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ABOUT SOME ASPECTS OF ADVANCED MANUFACTURING ENGINEERING DEPARTMENT IN WCM-ORIENTED PRODUCTION PLANTS

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Abstract

The modern companies, which are competing on product market, need to use innovative solutions, in order to become potential leaders. One of the modernization methods is rearrangement of organizational structure and redistribution of competence. The article describes the Advanced Manufacturing Engineering Department in production plant, which is an innovative initiative in worldwide organizational management. Some aspects including AME application in plant processes are highlighted. Some advanced techniques are presented. In the article summary, perspectives for the development of AME are included.

Keywords

Advanced Manufacturing Engineering (AME), World Class Manufacturing (WCM), Early Product Management (EPM), Design for Assembly (DFA), Design for Cost (DFC), Design for Manufacturing (DFM), Digital Mock-up (DMU).

Introduction. General characteristics of advanced manufacturing engineering

Literature on Advanced Manufacturing Engineering is well structured, however only few articles concern organization of *Advanced Manufacturing Engineering* Department in production plants. In this paper, general characteristics of Advanced Manufacturing Engineering in terms of *WCM* production system will be presented.

Advanced Manufacturing Engineering (AME) originates from industrially advanced countries, e.g. the USA, Japan, and Germany due to their supreme technological development and level of innovation [1]. Because of high cost (which was generated by arrangement of highly skilled professionals and use of high-tech resources), AME implementation was restricted only to large companies with extensive budget sourcing from the very beginning.

In many cases, AME stands for AMT (Advanced Manufacturing Technology). Paper of Small and Yasin is an example [2]. Herein, the research on adoption of advanced manufacturing technologies in 125 American firms was conducted. Based on literature review, seven hypotheses were used in order to evaluate successful AMT implementation. Some practical recommendations were presented:

- high project management skills among implementation team are required;
- implementation of AMT in company should be built into company's strategic planning;
- benchmark of successful implementations in other firms is desirable;
- considerable investment in human factor as well as integrating systems.

Starting from the early sixties, Advanced Manufacturing Engineering has played an outstanding role in manufacturing management methods. These methods have significantly influenced production processes, resulting in countable profit and uncountable benefit for companies. Today, it plays even more important – in many cases strategic role among corporations.

Case study of a strategic model for learning and evaluation of AME technology was presented in [3]. In their work, Mohanty and Desmukh analysed a joint venture enterprise between Indian and American companies – called XYZL. Its product offering included communication, information, industrial automation and control solutions.

The authors concluded, that knowledge is the unique resource for each company and the success of any AMT implementation is strongly connected with employees' *motivation*, *professional aspiration* and readiness to *group cooperation*.

In their work [4], Ghani, Yayabalan and Sugumar presented the influence of AMT on organisational structure in a developing country. The paper describes results of a cross-sectional survey among 27 Indian companies, which in order to achieve better productivity results, modified their organizational structure in parallel to new technology implementation.

Due to meagre background in literature, the research was based on 3 proposed hypotheses. These included difference in the means of organizational index within the years of implementation of AMT, its influence on firm productivity and comparison between observed organic index (OI) and proactive level (PL).

The authors concluded that successful AMT implementation requires *proactive planning* at high level, which facilitates better productivity results. Furthermore, only by their *organizational structure modification*, large companies, which were successful in traditional mechanistic structures, will ensure future development as long as new technologies are adopted.

Mital and Pennathur analysed correlation between human factor and advanced technologies. In their publication [5], the authors investigated the implementation of advanced technologies (generally correlated with process automation) in several industrialized countries using the comparison between employment trends in manufacturing sector and productivity rates. Only marginal increase in productivity was achieved which was disappointing in the era of phenomenal technological innovation and development.

Furthermore, it was pointed out that implementation of AMT had been highly economically demanding in respect to the expectation of high return on investment in the form of productivity increase. Although the importance of advanced technologies will increase, the human factor will inevitably bring flexibility and versatility.

An example of advanced manufacturing technology adoption in Germany was described in Hoffmann's and Orr's article [6]. Based on surveys distributed among manufacturers, the authors connected implementation of new technologies with the position of initiators in organizations and the type of production. The drawbacks which were presented in the report were:

- no particular type of manufacturer, which could prove outstanding success in advanced manufacturing methods implementation;
- little involvement of middle management in advanced manufacturing methods implementation.

In the meantime, some positive remarks were presented:

- significant initiative factor came from production departments;
- more than 93% respondents claimed that overall performance of investments was satisfactory or successful.

Implementation of AMT and Advanced Management Practices (AMP) in Italian firms was analysed by L. Lucianetti et al. in [7]. The authors pointed out several factors, that exert influence on successful implementation of AME and AMP, i.e.:

- environmental uncertainty;
- organizational decentralization.

Surprisingly, the research did not confirm the relationship between organizational strategy and the adoption of AME/AMP.

A study on available recent researches indicate significant importance of Advanced Manufacturing Engineering in the development of organizations. Industry 4.0, intelligent manufacturing systems, virtual and augmented reality applications are the examples of "future thinking" in manufacturing processing. However, how will these be connected with human factor? How challenging will be the integration between artificial intelligence and human mind?

Ben Wang tried to find an answer for these questions in his paper [8]. The author analysed past "technological breakthroughs" and analysed their influence on manufacturing processes through the years. Based on them and latest technological trends, a new perspective of future manufacturing was sketched – as a combination of hybrid relations between manufacturing systems and human interface, scalability of technology, concurrent maturation of technology, business cases and ecosystems.

To meet customer expectations and achieve shortest product delivery lead-time, highly effective task allocation among advanced manufacturing engineering must be implemented. Chen et al. analysed this problem in their work [9]. Based on literature review, the selected aspects of task allocation workflow in future manufacturing systems were presented, which consist of proper task description, modelling and execution. The optimization in this field will be concentrated on product life-cycle extension and creating social benefits.

The impact of advanced manufacturing processes adoption on product cost was covered in [10]. Farooq et al. conducted research on the implementation of lightweight die-casting in automotive and aerospace sector. The authors emphasized the importance of two main factors which drive the profitability of new technology adoption:

- high production volumes;
- size of parts and corresponding weight (material) reduction opportunities.

In conclusion, to summarize what Advanced Manufacturing Engineering stands for today, Mamalis' article should be quoted. In his paper, the author analysed micro and nanotechnology processing, including the potential of high-temperature superconductivity components made of ceramic materials [11]. By using advanced manufacturing techniques, optimization of product parameters is possible, which is especially important for high-tech applications in automotive and aerospace industry.

As expounded in the articles mentioned above, Advanced Manufacturing Engineering (or AMT) includes all breakthrough technologies and innovative materials used in manufacturing processes. By constant influence on organizational structure of company, proactive approach and involvement of team participants the goal is to upgrade productivity, deliver innovation and encourage employees to engage in self-development.

Early Product Management methodology in Advanced Manufacturing Engineering

In this text, the organization of Advanced Manufacturing Engineering Department in a division of a large well-known international automotive company will be presented. Its agriculture production plant will be considered, where the main technological processes are:

- laser cutting;
- plastic forming and bending;
- welding;
- assembly;
- painting.

Advanced Manufacturing Engineering Department was established in 2014 as an execution of general company policy. Its main objectives were set to:

- design and develop processes using techniques originating from World Class Manufacturing System (WCM);
- optimize product design using DFM/DFA methods;
- verify new product design by using CAD tools and add manufacturing remarks;
- improve productivity rate by implementation of innovative manufacturing technologies.

Early Product Management (EPM) methodology, is one out of ten technical pillars in WCM system (see Fig. 1) [12].

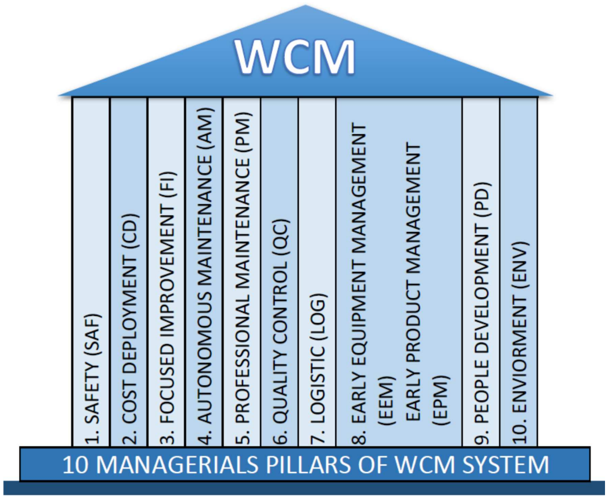

Fig. 1. WCM temple.

The general objective of EPM is bringing maximum added value by optimization of new product design, resulting from direct collaboration between manufacturing and product engineering. Several aspects are analysed in particular:

- cost of product;
- quality;
- material type;
- available technology;
- tools and equipment;
- logistics;
- safety and environmental regulations;
- documentation and technical requirements.

EPM methodology largely defines the Advanced Manufacturing Engineering concept in WCM system. To understand this approach, the general life cycle of a product must be referenced (Fig. 2).

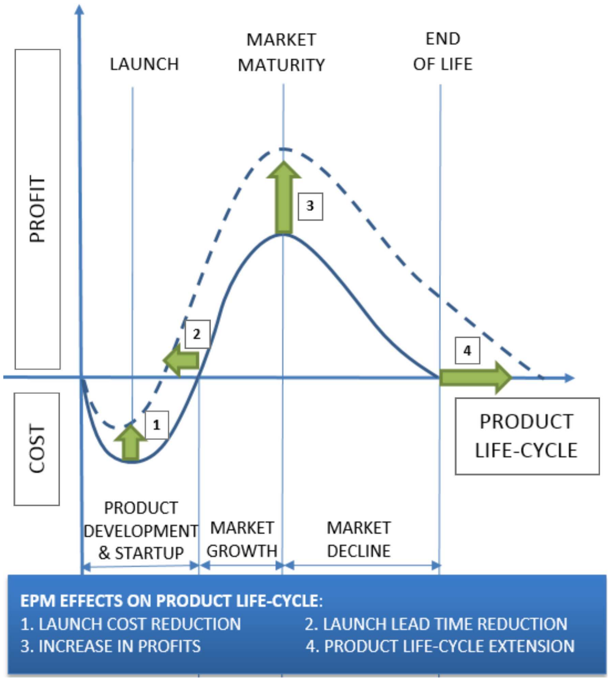

Fig. 2. Life cycle of a product and "EPM effect".

Four effects of EPM approach in product life cycle are significant:

- *Launch cost reduction*
  By utilizing knowledge from past implementations, repetitive errors and nonconformities are not observed. Hence, scrap losses, rework, inspection and excessive labour costs are avoided.
- *Launch (Start-up) lead time reduction*
  By standardized process of planning activities, recognition of roles and responsibilities within project flow.
- *Increase profitability of product*
  Product cost reduction and waste elimination by using more efficient manufacturing techniques, design simplification, standardization and operators' training.
- *Product life-cycle extension*
  By constant quality improvement and product performance tracking, innovation and new added features.

Herein, the main goal of EPM methodology and AME activities is to reduce loss generated by ineffective new product launches and related corrective actions.

The optimization process comes through seven certified steps, which indicate project maturity in technical and economic background. Each of them specifies activities and sets requirements before next step is taken. These activities were classified in 7 steps of EPM [13]:

Step 0 Knowledge Management: Step 1–7.
Step 1 Planning: Mission, Targets, Team organization.
Step 2 Develop concept: Line and cycle Macro-planning, Product concept alignment.
Step 3 Design Feasibility: Workstation concept, Pillars Proactive Analysis (1st).
Step 4 Design Optimization: Workstation detailed design, Pillars Proactive Analysis (2nd).
Step 5 Process Implementation: Workstation Off-line Test, Workstation installation.
Step 6 Process Verification: Production Trial, Workstation Certification.
Step 7 Optimization & Start-up: Production Start-up, Optimization.

The correlation between these steps was presented in Table 1.

Table 1
7 steps of EPM.

REACTIVE APPROACH			PREVENTIVE APPROACH		PROACTIVE APPROACH	
Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
PLANNING	DEVELOP CONCEPT	DESIGN FEASIBILITY	DESIGN OPTIMIZATION	PROCESS IMPLEMENTATION	PROCESS VERIFICATION	OPTIMIZATION AND STARTUP
STEP 0 KNOWLEDGE MANAGEMENT						

In order to optimize new product launches, special methods are used:

- *Lessons learned* – includes process corrections in current products.
- *Knowledge management* – covers fixes and improvements on current products, which can be transferred into a new design.
- *Frontloading* – refers to utilizing Knowledge management to validate the process and eliminate repetition of errors.
- *Design optimization* – indicates proactive activities for product cost reduction and quality improvement.
- *Value engineering* – verification of product function and cost from customer's perspective.

These methods are a part of Deming's circle in project management, which is based on recordings from previous implementations or currently manufactured products. The aim is to prevent repetition or continuation of past issues by finding alternative solutions at the earliest stage of new project design.

Furthermore, it is expected, that experience of past launches should bring reduction in implementation time and delivery of new product to customer [14]. These assumptions were graphically presented in Fig. 3.

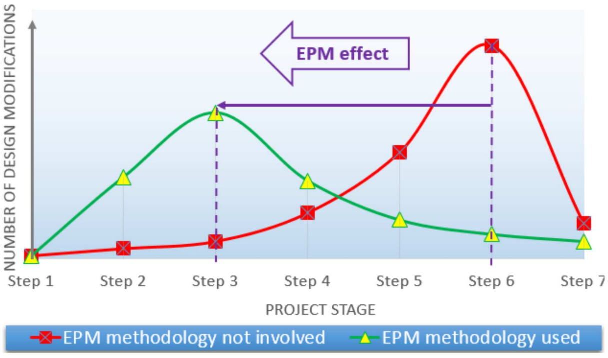

Fig. 3. Dependency between project stage and number of design modifications including with/without EPM implementation.

Advanced Manufacturing Engineering – an interdisciplinary bridge in project management

Success of any new product launch is closely connected with good team cooperation in terms of EPM methodology. The team should consist of different departments' representatives e.g. quality, logistics, etc., so that the information and knowledge input is used in the most effective way. What is more, this participation enables other departments to bring their own proposals and point out most concerning issues, letting them become active participants in project management flow. Therefore, it is up to advanced manufacturing engineers to lead this cooperation in a straightforward direction. In Fig. 4, cooperation of Advanced Manufacturing Engineering with other departments was presented.

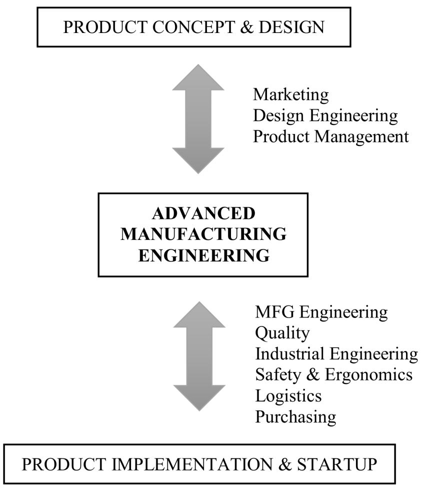

Fig. 4. Cooperation of Advanced Manufacturing Engineering with other departments.

Digital Mock-up concept (DMU)

The effective exchange of information between several project team members or company with external suppliers, is possible only by homogenized cooperation environment [15]. For this reason, Digital Mock-up concept (DMU) has been implemented.

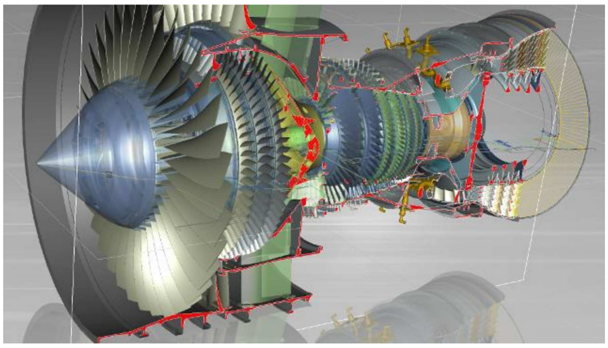

Fig. 5. Visualization of a turbine-engine in Teamcenter provided by PLM Software [16].

DMU originates from Data Envelopment Analysis and concentrates on evaluating the performance of peer entities [17]. In practical meaning, DMU consists of all engineering software and its properties, which is used during product design process. The output from this software should be universal and accessible by using the same type of program, for example: step, jt, stl or igs file extensions.

PDF 3D documents, which do not require installation of dedicated CAD software and enable quick sharing between users, become more and more popular. In Fig. 6, the same part model was opened in engineering-viewing software and pdf viewer.

a) b)

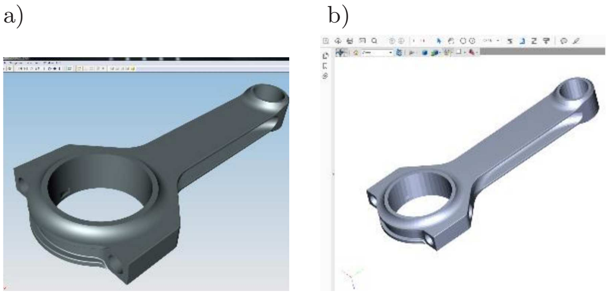

Fig. 6. The same crank model opened in a) Teamcenter Visualization (jt type file) and b) Acrobat Reader (3D pdf type file).

The development in information technology and computer efficiency allowed to implement advanced software designed for special, dedicated applications. In terms of modern manufacturing trends (smart factories, Industry 4.0), an example of this phenomenon is the integration of virtual reality and real working conditions. In many cases, the result of this combination is directed at detailed product design study, early-stage manufacturing input, workers' training or ergonomics analysis. An example of human-factor oriented including virtual reality elements software is Jack/TECNOMATIX, which enables visualization of manufacturing processes, workplace and human performance analysis (Fig. 7).

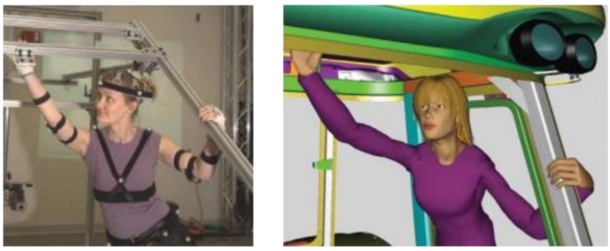

Fig. 7. Virtual reality in assembly process analysis lets verify the reachability to improve the design of product [18].

Advanced Manufacturing Engineer utilizes the available computer software in order to analyse 3D product models and related tooling. By using e.g. DFM, DFA, DFC methods (described below), remarks and proposals can be sketched and presented to product engineering.

Computer aided design software is indispensable in complex design study, especially when large number of components or complicated routing is incorporated e.g. electric harnesses routing, piping and hydraulic system layout, etc. (see Fig. 8). Due to two-dimensional character of standard paper documentation, some information cannot be provided thoroughly. By using digital model, the operators and engineers involved in prototype and first series builds can find missing views, features or dimensions.

In Fig. 9 a study on comparison between 2 types of engines (actual MY2018 and revised MY2019) was presented. The blue colour indicates common parts, whereas green and red those of system group 1 (current product) and system group 2 (updating change) respectively. This analysis enables location of unique parts and lets manufacturing engineers concentrate on specific areas of the machine in order to prepare technology and working instructions for assemblers.

A frequent problem in assembly operations is the tooling access issue. Fig. 10 presents difficult handling of wrench and hardware due to limited space between assembled components. AME analysed possible resolving options in terms of available tooling (meeting technical specifications – high torque application) and possible design modification. As a result, the component's shape was changed in order to suit the new-type wrench head.

Fig. 8. Electrical system routing in JT2GO.

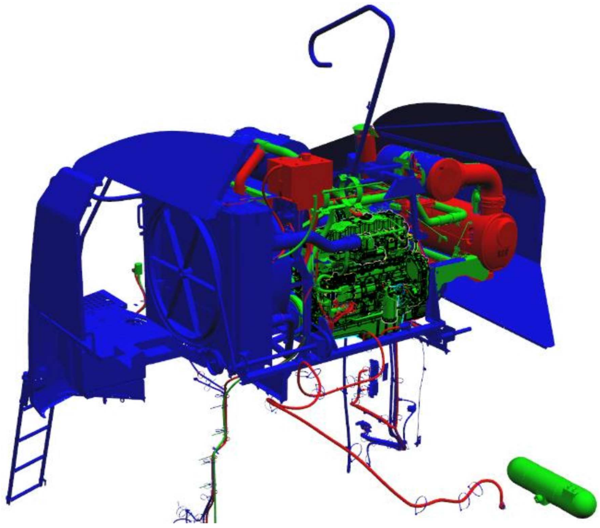

Fig. 9. Combine engines' comparison in VisMockup.

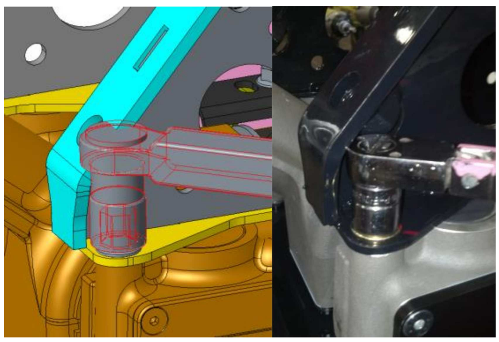

Fig. 10. Tooling access issue identified during model study and prototyping.

The above examples show some practical use of digital software in support of design and manufacturing problems. The opportunities of current computer programs are vast, and their further development is evident, especially in human factor-oriented direction [19].

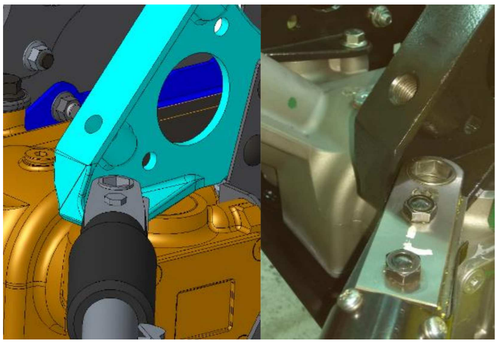

Fig. 11. Design modification and proper tooling selection as a solution for access issue.

Make/buy decision and critical part marking

Make/Buy decision process is one of the most important AME responsibilities. The evaluation is performed at an early stage of product maturity and is based on experience from knowledge management, including multidisciplinary input among company departments.

At this stage of the project, the product BOM is assigned into several categories which group the sourcing of the parts into Make (in-house production), Buy (suppliers) or COPP (components of buy parts). In some cases, In-sourcing from other company locations is considered.

The decisions are stored in NPCT (New Part Collaboration Tool) application. The interface of the program was presented in Fig. 12.

Fig. 12. NPCT application.

Another important aspect of AME activity is critical part flagging. This option is enabled in case of complicated design, specific technical/quality requirements or significant influence on plant manufacturing processes. This information is distributed to product management board and project members, to familiarize them with launch risk and preventive actions.

Design for manufacturing (DFM)

Due to AME's technical character, a strong connection with design engineering should be outlined. It is the advanced manufacturing engineer, who is generally the first level from plant technology department, and who is informed about new product implementations and technical requirements customized by design engineering and product managers. As the new design release will affect manufacturing processes- to avoid further complications, argumentative discussion must follow.

The general method of design optimization by analysing technical possibilities of plant production department is known as Design for Manufacturing [20]. DFM plays a key role in design optimization, and it is widely used in automotive and aerospace industry. Its philosophy is concentrated on reduction of tooling usage, its variety and cost of investment, by part simplification during design stage [21, 22]. In fact, DFM favours concurrent manufacturing approach [23–25].

The formal discussion between Design Engineering and Advanced Manufacturing Engineer is known as Design Review and is held generally between step 3 and step 5 of EPM methodology. During the meeting, AME presents remarks related to engineering drawings and adds his own proposals for improvements. These remarks may concern:

- errors on drawings, e.g. missing dimensions or remarks, wrong material assignment;
- unclear notes;
- unachievable tolerance requirements or tolerance chain stack up;
- the design of product is not suitable for manufacturing processes, e.g. limited or no access for welding torch;
- manufacturing constraints connected with available machines, their technical condition and usage;
- Over usage of advanced working centres, e.g. design requirement to use 5-axis CNC machine instead of 3-axis;
- range of tooling modifications and physical limits, e.g. update of weld fixtures, assembly templates or transport racks;
- enhancing manufacture-friendly solutions, e.g. harmonization of bend radius size among the part design, design symmetrical parts if possible, use of rivet nuts instead of welded nuts (see Fig. 13);
- promotion or elimination of distortion in welding-avoidance of unbalanced welds or using methods for reducing distortion;
- implementation of deep drawing parts instead of weld assemblies.

Fig. 13. Comparison between welding nut and rivet nut usage.

Design for assembly (DFA)

In order to simplify and speed up assembly operations, Design for Assembly technique is used. It was first introduced by Boothroyd [26] and its main principles are listed as below:

- minimizing the number of parts;
- standardization of parts and elimination of fasteners;
- assembly process simplification;
- removal of secondary assembly operations like gluing, soldering;
- focus on Poka-Yoke solutions;
- reduction of complex tooling and elimination of non-standard hand tools.

Based on aircraft design optimization, some further improvements were presented by Barbosa and Carvalho [27]:

- segmentation of big parts;
- ensuring easiness of maintenance activities in case of repairs and troubleshooting;
- concentration on ergonomics and safety condition.

Below, some DFA examples suggested by Advanced Manufacturing Engineer were presented.

In Fig. 14, a flange bolt with glue facility was proposed. The idea was to avoid huge NVAA activities related with preparation of bolt set, which included preassembly of screw, washer and spring washer. Additionally, in order to prevent nuts from further loosening, the thread was covered with a drop of locking liquid.

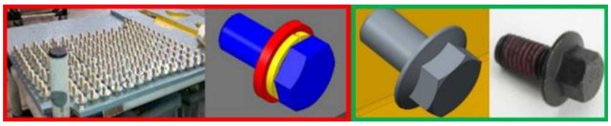

Fig. 14. Preassembly of bolt set and replacement by flange bolt with locking patch.

For serial production, the daily quantities reached volume of 1000 pcs, which generated enormous losses. After implementation of new hardware type, ineffective handling of parts was eliminated.

Another example suggested by AME, was the replacement of snap ring connections by cotter pins (see Fig. 15). This type of connection is based on precise nesting in hardware groove.

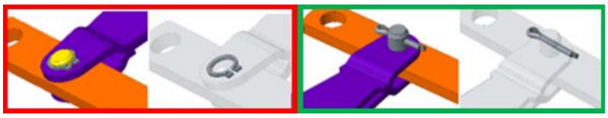

Fig. 15. Comparison between snap ring and cotter pin installation.

Installation of snap rings is usually very problematic, due to limited access for handling and visual inspection. As an alternative cotter pins were proposed. Easiness in pin assembly and explicit verification caused popularization in usage of this connection.

Design for cost optimization (DFC)

Every project should have specified drivelines and technical requirements, but the final economic score is the indicator of project success. For this reason, cost calculation for the new product is another field of AME interest. In literature, the cost structure was categorized into 4 main groups [28]:

- direct costs – that are expended solely to complete the activity or asset;
- indirect costs – include resources that need to be expended to support the activity or asset but that are also associated with other activities and assets;
- fixed costs – cost elements that must be provided independent of the volume of work activity or asset production that they support;
- variable costs – cost elements that must be provided and are dependent on the volume of work activity or asset production that they support.

Note, that fixed and variable cost may be either direct or indirect.

The cost of the project implementation from manufacturing perspective should be analysed in the following aspects:

- material type;
- manufacturing technology used;
- workforce input;
- machine efficiency and maintenance cost;
- expected yearly production batches;
- other specific investments related to new part design:
  - new jig, die or welding fixture;
  - infrastructure & building expenses;
  - updates in manufacturing technology e.g. creation or modification of machining program;
  - logistic engineering e.g. transport racks, means of transport- cranes, forklifts;
  - quality inspection tools, gauges.

Based on experience of current products, Advanced Manufacturing Engineer foresees changes in manufacturing processes for the new project and analyses them in terms of cost impact. Improvement suggestions related to cost reduction at earliest stage of project are essential.

In Fig. 16 a bracket model was presented as an example. The part was initially designed as aluminium machined block and welded in square tube. The opinion, which was presented by AME, indicated excessive cost generated by type of material, scrap, external sourcing and involved manufacturing processes (machining and aluminium welding operations). Additionally, joining of aluminium parts with significant difference in wall thicknesses was a serious concern, which could result in quality issues (cracks, deformations).

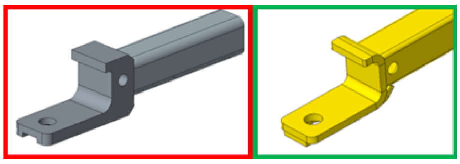

Fig. 16. Example of Design for Cost optimization technique.

Based on manufacturing input, the design was optimized. The cost of the part was reduced by 40%, by using standard steel material and simple bending operation.

Conclusions

In this article, general information about Advanced Manufacturing Engineering Department was presented. Some techniques, which are used during design and optimization process, were highlighted. Practical examples were shown.

The author's intention was to engage the reader's attention to selected problems in project management from design & manufacturing engineering perspective. Without doubt, adoption of EPM methodology enhances new products' launches and Advanced Manufacturing Engineer plays a vital role in their success.

For this reason, the author will continue research in this field, which will cover innovative tools and techniques dedicated to specific design optimization in line with Early Product Management Approach.

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