Technologies and Systems for Assembly Quality, Productivity and Customization

Proceedings of the 4th CIRP Conference on
Assembly Technologies and Systems

Editor: Professor S. Jack Hu

May 20- 22, 2012, Ann Arbor, Michigan, USA

Organizing Committee

Conference Chairs	S. Jack Hu, University of Michigan, USA
	Yoram Koren, University of Michigan, USA

International Scientific Committee

Tamio Arai	The University of Tokyo, Japan
Olga Battaia	Ecole des Mines de Saint-Etienne, France
Hulmut Bley	Saarland University, Germany
April Bryan	University of the West Indies, Trinidad and Tobago
Wayne Cai	General Motors Co., USA
Jaime Camelio	Virginia Tech, USA
Umesh Gandhi	Toyota Research Institute North America, USA
Dini Gino	Universita di Pisa, Italy
Jurgen Fleischer	Karlsruhe Institute of Technology, Germany
Erica Klampfl	Ford Motor Company, USA
Jeonghan Ko	Ajou University, Korea
Joerg Krueger	Technical University of Berlin, Germany
Terje Kristoffer Lien	Norwegian University of Science and Technology
Soh Khim Ong	National University of Singapore, Singapore
Matthias Putz	Chemnitz University of Technology, German
Gunther Reinhart	Technical University of Munich, German
Moshe Shpitalni	Technion – Israel Institute of Technology, Israel
Hui Wang	University of Michigan, USA
Wencai Wang	University of Michigan, USA
John Wang	General Motors Co., USA
Lianhong Zhang	Tianjin University, China

Local Organizing Committee

Tae Hyung Kim	University of Michigan, USA
Ben Palumbo	University of Michigan, USA

Table of Contents

Invited Keynote

Assembly Processes and Technologies

Reconfigurable Assembly Systems

IDEAS

Assembly Quality

Man-Machine Collaboration

Assembly System Planning

Beyond human tetris: simulation-based optimization of personnel assignment planning in sequenced commercial vehicle assembly

L. März[b,c], W. Mayrhofer[a,b], W. Sihn[a,b]
[a]Vienna University of Technology, Inst. of Mgt. Science, Theresianumgasse 27, 1040 Vienna, Austria
[b] Fraunhofer Austria Research GmbH, Theresianumgasse 7, 1040 Vienna, Austria
[c]LOM Innovation GmbH & Co. KG, Kemptener Straße 99, 88131 Lindau am Bodensee, Germany

Abstract: This paper presents a simulation-based planning software, that is developed for high complexity production settings and currently undergoes first real-data industry application tests. The software is tested in commercial vehicle assembly, but will be also employable in other industries with a sufficiently high number of different products and variants. The solution enables the forecasting of required personnel and the requirements with regard to temporary additional workers ("floaters") for every cycle at the production line. To this end, the software periodically collects process times, sequence and feature data for the vehicles. The cumulated workload is calculated under consideration of flexibilities. A web-based user interface enables to set and change reference data, define process simulations and allows for the compilation of diagrams and charts for the analysis of the results of the different simulation runs. Various filters as to time periods, vehicle types or feature variants allow the planner a target-oriented analysis and provide feedback for improving the tact of the production line. Finally, some qualitative results of a first industry test in commercial vehicle assembly are presented. Those preliminary results give valuable feedback about the usability of existing analytical features and desirable additional features.

Keywords: Production Planning, Productivity, Sequencing, Simulation

1. Variant-rich series production in sequenced assembly lines

The principle of variant-rich series production in sequenced assembly lines is current practice in the automotive industry [1]. Due to high wage and nonwage labour costs, available personnel has to be carefully planned with respect to changing requirements at the assembly line in order to evenly utilize capacity [2]. Hence, mixed-model assembly line production requires careful program and sequence planning. The key requirement is to distribute orders with different work content over the production program in a way, that overload and underutilization are avoided [3, 4, 5].

Present sequence planning systems are able to accommodate such planning objectives, by means of sequencing rules that stem from a multitude of vehicle criteria [6]. Yet, sequencing does not always prevent dynamic load peaks at certain stations, since sequencing rules are not created from a forecast, but are based on experiences from the line. Once an excessive peak load as a result of the sequence of vehicle types and/or configuration reaches a team, this specific overload can be avoided in the future by defining a rule, that will prevent this specific scenario causing the overload [7]. A variety of possible vehicle configurations can result in an overload and it is impossible to exclude all possible scenarios that lead to overload, for unacceptable computation runtime or lack of a solution at all [8]. In addition, increased processing time requirements which become apparent in the course of sequences built in the future are not detected. Reasons for this are rare vehicle sequences or shifts in the proportion of certain product types or configuration variants.

Hence, a preview of processing time requirements per cycle and team is of high value. A forecast of the impact on employee workload requires variables representing additional degrees of freedom stemming from the organization of labor within each team (i.e. negative or positive drift). Organizational measures such as "roll-over teams" with different characteristics regarding the execution of assembly tasks in comparison to station-bound teams, should be part of the analysis. Further, the extent of the individual processes that form a task affects the tact of the line.

It is daily practice that process time requirements exceed the capacity of the teams. The simulation is aimed at accurately forecasting process time requirements and resulting workloads of the assembly. This is the foundation of exact personal assignment planning and especially alerts the planner if provisions with respect to wo/manpower (i.e. floaters) are necessary. Hence, demand for assembly personnel is known even before assembly starts. Necessary measures can be taken to fulfill those capacity requirements. Its application is geared to personnel assignment planning in daily operations (shift) as well as in medium term (weekly preview) and strategic planning. With the planning assistant presented in this paper, transparency in the analysis and evaluation of planning data increases (Figure 1). Subsequently, with the application of mathematical optimization methods a comprehensive decision support system will be developed.

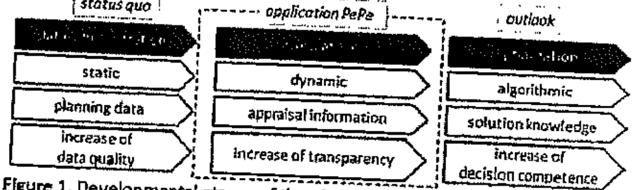

Figure 1. Developmental stages of the planned application

However, the application discussed in this paper so far does not optimize the planning results in a mathematical sense, but supports the finding of an "optimized" solution to the planning problem. This is achieved by making complex system behavior visible and further allowing a step by step optimization of to date mathematically unsolvable planning problems.

2. Objectives and input data for simulation

2.1. Objective

The objective of the development and implementation of the web-based simulation software was to allow continuous use in planning of operative personnel of assembly lines and to give planners a tool for line balancing [1, 9, 10, 11]. The following requirements were central to the design of the support system:

- It is developed for the analysis, evaluation and design of the personnel assignment of sequenced production lines.
- The simulation of staff workloads is based on operational process data and the sequence.
- The area of application shall range from daily operations (use of floaters) via medium-term planning (personnel assignment) to strategic aspects (line balancing).
- Each planner within the network shall, by means of a simple browser, be able to edit the data, simulate the sequence and to analyze the results.
- The functionalities for the evaluation of results will need to provide extensive capabilities and views for analysis, preparation, selection and export of diagrams and tables.

In a nutshell, the system will assist the planner in smoothing the personnel capacity demand curve and identify possible starting points. For this reason, the control variables with the greatest leverage effect on smoothing work content (capacity demand for work content) at the stations have to be identified.

2.2. Procedural aspects of a simulation application

A simulation application can be defined into the phases: model, scenario, calculation and evaluation. The model consists of master data and operational data (sequence, process and attribute data). The master and sequence data can be edited in the application and stored as data records. By selecting master and operational data as well as the depicted time period, a simulation scenario is defined. The calculation of personnel assignment will be performed by the simulation. Subsequently, different analysis functions are available for the interpretation of the results.

2.3. Model data

The master data set contains all elements needed to describe a production line. It represents the production system and all physical and organizational elements of a production line.

The operational data is split up in sequence, process time, and attribute data. The sequence represents the system load and depicts the order (vehicle) sequence. The sequence list contains product name, cycle (operating number within the sequence) and date of the laydown at the last station of the production line. The sequence is updated daily and stored in a separate sequence data set. Sequences can be duplicated, edited and created anew.

The process time data includes all process steps required for each vehicle. By creating a link between work plans and assembly positions, the interrelationship between to the affected teams can be established. Process time data is automatically updated daily and cannot be edited in the application.

The attribute data provide information about equipment options of the vehicles. The attribute data for each vehicle are automatically updated daily and with help of the filter function in the analysis of results allow the analysis of the effects of equipment related process-time strains.

2.4. Definition of simulation runs

The definition of the simulation configures a scenario for the simulation of the flow properties of the production line. The application is designed for

- manually triggered simulation runs and
- automatic simulation runs.

For a manually started simulation run a master data set, a sequence data set and the start and end cycle needs to be defined. For an automatic simulation, the master data set and the cycles to be simulated are to be specified. The sequence data are updated once a day together with the process time and attribute data and are available for simulation afterwards, allowing daily analysis of the current production program, particularly for floating staff deployment. The scenarios are simulated on a standard computer with a valid runtime license of the software simulation SLX.

3. Simulation of the assembly process

3.1. Balancing process time requirements with available capacity

Each task is assigned to a team that is qualified to perform certain tasks. The different teams have a spectrum of tasks often corresponding to a specific technical area (suspension, engine, cabin, etc.) the team is able to perform. Some manufacturers periodically move around their teams along the assembly line for job-enrichment and in order to have a more flexible workforce.

The predefined sequence of orders determines the position of the vehicle in the station at any given time. With the assignment of teams to the stations, the tasks per cycle and team can be identified. The process time requirements are matched with the available capacity of the teams. Should one station be short of staff, the tasks can start in the previous cycle (negative drift) or can be finished in the following tact (positive drift) [12]. The review of the process time requirements for each vehicle and team will be made before assigning employees. Basically, the following two scenarios can be distinguished (Fig. 2):

- Scenario 1: processing time requirements are less than the capacity of the team.
- Scenario 2: processing time requirements are greater than the available capacity of the team.

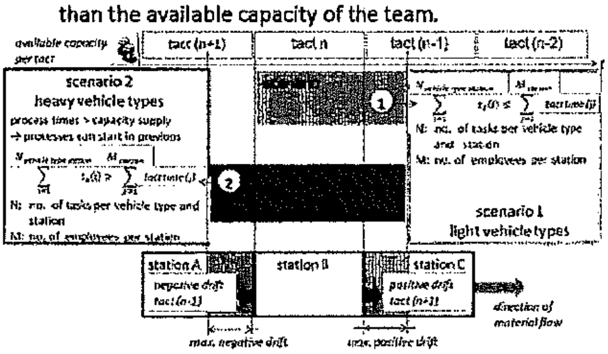

Figure 2. Comparison between processing time and capacity requirements

As long as process time requirements are higher than available capacity (Scenario 2), tasks might be pushed up. Whether this is possible depends on several factors:

- The team is allowed to move up-to what amount this is possible is defined in the table team.
- The workers still have idle capacity, which is evaluated at the simulation run and results from dynamic calculation.

In scenario 1 there is generally no negative drift. However, due to the size of the process modules and the necessity to deploy several workers to the process, it is possible that processing time exceeds the cycle limit. Typically, those time components are comparatively small. After balancing capacity demand with available capacity the simulation runs through a planning and implementation process. The optimization of the resources is supported through shifting of tasks and processes through the planner. The changed configuration subsequently can be evaluated and compared to the results of previous runs.

3.2. Assigning of workers

Employees are scheduled by booking of capacity "pots" per employee and cycle by means of assigning individual tasks [13]. Upcoming tasks are allocated by the following order of priority:

- tasks requiring more than one employee to be performed, sorted by the number of required employees per task
- tasks sorted by their process time in descending order.

Assigning of workers is done by debiting the capacity pots of the workers of the involved teams. To do so, the first worker's capacity pot is checked for sufficient capacity. If this is the case, the task is allocated to the worker's capacity pot. This results in (almost) filling up the capacity pot of the first worker before engaging a second worker. Whether the capacity of an employee is completely utilized depends on the process time variables. The smaller the process steps are, the higher is the chance to utilize a workers capacity to a high extent. The selected distribution logic is similar to the approach used for line balancing in planning.

The procedure covers checking capacity over the current cycle and previous or subsequent cycles in case of negative drift or positive drift. If the next worker does not have sufficient capacity, the employee after that will be checked. If there are no workers with free capacity in a team, an employee of the group of floaters, marked in the master data as such, will be summoned. The handling of the distribution of tasks in the floater group works similar as capacity assignment of the worker teams. The floaters have the same limits with regard to negative or positive drift as the teams to which the floaters are assigned. If the capacity of the floater group is exhausted, the superordinate floater group will be engaged. If there is no such floater group registered any more, a virtual floater will be created, who has no restrictions on positive drift. This prevents that operations with too high of a process time due to pre-, cycle and rework capacity cannot be modeled with the existing workers.

3.3. Carrying out of the tasks

The selected employees are assigned to tasks. At the time of the simulation run, the registered teams and floater groups are scanned for idle workers. Once all employees are available for one task, the employees are blocked for the process time. Contrary to task-allocation amid workers in planning, tasks are now distributed to each employee that turns idle, i.e. the first two tasks of a team can't be allotted to the first worker, since the worker is already busy carrying out the first task. The second task will be executed by the next idle worker. Compared to the original planning this altered allocation of tasks to workers might require a small positive drift. The selected assignment logic is similar to the real allocation of tasks at the line.

In case of increased or decreased processing time requirements cycle limits can be underrun (negative drift) or overrun (positive drift) [10]. The following basic configurations are possible in the case of process times that are less than twice the cycle time (Fig. 3). In the case of tasks exceeding cycle time limit, the time fraction per cycle is calculated and assigned to the respective cycle. The model does not use punishing factors, but attempts a representation of the processes at the line with high validity and all cases below can appear in reality.

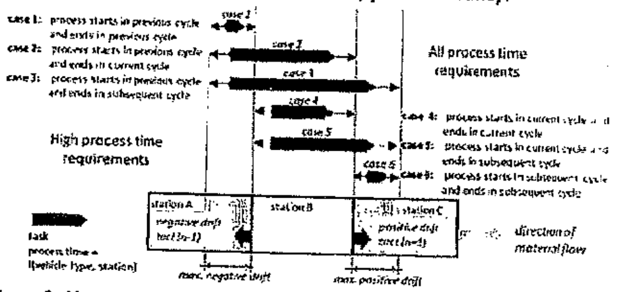

Figure 3. Alternative positions of process modules

4. Evaluation

4.1. Bar and matrix diagrams

Evaluation functionalities include a variety of diagrams and tables providing a variety of choice for analysis of results. Structure and arrangement of evaluation diagrams is oriented in such a way, that workloads (caused by the vehicles) are shown with respect to cycles and organizational units. By determining the organizational unit, capacities are defined and set in relation to processing time requirements per cycle and the division into temporal sections (cycles) is arbitrary and can be reduced or extended by changing line cycle time, thus affecting productivity. Spatial structuring in stations is not evaluated. However, a link is established by the cyclically releasing of the next vehicle into the line at station 1 and the gradual passing along during the next cycles as well as the assignment of the teams to stations. Dependent upon the view of the analysis of workloads, different types of diagrams (Figure 4) ensue.

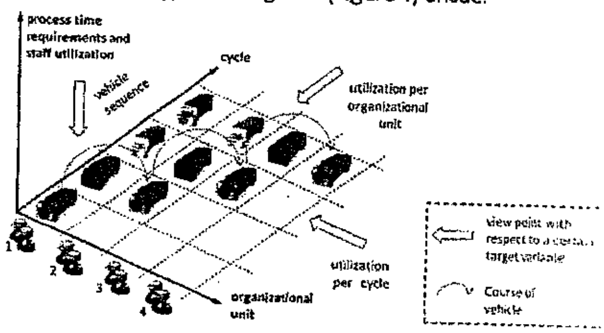

Figure 4. Types of diagrams for personnel assignment planning

The diagrams contain at least one structural component concerning the organization of personnel or is cycle time-related.

Table 1 shows the graph types dependant on the selected category (organizational unit and selection of type of diagram).

Table 1 Result chart types

	selection	chart	chart	chart	chart	chart	cha
organi-zational unit	team	utilization teams	utilization employee	over-view matrix cycles	over-view matrix product	process time distri-bution	spre of varia
	all others	utilization teams	aggregation over cycles				
assignment planning	group of jumpers	workload of jumpers	(-)				

The histograms showing process time quantity distribution and variant spread mainly analyze process time data in relation to the cycle time or the capacity of the teams.

4.2. Example: utilization diagram of a team

The chart 'workload group team' shows process time requirements and the utilization of a team per cycle (Fig. 6).

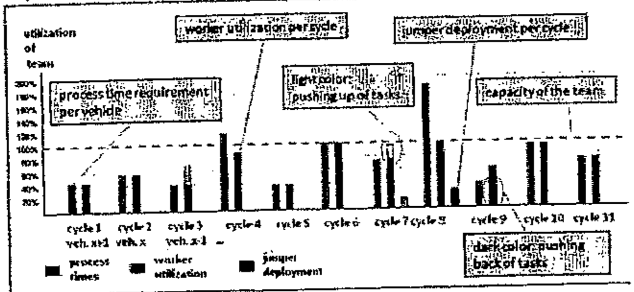

Figure 5. Example graph utilization staff group

Each cycle is assigned to a vehicle and the required process time represents the assigned work content, which results for the current vehicle in a cycle. One set of bars visualizes the work content in relation to the capacity of the team. Another set of bars shows the utilization of the team in the cycle for the vehicle. Work content can exceed the 100% level of staff capacity. In this case, the additional work can be visualized as follows:

- negative drift of the team
- negative drift of the floater group
- use of the floater group in the cycle
- positive drift of the team
- positive drift of the floater group

By clicking on a bar, a table below the chart will appear showing each process time data. In addition, filter functions allow the selective choice of results for products, product types, product attributes as well as cycles.

5. Conclusion

The described application is used in a commercial vehicle manufacturing company since mid-May 2011. With a run-time behavior of one second per cycle, simulation runs on the maximum preview horizon of up to 1,500 vehicles are possible in less than half an hour (is equivalent to a 10-day forecast). By means of the web-based application, the planners themselves can define scenarios and analyze the effects by means of analysis charts and filter functions. The integration of the application in the daily operations of the planners and segment leaders primarily assists in personal assignment and planning of floaters. By simulating the daily sequence, down time of floaters can be minimized by exact (to the cycle) scheduling of work assignments. Moreover, a better planning and use of non-productive time of the floaters will be enabled.

In medium-term planning workload matrices allow the assessment of the 'seriousness' of the expected program and an accurate prediction of the necessary weekly personnel resources. The goal of the further development of the application is to improve operational and evaluation functionalities. In future, the planning assistant is intended to be tied to an optimization algorithm to enable the management of headcount as a function of the applied sequence.

References

[1] Hu, S J, Ko J., Weyand L., ElMaraghy H. A., Lien T. K., Koren Y., Bley H., Chryssolouris G., Nasr N., Shpitalni M., 2011, Assembly system design and operation for product variety, Annals of the CIRP 60/2, 715-73.

[2] Bley, H.; Reinhart, G.; Seliger, G.; Bernadi, M.; Korne, T., 2004, Appropriate Human Involvement in Assembly and Disassembly, Annals of the CIRP, 53/2: 487-509.

[3] Boysen, N.; Fliedner, M.; Scholl, A., 2007, A classification of assembly line balancing problems, European Journal of Operational Research 183, 674-693.

[4] Drexl, A. Kimms, A., 2001, Sequencing JIT mixed-model assembly lines under station-load and part-usage constraints, Management Science 47, 480-491.

[5] Boysen, N., Fliedner, M., Scholl, A., 2009, Sequencing mixed model assembly lines: survey, classification and model critique, European Journal of Operational Research 192, 349-373.

[6] Mayrhofer, W., März, L., Sihn, W., 2011, Planning assistance for pearl chain forecasts and personnel assignment planning of sequenced assembly lines, Annals of the CIRP, 60/1, 481-484.

[7] Solnon, C., Cung, V.D., Nguyen, A. Artigues, C., 2008, The car sequencing problem: Overview of state-of-the-art methods and industrial case-study of the ROADEF'2005 challenge problem, European Journal of Operational Research 191, 912-927

[8] Kis, T., 2004, On the complexity of the car sequencing problem, Operations Research Letters Volume 32/4, 331-335.

[9]Janardanan, VK., Adithan, M., Radhakrishan, P., 2008, Collaborative Product structure Management for Assembly Modeling, Computers in Industry 59/8, 820-832.

[10] Eversheim, W., Abels, I., 2003, Simulationsgestützte Personaleinsatzplanung in der Pkw-Endmontage, in Eversheim, W., Abels, I., Simulationsgestützte Personaleinsatzplanung in der Pkw-Endmontage, Springer, 61-70.

[11] Iltzsche, L., Schmidt, P.M., Völker, S., 2011, Simulationsbasierte Optimierung der Einsteuerungsreihenfolge für die Automobil-Endmontage, in März , L. et al. (Ed.), Simulation und Optimierung in Produktion und Logistik, Springer, 117-132.

[12] März L., Tutsch H-J., Auer S., Sihn W., 2010, Integrated Productio Program and Human Resource Allocation Planning of Sequenced Productio Lines with Simulated Assessment, in Dangelmaier, W. et al, Advance Manufacturing and Sustainable Logistics,1st Ed., Springer, 408-418.

[13] Monden, Y., 1993, Toyota Production System. An integrated approac to just-in-time, 2. Edition. Norcross.