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CONCURRENT DESIGN AND REALIZATION OF AIRCRAFT PRODUCTION FLOW LINES – PROCESS CHALLENGES AND SUCCESSFUL DESIGN METHODS

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ABSTRACT
Engineering Design is more than creating technical products – it's the design of processes with both technological *and* human aspects. In this regard, the creation of a new production system is a cocktail of archetypical complex design tasks. This paper discusses the design work of the "New Factory" programme, which aims to ensure the future competitiveness of the fuselage production at Airbus in Hamburg. The targets of this programme are significant unit cost reductions, lead-time reductions and quality improvements. This can only be achieved by a change of paradigm in the production principle: Coming from a traditional dock manufacturing, a new "lean" manufacturing environment requires a flow production with a continuous flow of product and material. Thus, for both the single aisle aircraft family and the long range aircraft family, new structural assembly and equipment installation Flow Lines are in development and realization. These four projects contained a variety of design tasks and complex problem solving situations. Due to a very tight time schedule and limited budget, major challenges were to manage the extreme concurrent engineering and dynamic decision making in parallel to the ongoing construction process.
The paper presents typical episodes of the design process of the new factory, together with an analysis of the influencing factors, leading to success and failure. The adjustment of systematic design methods towards trouble shooting situations is presented and discussed.

Keywords: Context in Design; Design Management; Design for X

1 INTRODUCTION

Engineering Design is mostly understood as an activity focusing on the development of products, such as cars or other types of mechanical and electronic hardware. Step by step, with loops and concurrent design work, a product is defined, developed and tested [1]. Project management methods and systematic design methods are supporting this creative and collaborative work process [2].
When it comes to the development of a production system for the manufacturing of products, new dimensions are added to the traditional understanding of "product" development: not only the characteristics of hardware are to be defined (based on all lifecycle processes), but additionally all related production processes are to be developed in parallel.
This paper discusses critical situations of the simultaneous design and construction process of the "New Factory Programme" of Airbus in Hamburg. In the second section, the New Factory Programme is introduced by it's aims, organisation, design products, and achievements. The third section illustrates the specific process challenges by the analysis of episodes with typical 'critical situations'. Section four describes the methods, which were successfully used in those critical situations. The paper concludes with proposals for the adjustment of engineering design methods in specific trouble shooting set-ups.

2 THE NEW FACTORY PROGRAMME

2.1 Airbus fuselage production in Hamburg

Airbus is an European company with worldwide activities, producing commercial aircraft with a capacity of more than 100 seats. The product portfolio with the seat capacity and range is shown in figure 1. At the Hamburg site, Airbus is designing and manufacturing the front and aft fuselages for the single aisle and long range fleet, and for the A380.

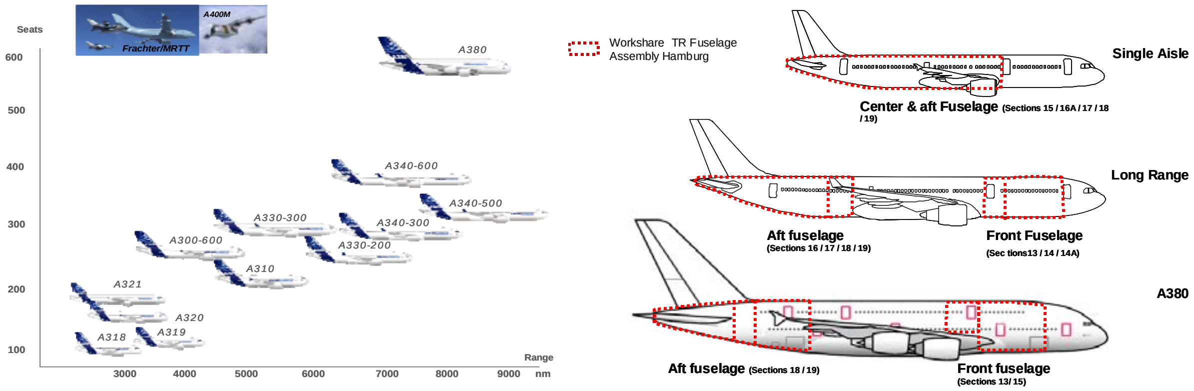

Figure 1. Airbus Product Range and Workshare in Hamburg (red markings)

The main production steps are the structural assembly of sections and fuselages, and then the equipment installation and testing of all systems, which are necessary for flight (see figure 2)

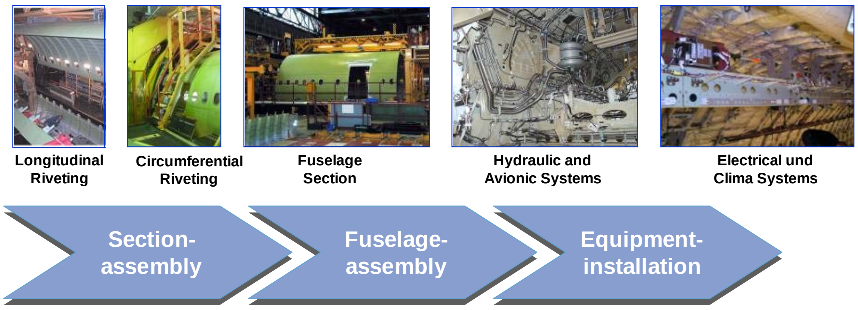

Figure 2. Main steps of the fuselage production process in Hamburg

The equipment installation of fuselage systems is an enormous workload of high tech manufacturing processes. Figure 3 illustrates the work packages of the equipment installation and test.

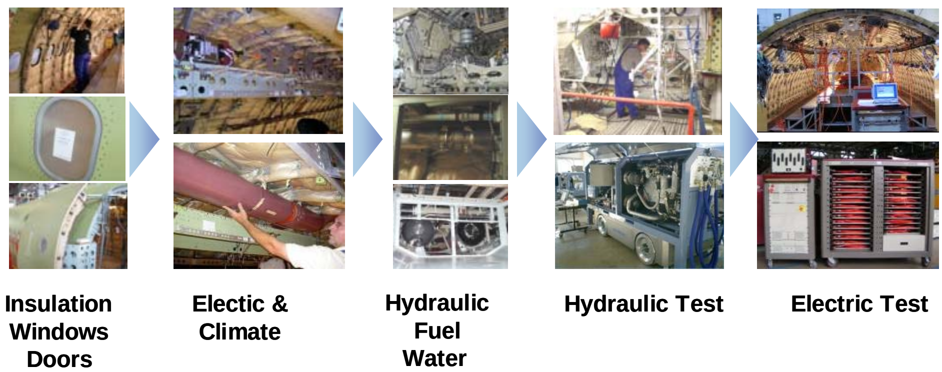

Figure 3. Equipment installation and test of fuselage systems

In Single Aisle, more than 630m of pipes are to be installed, and 22.000 electrical contacts to be tested. Figure 4 shows how condensed the systems are integrated in the fuselage of a single aisle aircraft (A320 family), especially in the landing gear bay and the climate bay. This means work on two levels, with the requirement to provide jigs for ergonomic access into narrow spaces.

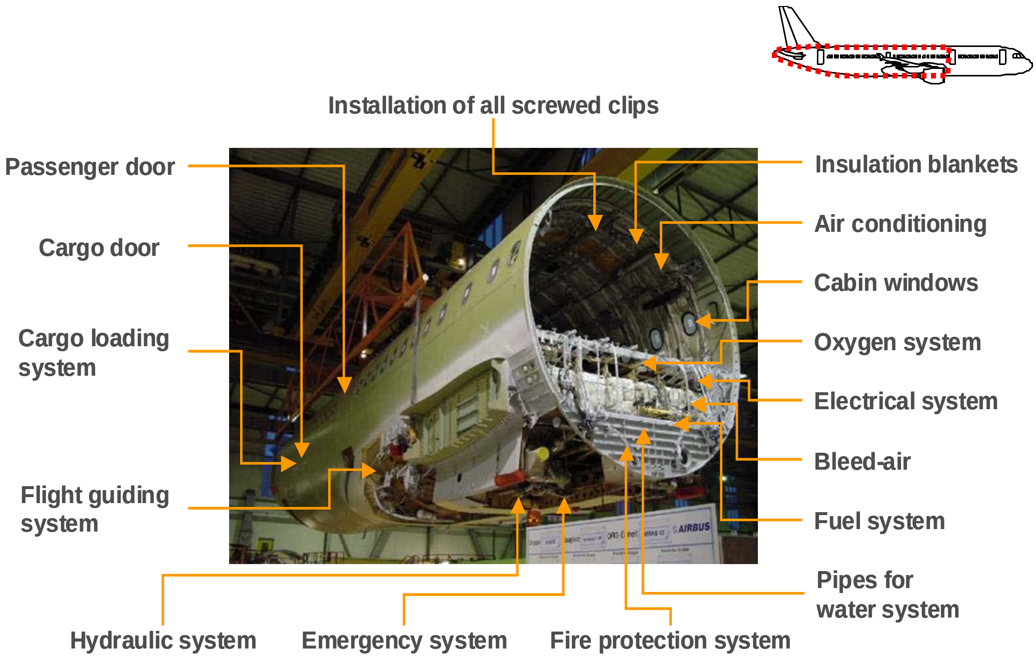

Figure 4. Equipment installation work packages for single aisle aircraft

2.2 Aims and organisation of the New Factory Programme

The "New Factory Programme" aims to ensure the future competitiveness of the fuselage production at Airbus in Hamburg. The targets are very ambitious in terms of significant unit cost reductions (~-35%), lead-time reductions (~-40%) and quality improvements. These targets can only be achieved by a change of paradigm in the production principle: Coming from a traditional dock manufacturing, a new "lean" manufacturing environment requires a flow production with a continuous flow of product and material [3]. Thus, for both the single aisle aircraft family (A318, A319, A320, A321) and the long range aircraft family (A330, A340, A350), new structural assembly and equipment installation Flow Lines are in development and realization. The planning, design, realisation and change management of these new production systems are managed under the responsibility of the new factory programme. In four projects, set up in a matrix organisation with sub-projects, all activities are coordinated. Sub-projects are dealing with the optimisation of the production processes and methods, the supply chain management, buildings and infrastructure, movables, the development of jigs and tools and transport vehicles, quality and tests, IT-management, human resources and work organisation, ergonomics, and communication and change management (see figure 5). Modern project management is the basis for the way of working in the New Factory Programme, supported by a project management office. Systematic design work is requested, but not always applied. Some episodes of success and failure are discussed in section 3. In total, about 100 people are working in the four projects.

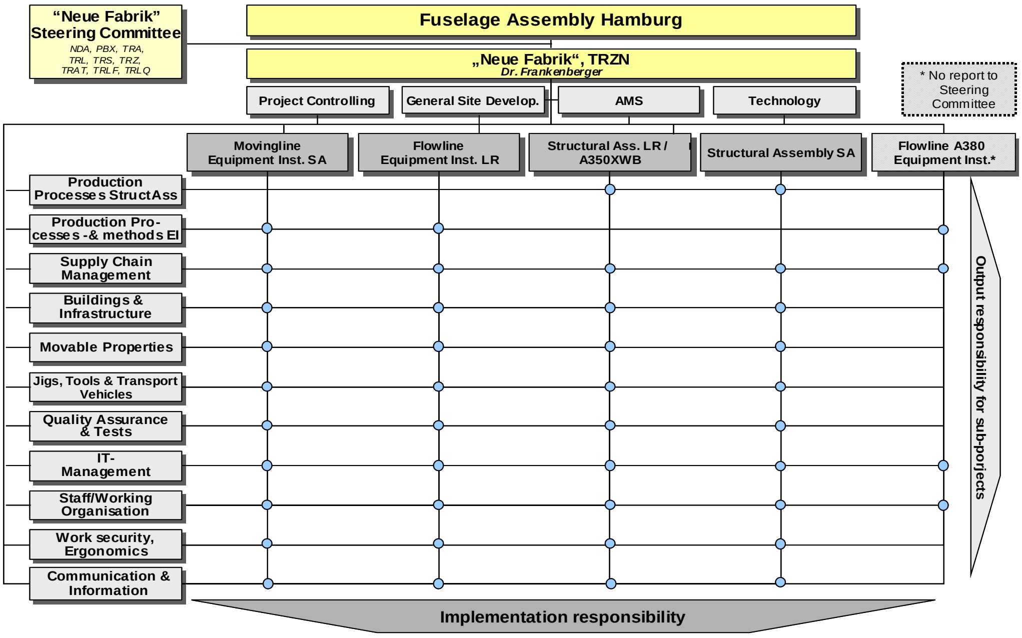

Figure 5. Organisation of the New Factory Programme

Today, the new "Moving line" for the equipment installation Single Aisle and the new "Flow line" for the equipment installation Long Range are already in operation, the new structural assembly flow line for Single Aisle is in realisation and the new A350XWB production lines are in development. Figure 6 illustrates the concurrent development and realisation of the new hangars and production systems.

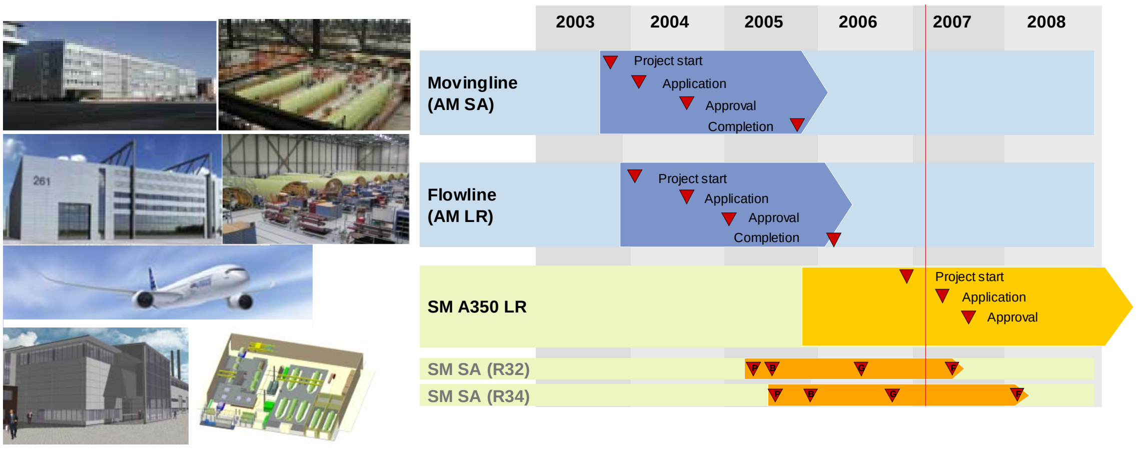

Figure 6. Content and schedule of the New Factory Programme

2.3 Typical Design Tasks of the New Factory Programme

The New Factory Programme consists of a variety of process-, IT- and hardware-design tasks. The first step was always the detailed analysis of the production processes and the optimization of work sequences. Therefore, large work orders were split into shorter work steps, which were then put in a network plan for integrating technological interdependencies and spatial constraints. For an optimal throughput time, the workload was balanced over the stations of the production lines (see figure 7).

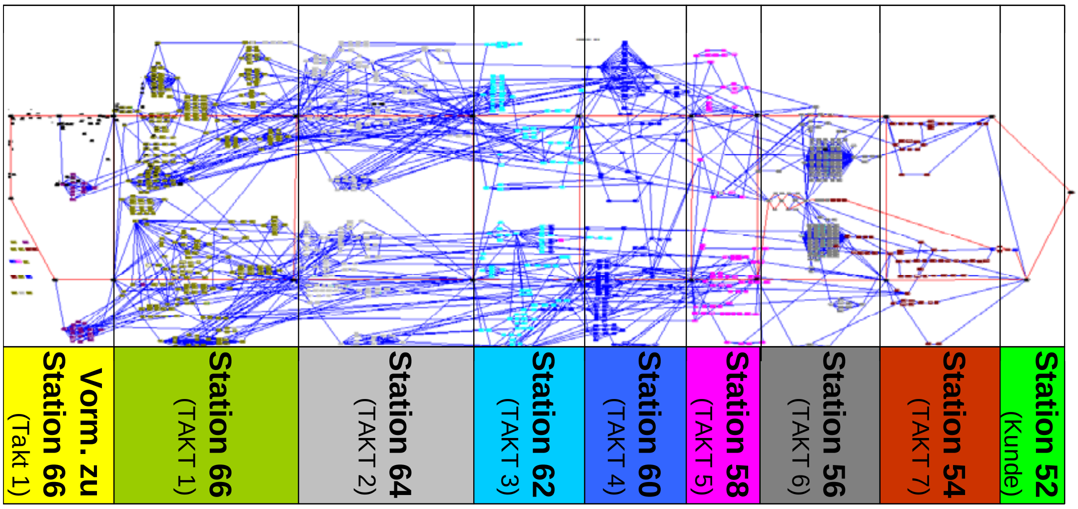

Figure 7. Example of a network plan for the equipment installation single aisle

Based on the process optimization and the content of work on each station (or takt) of the production line, the factory layouts, jigs & tools design, machinery and logistic equipment were developed. As an example of the various design tasks on all levels of detail in these projects, figure 8 shows the layout of the new "Moving Line" for single aisle fuselage equipping: The fuselages are laying on transport jigs and are moving from station to station constantly with a "speed" of 1m/h.

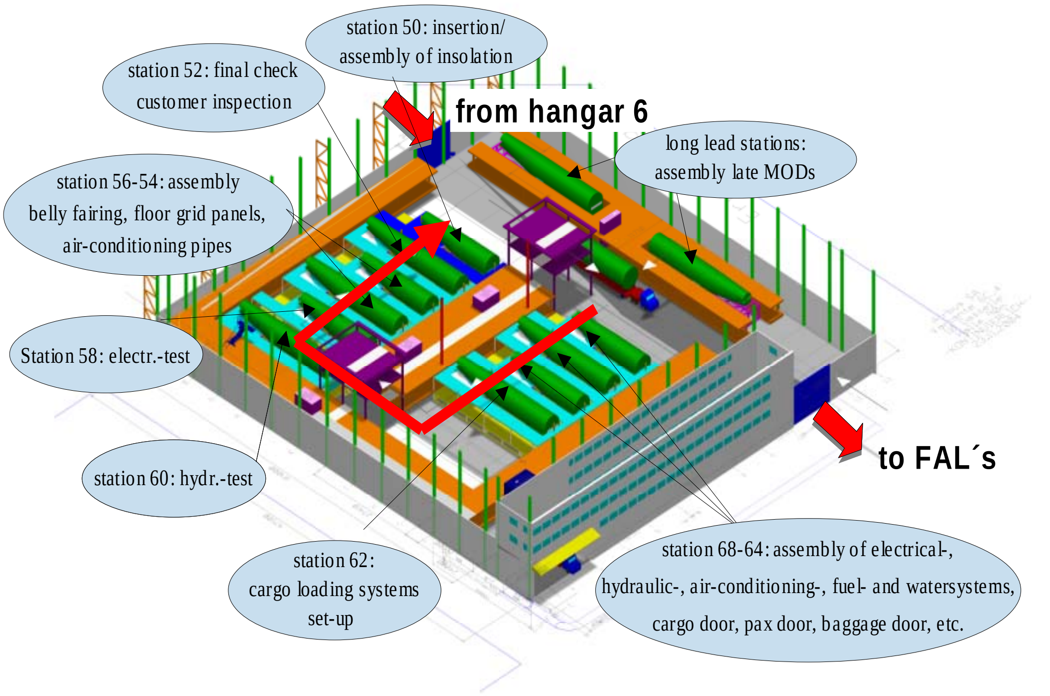

Figure 8. The single aisle Moving Line in hangar 8- a huge production system

Another example for design tasks are logistic equipment such as flexible distribution units for a variety of pipes and tubes for the hydraulic-, climate-, bleed-air- and fuel- system (see figure 9). Thereby, lean-manufacturing requirements and ergonomic demands were driving the design for a configured distribution of material directly to the stations, close to the fuselage, in order to minimize the walking distances for the workers. An episode of the design process of the pipe & tube distribution unit is discussed later in section 3.

Figure 9. Pipe & Tube Distribution Unit with flexible adjustments for various types of pipes

2.4 Achievements

Overall, the first two projects for the equipment installation single aisle and long range are a great success story: The two new hangars and production systems were realised in a tight schedule almost in parallel in 10 month and 12 month. The moving of the ongoing operations into the new production systems was supported by an extensive change management with trainings, booklets and flyers, goodies, information events and a professional planning of the move. Figure 10 illustrates a few of the creative "products", designed for supporting the human aspects of this shift of paradigm in equipment installation. Finally, the performance of the project team was honoured with an Airbus Award for Excellence for productivity.

Figure 10. Design Products too: Trainings, Booklets, Flyers, Boarding Card, and Goodies

The trough-put time was reduced in the Single Aisle Moving Line from 9 days to 5 days and in the Long Range Flow Line from 14 days to 8 days. The reduction of the working time is in the target range, the reduction of unit cost is an ongoing process. The most important success is, that the new Moving Line was able to manage the rate increase from 22 to 32 aircraft per month without a problem. All this sounds almost perfect. But our design process of the "New Factory" was not perfect in all situations. In section 3, the process challenges and recurring types of critical situations are discussed.

3 PROCESS CHALLENGES

Reflecting and analysing the design process is a basic prerequisite for any process improvement. The following post hoc analysis of the self-experienced design processes of the New Factory Programme is based on the "Critical Situations Approach" by Badke-Schaub and Frankenberger [4]. This approach focuses on so called 'critical' situations and episodes, which are of decisive importance for the further process and the later result. In these critical situations, the influence of factors from the external conditions and from the acting individuals and teams can be observed and analysed. After a short overview of the process characteristics and external conditions, critical situations of the problem solving process and of social processes are described in this section.

3.1 Tasks, Process Characteristics and External Conditions

For a new factory, typical process development tasks are related to the production technologies, manufacturing processes and work steps, new work organisation, logistic and supply chain, and the analysis of value streams and business processes. Based on the process development, the hardware and software development deals with plant layouts, new buildings, IT software for planning and operation, new machinery, jigs and tools, and logistic equipment. Thus, production-system- or factory-development is both 'product'- *and* 'process'-development. To make this task even more challenging, factory development has no prototypes – it is a technical 'first time right' exercise with many peoples involved. Moreover, in production environments, economic considerations are likely to be very ambitious – improvements are to be realized with a minimum of budget and very short return of invested capital (ROI). Mostly, the investment decisions are based on initial concepts on the maturity level of power point presentations – promising but gloomy. In particular, recurring cost savings are promised, without any details for the lean manufacturing processes and cost saving mechanisms or the necessary hardware. Last but not least, this type of development work is usually executed under the time pressure of an ongoing production.

In consequence, engineering designers have to perform a simultaneous designing and construction process of the new production system. From a methodological perspective, this setting creates specific challenges for the design work. The following episodes are describing critical situations of the design work in the New Factory Programme. Even though the team was extremely successful in general, some episodes of failure seem to be embarrassing. Nevertheless, our culture dealing with failure allows an open discussion of the underlying root causes, in order to avoid the mistakes in future. Unfortunately, our team was not always successful in making a failure only once.

3.2 Problem Solving Types of Critical Situations

The root cause analysis of failure and success in the design process reveiled weaknesses and strength in critical situations of the *problem solving process*. This paragraph is therefore structured according to the main phases of this process: Requirements analysis, solution search, and decision-making.

Requirements analysis

In the new hangar for the equipment installation of long-range Aircraft fuselages, large steel platforms for logistic supply are erected. The pre-manufactured piles and trusses are perfectly painted in light grey-blue. Unexpected and very late in the project, a 'new' requirement of the fire department is reported: According to general industrial law, the platforms need to stand 30 minutes of fire. Therefore, we are forced to paint the supporting construction of the platforms with piles and trusses with a special fire-protective coating. This took two unplanned weeks with disturbances of the further work, increased cost of 80.000 € and an ugly surface on the piles.

Why was this basic requirement not analysed in time, about 10 month before, when the specification for the new Flow Line jigs was written?

Obviously, systematic clarification of requirements was not a strength of our team at that time. For example, the specification of new jigs for suppliers were often based on the experience of existing stations, and not on the analysis of new lean work-processes.

Solution search

The team started to develop layouts for a new structural assembly Flow Line for fuselages. Several month and two Milestone reviews with large management attention later, layout No. 67F was presented in a powerpoint presentation as "the one and only" and best possible solution to the almost impossible task to integrate a 21st century structural assembly Flow Line into a narrow old hangar from 1937 with a minimum of budget. Again, time was very limited, the effort for solution search obviously enormous. Shortly after, when the embodiment design work in 3D started, it was discovered, that the roof of the hangar is too low to move shells and sections over the stations by crane. This was the first of about 7 other showstoppers. A further analysis of the variety of the more than sixty layout variants reveiled, that there where only 5 really different approaches, none of them a sufficient solution to the problem. The rest was just the combination and variation of minor elements, without touching the main functions. It was a hard work to re-direct the team and to tell them, that their "solution" is a "dead horse".

The lack of systematic solution search knowledge of the team, combined with the lack of real management attention and time pressure lead to this bad result. At the end, it was an individual effort to change this crucial development.

Decision making

There was a preferred solution for the new plant layout. Two other "victim" variants were developed to be presented as so called "alternatives" for the upper management. In a colourful powerpoint presentation, the three variants were discussed, evaluated by different criteria. The criteria were even balanced with weight factors. The management insisted to compare non-recurring costs (NRC) and recurring costs (RC) for different scenarios. The question, if the presented variants are the best possible solution alternatives, was not raised.

In general, it seems to be a bad habit to put pressure on the management to make decisions without appropriate information. Quite often, management reacts with methodological tasks, which are insufficient because the underlying problem is not questioned. When it comes to a systematic decision-making and evaluating, the definition of decision criteria is a major problem. Criteria are often not independent, but causal chains. This problem is covered by a one-to-one evaluation and priorisation of criteria. This even increases the effect of unbalanced evaluations.

3.3 Social Types of Critical Situations

There are not only problem solving related types of critical situations. Design work is a highly social activity of people from different departments, with different education, different mindsets and sometimes even different targets. This can lead to conflict situations with influence on the daily work. Moreover, management impacts, multi-project management and external requests can create disturbance situations. Disturbances cause interruptions of the work process and can be the origin of failure, when issues are missed afterwards.

Conflicts

It is not a surprise, that large project organisations with various customers and stakeholders from the line organisation create potential conflicts. But when it comes to the new setup of a whole factory, all business processes and departments are affected. Weaknesses in internal processes, unclear interfaces between departments, and unsolved old conflicts due to changes of responsibilities become obvious. In this regard, the New Factory Programme acts like a brush in a tube, pulling all hidden problems to the surface. An additional dimension is the lean manufacturing approach of the New Factory Programme, which implies massive changes in the way of working of production units. Some 'customers' from the production department are not very progressive and open for a radical change in their way of working. Lean manufacturing requires a strong management commitment and support for the change of work procedures on the shop floor and in all supporting departments. Moreover, budget limitations do not allow to realise planned improvements. The conflict between NRC savings and lost RC savings is a daily balancing task. Typical conflicts are also on the capacity and responsibility of people. In general, project work is a permanent political and psychological challenge. In consequence, we experienced a high effort for communication and active stakeholder management.

Disturbances

Probably the most disturbances are created unintended by the upper management. These situations are not only time consuming guided tours to the New Factory Flow Lines for very important visitors from government or executive board – these disturbances are also motivating. More disturbing are long organisational meetings and political power games, resulting in the fear to loose the established project conditions. Those problems usually capture the thinking of project managers and reduce concentration on the problem solving tasks. They do not only cost time, but also motivation. In the New Factory Programme, a major positive condition is the own building for the project team with own meeting rooms and space for team-work. This reduces disturbances from daily operational business.

4 METHODICAL PROPOSALS FOR HIGH SPEED DEVELOPMENT WORK

Based on the experience of the dynamic development work of a new production system, this section makes proposals on how to better perform in critical situations. In the New Factory Programme, we have applied these methods, and we are constantly adjusting them to the daily situation.

4.1 Methods for requirements analysis

A main problem in the analysis of requirements is the lack of systematic capturing. We have established an analysis of the product lifecycle with the identification of all stakeholders and their processes as an obligatory first step. The requirements-list is then structured according to the life cycle phases and their sub- processes. Figure 11 shows an archetypical lifecycle, which we use as a standard, in order to ensure a similar structure of our requirement documents. The next important step are interviews with all stakeholders to understand their processes and their needs, in order to evaluate together if a requirement is a ‘must’ or a ‘wish’. For asking the right questions, we are using a checklist based on a list by Birkhofer [5] (see excerpt in Figure 11, right side).

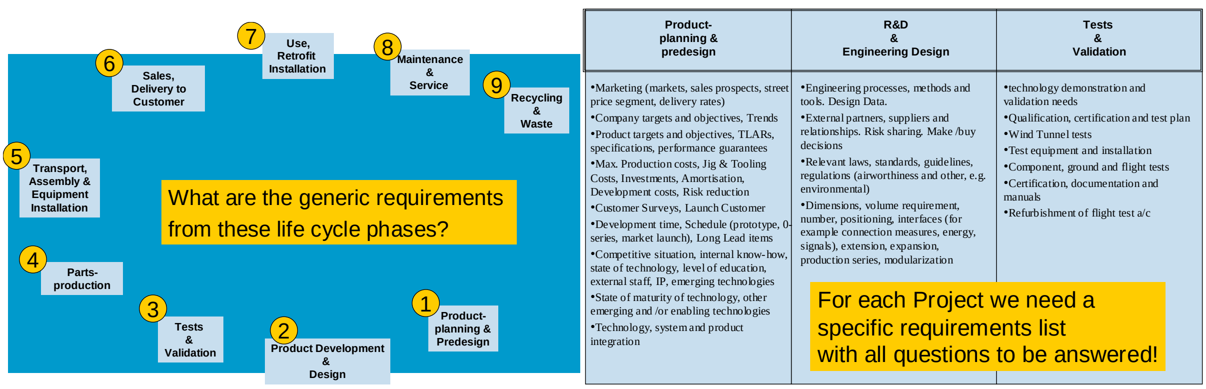

Figure 11. Product life-cycle phases and checklist for the systematic capturing of requirements

The distinction between must and wish-requirements is a key prerequisite for the later analysis, if an idea is a solution for our problem: A solution fulfills all must requirements! Other ideas can be eliminated - this is lean development work! The whole process of requirements capture and structuring according to the lifecycle, together with the checklist is supported by the tool ‘Prosecco’ [6].

4.2 Methods for solution search

Solution search is probably the phase with the greatest need for methodical support. Today, solution search is mostly just ‘brainstorming’. The most important first step of systematic solution search is the decomposition of a problem into it’s sub-problems or functions. For these functions, we can search for sub-solutions, supported by intuitive and systematic methods [1]. In the New Factory Programme, we have good experience with the morphological matrix by Zwicky [7]. Figure 12 shows an example from the solution search for the pipe & tube-holders of the Pipe & Tube Distribution Unit. This matrix was filled during a team workshop, which covered the whole design process of the pipe holders. We were able to eliminate all ideas for functions, which did not fulfill the must requirements. By combining the remaining sub-solutions, we have created three most promising overall-solutions.

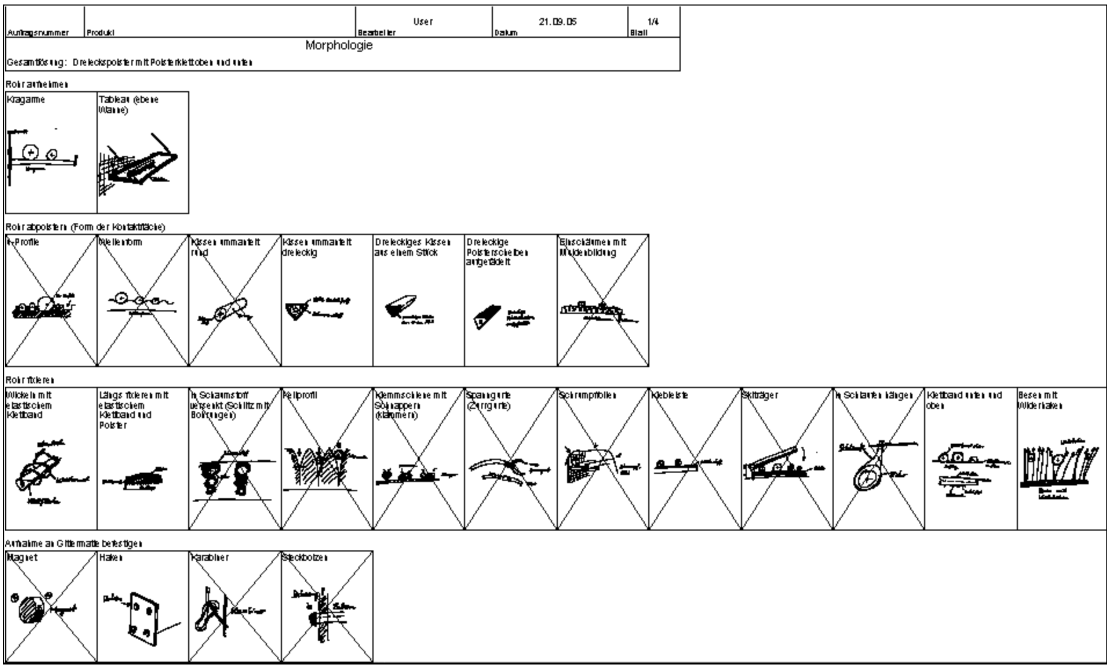

Figure 12. Morphological matrix of the pipe&tube holder

4.3 Methods for decision-making

There are two basic views on a solution. First a technical view from the customer's perspective: How good does the product perform and fulfils my requirements? Second an economic view from the manufacturer's perspective: How much effort is it to develop and produce the solution? This clear distinction of viewpoints ensures two independent dimensions of the evaluation. Figure 13 shows the discussion of pros and cons of the solutions and the result of the evaluation, again supported by the tool 'prosecco'. The realized solution (more than 1000 holders) is in successful operation since 15 month and a good example for systematic solution search.

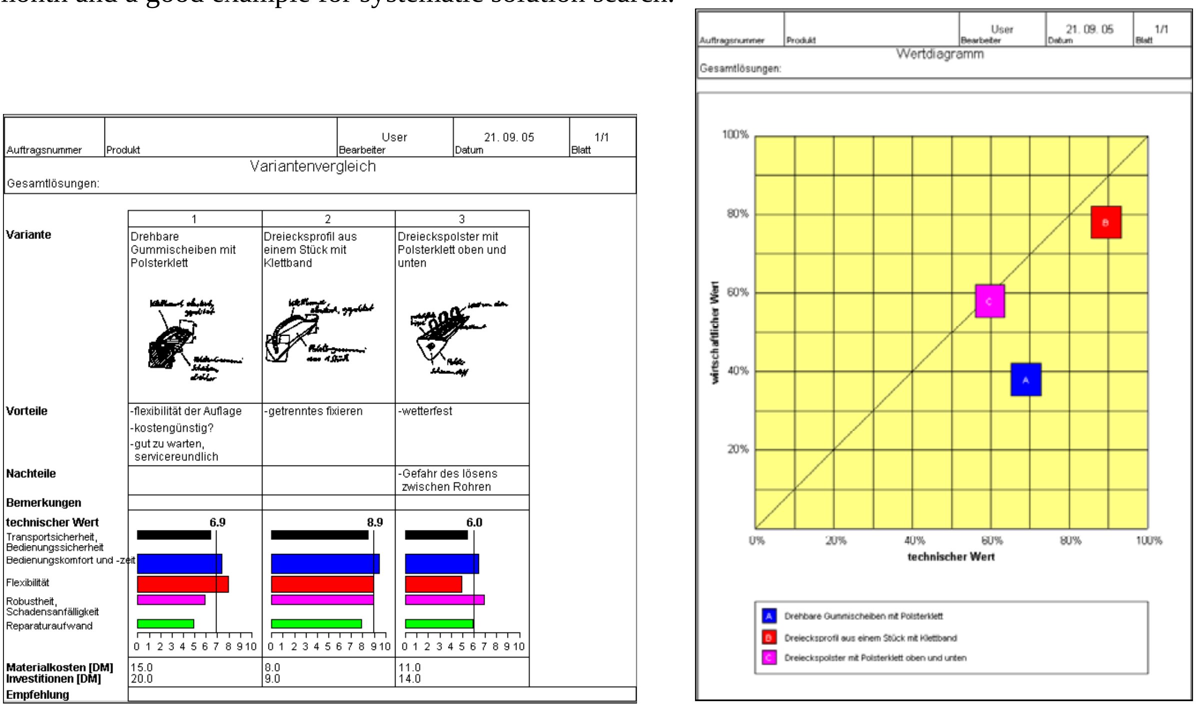

Figure 13. Solution discussion and evaluation

5 CONCLUSIONS

Leading a production system development project such as the New Factory Programme for aircraft fuselages at Airbus is not only a management task. Moreover, it is a permanent didactic challenge for the teaching and explaining of design methods and systematic design competences to the team. In milestone reviews, plateau meetings, project meetings, stakeholder reviews, steering committees and in the daily work, the activity can be compared to a simultaneous high-speed chess game: situation analysis, identification of problems and responsibilities, involving the right people, preventive conflict solving by extensive communication with stakeholders, setting up defined actions and checking the deliverables and effects of measures. Systematic design methods became a key success factor for our work, accelerating problem-solving processes and improving the solution quality. Especially under extreme time-pressure and the need for quick decision-making, design methods provided a guideline for an economic way of working. For team workshops and individual work, the support with a simple systematic design software tool was extremely helpful and provided easy access to the solution development process of team members. Additionally the re-use of documents with minor adjustments and effects of knowledge management enabled a lean development work. In this regard, the New Factory Programme did not just changed the Hamburg plant, but also provided a platform for the successful application of design methods and tools under the specific conditions of a production system development process.

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