Time, cost and quality trade-off in project management: a case study

Do Ba Khang* and Yin Mon Myint
School of Management, Asian Institute of Technology, P.O. Box 2754, Bangkok 10501, Thailand

In 1996, Babu and Suresh proposed a framework to study the trade-off among time, cost and quality using three inter-related linear programming models. This paper describes our attempt to apply the method to an actual cement factory construction project. The purpose is to evaluate the practical applicability of the method by highlighting the managerial insights gained, as well as pointing out key problems and difficulties faced. As consequence, the paper helps practicing project engineers to have realistic expectations of the method. It also provides suggestions to overcome some practical problems if the method is to be applied in real industrial projects.

Keywords: critical path method (CPM), time, cost, quality trade-off, case study

Introduction

The critical path method (CPM) provides not only an excellent way of calculating the shortest completion time and the critical activities for a project, but also a framework to analyze the time/cost trade-off. In practice, however, one of the critical measures of project success is the quality of its performance that may be affected by attempt to crash the completion time with additional budget. In this context, the traditional CPM method is inadequate to help the project manager make informed decisions on project progress and performance. Many attempts have been recorded in the literature to improve the method since its inception in the late 1950s. However, most of this research either focused on improving the efficiency of the project-crashing algorithm, or on relaxing on the assumption of the linear relationship between cost and time factors. In 1996, Babu and Suresh proposed a new method to study the tradeoff among time, cost and quality using three inter-related linear programming models. Their approach is based on the linear relationship among the project cost, the quality measure and the project completion time. The method is illustrated with a small textbook example taken from Hillier and Lieberman.

This paper describes an attempt to apply the Babu and Suresh method to an actual cement factory construction project in Thailand. With the purpose of evaluating the practical applicability of the method, the basic assumptions are investigated, major problems in estimating input parameters are pointed out, and the resulting managerial insights are highlighted. As consequence, the paper helps practicing project engineers to have realistic expectations of the method. It also provides suggestions to overcome various practical problems if the method is to be applied in real industrial projects. This research also validates with real data most of the conceptual findings by Babu and Suresh in their original work.

Review of Babu and Suresh cost–time–quality trade-off models

Babu and Suresh developed their method by assuming that the project activities and their precedence relationships are determined. Each activity has a normal time of completion and a crash time of completion. Associated with the normal time are normal cost and normal performance quality, and with crash time are crash cost and crash quality. It is assumed that the cost and quality of an activity vary as linear functions of the completion time. Given individual activity completion times, the total project completion time can then be calculated using the traditional CPM method. The total cost is simply the sum of individual activity costs, and the total project quality is measured by the average of the individual activity quality measures.

Babu and Suresh suggest three optimization models as a framework to analyze the trade-off among the cost, time and quality factors of a project. In order to formulate these models in the familiar linear programming (LP) format, the activity-on-arc (AOC) network convention and the following notation will be used:

- M: Number of events
- N: Number of activities

*Corresponding author. Tel.: 00-662-524-5658; Fax: 00-662-524-5667.
The crash time: from above by the normal time, and from below by letting \( t'_{ij} \). Normal cost for activity \((i,j)\) \( c_{ij} \). Normal quality for activity \((i,j)\) \( q_{ij} \). Crash quality for activity \((i,j)\) \( q'_{ij} \).

Notice that a dummy activity can be indicated by letting \( t_{ij} = t'_{ij} = 0 \). The constraints common to all the LP problems can then be summarized as follows:

(a) The project is started at time zero.

\[
Y_1 = 0
\]  
(1)

(b) Each activity completion time \( X_{ij} \) is bounded from above by the normal time, and from below by the crash time:

\[
t_{ij} \geq X_{ij} \geq t'_{ij}
\]  
(2)

(c) For each activity \((i,j)\),

\[
Y_i + X_{ij} - Y_j \leq 0
\]  
(3)

The objective function for the first LP model is the project completion time that is simply the earliest time of the last "finish" event:

\[
TF = Y_M
\]

For the second model, the objective function is the total cost of the project. By assuming the linear relationship of the activity cost and completion time, the total project cost is estimated as a linear function of the individual activity times:

\[
CF = \sum_{(i,j)} (A_{ij} + B_{ij} \times X_{ij}),
\]

where \( B_{ij} = (c'_{ij} - c_{ij})/(t_{ij} - t'_{ij}) \) and \( A_{ij} = c_{ij} - B_{ij} \times t_{ij} \) are the slope and intercept of the cost curve for activity \((i,j)\). For the third model, the objective function is the project's overall quality that is calculated as the average of the individual activity qualities, that is

\[
QF = \sum_{(i,j)} (A'_{ij} + B'_{ij} \times X_{ij}),
\]

where \( B'_{ij} = (q'_{ij} - q_{ij})/(t_{ij} - t'_{ij}) \) and \( A'_{ij} = q_{ij} - B'_{ij} \times t_{ij} \) are the slope and intercept of the quality curve for activity \((i,j)\).

Thus, assuming that \( T \) and \( Q' \) are the lower bounds for project completion time \( TF \) and average quality \( QF \), and \( C \) is the upper bound for total cost \( CF \), the models can be simply written as:

Model 1: Minimize \( TF \) subject to (1–3) and \( CF \leq C \) and \( QF \geq Q' \);

Model 2: Minimize \( CF \) subject to (1–3) and \( TF \leq T \) and \( QF \geq Q' \);

Model 3: Maximize \( QF \) subject to (1–3) and \( CF \leq C \) and \( TF \leq T \).

For different budget levels and the quality tolerances, the first model yields the corresponding shortest completion times, and thus provides a framework for the trade-off analysis by considering project completion time as a function of budget and quality constraints. In a similar way, the second model searches for the lowest cost to complete the project as a function of completion due dates and quality tolerance allowed, while the third model yields maximum overall project quality subject as a function of budget constraints and completion due date.

Case study and parameter estimation

TPI Polene Public Company Limited (TPIPL) is located about 134 km north of Bangkok, Thailand. The company currently operates three cement factories with an annual capacity of 9 million tons per annum. The fourth factory is now under construction and is expected to be in operation by 1998, which will bring the total cement capacity to 12.3 million tons per annum. The total cost for this new construction project is estimated to be baht 9.6 billion (or roughly US$375 million). The scope of work for the whole project is large and complex with 35 different sub-projects and more than 1000 separate activities. Partly because of this complexity, and partly due to the fact that the completion of the project is subject to a large number of exogenous factors, both economical and political, beyond the control of the top management, it was decided to focus this research on only one of its sub-projects. The sub-project chosen is one of erecting the Dolop pre-heater tower, which is the most time consuming and problematic sub-project in the whole factory construction project. In fact, the pre-heater tower erection is so important that its schedule is used by project engineers as the benchmark to adjust the schedule of all other sub-projects. It is believed that using this sub-project in evaluating the practical value of the method will not affect the validity of the conclusions.

The activities of the sub-project to erect the Dolop pre-heater tower can be grouped into 52 work packages under four main categories: civil work (leveling, excavation, foundation and construction), mechanical work (fabrication, erection, refractory and cold test run), electrical work (power distribution, substation and transformer, MCC control, cable rack installation, power supply) and automation (Plc cabinet, safety and local control). Each work package consists of numerous related specific activities that are normally carried out under a single supervisor or subcontractor. The work packages are identified so that activities of different work packages do not use the same resources at the same time, and therefore can be scheduled relatively independently. Care is taken that completion time and cost of individual work packages can be estimated relatively easily and accurately. The list of these work packages and their brief description is given in Table 1.

Estimating the relevant input parameters for work packages was probably the most time consuming task in applying the Babu and Suresh method to the sub-project under study. The work was done in close consultations with site managers. Below is described the way these parameters were estimated as well as the difficulties encountered.
labour cost is the major component. Since the relative

Thus the cost data used in the calculations (see also

Although being a major part of the total cost, were not

Excluded from these cost parameters. In fact, all site

Crashing the activities, all fixed costs of equipment and

Normal time cost and quality parameters

The time and cost parameters under assumed normal conditions were easiest to estimate. In fact, the normal completion time of activity was taken from the existing project schedule that had been prepared by project engineers with care taken to all technical details. For the purpose of studying the inter-relationship among the cost, time and quality dimensions of the project in crashing the activities, all fixed costs of equipment and materials procurement, and the overhead were excluded from these cost parameters. In fact, all site managers and engineers believed that these costs, although being a major part of the total cost, were not affected by decisions of crashing the project activities. Thus the cost data used in the calculations (see also Table 1) include only the variable costs of which labour cost is the major component. Since the relative quality reduction due to crashing activities is the focus of interest in this research, the performance quality expected under the normal conditions is assumed to be at 100% level for each activity. This assumption reflects the research objective of investigating only the impact of the time/cost factor, and not any other influence, on the project’s overall quality.

Crashing time, cost and quality

Most of the work at the pre-heater tower is labour intensive with relatively clear definition. As it is typical for construction sites in Thailand, the number of workers working 6 days a week at the project is already at the maximum due to the limited work area. Thus, according to the managers, the only way activities can be accelerated is through using overtime. Since the maximum overtime allowed is 4 hours on top of

<table>
<thead>
<tr>
<th>Work-package</th>
<th>Brief description of work</th>
<th>( t_{ij} ) (days)</th>
<th>( t'_{ij} ) (days)</th>
<th>( c_{ij} ) (million baht)</th>
<th>( c'_{ij} ) (million baht)</th>
<th>( q_{ij} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Procurement of Rebars</td>
<td>33</td>
<td>22</td>
<td>5.50</td>
<td>8.25</td>
<td>0.90</td>
</tr>
<tr>
<td>B</td>
<td>Procurement of steel section, plates, pipes, etc.</td>
<td>33</td>
<td>22</td>
<td>58.40</td>
<td>87.60</td>
<td>0.90</td>
</tr>
<tr>
<td>C</td>
<td>Excavation</td>
<td>33</td>
<td>22</td>
<td>0.50</td>
<td>0.75</td>
<td>0.90</td>
</tr>
<tr>
<td>D</td>
<td>Foundation</td>
<td>33</td>
<td>22</td>
<td>6.50</td>
<td>9.75</td>
<td>0.95</td>
</tr>
<tr>
<td>E</td>
<td>Concrete columns to first floor (188 m)</td>
<td>22</td>
<td>15</td>
<td>3.40</td>
<td>5.10</td>
<td>0.95</td>
</tr>
<tr>
<td>F</td>
<td>Concrete floor and beams to first floor</td>
<td>22</td>
<td>15</td>
<td>3.50</td>
<td>5.25</td>
<td>0.95</td>
</tr>
<tr>
<td>G</td>
<td>Concrete columns to second floor (200m)</td>
<td>22</td>
<td>15</td>
<td>2.50</td>
<td>3.75</td>
<td>0.95</td>
</tr>
<tr>
<td>H</td>
<td>Fabrication of beams, steel floor and staircase (second floor)</td>
<td>44</td>
<td>29</td>
<td>1.09</td>
<td>1.63</td>
<td>0.83</td>
</tr>
<tr>
<td>I</td>
<td>Fabrication of kiln inlet and transaction piece</td>
<td>75</td>
<td>50</td>
<td>1.84</td>
<td>2.76</td>
<td>0.83</td>
</tr>
<tr>
<td>J</td>
<td>Erection of kiln inlet and transaction piece</td>
<td>75</td>
<td>50</td>
<td>1.10</td>
<td>1.65</td>
<td>0.85</td>
</tr>
<tr>
<td>K</td>
<td>Installation of beams, steel floor and staircase (second floor)</td>
<td>44</td>
<td>29</td>
<td>1.95</td>
<td>2.93</td>
<td>0.85</td>
</tr>
<tr>
<td>L</td>
<td>Fabrication of beams, steel floor and staircase (third floor)</td>
<td>55</td>
<td>37</td>
<td>2.22</td>
<td>3.34</td>
<td>0.83</td>
</tr>
<tr>
<td>M</td>
<td>Installation of steel structure to 3rd floor (217 m)</td>
<td>55</td>
<td>37</td>
<td>4.00</td>
<td>6.00</td>
<td>0.85</td>
</tr>
<tr>
<td>N</td>
<td>Erection of 1st stage cyclones and ducts between 3rd and 4th floors</td>
<td>30</td>
<td>20</td>
<td>1.80</td>
<td>2.70</td>
<td>0.85</td>
</tr>
<tr>
<td>O</td>
<td>Fabrication of 1st stage cyclones and ducts (3rd floor)</td>
<td>30</td>
<td>20</td>
<td>1.08</td>
<td>1.61</td>
<td>0.83</td>
</tr>
<tr>
<td>P</td>
<td>Refractory works (kiln inlet, transaction pieces, column ducts)</td>
<td>40</td>
<td>27</td>
<td>2.85</td>
<td>4.28</td>
<td>0.90</td>
</tr>
<tr>
<td>Q</td>
<td>Electrical works in 1st, 2nd and 3rd floors</td>
<td>40</td>
<td>27</td>
<td>2.50</td>
<td>3.75</td>
<td>0.70</td>
</tr>
<tr>
<td>R</td>
<td>Fabrication of beams, steel floor and staircase (4th and 5th floors)</td>
<td>55</td>
<td>37</td>
<td>3.15</td>
<td>4.73</td>
<td>0.83</td>
</tr>
<tr>
<td>S</td>
<td>Erection of beams, steel floor and staircase for 4th and 5th floors (251 m)</td>
<td>55</td>
<td>37</td>
<td>5.68</td>
<td>8.51</td>
<td>0.85</td>
</tr>
<tr>
<td>T</td>
<td>Erection of 2nd stage cyclones and transfer ducts</td>
<td>40</td>
<td>27</td>
<td>1.65</td>
<td>2.48</td>
<td>0.85</td>
</tr>
<tr>
<td>U</td>
<td>Fabrication of 2nd stage cyclones and transfer ducts</td>
<td>40</td>
<td>27</td>
<td>2.75</td>
<td>4.12</td>
<td>0.83</td>
</tr>
<tr>
<td>V</td>
<td>Refractory works at 1st stage cyclones and ducts</td>
<td>44</td>
<td>29</td>
<td>2.54</td>
<td>3.81</td>
<td>0.90</td>
</tr>
<tr>
<td>W</td>
<td>Fabrication of beams, steel floor and staircase (5th and 6th floors)</td>
<td>55</td>
<td>37</td>
<td>1.99</td>
<td>2.99</td>
<td>0.83</td>
</tr>
<tr>
<td>X</td>
<td>Erection of beams, steel floor and staircase (5th and 6th floors)</td>
<td>55</td>
<td>37</td>
<td>3.59</td>
<td>5.38</td>
<td>0.85</td>
</tr>
<tr>
<td>Y</td>
<td>Erection of 3rd stage cyclones</td>
<td>30</td>
<td>20</td>
<td>0.80</td>
<td>1.20</td>
<td>0.85</td>
</tr>
<tr>
<td>Z</td>
<td>Fabrication of 3rd stage cyclones and ducts</td>
<td>30</td>
<td>20</td>
<td>1.34</td>
<td>2.01</td>
<td>0.83</td>
</tr>
<tr>
<td>AA</td>
<td>Refractory works at 2nd stage cyclones and ducts</td>
<td>44</td>
<td>29</td>
<td>2.54</td>
<td>3.81</td>
<td>0.90</td>
</tr>
<tr>
<td>AB</td>
<td>Electrical and instrument cable racks etc. (4th and 5th floor)</td>
<td>22</td>
<td>15</td>
<td>1.50</td>
<td>2.25</td>
<td>0.70</td>
</tr>
<tr>
<td>AC</td>
<td>Installation of 2 Poldcos-feeding equipment in 1st floor</td>
<td>30</td>
<td>20</td>
<td>1.20</td>
<td>1.80</td>
<td>0.85</td>
</tr>
<tr>
<td>AD</td>
<td>Installation of shock blowers (M.E) in floors 1,2 and 3.</td>
<td>30</td>
<td>20</td>
<td>1.25</td>
<td>1.88</td>
<td>0.85</td>
</tr>
<tr>
<td>AE</td>
<td>Fabrication of beams, steel floor and staircase (6th and 7th floors)</td>
<td>55</td>
<td>37</td>
<td>1.59</td>
<td>2.39</td>
<td>0.83</td>
</tr>
<tr>
<td>AF</td>
<td>Erection of beams, steel floor and staircase for 6th and 7th floors (268 m)</td>
<td>55</td>
<td>37</td>
<td>2.87</td>
<td>4.30</td>
<td>0.85</td>
</tr>
<tr>
<td>AG</td>
<td>Erection of 4th stage cyclones on 6th floor</td>
<td>30</td>
<td>20</td>
<td>0.69</td>
<td>1.04</td>
<td>0.85</td>
</tr>
<tr>
<td>AH</td>
<td>Fabrication of 4th stage cyclones etc.</td>
<td>30</td>
<td>20</td>
<td>1.16</td>
<td>1.73</td>
<td>0.83</td>
</tr>
<tr>
<td>AI</td>
<td>Refractory works at 3rd stage cyclones and ducts</td>
<td>44</td>
<td>29</td>
<td>3.25</td>
<td>4.88</td>
<td>0.90</td>
</tr>
<tr>
<td>AJ</td>
<td>Electrical and instrument cable racks etc. (6th floor)</td>
<td>22</td>
<td>15</td>
<td>1.50</td>
<td>2.25</td>
<td>0.70</td>
</tr>
<tr>
<td>AK</td>
<td>Fabrication of beams, steel floor and staircase (7th and 8th floors)</td>
<td>72</td>
<td>48</td>
<td>1.50</td>
<td>2.31</td>
<td>0.83</td>
</tr>
<tr>
<td>AL</td>
<td>Erection of beams, steel floor and staircase for 7th and 8th floors (291 m)</td>
<td>72</td>
<td>48</td>
<td>2.77</td>
<td>4.16</td>
<td>0.85</td>
</tr>
<tr>
<td>AM</td>
<td>Erection of 5th stage cyclones on 7th floor</td>
<td>40</td>
<td>27</td>
<td>0.62</td>
<td>0.93</td>
<td>0.85</td>
</tr>
<tr>
<td>AN</td>
<td>Fabrication of 5th stage cyclones and ducts</td>
<td>40</td>
<td>27</td>
<td>1.04</td>
<td>1.55</td>
<td>0.83</td>
</tr>
<tr>
<td>AO</td>
<td>Refractory works on 4th stage cyclones and ducts</td>
<td>44</td>
<td>29</td>
<td>3.25</td>
<td>4.88</td>
<td>0.90</td>
</tr>
<tr>
<td>AP</td>
<td>Fabrication of structure for the beams for 8th floor</td>
<td>55</td>
<td>37</td>
<td>1.23</td>
<td>1.85</td>
<td>0.83</td>
</tr>
<tr>
<td>AQ</td>
<td>Erection of the structures for 8th floor</td>
<td>55</td>
<td>37</td>
<td>2.22</td>
<td>3.33</td>
<td>0.85</td>
</tr>
<tr>
<td>AR</td>
<td>Erection of 6th stage cyclones on 8th floor</td>
<td>40</td>
<td>27</td>
<td>1.19</td>
<td>1.79</td>
<td>0.85</td>
</tr>
<tr>
<td>AS</td>
<td>Fabrication of 6th stage cyclones on 8th floor</td>
<td>40</td>
<td>27</td>
<td>1.98</td>
<td>2.97</td>
<td>0.83</td>
</tr>
<tr>
<td>AT</td>
<td>Refractory works on 5th stage cyclones and ducts</td>
<td>44</td>
<td>29</td>
<td>1.66</td>
<td>2.49</td>
<td>0.90</td>
</tr>
<tr>
<td>AU</td>
<td>Fabrication of second gas duct</td>
<td>165</td>
<td>111</td>
<td>3.55</td>
<td>5.32</td>
<td>0.83</td>
</tr>
<tr>
<td>AV</td>
<td>Refractory work on 6th stage cyclones completed</td>
<td>66</td>
<td>44</td>
<td>3.26</td>
<td>4.90</td>
<td>0.90</td>
</tr>
<tr>
<td>AW</td>
<td>Electrical and instrument cables on 7th floor</td>
<td>30</td>
<td>20</td>
<td>1.50</td>
<td>2.25</td>
<td>0.70</td>
</tr>
<tr>
<td>AX</td>
<td>Installation of local instruments</td>
<td>88</td>
<td>59</td>
<td>5.23</td>
<td>7.85</td>
<td>0.85</td>
</tr>
<tr>
<td>AY</td>
<td>Insulation for gas ducts and 6th stage cyclones connection</td>
<td>66</td>
<td>44</td>
<td>2.28</td>
<td>3.62</td>
<td>0.85</td>
</tr>
<tr>
<td>AZ</td>
<td>Readying for test run</td>
<td>5</td>
<td>3</td>
<td>0.50</td>
<td>0.75</td>
<td>0.85</td>
</tr>
</tbody>
</table>
the regular 8-hour working day, activities may be crashed on average at a ratio of 2:3. These crash times were then adjusted for each of the 52 work-packages taking into account the possibility that workers may sometimes be asked to work on Sunday also, and that some work would permit less hours of overtime due to lighting conditions and safety reasons. The results are the maximum crash times \( t_{ij} \) used in the LP models. Site managers also believed that when activities need be crashed, the cost increase is mostly due to the double rate for overtime. As consequence, they had no problem in accepting the assumption of linear relationship between cost escalation and time crashed which is fundamental in the Babu and Suresh method.

The estimation of the quality reduction due to crashing was more difficult and elaborate. There were two major obstacles in arriving at an acceptable measurement of quality reduction. First, and not surprisingly, it was found that the practicing managers and engineers were very sensitive to the idea that the quality of the project could be compromised at all by crashing. Second, the quality of an activity can be usually measured only by subjectively using managers' judgement. In a few cases when quality can be determined quantitatively and objectively using technical specifications, these specifications were to be adhered to rather strictly, and the quality measure was not noticeably affected by the use of overtime. The common reaction was that ‘quality reduction due to overtime is negligible and cannot exceed 2–3%, even if the maximum amount of overtime is used’. With the objective of arriving at workable estimates of quality reductions in project activities due to crashing, the following principles were agreed:

1. In interpreting the results of the models, it is not the absolute value of the quality measure that is relevant, but the relative quality values of the individual activities when crashing is performed.
2. These relative values should reflect two considerations:
   - Some works (such as painting works) are more prone to the measurable quality reduction when crashed;
   - Some works (such as welding or electrical works) are so important and critical that a minor reduction in quality may seriously compromise the whole project performance.
In both cases, crashing should induce a relatively large reduction in the quality measures of the activities.
3. If a work-package has more than one activity then its quality is measured as the weighted average of the individual activities’ quality where the weights are proportional to the contractual values of the activities.

Based on this common framework, the researchers and the managers together compared the individual activities to estimate the relative quality reductions due to crashing. The last column of Table 1 is the result of this time consuming process. The numbers in that column indicate the relative, and at times subjective, assessment of the quality of the individual project activities when maximum crash is performed. It is presumed then that the quality measure will decrease as a linear function of activity completion time from the normal value of 1.00 to this lower bound.

![Figure 1](https://via.placeholder.com/150)

**Figure 1** Optimal completion time when costs and quality are bounded
Analysis of computational results

Once the parameters are estimated, the computation of the three models, using software LINDO (version 5.1), is simple since the size of the LP problems is relatively small (104 variables and 231 constraints for each model). All these problems were solved repeatedly using different values for the goal constraints in cost, time and quality. The maximum budget varied with increments of 10 million baht—except for the last increment—from the normal cost of 175.60 million baht to the maximum crash cost of 263.60 million baht. The lower bound for completion time was allowed to change in increments of 20 days—or 21 days for the last three increments—from the maximum crash time of 371 days to the normal time of 554 days. Five different quality levels were considered in the models: 85%, 89%, 92%, 95% and 98%.

The computational results of the three models are summarized in Figures 1–3 and Tables 2–4 which bear much similarity to the corresponding results obtained by Babu and Suresh with their textbook example. In particular, the following major findings can be noted:

- For each given quality level, there exists a budget threshold beyond which there would be of little value to increase budget in the hope of expediting further project completion. These thresholds are given in Figure 1 as 185.60 million baht at a 98% quality allowance, 195.60 million baht at a 95% quality allowance, and 215.60 million baht at a 92% quality allowance. The corresponding completion times are 482 days, 431 days and 391 days, respect-
ively. At the lower quality levels of 89% and 85%, the thresholds are not as sharp as with the higher quality tolerances.

- If the average quality requirement is decreased, these budget thresholds, which can be interpreted as the practical limiting costs for crashing, will increase, which in turn allows for a further reduction in project completion time.

- Project cost is almost independent of the quality requirement and therefore, the cost/time curves in Figure 3 coincide for all quality levels. This fact is not surprising because the performance quality at each activity was assumed to be a function of the time factor only.

- There is a critical value for project completion time, beyond which it would be extremely expensive to crash further. Figure 2 indicates that this critical value is around 400 days.

In order to help managers to gain better insight of the trade-off among time, cost and quality factors of the project, the output of Model 1 is re-organized by quality requirements. Wherever an increase in budget is not accompanied by a reduction in completion time, only the minimum budget required for that time is recorded. The results are summarized in Tables 5 and Figure 4. It is now clear that managers may not expect to crash the project completion time below 482 days without compromising the high quality level of 98%

### Table 2 Optimal completion time (in days) when costs and quality are bounded

<table>
<thead>
<tr>
<th>Upper bound on project costs (million baht)</th>
<th>Lower bound on project quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>175.6</td>
<td>554</td>
</tr>
<tr>
<td>185.6</td>
<td>470</td>
</tr>
<tr>
<td>195.6</td>
<td>426</td>
</tr>
<tr>
<td>205.6</td>
<td>400</td>
</tr>
<tr>
<td>215.6</td>
<td>381</td>
</tr>
<tr>
<td>225.6</td>
<td>378</td>
</tr>
<tr>
<td>235.6</td>
<td>375</td>
</tr>
<tr>
<td>245.6</td>
<td>371</td>
</tr>
<tr>
<td>255.6</td>
<td>371</td>
</tr>
<tr>
<td>263.6</td>
<td>371</td>
</tr>
</tbody>
</table>

### Table 3 Optimal project cost when completion time and average quality are bounded

<table>
<thead>
<tr>
<th>Upper bound on completion time (in days)</th>
<th>Lower bound on project quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>371</td>
<td>246.48</td>
</tr>
<tr>
<td>391</td>
<td>209.42</td>
</tr>
<tr>
<td>411</td>
<td>200.97</td>
</tr>
<tr>
<td>431</td>
<td>194.21</td>
</tr>
<tr>
<td>451</td>
<td>189.32</td>
</tr>
<tr>
<td>471</td>
<td>185.41</td>
</tr>
<tr>
<td>491</td>
<td>182.48</td>
</tr>
<tr>
<td>512</td>
<td>179.67</td>
</tr>
<tr>
<td>533</td>
<td>177.08</td>
</tr>
<tr>
<td>554</td>
<td>175.60</td>
</tr>
</tbody>
</table>

### Table 4 Optimal average quality when cost and completion time are bounded

<table>
<thead>
<tr>
<th>Lower bound on project costs (in million baht)</th>
<th>Upper bound on completion time (in days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>175.6</td>
<td>185.6</td>
</tr>
<tr>
<td>371</td>
<td>INF</td>
</tr>
<tr>
<td>391</td>
<td>INF</td>
</tr>
<tr>
<td>411</td>
<td>INF</td>
</tr>
<tr>
<td>431</td>
<td>INF</td>
</tr>
<tr>
<td>451</td>
<td>INF</td>
</tr>
<tr>
<td>471</td>
<td>INF</td>
</tr>
<tr>
<td>491</td>
<td>INF</td>
</tr>
<tr>
<td>512</td>
<td>INF</td>
</tr>
<tr>
<td>533</td>
<td>INF</td>
</tr>
<tr>
<td>554</td>
<td>INF</td>
</tr>
</tbody>
</table>
or running to an exceedingly high cost. Similarly, if 95% average project quality is the performance that can be accepted, then trying to complete the project in less than 431 days may be very expensive.

Assessment of the method and conclusions

The linear programming models proposed by Babu and Suresh are conceptually easy to understand, and computationally easy to solve. All managers and engineers are interested in the possibility of incorporating performance quality in the time and cost scheduling. The results obtained, when presented using proper graphics, provide insightful information that can help the managers in making trade-off decisions. At the early stage of the cement factory construction project when the research was conducted, the goal of completing the construction in time was the most important for the managers. Thus, Model 1 was judged as the most relevant and interesting. However, it is possible to foresee a situation where Model 2 becomes prominent, especially when some cost overrun has occurred in the project and the task of minimizing expenditures is of the top priority. In any case, the two models 1 and 2 are dual in the linear programming sense, and can always be considered together with quality levels as parameters. Model 3, although playing a rather symmetric role with the other two, is less appealing to practical managers and engineers. The main objection to this model is that the quality measurements are sometimes too subjective and inaccurate to be considered as an objective function in an LP formulation. At the same time, it can be observed that, while all managers, understandably, are sensitive to the issue of quality reduction due to crashing work, they are also reluctant to consider improving an already acceptable quality level at extra expenses or by delaying the project completion.

As already pointed out by Babu and Suresh, the solutions of the models support the common intuition regarding effects of time, cost and quality in project management. The most valuable finding to managers participating in the research, and probably a surprising one for some, is the recognition of the existence of the different budget thresholds for the time/cost curve at different quality levels. These thresholds, not mentioned by Babu and Suresh, are explicitly presented in Figure 4, and judged as most useful in helping managers making trade-off decisions.

The managers involved in this research consider as reasonable the assumption of linear relationship between cost and time. The fact that crashing this particular project was practically possible only through overtime not only made the assumption readily accep-

<table>
<thead>
<tr>
<th>Optimal duration (in days)</th>
<th>Minimum cost (in million baht)</th>
<th>Quality level</th>
</tr>
</thead>
<tbody>
<tr>
<td>554</td>
<td>175.6</td>
<td>0.98</td>
</tr>
<tr>
<td>482</td>
<td>185.6</td>
<td></td>
</tr>
<tr>
<td>479</td>
<td>195.6</td>
<td></td>
</tr>
<tr>
<td>478</td>
<td>205.6</td>
<td></td>
</tr>
<tr>
<td>477</td>
<td>215.6</td>
<td></td>
</tr>
<tr>
<td>477</td>
<td>225.6</td>
<td>0.95</td>
</tr>
<tr>
<td>470</td>
<td>185.6</td>
<td></td>
</tr>
<tr>
<td>431</td>
<td>195.6</td>
<td></td>
</tr>
<tr>
<td>428</td>
<td>205.6</td>
<td></td>
</tr>
<tr>
<td>426</td>
<td>215.6</td>
<td></td>
</tr>
<tr>
<td>424</td>
<td>225.6</td>
<td></td>
</tr>
<tr>
<td>424</td>
<td>235.6</td>
<td></td>
</tr>
<tr>
<td>426</td>
<td>195.6</td>
<td>0.92</td>
</tr>
<tr>
<td>399</td>
<td>205.6</td>
<td></td>
</tr>
<tr>
<td>391</td>
<td>215.6</td>
<td></td>
</tr>
<tr>
<td>388</td>
<td>225.6</td>
<td></td>
</tr>
<tr>
<td>386</td>
<td>235.6</td>
<td></td>
</tr>
<tr>
<td>384</td>
<td>245.6</td>
<td></td>
</tr>
<tr>
<td>381</td>
<td>215.6</td>
<td>0.85–0.89</td>
</tr>
<tr>
<td>378</td>
<td>225.6</td>
<td></td>
</tr>
<tr>
<td>375</td>
<td>235.6</td>
<td></td>
</tr>
<tr>
<td>371</td>
<td>245.6</td>
<td></td>
</tr>
<tr>
<td>371</td>
<td>255.6</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4  Trade-off among optimal cost, time and quality requirement
table, but also facilitated estimating the necessary parameters. The linearity assumption between quality and time is more problematic. In fact, the most difficult, and probably most controversial, task in applying the method in the case project was to assess the quality reduction associated with crashing. In the current research, this is achieved, to a certain degree of satisfaction of both the researchers and practitioners, through the framework outlined in the chapter on parameter estimation. Even then, it is recognized that the quality measures at best reflect only relative performance levels of different activities with different crashing decisions. The difficulty also highlights a major limitation of the method: in all practically justifiable measurements of quality, only a very small portion bears direct relation with crashing decisions. Thus, the quality factor considered in the models accounts for only a small, and unfortunately usually not the most relevant, part of the performance of managerial interest. This leads to an interesting research question of finding a more holistic measurement for performance quality, and a more realistic model to describe the relationship among quality of individual activities, and therefore of the whole project, and the budget and time allowed.

Acknowledgements

The authors gratefully acknowledge the support of Mr Maung Maung Myint, Chief Erection Manager, and Mr Zaw Win, Site Manager, from TPI Polene plc. in carrying out this research.

References

Quality- and Lifecycle-oriented Production Engineering in Automotive Industry

Jens Kiefer*, Sebastian Allegretti, Theresa Breckle
University of Applied Sciences Ulm, Prittwitzstraße 10, 89075 Ulm, Germany

* Corresponding author. Tel.: +49-731-50-28188; fax: +49-731-50-28458. E-mail address: jens.kiefer@hs-ulm.de

Abstract
This paper presents a new quality- and lifecycle-oriented approach of integrated production engineering in automotive industry. In a first step, current production engineering projects are analyzed and present methodical, information-technical and organizational challenges regarding the project phase of concept planning are depicted. Based on this, existing industrial- and research-oriented solution approaches are illustrated and critically evaluated. Considering the weaknesses of these solutions, this paper introduces the new developed quality- and lifecycle-oriented production engineering approach. As one key issue of this new planning approach, the idea of using a model- and rule-based configuration system is presented.

Keywords: production engineering; quality management; lifecycle management; data integration

1. Introduction

In order to gain important market shares, car manufacturers (OEMs) are currently engaged in an innovation race characterized by the following market-driven key demands:

- Soaring number of product variants with many product derivates
- Increasing product complexity due to increasing quality demands and increasing mechatronic components (e.g. powerful and reliable driver assistance systems)
- Increasing time pressure due to decreasing innovation and model cycles
- Reduction of internal costs (e.g. development costs)

These global trends inevitably have an effect on all phases within the overall product creation process – especially on the project phase of production engineering. On the one hand, the processes within production engineering become increasingly more complex and, in consequence, more error-prone. On the other hand, the time for production engineering has to be cut to the bone. In addition, these trends cause extensive changes of the production systems: Production facilities become more and more flexible (as base for producing several product types into one production line), their lifecycles extend and the number of worldwide production ramp-ups will be continually rising – especially after integration processes during running production.

As portrayed in Fig. 1, this paper focuses on the project phase of concept planning in the field of automated assembly systems (e.g. car marriage). Dependent on the special car project, the concept planning phase starts about 1.5 years before SOP (start of production) and has a duration of about half a year. The tasks within concept planning are very different and can be divided into technical, economic and organizational tasks. Examples of these tasks are the development of the concept of the production line (e.g. the degree of flexibility), the process sequences, the layout of the production line including the line-specific bill of material as well as the accomplishment of economic calculations or the definition of the project plan for the phases of detailed planning, realization and ramp-up. All these results lead into specification documents. These specifications form the basis for the later placing of the respective production facilities.
In general, production engineering takes place within two different application fields: the first planning of a new production line (green field) and the re-planning of an existing production line (brown field). Due to economic issues, the number of brown field projects will be more and more rising in the future. More information regarding these integration projects can be found in [1]. As depicted in Fig. 1, in both scenarios production engineering forms the linkage between product development and production.

Due to the described global trends and the key position of production engineering within product creation process, there are various challenges and goals regarding the project phase of concept planning such as:

- Reduction of engineering times and lifecycle costs
- Highest engineering quality as basis both for shorter and more robust production ramp-ups and highest production quality
- Managing of rising product, process and resource complexities and risks
- Managing of rising heterogeneous data (goal: seamless digital CAx process chain)
- Seamless change management between product development, production engineering and production
- Unified and standardized specifications as base for short allocation phases
- Seamless and standardized communication and data exchanges between OEM and line builder

2. Current solution approaches

In order to cope with these various challenges in the field of concept planning, different industrial- and research-oriented solution approaches have already been developed. The following sections illustrate both the characteristics and the critical evaluation of the most essential solutions with the special focus on the planning process of automated assembly systems.

2.1. Methods of quality management

Advanced quality planning is a crucial element of an operating management system. Its target lies on a logical and structured planning process ensuring best possible quality for the lowest costs. Within automotive industry, the method of Advanced Product Quality Planning (APQP) is an established standard. APQP is a framework, which includes quality-oriented procedures and tools within the product creation process. APQP postulates to establish in

- establishing interdisciplinary teams working efficiently on procedures and tools
- use of different methods of quality management (e.g. QFD: Quality Function Deployment, FMEA: Failure Mode and Effects Analysis)
- documentation of results

Within the product creation process, APQP mainly covers the phases of product development, realization and product launch. As illustrated in Fig. 2, APQP includes five major activities, which can be divided into five phases: Phase 1 stands for the planning and definition of the program. Product design and development verification (second phase) uses preventive quality methods such as FMEA or FTA (Fault tree analysis). Within the third phase, process design and development verification, the main features of the production system are evaluated. Used methods in this phase are for example the process FMEA, process charts or standard operation procedures. Product and process validation as next phase assess the production system and the containing processes by using e.g. pilot production and approvals. The last phase includes launch of production, assessment and corrective action [2].
Concept planning of an assembly system covers the third phase of APQP. Within this phase, the method of FMEA is used. In general, FMEA is described as highly structured and systematic method for failure analysis based on experiences e.g. with similar or former products and processes. As method for preventive system and risk analysis, FMEA already starts in an early state of the product creation process. By applying FMEA, weak points of the considered system are analyzed, measurements are initiated and risks are assessed. In this way, FMEA focuses on the prevention of potential product and process failures within product creation process [2].

APQP is mainly used for product development. For the project phase of production engineering it is not exhaustively applied due to following reasons:
- Project time is limited
- Main focus lies on other priorities
- Sustainable FMEA needs resources and knowlegde

Big OEMs has detected the problem and qualify their engineers in advanced quality planning methods. At present, there is a large gap between theory and practical application.

2.2. Risk Management

Risk is not only described as negative effects facing a company but also the conditions and environment within or outside the company, which could cause negative effects [4]. In literature, the term of risk is defined in several ways [2, 5, 6]. Managing business risks in a systematic way is the main goal of risk management, including all activities of a company coordinating extensively and coherently their risks for managing and controlling [5]. The new approach regarding risk management is Enterprise Risk Management (ERM). ERM describes an integrated management of all risks an organization faces and conciliates risk management with corporate governance and strategy. Manifold definitions are listed in [7]. Risk management is described as process [5]:
- Identify risk aims to carve out potential threats [2]
- Analyze and rate risks based on identified risks; requires comprehensive analyzing methods e. g. FMEA [3]
- Evaluate identified and analyzed risks; choose criteria
- Full risk assessment with two dimensions: probability and severity; followed up by an illustration e.g. in a risk portfolio diagram [7]
- Depict risks strategies execute for the risks’ treatment [2]
- Implement and follow up measurements for treatment

Different approaches for risk classification as context-oriented, cause- and effect-related or related to project-management. There are a non-exhaustive enumeration of risk classifications [3]: Technical, organizational, contractual as well as financial, internal and external, political and sociocultural.

Early prevention of production planning failures and failures within product development is one of the most frequently mentioned reasons for risk analysis according to [8] in a manufacturing company. All classifications of risk occur in production engineering projects. Risk management is a vital method, but following aspects reduce its power:
- Risk management as process is not installed as mandatory within the concept phase
- Risk awareness according to multiplicity of decisions in the concept phase is often lacking
- Systematic and structured risk prevention is not used

2.3. Changeable Manufacturing – (Re-)configuration

ElMaraghy defines changeability as “an umbrella framework that encompasses many paradigms, such as agility, adaptability, flexibility and re-configurability” [9]. Changeability can be accomplished by a system and its components possess certain properties. According to Wiendahl only these certain system-properties or features allows the system to transform. Defined as change enablers there are universality, mobility, scalability, modularity and compatibility [10]. Due to modularity acts as a booster for all change enablers, it is recognized as an elementary key-demand of a changeable system [11]. Changeability represents the characteristic of a production, which allows an adaption of the production system. For this purpose both technical requirements and conditions like a consequent modularized, standardized and mobile production equipment and organizational requirements and conditions have to be defined. Existing approaches and concepts for a changeable production system are listed in [12].

Modularity represents the idea of “plug and produce”. This means standardized and pre-tested units and elements, which are separated of each other and regards technical facilities of the factory as well as structures of the organization [11]. A module embodies all resources needed to ensure its functionality and autonomy and presents the smallest element of a system that can be multiplied, displaced or eliminated as a hole [13]. According to Pahl and Beitz, modularity effects more benefits as there are re-use and re-combination of modules and upgradeability [14]. Modularity is the basic requirement for reconfiguration. Mittal and Frayman define a configuration task as found in [15]. According to this definition, a configuration task requires components, which are specified, able to connect and with inherent properties.
Configuration includes two aspects: modularization and integration [12]. Only the connection of modularity and the change-enabler compatibility creates a valid functional unit [10]. Reconfiguration means the ability to adapt a manufacturing system on a fast, target-oriented and economic way in relation to functionality, capacity and technology. As an answer to changing specifications components, machines, cells etc. are able to adapt (adding, removing, interchanging or adjusting). Integrating modules rapidly and precisely will be provided by standardized mechanical, informational and control interfaces for an automated assembly system [16].

The approach of integrated product and assembly configuration presented by Landheer premises a consequent function-oriented modularization. Within the concept-phase there are some limitations such as:

- Configuration is not comprehensively used
- Reconfiguration-enablers require inherent properties
- Re-use of parts of existing assembly systems limited due to missing connectivity
- Configuration-tool for concept planning is missing

2.4. Life Cycle Costing

Life cycle Costing (LCC) is a specific and holistic way of accounting used for technology [17]. LCC summarizes all costs which are generated during planning, initial acquisition, implementation, operations, maintenance, reconfiguration, shutdown and recycling [10]. Derived from the factory life cycle and the reasons for planning there exists six planning types: re-planning, extension, re-newal of structure, reduction, transfer and outsourcing. Including a methodology of strategic planning of reconfiguration within the initial planning process requirements for reconfiguration could be integrated and depicted within LCC. Hence, the planning methodology described by Karl, have to be executed during the purchasing or designing phase and the re-configuration have to be planned before implementation [18].

Methods of LCC are effectively for comparison all costs evoke during life cycle in case of evaluation of planning alternatives methods of a configured production object. Allowing an efficient comparison between different planning alternatives, LCC provides a holistic life cycle-oriented fundament for a decision.

Usually, in the planning process LCC is not applicable for following reasons:

- Capital expenditure for production equipment etc. kept down due to low manufacturing costs and low project costs, including cost-cutting measurements.
- Benefits of changeability due to modularity just estimated and uncertain [10, 18].
- Requirements for flexibility, changeability and specifications for re-use not mandatory and target within the project.

2.5. Data Management

Data management contains all organizational and technical tasks regarding the process by which the required data is acquired, validated, stored, protected, and processed, and by which its accessibility, reliability, and timeliness is ensured [19]. Managing product data (Product Data Management) and extended over the whole product life cycle (Product Lifecycle Management) the complexity and variety rise up. An ideal PLM system is able to manage diverse information: technical data, knowledge of constraints and requirements, capabilities as well as marketing specifications. Several approaches could be found in [20, 21]. Including all data and information of an organization for all business processes there are several data management systems such as PLM and ERP [22].

According to [23], used software tools within the phases of product development and production engineering are classified into:

- CAx- and office-tools
- PDM-, ERP and PLM-tools as integration platform or as data backbone
- Visualization tools

In connection with production engineering and digital factory the requirements for data management could be found in [23]. Linking methods, models and tools for modelling product, process and resource data require a holistic and integrated data and IT management. The postulated completely integrated and seamless data management is still not existing. Furthermore, the controlling of increasing complexity of data management is rudimentary. An integrated data management is essential, but there are following restrictions:

- Changes demand actualization in all models and affected uses; often no automatic updates
- Data management overall business processes is not completely integrated
- Interfaces between tools and models, standalone solutions hinder the collaboration and change management

2.6. Digital validation methods (as part of digital factory)

Within the development process of automated assembly systems, the use of digital validation methods is well established in automotive industry. As portrayed in [24], digital validation methods are defined as methods to check and evaluate specific product-, process- or production-related quality characteristics using digital data models. Examples of such used digital validations solutions are the powerful methods of virtual engineering and virtual commissioning. The development of further production-oriented digital validation methods such as physics-based analysis, tolerance analysis or mixed reality are currently in progress.

As a part of digital factory production-oriented digital validation methods have apart from many powerful benefits some limitations such as:

- Methods are not widespread used; application criteria are not described in a standardized way
3. Quality- and lifecycle-oriented production engineering

A holistic quality and lifecycle-oriented production engineering approach requires a concept containing technical, economic and organizational domains and tasks. Within production engineering, there are manifold aspects regarding quality, lifecycle, risk, digital factory and LCC. As discussed above, there are several approaches and methods in the context of production engineering. However, regarding the mentioned issues and goals within concept planning, the explained solution approaches don’t achieve a holistic and sustainable approach. Considering these quality- and lifecycle aspects, the new concept integrates and links the explained methods within the production engineering process as illustrated in Fig. 3.

Fig. 3. Quality- and lifecycle production engineering concept

Advance quality planning offers diverse quality methods for an integrated planning. Implement FMEA by applying its continuous updated data within the product and production system lifecycle improve permanently outcome. By using the method FMEA the planner is supported in focusing on main risks and in capturing structural and preventive measurements for risks’ treatment. As described above, the method is suitable to prevent risk in the early phase of the production engineering process.

Considering risk management as a process it has to be completely integrated into production engineering process. Output of risk management have to be deep-seated in the project milestones. Measurements out of risk analysis have followed up structurally and sustainably. Risk management should implemented in an early stage of planning ensuring a reduced risk in the entire production life cycle. Manufacturing knowledge and experience out of previous projects and daily business should be integrated into new projects in a structural way to speed up time to production and efficient planning outputs. Postulating a seamless planning process an integrated communication system, a consistent knowledge and information data management is a cornerstone for high-quality planning results. A coherent, agile data management and a seamless digital CAx process chain is essentially for processing changes within the planning phase.

Questions regarding economic efficiency in a quality- and lifecycle-oriented production engineering concept requires an integrated approach, too. LCC offers a calculation formula. But guidelines and objectives for a financial project controlling over the life cycle needs a corporate-wide standardized target given by board of management. Integrating the economic and financial aspects LCC needs to be adjusted for production engineering for a quality- and lifecycle-oriented focus. Project-KPIs needs to be defined covering the new aspects.

Specification documents are specified as a crucial result of the planning process. Using the idea of a changeable manufacturing by planning an assembly line composed of modules with inherent properties (considering change enablers) offers the planner new possibilities for changes in the lifecycle of the automated assembly system.

Production engineering takes a key position within the product creation process and within the lifecycle of an automated assembly system as well. Hence, requirements on the planning process and its influence on the output is highly rated in order to reach the goals regarding the project phase, e.g. to reduce engineering time. As evaluated, a holistic production engineering approach containing and processing questions and requirements regarding quality, risk, LCC, changeability and flexibility in an integrated data management is missing. But a fast and efficient way of concept planning is one of the most important goals. That requires an approach for processing these versatile and partially interdependent data and information within the process. A model- and rule-based configuration system could be a basic approach for the design of such a complex system like an assembly system in order to reach standardization and speed within the concept phase.

As depicted in Fig. 4, a model- and rule-based configuration system processes as input data, information and parameters of all domains. Following items stands for an exemplary input list:

- Project characteristic numbers (e.g. yearly production output)
- Product data (e.g. CAD data, bill of material)
- Target production costs
- Financial budgets (e.g. for assembly system)
- Project specific framework (e.g. re-use of assembly system modules)
- Assembly specific targets (e.g. cycle time, scrap rate)

These inputs will be processing within a rule-based configuration system. Knowledge bases, which contain experiences and best practice from former projects, can be included to
profit from this knowledge. Rules for configuration process could be for example:

- Structure of an assembly system
- Specifications for modules (e.g. preselection due to single supplier for modules)
- Process specific rules (e.g. sequence planning)
- Calculation formula (e.g. for production costs, amortization)

The configuration system needs to process models as well as it configure models. After the configuration process, for all domains (e.g. process planning, material flow, quality, costs) an output should be available. Typical outputs of the model- and rule-based configuration system are for example:

- Specification of assembly system (as base of allocation phase)
- Lifecycle costs
- Quality aspects (e.g. risks)
- Layout and resources
- Manufacturing bill of material

4. Conclusion and Outlook

This contribution present a new sustainable and holistic developed quality- and lifecycle-oriented production engineering approach. Integrating the described methods like APQP and risk management into the planning process empowers to reach the above-mentioned goals within the concept planning. As an integrated configuration tool, the introduced model- and rule-based configuration system affords further research. This powerful system needs to be designed and evaluated. In order to integrate all domains within the planning process to speed up the process and receive higher quality, standardized and holistic outputs of the concept planning are necessary.

Acknowledgements

Parts of this contribution are developed within the ZAFH project "Digitaler Produktlebenszyklus (DiP)". More information about this project is available at: https://dip.reutlingen-university.de

References

Conceptual model of management in automotive projects

Laurentiu Margineanu*, Gabriela Prostean, Serban Popa

Polytechnic University Timisoara, Faculty of Management in Production and Transportation, Str. Remus, No.14, 300191 Timisoara, Romania

Abstract

In automotive industry the development of new products, involve complex engineering processes subject to time pressures and fierce competition on the automotive market. An important role in the development of such projects it is the process planner. The position of process planner involves the interface between the department of design and development and production department, managing the projects in terms of technic side till implement them in series production. This paper develops in teach mode a conceptual model to scroll the successive phases of the project, designed to position the process planner, in order to transfer the knowledge to the students, in the field of project management of new product development in the automotive industry. Through a case study it will be creates a conceptual model in methodological way, namely that exemplifies the main phases of automotive projects: the quote, concept, release of design, testing and qualification of product and final phase of preparing and launching in series production. Preliminary phase namely quotation phase includes defining the project team and submitting the offer. Process steps are established for each operation and the estimated cost for devices and equipment, project time planning, and can generate the first effective phase of the project, namely the concept phase, called the foundation project also. Next phase of concept phase is the release of design, thereupon the design is frozen, as well as the product bill of materials. PP sets: final steps of the process; production line (cell layout design); material flow; Process Failure Mode and Effects Analysis (P-FMEA) and highlighting the top 5 risks assumed; In testing phase and product qualification, the PP manages and harmonizes in the smallest detail in order to achieve this target, to complete the preparation and launch in series production.

© 2015 The Authors. Published by Elsevier Ltd.

Keywords: process planner, automotive, project management; product emergence process

* Laurentiu Margineanu. Tel.: +40-721788883.
E-mail address: lau_margineanu@yahoo.com

© 2015 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Peer-review under responsibility of Academic World Education and Research Center.
1. Introduction

Project management is in continuous development and a topical issue in recent years in the automotive industry, one of the most severe competitions in the market, and where innovations are in continuous motion and succeed with rapidity and an amazing pace.

Most companies in the field of automotive project management using the same scheme that we meet in the paper of Gofer, Schulz "Supply chain during the product design emergence process - The example of the German car industry", published in the International Journal of Engineering Science and Technology, vol. 5, no. 2, 2013, pp. 110-118. The adapted scheme from this paper is presented in the figure 1.

![Figure 1. Product emergence process](image)

The scheme is very good and also at present is successfully used by large companies with tradition, where employees have extensive experience in project management. But younger companies on the market which try to use this scheme, do not always bring the desired result, because "not all projects are blessed with superstars." As Joan Knudson and Ira wrote in chapter Managing the team Bitz During the Project of Book Project Management published by AMACOM Books' ISBN: 0814450431 Pub Date: 01/01/91. Studying in detail the scheme can not be clearly observed phase sequence, and just grouping them in a certain period of time, and do not notice the interaction with the customer. Also in this scheme does not mention anything about the quotation phase, phase that helps to have a new project, and it is difficult to be interpreted by a person from outside the system, which means difficulty in understanding also for students.

Most automotive companies, wishing to initiate future employees since the time schools, but also because people who come from outside the company, can see the things from another angle and then offers a new and innovative idea, collaborate more and more with prestigious university worldwide, therefore the project management discipline has become a specialized study in college. In project management literature has been extensively studied, searching methods, tactics and tools to make it easier the project management activity, one of the reference book is Practical Project Management Tips, Tactics, and Tools, by Harvey Levine; Project Management A Systems Approach to Planning, Scheduling, and Controlling Seventh Edition, by Harold Kerzner, Ph.D. Division of Business Administration Baldwin-Wallace College Berea, Ohio).

This paper develops a conceptual model of the development phases of a new product in the automotive industry, a concept can be used as a model for introduction of students in project management of new product development in the automotive industry. The model is intended to be a summary of project management, that the paper treats them in the next pages using an original concept models.

2. The conceptual model of project management

In the paper that follows, it presents a new possible approach for new product development projects in the automotive industry. In this paper, the project team consists of project manager, process planner, designer, quality planner and cost evaluator. Project manager is the interface between the client and design department and manage
project activity, he is responsible for ensuring the finished product in time to the customer. Process planer is the interface between the design team and series production and manages the project from a technical point of view, he is responsible for project implementation in production. The designer is responsible for product development in accordance with customer requirements.

The first phase presented in the proposed scheme, is the quote phase, and it is very important in winning new projects and ensuring future of the series production. Many companies do not treat seriously this phase, relying on their brand reputation, and relationships over time with their customers. This approach becomes increasingly inefficient because more and more suppliers from the Asian market launches in the automotive market. As a solution to the fierce competition in the market, in the above scheme the quote phase was included in development phases of new products, involving the design team since this phase in the project in order to presenting them the hard competition on the market, motivating them to develop new products in the best possible lowest price. Thus they realize the importance of this phase in order to winning new projects and motivate them to provide the best solutions. In this way the project manager can offer the best price to the customer.

Concept phase is the next phase, if the quotation phase was won, and is the phase in which the product begins to take shape, become palpable. After the concept is ready, A samples are built and sent to the customer for verification and validation of the concept. In contradistinction to the current approach used, process planer begins in this phase to define the process flow that will be used in serial production of the new product, checking difficulty of the manufacturability of product, and presents information about product to the designer in order to improve the concept of product, and avoid additional costs in the project when the product is ready to launch into production. Also in this phase Quality Planner start the D-FMEA (Design - Failure Mode and Effects Analysis) so necessary to develop a more reliable design which ensure a low risk of functionality for the finished product.

After the customer has studied the concept and samples A, validates the concept stage and begin final design phase. The design phase must be developed to reach maturity and design should be frozen in final form, as well as the list of materials that compose the product. The proposed management model, in this phase is formed the team of implementation of the project, this team is led by process planer. The team is composed from representatives of each department: manufacturing, engineering, logistics, quality and acquisitions. Also in this phase process planner starts work on defining the inquiry sheets of material, fixture and equipment. The inquiry sheets are necessary for project buyer, representative of the purchasing department, to prospect the market and define the list of potential suppliers. Also important is the initiation of PFMEA in this phase, the activity is coordinated by process planner. The team that worked in this activity is composed from process planer, quality planer, and one representative of each departments: production, engineering, and quality. Once the design is completed, samples B are built and checked within the team if it covered all customer requirements. If B samples do not meet all requirements, then must be reviewing the design. After the design is reviewed, C samples will be built, and together with the final design are sent to client for validation.

Once the design is approved by the customer, testing and qualification phase of product begins. What's new in proposed scheme is that in this phase the implementation team in series production (team coordinated process planer), is very involved in the project. Project buyer from purchasing department, places purchase order for new materials, devices and equipment. Representative of logistics check stocks of materials that are common in mass production projects, and new development project in order to increase the new orders with necessary quantities. Also in this phase, process planer is closely related in relationship with supplier of devices and equipment and supplied them with all the technical details necessary to build equipment and devices. Very important is the planning and construction of samples required for testing and qualification samples, which must be ensured throughout the process planer.

After all tests were passed successfully, begin practical training phase and launch into mass production. The proposed concept divides this phase in 3 stages. The first stage is the stage of final acceptance of the equipment and devices, the second stage is the stage of pre-production, also called Full Test Run phase, and the third stage is the stage of the release in the series, the start of production. Once the project released in the series follow a stage up to 6 month ramp-up where the project manager and process planer are still responsible for the optimum production processes but also for the quality of the products, after which the project is closed and full responsibility is transferred to the production department.
3. Conclusions

As a conclusion, the above process is a simple description, exposed in a fluid layout, in order to be able to understand the continuity of projects phases of launching new products. As can be seen every phase diagram shows special items allocated "Lesson Learnt", elements that ensure continuous improvement of the activity of project management.

This scheme can be used successfully in ISO TS certification audits, or in the customer audits in order to present the work and phases of the project in a developed and elaborated way, always a diagram or picture being more explicit than a thousand words together.

The scheme is very useful in teaching environment in initiating students in project management, but also in facilitating understanding of each phase of new product development projects, the scheme proposed conceptual model representing the skeleton of conceptual model.

Reference


