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Scheduling in an Automobile Supplier. Models and heuristics.

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Outline

- Introduction
- Overall Situation at the studied company
- Problem description
- A mathematical model. Computational experiences
- Heuristic approaches. Computational experiences
- Implemented solution
- Conclusions and future work

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Introduction

- A realistic problem in an automotive supplier is presented.
- We deal with the problem of scheduling in a single facility with sequence-dependent setups.
- The real problem is described and formulated, considering all the restrictions and variables of the problem.
- Some solution procedures are formulated and implemented

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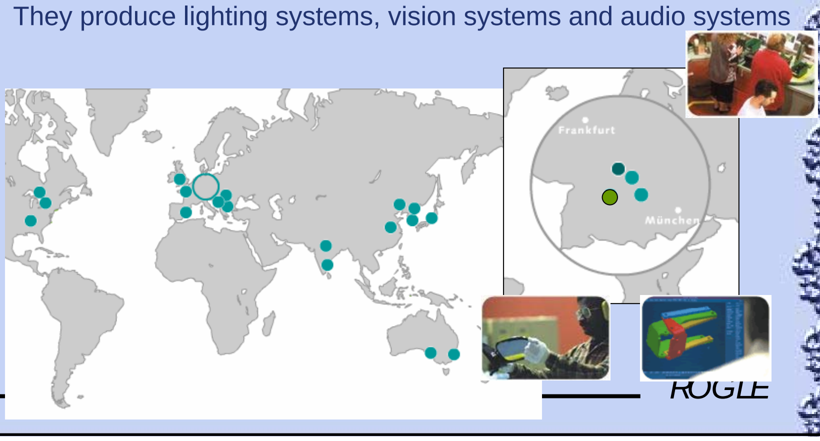
Overall Situation at the studied company

- They supply products for the automotive sector.
- The company has a world wide manufacturing network with many factories.
- They produce lighting systems, vision systems and audio systems



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Overall Situation at the studied company

– Most of the automotive manufacturer are clients of the studied company, and therefore their concerns are associated to them:
  - Increasing number of colors and models,
  - pressure on prices,
  - and ever growing quality controls.
– Moreover, every year new models appear and products became obsolets for large production, but have to be kept on production.

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Problem description

– The studied facility paints rear view mirrors of varying models and colours.
– The whole process includes plastic injection and assemblying components.
– It is a Painting Plant. It received plastic components to be painted.
– The paint line consists of a moving train that forms a closed continuous loop.
– The loop contains a fixed number of hollow spaces.
– The products are fixed on each hollow using a special fixture which is known as a jig.

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Problem description

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Problem description

- The jigs pass continually through a painting area located at a fixed position on the line where the products pertaining to different car models and colours are painted.
- The Painting Facility has 650 Jig Positions.
- Each of the jig had a variable capacity from 6-18 Parts/Jig
- Every 4,35 hours time one loop is finished (31 loops per week).
- When changing colors/jigs capacity is lost.
- The plant has to produce about 42 different parts (21 Projects) with 15 different colors.

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Problem description

- The production schedule is complicated by certain production constraints on the sequencing of the paint schedule.
- For example, within any given number of consecutive positions, the number of colour changeovers is limited due to paint supply restrictions ("no more than 8 colours of 24 blocks").
- It is important to note that each model uses a different type of jig, but that the same jig can be used for multiple colours. This means that when the product model to be painted is changed, the jigs must also be changed, but when there is only an alteration in the colour then it is not necessary to change the jigs.

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Problem description

- Every type of jig supports a defined number of parts according to the model.
- In the system, different quantities of jigs exist for each model and it is not possible to exceed the maximum number of jigs per model daily.
- Jigs are changed manually by workers spending a finite quantity of time.
- So, this fact imposes a restriction to the number of jig changes ("no more than 5 jig changes out of 24 blocks).
- As a result, the schedule for each loop should make sure not to have more jig changes than the worker capacity to do such changes, as each jig change requires a certain amount of labour that might not be readily available.

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Problem description

- There are three types of setups that can occur at the loop:
  - Model changes: when a model change is required in the same loop, a jig change must be carried out. Workers must make this change during a finite time by allowing some empty jigs to pass through during the moving of the loop. As such, a given number of empty jigs are left to enable the setup of the jig change within the same loop. Based on this information, it is clear that any changeover of model between any two given blocks will cause a loss in paint line capacity.
  - Jig changes: for this problem, a second setup is necessary when there is a model change between two consecutive loops in the same position. In this case no empty jigs remain.
  - Colour changes: when a colour change occurs between two consecutive blocks it is also necessary to leave some empty jigs between these blocks because a change in the colour involves removing the old colour, cleaning the robot used for the painting and finally, inserting the new colour. All this must be undertaken in a finite time during the motion of the loop.

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Problem description

- Due to the continuous movement of the loop and the limited capacity of the workers to carry out such changes, the number of jig changes during each loop is limited.
- The change between consecutive blocks of different models makes it necessary to include empty jigs in the sequence.
- This setup is necessary if consecutive blocks have different model types.
- When carrying out a model change, one hollow in the first block must be empty and two hollows in the next block must also be empty.
- If a product is going to be scheduled on a block which in the previous loop contained a product with a different model type, then the jigs must also be changed.

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Problem description

- Another kind of setup is also required if consecutive blocks have different colour types. When conducting a colour change, any traces of the old colour must be removed. In this case, three hollows at the end of the first block must be empty and the three hollows at the beginning of the following block must also be empty. In addition, there is a cost related to the use of solvents needed to clean the pipes. It is important to note that there is a limit to the number of times the colour or the model in the same loop can be changed and this cannot be exceeded. As such, within a given number of consecutive blocks, the number of colour changes is limited according to the paint supply constraints.

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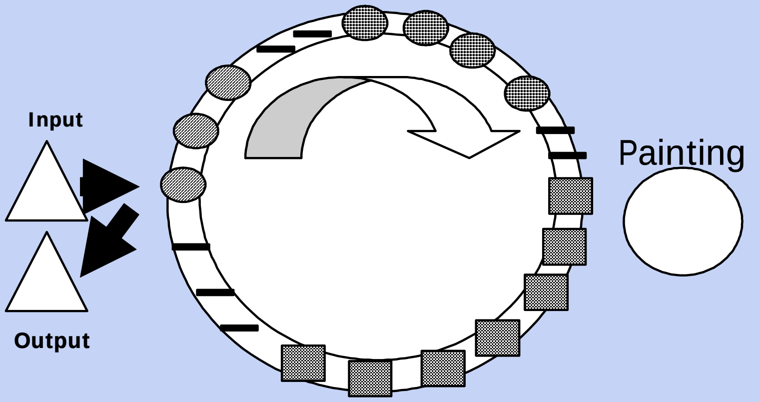

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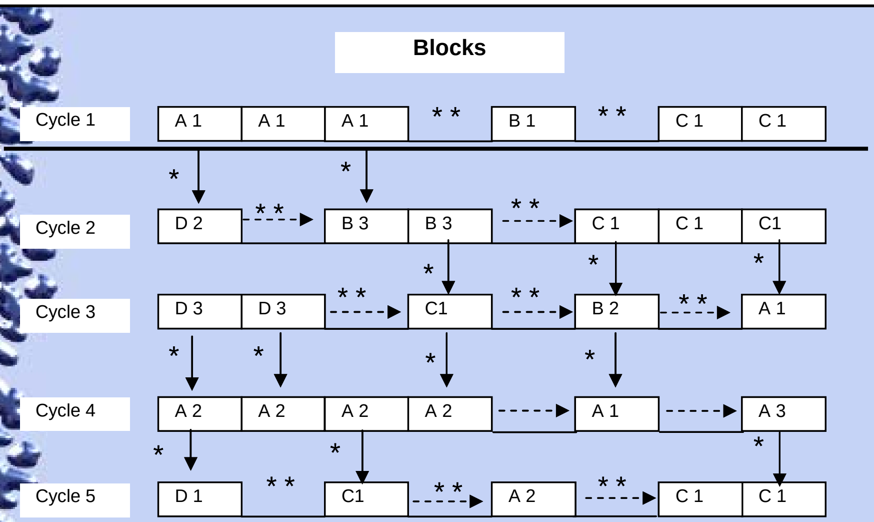

The figure shows a number of cycles or loops with a number of different colours (marked 1, 2 and 3) and models (marked A, B, C and D) in each loop. The colour changes and the jig changes are also shown.

** jig change in the same loop.

* jig change between consecutive loops.

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Problem description

- Every product has a defined model and colour (for example A1). In tehe previous figure, six blocks have been scheduled in the first loop. The first three blocks have the same model and colour. Therefore, they are assigned directly behind each other without any space between them. Next a model change from A to B occurs, while maintaining the same colours. As such, empty jigs are required in order for the workers to change the jigs. It can be seen that when the model changes in consecutive cycles at the same position, a setup is needed and when the colour is different at consecutive blocks another setup is required.

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Problem description

- Thus, the problem may be stated as follows: given a set of products to manufacture (defined by their model, colour and minimum and maximum daily production quantity) and the number of blocks per loop (the system capacity), the objective is to schedule the products in a number of blocks in an attempt to reduce the set-up costs and take into account the constraints related to the jig changes, jig availability and the number of colour changes.

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Problem description

- A summation of the empty jigs resulting from the colour change and the empty jigs resulting from the model change must also be carried out and can be used to calculate the total number of empty jigs in the loop.
- To simplify the problem would involve having just one colour and one model in each block within the loop, thus a block with more than one colour and one model would not be possible. For example, in order to allocate the colours in the blocks, it would be necessary to define the actual presence of products in the block and then define their colour. The next step would be to establish if there is a colour change after this position or not. Finally, the quantity to be produced from each colour and model cannot exceed the minimum and maximum levels as defined by the data of the problem.

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Mathematical model

Index

- *i, g : Blocks*
- *j : Products*
- *h : Models*
- *k : Colors*
- *t : Days*
- *g : Loops*
- *s : shifts(1..3)*

Parameters

- *H(j): Model of product j*
- *K(j): Colour of product j*
- *I(j): Inventory start level per product j*
- *BPL: Number of blocks per loop*
- *JPB: Number of Jigs per block*
- *CP: Empty jigs per previous colour change*
- *CF: Empty jigs per following colour change*
- *MP: Empty jigs per previous model change*
- *MF: Empty jigs per following model change*
- *SPJ(h): Scalps per jig and model*
- *D(j,t): Demand per day and product*

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Mathematical model

Parameters

- *MK(s): Maximum number of colour changes at shift s*
- *LK(s): Considered window to apply colour changes*
- *MH(s): Maximum number of model changes at shift s*
- *LH(s): Considered window to apply model changes*
- *S(i): Shift of block i*
- *JA(h): Jig availability of model h*
- *SCRAP(j): Scrap per product j*
- *MAIL: Maximum average inventory level*
- *SMIN(j):Minimum stock level per product j*

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Mathematical model

Variables

$x(i): product\_at\_position\_k$

$\delta(i):\{0,1\}\ Color\_change\_after\_position\_i$

$\phi(i):\{0,1\}\ Jig\_change\_at\_position\_i$

$\eta(i):\{0,1\}\ Model\_change\_after\_position\_i$

$\omega(i):\{0,1\}\ Product\_change\_after\_position\_i$

$z(j,g): Stock\_level\_at\_end\_of\_day\_t\_of\_product\_j$

$y(j,t): Quantity\_\mathrm{Pr}oduced\_at\_the\_day\_t\_of\_product\_j$

$v(i): Empty\_jigs\_at\_block\_i$

$\alpha(i,j):\{0,1\}\ if\_product\_j\_is\_at\_block\_i$

$\beta(i,j):\{0,1\}\ if\_product\_j\_is\_at\_gap\_after\_block\_i$

$\varepsilon(i,h):\{0,1\}\ if\_\mathrm{mod}el\_h\_is\_at\_block\_i$

$\theta(i,h):\{0,1\}\ if\_\mathrm{mod}el\_h\_is\_at\_gap\_after\_block\_i$

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Mathematical model

- Objective

$$Min\sum_i v_i$$

- The objective function in this problem is to minimize the total number of empty jigs in the blocks or maximize the capacity of the facility due to the fact that every empty jig represents a loss of capacity for the system. In other words, the aim is to minimize the number of colour and model changes in the production line, in order to increase production and minimize the number of empty jigs.

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Mathematical model

- Constraints

One Partnumber per position.

$$\sum_{j=1}^{J} j\alpha_{i,j} = x_i$$

$$\sum_{i} \alpha_{i,j} = 1$$

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Mathematical model

- Constraints

Relationship to measure changes

$$K(x_i) <> K(x_{i+1}) \rightarrow \delta_i = 1$$

$$H(x_i) <> H(x_{i-BPL}) \rightarrow \phi_i = 1$$

$$H(x_i) <> H(x_{i+1}) \rightarrow \eta_i = 1$$

Number of colour changes is limited differently per working shift.

$$\sum_{g=i+1-LK(S(i))}^{i} \delta_g \leq MK\left(S(i)\right)$$

- This constraint should be read as: “No more than MK colour changes each LK consecutive blocks”

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Mathematical model

- Constraints

Number of jig changes is limited differently per working shift.

$$\sum_{g=i+1-LH(S(i))}^{i} \phi_g \le MH(S(i))$$

This constraint should be read as: “No more than MH jig changes each LH

The number of empty jigs at each block is

$$v_i = MP \cdot \eta_{i-1} \cdot (1-\delta_{i-1}) + MF \cdot \eta_i \cdot (1-\delta_i) + CP \cdot \delta_{i-1} + CF \cdot \delta_i$$

Number of Jigs is limited.

$$H(x_i) = h \to \varepsilon_{i,h} = 1$$

$$\sum_{\text{g=i-BPL+1}}^{\text{i}} \left(\varepsilon_{\text{g,k}} \cdot (JPB - v_g)\right) \le JA(h)$$

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Mathematical model

- Constraints

Inventory should be between the minimum for each partnumber and the maximum for all the products.

$$z_{j,t} \ge SMIN_j$$

$$\sum_j z_{j,t} \le MAIL$$

Inventory at the end of the day is the inventory of the previous day minus the demand plus the produced quantity of each product.

$$z_{j,t} = z_{j,t-1} - D_{j,t} + y_{j,t}$$

$$z_{j,0} = I_j$$

Production of each partnumber at each day should consider scrap.

$$y_{j,t} = \left(\sum_{i/D(i)=t} \alpha_{i,j} \cdot SPJ(H(j)) \cdot (JPB - v_i) \right) \cdot (1 - SCRAP_j)$$

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Computational experiences

- For small samples, the model is solved with a calculation time under ten minutes.
- When samples with more than 6 changes per colour or model are considered, the calculation time increases exponentially, and their resolution is unattainable.
- There is a relationship between the production level for each model and colour and the computation time. Hence, increasing the production quantity for each model and colour will increase the time needed to conduct the experiment and as such, more blocks will be filled in the loops.
- When more loops are considered, then this results in fewer empty jigs and consequently, more products can be painted in the production line.

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Solution procedures. B&B

- An exact process to solve the problem based in Branch and Bound has been designed.
- Branching is based on the different products at each block.
- If a part number is not fulfilling hard constraints (jig availability, jig changes during night shifts) it is not considered for the global evaluation.
- Bounding is based on the number of empty jigs required for the sequence (as less colour changes, better the result).
- Unfortunately, at this moment, computational time is too high to have Branch and Bound procedure competitive (up 48 hours).

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Solution procedures. Beam search.

- To solve the problem a Beam Search procedure has been implemented.
- It consists to limit the number of branches of the procedure (three open branches at a time).
- Unfortunately, the Beam Search computation time exceed the time limit imposed by the automotive supplier (up ten minutes) so some heuristic are preferable to the real case implementation. Nonetheless to compare with optimum solutions the B&B process and the Bean Search algorithm have been used.

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Solution procedures. Heuristics

- Given the set of products to be scheduled with its related parameter (model, colour, minimum and maximum number of blocks) a number of constructive local search heuristics and have been developed in order to improve the quality of the solution and the time devoted to solve them.
- Heuristics are based on the idea of assigning products to blocks, block by block, from the set of feasible products, eliminating from the original list those products that *not fulfil constraints,* if the set of remaining products is empty, a *no-product* is inserted. If such set is not empty next product is selected according to different criteria that have been tested.
- The local search procedure that has been tested is the classical swap movement. Before doing the movement the pair of blocks is evaluated according to their cost of jig changes and colour and model changes. In the case that the sum of cost (before the movement) is bigger than half the total possible cost, the swap is tried, and is accepted if the cost is improved.

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Solution procedures. Heuristics

- For each block to be sequenced
  - Is there any compulsory product? If not…
  - Evaluate for each product if there are available jigs and if it is a forbidden product.
  - Evaluate for each product constraint violation of:
    - Color changes
    - Model Changes
    - Maximum Stock Levels
  - Evaluate for each product
    - Number of empty jigs related to its introduction (or)
    - Run Out Times (or)
    - Stock Levels
  - Select the product to be introduced

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Solution procedures. Heuristic

- It works day per day.
- The day starts on the previous Night Shift (22:00).
- For each day, the demand, stock and backlog are evaluated.
- Constraints are considered in a hierarchical way:
  - Jig Availability
  - Number of Colours
  - Forbidden Products, Colours or Models.
  - Minimum Stock Levels
  - Jig Changes
  - Maximum Stock Levels

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Computational experiences

- Some computational experiences have been carried out with the real data from the automotive industry. The main results are summarised in the next table and comparised with the solution given by the manufacturer:

Procedure	**Random sequence**	**Heuristic**	**Heuristic+local search**	**Beam search**	**Branch and Bound**
Computacional time	25 seconds	60 seconds	120 seconds	Up 15 minutes	Up 48 hours
% of improvement	-5%	28%	30%	31%	35%

- Finally, the manufacturer chose the heuristic with local search although the difference with the heuristic alone was only 2%.

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Implemented solution

- Data is taken from Baan in an XML format.
- Data is then extracted by Kula Scheduling Software.
- Evaluate the data obtained in order to see if there are any configuration errors or incorrect or impossible values in either demand or stock levels.
- The program will calculate the actual levels of stock and initialize the internal stock levels of the program.
- Given a by-shift workcalendar, the actual stock levels, the daily demand, and the maximum and minimum stock levels of every product, schedule will be calculated.
- When the program has been generated, the solution will be evaluated.

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Implemented solution

- With such evaluation the operator will modify, if required, the solution. Such changes could include interchanging products, inserting new blocks, erasing products, etc.
- After the pertinent modifications have been made, the solution data will be re-generated using the new modifications, and this information will be send to KULA.
- All of the solution data, the modifications, will be saved, and finally the production plan will be generated.

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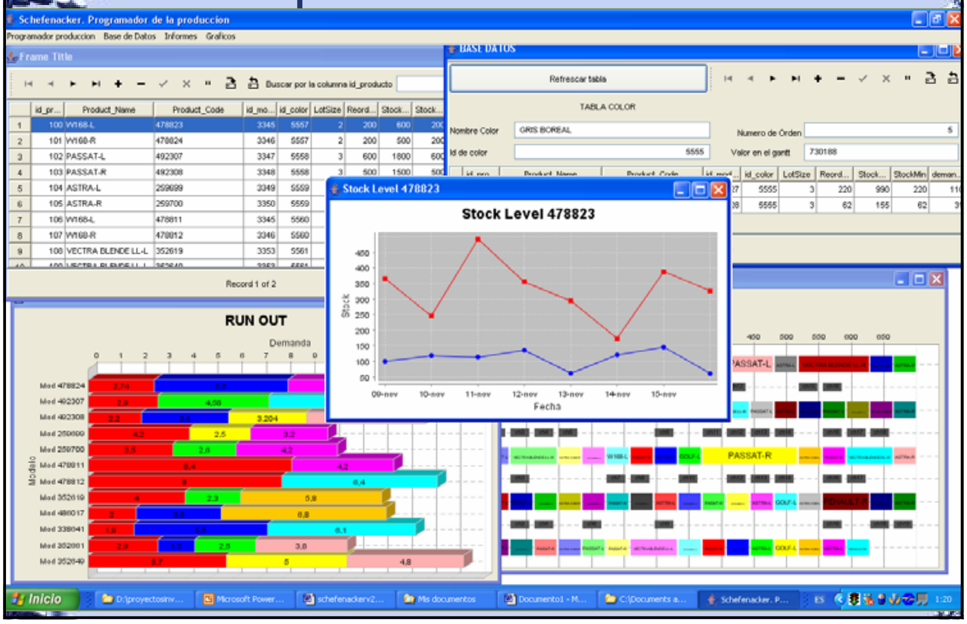
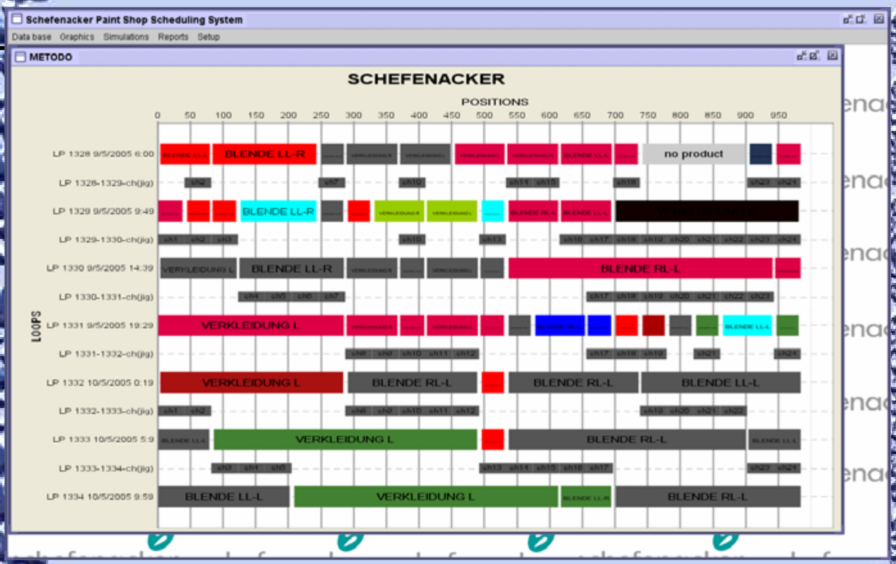
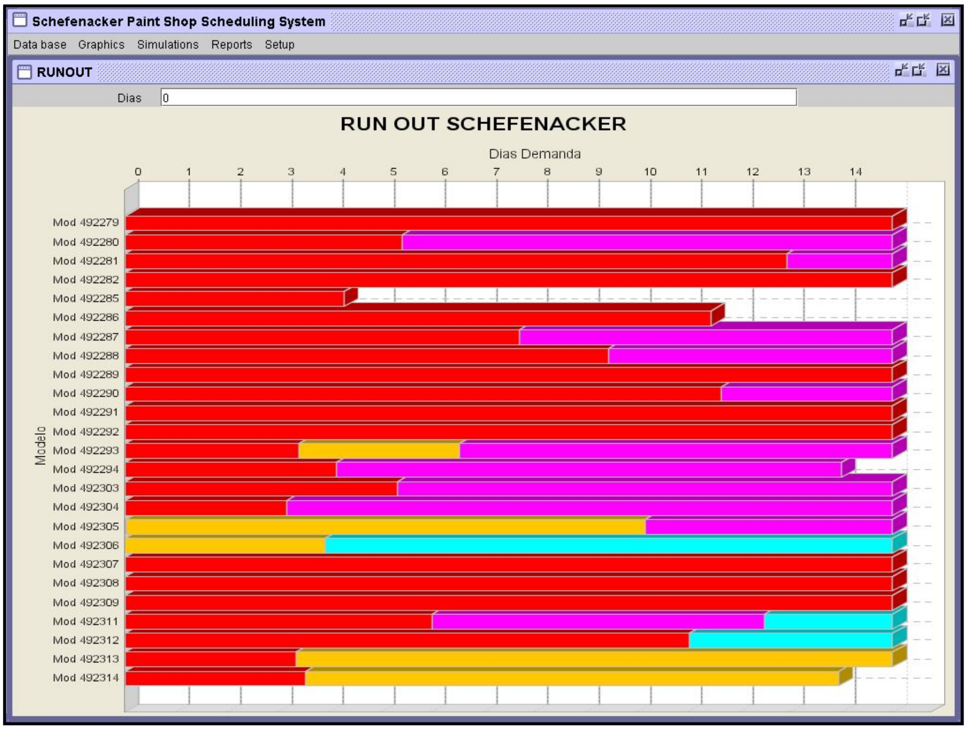
Implemented solution.



Implemented solution





Conclusions

- We have addressed a real-life scheduling problem in a automotive supplier wich produces rear-view mirrors.
- The production system is a closed loop where different batches with sequence-dependent setup time are produces continuously.
- The objective is to schedule one week's mix of batches through the shop such that the quantity production objectives are achieved.
- The case treated does not fall into any category of the known scheduling problems in the literature, but it bears certain.
- Similarities with cyclic scheduling, batch scheduling or flowshop sequence dependent scheduling can be stablished.

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Conclusions

- A MILP model and some heuristics are developed.
- As the heuristics are based on the specific requirements of the system, it can effectively improve the performance of the system.
- The management is currently developing a production management system, which includes order treatment, scheduling, inventory control and capacity planning modules.
- As the heuristic is beneficial to the company, it is being used now.
- Although the heuristic is developed for the specific system, it can be used, with appropriate modifications, in other scheduling problems with similar features.

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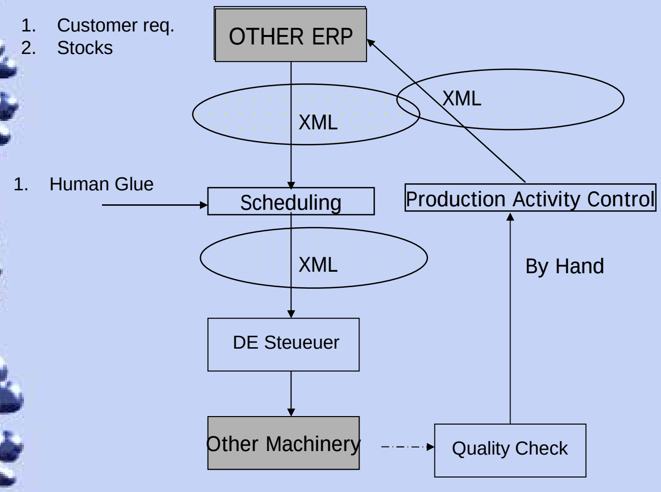
Future work

Proposed Information Flow



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Thanks for your attention

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