Proceedings of the 2009 Industrial Engineering Research Conference

Post-certification engineering taxonomy and decision making optimization in the aerospace industry

Mr. Yvan Beauregard
Department of Mechanical and Industrial Engineering, Concordia University,
1455 de Maisonneuve Blvd. West, Montréal, Québec, H3G 1M8

Dr. Nadia Bhuiyan
Department of Mechanical and Industrial Engineering, Concordia University,
1455 de Maisonneuve Blvd. West, Montréal, Québec, H3G 1M8

Dr. Vincent Thomson
Werner Graupe Professor of Manufacturing Automation,
Mechanical Engineering, McGill University,
817 Sherbrooke St. W., Montreal, Quebec, Canada H3A 2K6

Abstract

This paper proposes a novel taxonomy of post-certification engineering activities, as a first step towards true lean product development (PD). Relying on key notions developed in a novel lean engineering performance model, the authors compare the leanness of post-certification versus pre-certification jobs. Discrete event simulation and integer linear programming models are developed to help ascertain the influence of factors, such as multitasking, concurrency, charge size, job value and post-certification budget decision making, on lean engineering PD performance. The models developed provide the foundation for enhanced PD performance, and establishment of optimal PD process parameters.

Keywords
Lean engineering, simulation, optimization, lean performance metrics, project management

1. Introduction
With challenging economic conditions, introducing and implementing new approaches to help management improve the performance and value delivered by their organizations are more critical than ever. Developing innovative ways to help organizations understand, measure, manage and optimize the work of individuals involved in complex 'white-collar' activities, such as aerospace product development (PD), is not an easy task [1]. In many regulated sectors, PD efforts usually proceed through different pre-determined phases towards a key milestone represented by the granting of certification from regulatory authorities.

Although much effort is spent focusing on timely delivery of quality product within budget in the pre-certification phase through approaches such as project management and system engineering [4, 7], it is not unusual for further engineering resources to be expended in the post-certification phase. To shed some light on the nature of these activities, a post-certification taxonomy and decision tree is developed; findings from a lean engineering performance benchmarking study are shared, with post certification improvement potential characterized by comparing the performance of pre-certification versus post-certification jobs.

From an operational standpoint, improving flow of post-certification tasks represents a key objective to improve PD performance [5, 13, 15, 21]. Arguments have been presented for an appropriately sized work breakdown structure, but nothing was specified about how to establish optimal size [22]. In this paper, the influence of factors affecting PD performance, including intensity of concurrent PD, level of multitasking and charge size are assessed via a discrete event simulation model.

From a business standpoint, the strategic and financial value of pre-certification PD activities is generally well understood. Executive attention, decision making and appropriate processes [11] are available to ensure continued alignment of available resources and prioritization of corporate objectives. However, in the post-certification world, the higher number of disparate jobs, the less there are well understood and coordinated dimensions concerning value. As well, the focus on earnings before interest and taxes makes easy alignment of resources more difficult.

A multi-criteria decision making model incorporating the various dimensions of post-certification decision making is developed. A case study shows that consideration of the multi-facetted dimensions of value in engineering post-certification activities leads to enhanced value from the resource allocation point of view versus a throughput maximization approach. Finally, implementation considerations and results to date are discussed.

This paper begins with a presentation of a post-certification decision tree, lean engineering performance, simulation model, and multi-criteria optimization model. Results from the models are then presented. A two stage post-certification decision making model is developed. Finally, a review is made of implementation success factors, and future work examining the influence of additional factors affecting PD performance closes the paper.

2. Post certification, lean engineering performance, simulation and decision making models

The stage-gate process, introduced by Cooper, is a popular decision making approach in the portfolio management domain [12]. According to widely used project management standards [3], this decision making process persists until some time after the product is delivered, i.e., post-mortem reviews are conducted to enable propagation of lessons learned to future projects, and the new PD project is closed. Once certification is obtained, activities remain. In the post-certification phase, jobs of different nature compete for limited post-certification engineering resources.

Work on post-certification activities can represent a sizeable portion of the engineering budget. Early detection of problems in PD is less expensive than late detection [9]. Accordingly, much research has been done on identifying factors susceptible to improve the PD front end [10]. However studies on the nature of post-certification activities and their performance are lacking. Continuous improvement in the post-certification phase is difficult for all involved, given the wide variety of tasks performed, and the lack of information about how value is created, as well as the progressive reallocation of engineers to new PD projects. As a consequence, “managers have greater difficulty measuring, managing and optimizing work” [1].

Benchmarking exposes participants to new ideas, provides a sense of urgency to continuously improve and to be aware of best practices [8]. The post-certification taxonomy has been developed to help ascertain the source of post-certification work and to ensure alignment and consistent classification of post-certification engineering PD jobs. The classification scheme of post-certification engineering tasks is influenced by factors such as the origin of need, clarity and completeness of requirements defined during fuzzy front end requirements phase, effectiveness of PD process delivering expected performance level, and compliance to engineering PD standards. Jobs are classified into the following 6 categories, according to the above-mentioned factors: pre-certification, product repositioning, product improvement, post-certification, new learning/best practices, and quality.

Lean is a term that has been first used in the 1990’s at MIT to describe the Japanese production system, where use of less effort, space, and material resulted into higher output and quality [4]. Womack describes lean thinking as being comprised of the following steps: define value, define value stream, remove barriers to flow, enable pull, and strive for continuous improvement [12]. PD performance can be measured along different dimensions. Enhancing the flow of information in PD is a key goal being actively pursued [8, 14-16]. McManus referred to the concepts of ‘better, faster, and cheaper’ to describe lean product development [7]. Notions of effectiveness and efficiency have been proposed to respectively measure the ability of product development activities to meet product requirements, and the productivity with which these activities are carried on [6]. Browning expanded the notions of PD performance to suggest a value based PD performance model for product availability and affordability with the right technical performance developed by efficient PD processes [5].

An effective PD project is one that “arrives at new and unique solutions that achieves the requirements/specifications of the project” [6]. Lean product development consists of the following objectives: providing the right product with efficient processes and effective integration [7]. While the ultimate success of a PD endeavor may be measured by marketplace response, engineering management requires more immediate measurement of PD efficiency. Understanding the influence of key PD process parameters on flow performance supports Womack's lean thinking approach [12]. Given its influence on work in progress, lead time (LT_j) is used as an estimator of flow ($\hat{F}_n$), and provides a measure of value stream improvement potential [2], when comparing post- to pre-certification job performance, as follows:

$$\hat{F}_n = \sum_{j=1}^{m} LT_j = \sum_{j=1}^{m} E_j - S_j,\ j = 1,\ldots,\ m \tag{1}$$

where E_j is the end date of job j, and S_j the start date of job j, and n represents pre- or post-certification, for m jobs.

Discrete event simulation has been used over the years to evaluate the performance of complex systems. To help ascertain the influence of factors such as the level of multitasking, concurrency and average job charge size on PD process flow, a discrete event simulation model was developed.

The model covers the key PD phases of design, prototype manufacturing, and validation testing. Data inputted into the model consists of exponentially distributed, randomly generated charged hours by job. The generated charged hour stream replicates the observed time card charged hour pattern. Key groups of employees are established, and determination of which group will be performing the work is made during simulation. The start of each phase is modulated by the percent completion of the previous phase, thus allowing some level of concurrency. A high level of multitasking has been observed in the data gathered. Capabilities are provided to study the influence of this factor.

Managerial decision making during post-certification involves consideration of a number of criteria that support job prioritization as well as allocation of limited post-certification budgets and engineering resources. Multi-attribute value theory (MAVT) is based on the assumption that decision makers attempt to maximize an implicit value function, V. Many definitions of value have been proposed over time [16-18]. Consistently aligning multiple decision makers with common value criteria to prioritize jobs and optimize resource allocation is a challenge in PD projects [6].

Effective managerial decisions begin with consideration of multiple dimensions of value [23]. Explicit decision factors are incorporated into a decision model to improve decision making consistency. The multi-attribute value index approach involves constructing an aggregate value index by combining various attributes for each post-certification task into an ordinal scale of value. Benefits include simplicity, consistency of decision making across decision makers, and a sense of priority to engineering personnel having to select on which job to work. The general form of the value function V for a job j is as follows:

$$V_j = \sum_{i=1}^{n} w_i(c_i)v_l(c_i), i = 1,\ldots n, l = 1,\ldots,o,\ j = 1,\ldots m \tag{2}$$

where different value criteria v_l are evaluated for each job on a [0,10] scale, with weights w_i reflecting the relative importance of each criterion c. To reduce evaluation variability among decision makers, a short text is provided to describe the criteria for each level.

Coupled with the value index introduced above, a post-certification decision support model is required given the high number of decision makers and jobs, and the limited resources available. Here, the objective of managerial decision making is to decide which post-certification jobs to pursue, given limited resources and budgets. Assumptions are as follows: (i) job (j) originating from project (k) progresses via effort expended by engineering groups (i); (ii) the estimated effort to complete the job (ETC) over the next 12 months is available, and job value (V) is pre-established as per above; (iii) limited capacity (C) exists in engineering groups that work on jobs; (iv) limited post-certification budgets (B) are available for each project.

Variables are as follow: (i) B_p represents the pre-determined post-certification budgets in hours associated with each project; (ii) C_e represents specialist engineering groups post-certification capacity in hours; (iii) ETC_{je} denotes demand in hours; (iv) V_j is a pre-determined variable that conveys the value of job j; (v) $O_j = 1$ if a job is completed, otherwise $O_j = 0$; (vi) $P_{jk} = 1$ if job j is related to project k, otherwise $P_{jk} = 0$; (v) X_{je} represents the hours allocated by engineering group e on job j. The decision making model to maximize the realized value on completed jobs is as follow:

$$Max \sum_j O_j V_j \tag{3}$$

To ensure demand is met for each job for each engineering group, the following constraint is required:

$$\sum_e X_{je} = \sum_e ETC_{je} O_j \tag{4}$$

Engineering group capacity is not to be exceeded:

$$\sum_j X_{je} \leq C_e \tag{5}$$

Project budget is not to be exceeded:

$$\sum_j \sum_e X_{je} P_{jk} \leq B_k \tag{6}$$

3. Results

Examination of job classification over a one year horizon, using the post-certification taxonomy and decision tree, reveals that over 40% of the tasks fall into the post-certification category; further examination of the relative performance of this type of job is thus warranted by its relatively higher frequency of occurrence.

Key lean engineering performance benchmarking metrics comparing pre-certification and post-certification jobs performance have been evaluated using a recently published lean engineering model [2]. More than two million time card entries have been analyzed for over 70 jobs. Comparisons were made within the same product family.

The PD benchmarking data provided evidence that the pre-certification engineering environment is a leaner PD environment than the post-certification one, according to lean engineering performance metrics of time and invested intellectual capital (using Little's law relation), even when adjusted for an average effort differential of 30% higher for post-certification. A similar time frame has been used to collect data for both types of jobs. From a lead time (LT) standpoint, the post-certification environment requires on average 80% more time completing a job; wasted effort is 5.8 times higher than in the pre-certification environment; 8.4 times more people charge time on post-certification jobs. Post-certification jobs are delayed by non-progression as shown by the touch time ratio (TTR) at a 10% higher rate than pre-certification jobs. Finally, in the period studied, the focus (i.e., inverse of multitasking) of employees working on pre-certification jobs as evidenced by their time card charge pattern versus other jobs is about 17 times higher than that for employees working on post-certification jobs.

To further examine the influence of focus and concurrency on lean PD performance metrics, a case study was built from sample post-certification observation data. A full factorial design of experiment with r=3 replications was conducted for k=3 factors (focus, phase concurrency, and mean of the charged hour distribution) at n=2 levels (high, low). Two lean PD performance response metrics were calculated. Response variables were lead time (LT) and touch time ratio (TTR). Interaction plots show that the charge size does not appear to have a significant impact on LT, while focus has the highest influence on LT, and concurrency has a moderate one. Analysis of variance confirmed that focus, concurrency and 2 way interactions were significant factors affecting LT with p-values $\leq$ 0.05. Linear regression was conducted and the model was explained.

In a lean PD environment, value is realized upon job completion. Leveraging a previous case study, four alternative decision making environments were evaluated. A full factorial design of experiments with r=1 replication was conducted for k=2 factors at n=2 levels (post-certification budgets for project or entire, and job value index at unity or unrestricted). Response variables were throughput and realized value. Results obtained showed that decision making value improvement in excess of 50% could be realized when optimization considered entire post-certification budget and jobs rather than the local project based optimization approach with unity value index. To a lesser extent the consideration of a value index different from unity also improved value realized from between 4 to 9%. However, the use of unrestricted job value in decision making resulted in 10% less throughput in the local project budget case.

4. Discussion and future work

Various mechanisms were investigated to decrease the level of multitasking, to improve on focus factors and to support flow enhancement via LT reduction in the PD process. This included management of demand with release predicated upon a constant level of jobs in the PD system as well as consideration of cellular product design.

Comparison with actual results observed on the sampled jobs point to limitations in the current discrete event simulation model. Although the nature of PD is such that a job is handled by specific engineers with adequate knowledge, limitations with the number of blocks in the version of the simulation software used mandated the use of n-server blocks, which did not model adequately the observed, real life design behavior. These limitations considerably biased the experimental LT and TTR observations. Further model development with an unrestricted version of the simulation software is underway.

This improved model will enable assessing the influence of items such as rework, job size, dynamic job value assignation, alternate prioritization schemes (earliest due date, shortest weighted remaining processing time [20]), on previous lean measurements, as well as on metrics that could not previously be measured via simulation such as waste, work in progress, number of nodes, TTR, number of tardy jobs, etc. The simulation model will be validated by results from actual observations from the same jobs. Ultimately, the transformation of multiple lean performance criteria into a single lean quantity should lead to the determination of an optimal PD process job size.

There are a few challenges with the post-certification decision making optimization modeling. From a political standpoint the deployment of such an approach requires buy in from all decision makers with executive support to help demonstrate benefits of enhanced decision making ability. From a more technical standpoint, the current integer linear programming optimization approach is limited to smaller problems, given the high number of alternatives that would have to be investigated by the branch and bound solution approach (NP hard). Further research will be conducted to develop appropriate heuristics for industrial sized problems, such as GA based meta-heuristics [19]. From a practical standpoint, an important issue relates to the quality of data available to decision makers. As with any enterprise resource planning system, there is notionally a maximum of data defects above which quality decision making will not be possible. 80,000 defects per million opportunities (DPMO) is recommended before implementation of a DSS [20]. Data envelopment analysis (DEA) techniques should be used to evaluate the appropriateness of weights used in the MAVT approach.

5. Conclusion

This paper started with a review of a novel post-certification taxonomy and decision tree. Then, the concept of a lean PD benchmarking study of engineering post- to pre- certification activities has been introduced, followed by a discrete event simulation model of the post-certification PD process. Finally, the concept of MAVT and post-certification decision support optimization model was presented.

Next, results emanating from the classification of a sample of jobs were shared, emphasizing the adequateness of focusing on post-certification jobs. Results from the lean PD benchmarking model confirmed the improvement opportunities with post-certification jobs, and then a discrete event simulation model showed that LT performance is significantly influenced by the level of multitasking, and to a lesser degree by concurrency. Finally, results from the post-certification decision making model showed that over 50% realized value improvement could be achieved with global post-certification project budget and resource allocation optimization, and up to 10% more using a value index.

Future work will involve the development of an enhanced simulation model, as well as the development of a meta-heuristic approach suitable for industrial size problems. Also there will be further research towards the establishment of optimal PD process parameters, including the determination of the optimal job size.

References

1. Aral, S., Brynjolfsson, E., Van Alstyne, M., 2007, "Information, technology and information worker productivity: task level evidence", National Bureau of Economic Research, Massachusetts.
2. Beauregard, Y., Thomson, V., Bhuiyan, N., 2008, "Lean engineering logistics: load leveling of design jobs with capacity considerations", Canadian aeronautical and space journal, 54(2), 19-33.
3. Project Management Institute. 1996. A guide to the Project Management Body of Knowledge. Project Management Institute Standards Committee.
4. Murman, E., Allen, T., Bozdogan, K., Cutcher-Gershenfeld, J., McManus, H., Nightingale, D., Rebenstish, E., Shields, T., Stahl, F., Walton, M., Warmkessel, J., Weiss, S., Widnall, S., 2002, Lean enterprise value: insights from MIT's lean aerospace initiative, Palgrave , New-York.
5. Browning, T., 2000, "Value based product development: refocusing lean", Engineering management society, Proc. of the 2000 IEEE, August 13-15, Albuquerque, NM, 168-172.
6. Kratzer, J., Gemunden, H.G., Lettl, C., 2008, "Balancing creativity and time efficiency in multi-team R&D projects: the alignment of formal and informal networks", R&D management, 38(5), 538-549.
7. McManus, H., Haggerty, A., and Murman, A., 2005, "Lean Engineering: Doing the right thing right", 1st International Conference on Innovation and Integration in Aerospace Sciences, 4-5 August, Queens University, Belfast, North Ireland, UK.
8. Beitz, A., Wieczorek, I., 2004, Applying benchmarking to learn from best practices, Springer, Berlin.
9. Wirhtlin, J.R., 2000, "Best practice in user needs/requirements generation", Master Thesis, MIT.
10. Walton, M.A., 1999, "MIT, Strategies for lean product development", Lean aerospace initiative, Massachusetts.
11. Cooper, R.G., Edgett, S.J., Kleinschmidt, E.J., 2001, Portfolio management for new products, 2nd edition, Perseus, Massachusetts.
12. Womack, J. P., Jones, D., 2003, Lean thinking banish waste and create wealth in your corporation revised and updated, Free Press, New York.
13. Reinertsen, D., 2007, "Rethinking lean NPD", Strategic directions, 23 (10), 32-34.
14. Taylor, D. H., 2005, "Value Chain Analysis: an approach to supply chain improvements in the agri-food chain", International journal of physical distribution and logistics management. 35(10), 744-761.
15. Oppenheim, B., 2004, "Lean product development flow". Systems engineering, 7(4), 352-376.
16. Dowden, T. D., 2005, "Exercising a multi-attribute value method for business airplane product assessment", 43rd AIAA Aerospace Sciences Meeting and Exhibit - Meeting Papers , Jan 10-13, Reno, N, 8757-8769.
17. Park, R.J., 1998, Value engineering: a plan for invention, St-Lucie Press, New York.
18. Slack, R., 1999, "The lean value principle in military aerospace product development", MIT lean aerospace initiative report series RP99-01-16, Cambridge.
19. Hillier, F.S., Lieberman, G.J., 2005, Introduction to operations research, 8th edition, McGraw Hill, New York.
20. Sipper, D., Bulfin, R., 1997, Production Planning, Control & Integration, McGraw-Hill, New York.
21. Hines, P., Found, P., Griffiths, G., Harrison, R., 2008, Staying lean: thriving, not just surviving, Lean enterprise research center, Cardiff.
22. Storch, R. L., 1999, "Improving flow to achieve lean manufacturing in shipbuilding", Production planning and control, 10(2), 127-137.
23. Mavrotas, G., Panagiotis, T., 2005, "Multi-criteria decision analysis with minimum information : combining DEA with MAVT",Computers & operations research, 33(2006), 2083-2098.