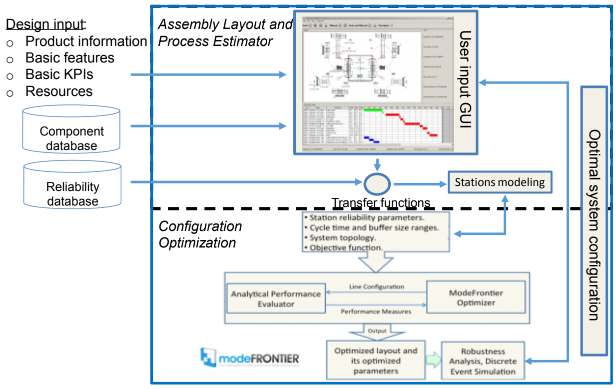


Fig. 1. Phases of the developed assembly line design approach.

3. METHODS AND TOOLS DESCRIPTION

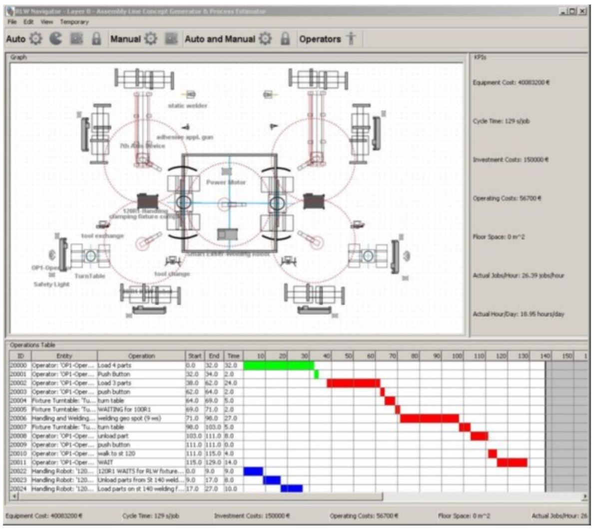
3.1. *Assembly Layout and Process Estimator*

The first module of the system configuration platform adopts an expert-driven approach. Although advanced algorithms and methods might support some activities performed at this stage (for example Assembly Line Balancing (ALB) tools (see Boysen et al., 2006 and Rekiek, B. et al., 2002)), a specific requirement from industrial partners of the RLW Navigator project was to keep this procedure driven by the experts' knowledge. The main reason is to ensure the usability of the platform and the full control of the user on the design procedure. The *Assembly Layout and Process Estimator* is composed of several tools that support the following activities:

1. Design requirements and constraint assignment;
2. Selection of resources from a database;
3. Task assignment and sequencing;
4. Clustering resources into stations.

In the first activity, the user can define a set of design requirements associated to the assembly line, like the maximal annual volume, the annual working days, the working shifts per day, the working time per shift and the expected average OEE (Overall Equipment Effectiveness), typically fixed to 80%. In addition to these requirements, the designer can specify custom constraints and requirements, in order to guarantee a complete control on the design process.

For supporting the second activity, the industrial experts within the project have populated a database of resources. The resources in the database are characterized by several attributes, including the cost, the required floor-space and the size (small, medium and large). The characterization of the resources has been specifically targeted to an early-design phase, thus avoiding specific technical details. For example, from this database it is possible to select fixtures, pedestal spot welders, turntables, 6-axis and 7-axis robots, laser welding robots, laser sources, process monitoring devices, etc. The resource database can be extended with new resources, according the specific company needs. Upon selection, the software visualizes the presence of these elements in a 2D workspace with basic icons. The user can interact with this workspace, by moving and arranging all the icons involved in the configuration process. An example of this workspace is reported in the upper part of Fig. 2.



Equipment Cost: 40083200 €
Cycle Time: 129 s/job
Investment Costs: 150000 €
Operating Costs: 56700 €
Floor Space: 0 m^2
Actual Jobs/Hour: 26.39 jobs/hour
Actual Hour/Day: 18.95 hours/day

ID	Entity	Operation	Start	End	Time
20000	Operator: 'OP1-Oper...	Load 4 parts	0.0	32.0	32.0
20001	Operator: 'OP1-Oper...	Push Button	32.0	34.0	2.0
20002	Operator: 'OP1-Oper...	Load 3 parts	38.0	62.0	24.0
20003	Operator: 'OP1-Oper...	push button	62.0	64.0	2.0
20004	Fixture Turntable: 'Tu...	turn table	64.0	69.0	5.0
20005	Fixture Turntable: 'Tu...	WAITING for 100R1	69.0	71.0	2.0
20006	Handling and Welding...	welding geo spot (9 ws)	71.0	98.0	27.0
20007	Fixture Turntable: 'Tu...	turn table	98.0	103.0	5.0
20008	Operator: 'OP1-Oper...	unload part	103.0	111.0	8.0
20009	Operator: 'OP1-Oper...	push button	111.0	111.0	0.0
20010	Operator: 'OP1-Oper...	walk to st 120	111.0	115.0	4.0
20011	Operator: 'OP1-Oper...	WAIT	115.0	129.0	14.0
20022	Handling Robot: '120...	120R1 WAITS for RLW fixture...	0.0	9.0	9.0
20023	Handling Robot: '120...	Unload parts from St 140 weld...	9.0	17.0	8.0
20024	Handling Robot: '120...	Load parts on st 140 welding f...	17.0	27.0	10.0

Equipment Cost: 40083200 € Cycle Time: 129 s/job Investment Costs: 150000 € Operating Costs: 56700 € Floor Space: 0 m^2 Actual Jobs/Hour: 26

Fig. 2. Screenshot of the *Assembly Layout and Process Estimator.*

The next activity the user can perform is task assignment. For each resource, the designer can select one or more activities from a comprehensive list of typical operations performed in automotive assembly lines. For example, clamping, riveting, welding, brazing, but also transfer, load, unload, etc. operations are selectable. To each activity, an execution time can be assigned. Then, in the task-sequencing phase, the user can create relational links (precedence, parallel execution) between these activities. A task sequence graph, similar to the one reported in the lower part of Fig. 2, is automatically generated. The user can directly interact with this activity schedule to adjust the plan with respect to the design cycle time requirements, also visualized in this map. Finally, the user can cluster the resources into stations; if a resource is shared between more stations, specific operation units can be explicitly assigned to different stations.

3.1.1. Transfer functions

Once these phases have been performed, knowledge based algorithms are embedded to automatically pre-process the data and transfer them, in a structured format, to the *Configuration Optimization*. In details, the activities performed by these pre-processing functions are:

- Gathering of reliability parameters from a database.
- Station model and system topology generation.

For each one of the selected components, reliability data consisting of Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR) are extracted from a reliability database. In the developed platform, the reference database is the one adopted by the industrial partner of the project. Starting from these data at component level, the station models are generated. Each station is characterized by multiple failure modes, each one being connected to a resource that is part of the station. If a resource is shared among multiple stations, a weighting factor is used to adjust the probability of failure proportionally to the time of the operation units executed in each station. For example, a station formed of five resources will have five different failure modes, each one with its specific MTTF and MTTR. The cycle time of the station is also calculated by the execution times of the individual processes and the loading / unloading times.

Finally, according to the user input, the system topology is automatically built. In particular, the assembly line is modeled as a directed, asynchronous and continuous flow network formed by NS stations and NS-1 buffers of finite capacity, configured in non-linear layout (upper part of Figure 3). Stations (light blue squares), in the set M, are denoted as S_k, $k=1,..,NS$, and buffers are denoted as $B_{i,j}$ where i and j refer to the upstream and downstream stages, respectively. The capacity of each buffer is $N_{i,j}$. that is a real number. If no buffer is present between two stations, $N_{i,j}$ can assume value ‘0’. The topology of the system is described by the set Γ of its directed connections, or branches, from stage i to stage j. This formally organized set of data, together with the target requirements set by the user, is the input of *Configuration Optimization*.

3.2. *Configuration Optimization*

The overall goal of this module is to solve an optimization problem to find all the system configurations the lay on the Pareto frontier, namely candidate configurations for the subsequent implementation. In order to solve efficiently this problem, the adopted approach integrates an optimization algorithm with an analytic performance evaluation model. The control of the flow of information between these modules and the execution of the optimization algorithm is performed by a workflow implemented within the commercial software platform modeFrontier 4.5, developed by ESTECO S.p.A. This software supports multi-objective optimization and integration between multi-domain software modules. The analytical method is used within the workflow as an executable kernel. This workflow control the exchange of data between the optimization algorithm and the performance evaluation module.

In this layer, starting from the initial line design, a set of several alternative line configurations are generated. Then, these configurations are evaluated against multiple KPIs. At this phase of design process, the station reliability parameters are used to reproduce stations failure due to random disturbances. Such failures, generates the propagation of blocking and starvation events throughout the line. The multi-objective optimization problem solved in this layer is formulated as follows:

$$
\begin{aligned}
& min\left(E_{hour}, C_{tot}, R_{tot}, N_{tot}, \frac{1}{\mu_i^{RLW}}\right) \\
& s.t.: \\
& TH \geq TH^{target} \\
& LB(CT_i) \leq CT_i \leq UB(CT_i) \\
& LB(N_{i,j}) \leq N_{i,j} \leq UB(N_{i,j}) \\
& N_{tot} = \textstyle\sum_{(i,j)\in\Gamma} N_{i,j}
\end{aligned}
\tag{2}
$$

LB and UB are respectively lower and upper bounds set by the user as constraints and retrieved directly from the GUI. The KPIs that compose the objective function are as follows:

- E_{hour}: energy consumption required by the welding process, scaled to a time unit.

- C_{tot}: total cost of the configuration, including both investment and operational costs, scaled to a time unit.
- R_{tot}: total number of robots involved in the line configuration.
- N_{tot}: total buffer space, directly related to the total floor-space of the system.
- $1/\mu_i^{RLW}$: overall cycle time associated to the Remote Laser Welding station.

In addition, a constraint on the minimal required production rate (*TH,* measured in Jobs per Hours (JPH)) is considered. The decision variables of the problem include the size of each buffer, $N_{i,j}$, the cycle time allocated to each station, CT_i and the number of robots per station, R_i.

The specific optimization algorithm can be selected among a pre-defined suite of algorithms already implemented in modeFrontier, including genetic algorithms, simulated annealing, gradient-based algorithms, and other optimization techniques. Moreover, the software platform provides a set of pre-defined graphical templates to visualize the optimization output.

Overall, this integrated platform allows exploring thousands of alternative line configurations in less than 1 hour, thus drastically reducing the assembly line design times.

3.2.1. *Analytical performance evaluation model*

The core of the *Configuration Optimization* is the evaluation module. In the software platform, this module is tool that implements an approximate analytical method, based on the decomposition technique. One of the main advantages of this technique is the capability of achieving a fast estimation of system performance (typically less than 1 second), having a small error (usually comprised between 1 and 3%) when compared to an exact system simulation.

The grounding idea of decomposition-based methods is to split an entire production system into several subsystem composed by two machines and one intermediate buffer, for which it is possible to create an exact analytical solution. Then, these subsystems are connected one to the other by means of a proper set of decomposition equations, which can be used to estimate the performance of the entire system. In the specific case, the system composed by *NS*-station is divided into a set of *NS-1* two-machine one-buffer subsystems, Each two-machine line $b(i,q)$ is associated to a specific buffer $B(i,q)$, with (i,q) in Γ, of the original system. In details, this logic aims at modelling all the interruptions in the part flow (blocking and starvation) within a buffer B_k. To model these events, each machine of a building block $b(i,q)$ is considered as a pseudo-machine, namely $M^u(i,q)$ ($M^d(i,q)$). The parameters of these pseudo-machines are updated by considering the performance of neighbor building blocks, using the aforementioned decomposition equations. This procedure is repeated iteratively until a convergence criterion is met. After this, it is possible to estimate the main system performance measures. An example of such decomposition is reported in Fig. 3. The exact analytical solution provided in Gershwin and Tan, 2009 is used for evaluating the two-machine one-buffer subsystems.

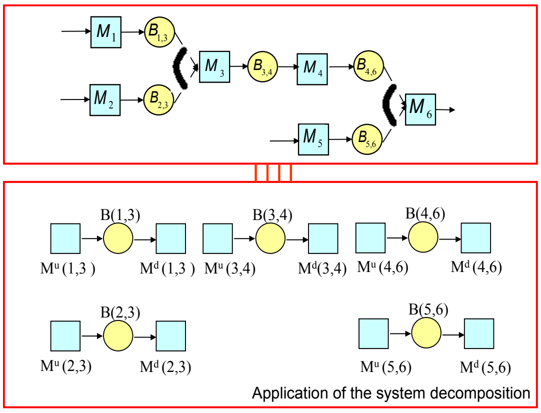


Fig. 3. Approximate analytical performance evaluation method based on the system decomposition.

In the context of the RLW Navigator project, the class of systems of interests is about assembly lines. The decomposition equations used in the project are derived from the ones proposed in Colledani and Tolio, 2005. These equations are not reported in this paper due to space limitations.

During the project, this module was vastly proved to be accurate in estimating the system KPIs, showing errors against simulation below 0.5% while estimating the throughput, and below 2% when estimating the total number of work in progress. The module was verified on large test cases (up to 20 stations and finite buffer capacities), with a negligible computational time increase.

An advantage of this approach is that the *Configuration Optimization* can be easily adapted to evaluate other system topology by changing the evaluation module. An example can be the evaluation of multi-product assembly lines (Colledani et al., 2014).

3.2.2. *Post-processing tools and analysis*

The optimization activity performed by the *Configuration Optimization* calculates all system configurations that lay on the Pareto frontier, namely candidate configurations. All these configurations are equivalent from the multi-objective optimization viewpoint. In fact, for each one of these configurations it is not possible to improve one objective function in value without degrading one or more of the other objectives. However, in order to help the designer with the selection of the most proper solution among the ones on the Pareto frontier, a set of additional analysis tools are included in the software platform. These tools are *robustness analysis* and *Discrete Event Simulation*. In fact, these techniques can be used candidate configurations only, reducing the computational effort of the post-process activity.

The goal of *robustness analysis* module is to provide a precise answer about the robustness of a given system configuration to obtain the target production values. This analysis relies on the uncertainty in the input reliability parameters. As already mentioned, the reliability parameters used by *Configuration Optimization* are obtained from a database that contains nominal MTTFs and MTTRs. However, in practice the observed failure and repair rates for a specific station are deeply influenced by several implementation decisions, including the maintenance activity and the skill of the operators. These factors are typically not considered in the early-stage design phase (Colledani and Teferi, 2013). This phenomenon can cause a bias between the reliability parameters contained in the database and the ones observed in practice. Neglecting this uncertainty might increase the risk of missing the required production targets.

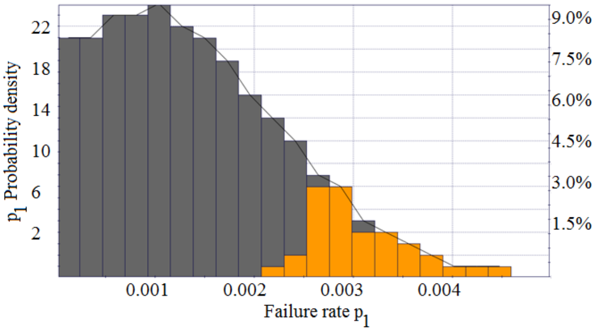


Fig. 4. Example of robustness analysis output using a failure rate.

The *robustness analysis* implemented in the platform considers as uncertain the following decision variables:

- Failure and repair rates for all the workstations *M* and for all the failure modes.
- Buffer capacities $N_{i,j}$ for all the buffer of the system configuration.

To model this uncertainty, the tool creates a perturbation on the input decision variable by calculating a nominal distribution for each uncertain parameter. The magnitude of the robustness is defined according to predefined levels, selected by the designer in the user-interface, using a Coefficient of Variation (CV); three levels of magnitude can be set: low (CV = 0.5), medium (CV = 1.0) and high (CV = 1.5). When the distributions are calculated, the cumulative distribution function of the production rate achieved by the different configurations in the Pareto front is estimated using a Monte Carlo approach. The result is the estimate of the probability to achieve the desired throughput constraint under defined uncertainty levels, for the Pareto optimal solutions.

The output of this calculation is handled directly by modeFrontier, capable of providing a set of predefined graphs for distribution report. An example of this output is reported in Fig. 4. This figure reports a probability density function of a failure rate. The grey bars correspond to a feasibility region, while the orange bars to an infeasibility one. In other words, if the real failure rate of that specific failure mode is greater than 0.002, then the system will not be able to achieve the required throughput. Similar analysis can be done for all failure and repair rates, as well as all the specific design requirements, i.e. total configuration costs, work in progress, etc.

Another example of robustness analysis result is reported in Fig. 5. This Figure shows the cumulative distribution function of the production rate, resulting from the selected uncertainty level. Such kind of information is a valuable insight for the management that can be used for making decisions that are more correct.

The goal of *Discrete Event Simulation* is to provide a precise estimate of the main KPIs of interest, only for the promising system configurations. In fact, although the incurred error of using the analytical methods is almost negligible, a precise estimate for candidate configurations is needed. In the platform, a non-commercial DES module is included for post-processing and validating only the configurations laying on the Pareto frontier. If the performance predicted by the analytical method is confirmed by simulation, then the optimal solution can be exported to the GUI to be visualized to the user. Otherwise, a different validated solution in the Pareto-front should be selected.

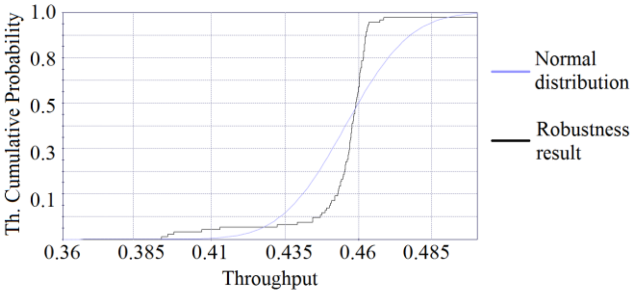


Fig. 5. Example of robustness analysis output using cumulative distribution of production rate.

4. APPLICATION TO A REAL AUTOMOTIVE LINE

The platform presented in this paper has been used to support the re-design of the Evoque L538 door assembly line in Jaguar Land Rover. In the current configuration, the only adopted assembly technology is RSW. The goal of the design process is to enable to integrate in the system both RSW and RLW technologies, thus reconfiguring the line into a hybrid assembly system.

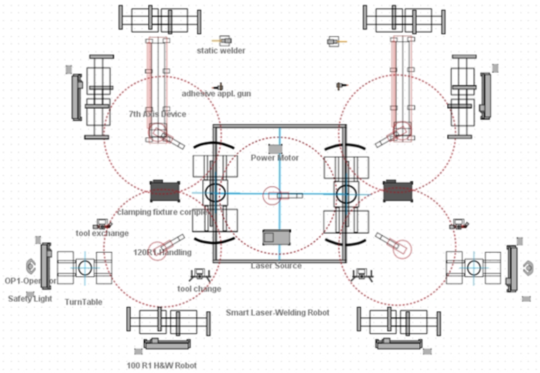


Fig. 6. Re-designed hybrid door assembly line in JLR.

The current system configuration is briefly discussed in the following. The front doors for the 3-door and 5-door models are currently assembled in two identical and parallel lines, respectively assembling the left and right doors. The rear doors are assembled in a different line, where left and right doors are assembled sequentially in batches. This study is focused on the front door lines, currently composed of 28 robots.

The aim of the analysis is to propose an optimized reconfiguration of these lines including the RLW technology and enabling to process both left and right doors in the same line, thus exploiting the flexibility of the laser welding process. To achieve this objective, the RLW Navigator consortium, have proposed progressively refined configurations of this new line. Due to space limitation, in this paper we discuss the application of the proposed approach only to the most advanced line configuration, reported in Fig. 6.

In terms of assembly flow, the halo sub-assembly is assembled by spot welding (9 spots), the door inner sub-assembly is dimpled and assembled by remote laser welding and the latch reinforcement is assembled by spot welding (re-spot). Then, coning, hamming and curing are performed for the door outer assembly. The RLW station is shared between the left and right door flows, while the spot welding and load/unload robots are dedicated to each part flow. The optimization has been performed by using a genetic algorithm (MOGA II) for the generation of the optional system configurations. More than 1500 optional configurations are investigated in less than 20 minutes on a Alienware computer with 2.0 GHz Intel Core i7, with 8 Gb of RAM. The analysis generated a Pareto frontier populated with 22 candidate system configurations. Then, in the post-processing phase the *Discrete Event Simulation* module has been executed to validate the results of the approximate analytical method. The results showed that the provided performance estimates were always within the 95% confidence interval of the simulation. Finally, *robustness analysis* has been applied to screen the configurations in terms of probability of meeting the target throughput under uncertainty in the reliability parameters. The dominating system configuration provided a probability of 0.84 of exceeding the target throughput constraint with a high uncertainty in the input data (CV, Coefficient of Variations, equal to 0.25). A summary of the optimal line KPIs is reported in Table 1, as compared to the current line configuration. As it can be noticed, the optimized line including RLW processes consistently decreases the total cost and the energy consumption, while meeting the target throughput. These results are obtained with a significantly lower number of robots (from 28 to 17). The developed platform efficiently supported the design process by reducing the optimization time to less than one hour.

5. CONCLUSIONS

In this paper, a new methodology supported by a software platform for the early-stage design of assembly lines is presented. This method drastically reduces the time to evaluate a large number of optional system configurations, enables knowledge re-use and increases the ability to provide right-first-time designs. It is worth to highlight that by using simulation as an evaluation tool, the same set of input data and the same level of detail of the analysis, that is typical of early stage design, would have been adopted (Spieckermann, et al., 2000). Although the developed platform has been specifically designed for hybrid automotive assembly lines, it can be applied to system design problems in different industries. Future research will be devoted to the integration of the *Configuration Optimization* with a lower-level fixture design tool and a robot path planning and off-line programming tool for obtaining a holistic and integrated multi-disciplinary line design and optimization platform.

6. ACKNOWLEDGEMENTS

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Table 1. Comparison among the current and the new line configuration (the time unit length is omitted for confidentiality reasons)

KPI	Current configuration	Hybrid RLW configuration	Δ%
Throughput [part/t.u.]	0.455	0.46	+1%
Total cost [Euro/t.u.]	0.55	0.38	-30%
N° robots	28	17	-39%
Energy [kJ/t.u.]	194.5	83.2	-57%

7. REFERENCES

Boysen, N., Fliedner, M., Scholl, A., (2007). A classification of assembly line balancing problems. *European Journal of Operational Research*. 183(2), 674-693.

Colledani, M., Ratti, A., Senanayake, C. (2014). An Approximate Method to Evaluate the Performance of Multi-Product Assembly Manufacturing Systems. *Proceedings of the 9th CIRP Conference on Intelligent Computation in Manufacturing Engineering, Procedia CIRP, Naples, Italy, 23-25 July 2014.*

Colledani, M., Teferi, A. (2013). Impact of Machine Reliability Data Uncertainty on the Design and Operation of Manufacturing Systems. *Procedia CIRP 7*, 557-562.

Colledani, M., Tolio, T., (2005). A Decomposition Method to Support the Configuration/Reconfiguration of Production Systems, *Annals of the CIRP*. 54/1: 441-444.

Genikomsakis, K., Tourassis V., (2008). A simulation based assessment of alternative assembly line configurations. *IEEE International Conference on Systems, Man and Cybernetic*.

Gershwin, S-B., Tan, B., (2009). Analysis of a General Markovian Two-stage Continuous Flow Production System with a Finite Buffer, *International Journal of Production Economics*, 120, 2, 327-339.

Hu, S.J., Ko, J., Weyand, L., ElMaraghy, H. A., Lien, T. K., Koren, Y., Shpitalni, M., (2011). Assembly system design and operations for product variety, *CIRP Annals – Manufacturing Technology*, 60/2: 715-733.

Michalos, G., Makris, S., Mourtzis, D., (2012). An intelligent search algorithm-based method to derive assembly line design alternatives. *International Journal of Computer Integrated Manufacturing*. 25, No.3, 211-229.

Michalos, G., Makris, S., Papakostas, N., Mourtzis, D., Chryssolouris, G., (2010). Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach. *CIRP Journal of Manufacturing Science and Technology*. 2(2), 81-91.

Rekiek, B., Dolgui, A., Delchambre, A., Bratcu, A., (2002). State of art of optimization methods for assembly line design. *Annual Reviews in Control*. 26, 163-174.

Spieckermann, S., Gutenschwager, K., Heinzel, H., Voß, S., (2000). Simulation-based Optimization in the Automotive Industry - A Case Study on Body Shop Design. *Simulation*. 75(5), 276-286.