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CRITERIA FOR EVALUATING THE SUCCESS OF LARGE-SCALE ENGINEERING PROGRAMS

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1. Introduction and context

1.1 Challenges of managing complex engineering programs

Managing large-scale engineering programs has proven to be difficult. There are numerous reports that describe schedule delays, massive cost overruns and a shortfall in performance. The development programs sponsored by the US Department of Defense for example are on average 22 months behind schedule. The development programs currently being underway have accumulated a cost overrun of close to $300 billion [GAO 2009]. Transportation infrastructure programs, still formidable engineering challenges but not as plagued by low levels of technology readiness, also perform poorly with average cost overruns of 30%-50%, this time attributable to changing stakeholder requirements [Cantarelli et al. 2010]. Other research highlights the cost and schedule impact that the development and production supply chain has, for example in large commercial aerospace programs [Tang et al. 2009].

1.2 Existing program management standards and the complexities of measuring success

Management organizations have realized that in order to successfully execute such endeavors, good project management alone is not sufficient. Subsequently, several program management standards emerged to address this challenge, for example the Standard for Program Management by the Project Management Institute [PMI 2008], Managing Successful Programs by the UK Office of Government Commerce [OGC 2007], the Defense Acquisition Guidebook by the US Defense Acquisition University [DAU 2011], or more engineering-focused standards such as the Handbook for Systems Engineering published by the International Council on Systems Engineering [INCOSE 2011]. While all standards have a slightly different view and understanding of programs, we define programs following as multiple related projects and their resulting enterprise that exist over an extended period of time to deliver a complex value proposition over and above the individual projects' benefits and utilize efficiency and effectiveness gains between these projects [Oehmen et al. 2011], [OGC 2007]. While these program management standards are under continuous development and improvement, one critical question remains open: How can an organization assess the success of a program?

1.3 The concept of program success and its measurement

While on the surface the answer seems easy – rely on typical high-level success metrics that are familiar from project management, such as cost, schedule and performance [Delano 1998] – the situation in programs is more complex. Hence, the definition of "success" becomes more complex [de Wit 1988]. While the timeframe of a single (sub-) project may be very well defined, programs can easily last for 20-30 years or longer. Planning assumptions are often characterized by a high degree of

uncertainty, both on the requirements as well as the capabilities side, making frequent recalibration necessary and the tracking of "target achievement" difficult. It also makes it imperative for the program enterprise to be able to learn, change and adapt easily and efficiently. Also due to the long time scales, other organizational elements might become much more important, such as maintaining or building capabilities (e.g. accepting a financial "loss" for several years to acquire or maintain a critical technical competence).
At the same time, being able to track and evaluate program performance has never been more important: Programs are typically large, requiring investments on the order of hundreds of million or billions of dollars. The need for accountability on what this money "buys" is correspondingly large as well, both in the public and private domain [Cook et al. 1995], [Scheirer and Newcomer 2001]. Clear success metrics are also relevant for any type of benchmarking effort [Scheirer and Newcomer 2001] or self assessment tool [Knoblinger et al. 2011]. Similarly, clear, plannable success criteria are relevant to set appropriate goals and facilitate stakeholder discourse [Acosta et al. 2002], [Scheirer and Newcomer 2001].

1.4 Research objectives and approach

In this paper a framework is presented addressing the issue of success measurement in the context of large-scale engineering programs (Section 4.). To improve the current state of practice, this paper synthesizes a wide range of metrics from the literature (Section 3.2) into a coherent multidimensional framework according to the idea of a balanced scorecard (Section 2.2) to address the complexities of program management. It furthermore provides a collection of concrete metrics in each category (Table 2). The framework is then reviewed and validated by an industry focus group (Section 3.3).

2. Literature review

2.1 Program success

One way to categorize programs is the split into three types: 1. Technology, engineering and infrastructure related programs that aim at creating an artifact, 2. Business change programs, aiming to institutionalize organizational and process change, such as cost reduction or continuous improvement, and 3. Public service programs that strive to improve the quality of life and well-being of the general public, for example increase mobility or reducing instances of childhood obesity [OGC 2007]. Large-scale engineering programs are not confined to the first category: They present formidable engineering and technology challenges (category 1), must create a highly efficient organization that supports and executes them (category 2) and are aimed at delivering a "greater good" to society (category 3). Therefore, when evaluating their overall success, criteria that address all categories must be taken into account [Martinsuo and Lehtonen 2007], [Pellegrinelli et al. 2007].
When reviewing current literature on the concept of success in product development bearing in mind the wider context of large-scale engineering programs, the latter two categories are hardly represented. Especially in the context of product development even very comprehensive approaches to success measurement seem to miss these aspects of large-scale engineering programs [Griffin and Page 1996], [Griffin and Page 1993], [Hart 1993], [Jiménez-Zarco et al. 2006], [Kazerouni et al. 2011]. Some authors aggregate success to a small number of primarily financial metrics [Cooper and Kleinschmidt 1996], [de Brentani 1989], [Cooper 2006], [Hollins 2008]. Others leave it open, relying on the individual person assessing program success to use their own definition in a statement of overall program success [Barczak et al. 2009], [Dobbins and Donnelly 1998].
On the other hand there are frameworks for success measurement that do address all three aspects of program success. These frameworks are designed for programs in general, but do not specifically focus on engineering programs. Therefore, they lack a sufficient technical perspective crucial for success of large-scale engineering programs [Atkinson 1999], [Patanakul and Shenhar 2007], [Chan 2004]. Furthermore, when trying to incorporate a wider view of "success", one is inevitably confronted with the trade-off between being inclusive in the description of the various aspects of program success, but not too vague. A number of the reviewed frameworks do indeed comprise a

wider set of dimensions but fail in providing specific metrics to measure success within these dimensions [Lycett et al. 2004], [Poister 2010], [Shenhar et al. 1997], [Balachandra and Friar 1997].
Table 1 presents an overview over the reviewed approaches to success measurement. In the table the publications are clustered according to their specific focus on product development (PD), project (PM) and program management (PgM) or services (Service). Furthermore, it is assessed to what extent the three dimensions of large-scale engineering programs are represented in the success definitions. Finally we differentiate those definitions that provide detailed metrics as opposed to general success dimensions. Neither one publication equally addresses all aspects of large-scale engineering programs and at the same time provides a set of detailed metrics. This paper therefore aims to provide a framework that balances the width of embracing all relevant perspectives and depth of providing concrete metrics.

Table 1. Literature review on success measurement

Publication	Focus	Technical Perspective	Change Perspective	Public Service Perspective	Detailed Metrics
Balachandra & Friar 1997	PD	◕	◑	◑	no
Cooper & Kleinschmidt 1996	PD	◑	○	○	yes
Griffin & Page 1996	PD	●	○	○	yes
Hart 1993	PD	●	◔	○	yes
Jiménez-Zarco et al. 2006	PD	●	◔	○	yes
Kazerouni et al. 2011	PD	●	◔	○	yes
Atkinson 1999	PM	◔	●	●	yes
Devine et al. 2010	PM	◑	◕	○	yes
Shenhar et al. 1997	PM	◑	◑	○	no
Delano 1998	PgM	●	○	○	no
Lycett 2004	PgM	○	●	○	yes
Patanakul & Shenhar 2007	PgM	○	●	○	yes
Poister 2010	PgM	◔	◕	◔	no
Shao & Müller 2011	PgM	◑	●	●	yes
Shao et al. 2012	PgM	●	◔	○	yes
Chan 2004	Service	○	◕	●	examples
de Brentani 1989	Service	◕	○	◕	no

○ not at all addressed, ◔ partially addressed, ◑ addressed, ◕ extensively addressed, ● fully addressed

2.2 A balanced scorecard approach for measuring program success

Success of product development activities is a complex phenomenon influenced by many more factors than financial, schedule and technical performance of the program. A framework for measuring success has to account for this multidimensionality. Authors from all three perspectives of large-scale engineering programs, product development [Bremser and Barsky 2004], change management [Feurer and Chaharbaghi 1995] and public services [Poister 2010], call for a more balanced set of performance dimensions and metrics to account for the level of complexity. Accordingly they refer to the idea of the balanced scorecard model presented by [Kaplan and Norton 1992] to resolve this issue.
The balanced scorecard was initially presented as a performance measurement system and later evolved into a strategic management tool. It takes different perspectives on performance to complement financial measurement with a customer, internal process oriented and a learning and growth perspective [Kaplan and Norton 1992], [Kaplan and Norton 2001].
The idea of a multidimensional set of metrics has quickly been applied to other areas than corporate strategy including product development activities [Devine et al. 2010], [Chan 2004], [Jiménez-Zarco et al. 2006]. [Jiménez-Zarco et al. (2006)] state that an adoption of the concept bears the chance for substantial improvements for measuring development success but not without adapting the dimensions to the specific context away from the corporate strategy level to the development project level. The same applies to large-scale engineering programs.

3. Research method

3.1 Data gathering and relevant literature

As a first step we reviewed literature providing a definition of success in the investigated context of large-scale engineering programs as described in the previous section. From the publications presented in Table 1 we extracted the core elements of the respective definitions, dimensions and/or concrete metrics of success. We collected both dimensions (i.e. categories) of success metrics as well as the success metrics themselves. The overall goal was developing a balanced scorecard-type approach to measuring success in engineering programs. The results were two sets of raw data: 72 dimensions and 314 metrics. Not surprisingly, both sets contained a number of duplicates.

3.2 Data analysis

3.2.1 Success dimensions

We designed the success dimensions taking into account that there is more than one aspect of success in the context of large-scale engineering programs as outlined before. Therefore, in addition to the set of 72 dimensions we also incorporated aspects of all three types of programs (1. technology, engineering and infrastructure, 2. business change, and 3. public service). Hereby, we ensured that the crucial elements of success for either type are represented at the dimension level. Furthermore, we incorporated the five program performance domains [Norman 2011]. The five domains (1. Program Strategy Alignment, 2. Program Benefits Management, 3. Program Stakeholder Engagement, 4. Program Governance and 5. Program Lifecycle management) provide a guideline for the program execution with activities in each of the domains.
When defining the dimensions we started with the original perspectives of the balanced scorecard, namely 1. Finance, 2. Customer, 3. Internal Processes, and 4. Learning and Growth. The four perspectives were matched with the program categories and performance domains. We ensured that the 72 dimensions identified in the literature could be assigned to at least one of the newly designed dimensions. This resulted in the dimensions presented in the next part of this paper.

3.2.2 Success metrics

For the metrics we first consolidated the set of 314 metrics derived from literature. As a first step we developed cluster of literally identical metrics as well as metrics closely related with regards to content. As an example we found reference to *cost effectiveness* in several publications. In addition other authors referred to more concrete techniques of measuring cost effectiveness like *internal rate of return*, *return of investment*, or *payback time.* As a result of this task we had a list of metrics with their respective number of referrals in the reviewed literature and the exact terms used to refer to them. In total we summarized the 314 metrics to 109 with 83 being referred to only once and 26 twice or more. For reasons of better manageability and to filter single opinions we continued working only with the 26 metrics quoted by at least two authors. We assigned these metrics to one of the five dimensions defined in the previous step to develop the first draft of the complete framework for measuring success of large-scale engineering programs, which was subsequently validated and refined by an industry focus group.

3.3 Validation

In order to ensure validity of the results and applicability in practice we consulted a group of 8 subject matter experts with program management experience primarily from an aerospace and defense industry background, to review the draft of the framework and provide additional feedback. The results were threefold: 1. The dimensions needed further explanation. In some cases it was not clear from the name what the metric aimed for. Therefore, we added a brief explanation of the dimensions and metrics as outlined in the following section. 2. The metrics displayed in the first draft did not always reflect the same level of abstraction. Where some were too vague they had to be decomposed in more concrete metrics. On the other hand very specific metrics had to be abstracted to a higher level ensuring consistency throughout the framework. 3. Once clarified the expert group assessed the framework as very comprehensive, accounting very well for the complexity of large-scale engineering

programs. Its final, reviewed version of the framework consisting of 26 metrics in five dimensions is presented in more detail in the following section.

4. A framework for measuring program success

With the afore mentioned methodology we designed the framework for measuring program success. The framework consists on the top level of five dimensions: I. Enterprise Strategy Alignment, II. Product and/or Service Performance and Quality, III. Learning and Change, IV. Program Management Process Quality and Efficiency and V. Financial and Business Success. On the second level it comprises of a set of 26 metrics assigned to one of the dimensions. The following sections briefly introduce the success dimensions, describe the metric types, as well as present concrete example metrics gathered from the literature review in Table 2.

4.1 Enterprise strategy alignment

Within the dimension of Enterprise Strategy Alignment the evaluated program is assessed regarding its contribution to and alignment with the overall strategic goals of the program enterprise. These goals can vary from market-oriented goals, image campaigns to social and environmental benefits. The metrics associated to Enterprise Strategy Alignment are:

- **I.1. Social and Environmental Benefits** assesses the positive impact on the social and ecological environment within and around the program enterprise.
- **I.2. Stakeholder Satisfaction** considers the wishes and requirements of the wider set of involved persons than just the shareholders or program sponsors. It measures to what degree the different groups of stakeholders were satisfied with the results and execution of the program.
- **I.3. Competitive Position** describes the program enterprise in its competitive environment in terms of a dominating role and the influence the evaluated program had on improving or sustaining it as well as any kind of competitive advantage gained through the program.
- **I.4. Reputation** measures the influence the program had on helping to establish and maintain a specific desired image of the program enterprise to the customers but also the general public.
- **I.5. Strategy Alignment** assesses the consistency of the program, its goals and the way it is executed with the enterprise strategy.

4.2 Product and/or service performance and quality

The program success dimension Product and/or Service Performance and Quality comprises success metrics directly related to the technical (product) or delivery aspect (service) of the desired outcome, as well as their acceptance by the customers. The metrics are:

- **II.1. Performance** measures the technical success in terms of the compliance of the end product with the initially set performance specifications.
- **II.2. Quality** measures the compliance of the end product with the initially set quality specifications. Furthermore, reliability and maintainability of the product in use are taken into account.
- **II.3. Technological Achievement** assesses the inventive and innovative character of the program. There is more of strategic component to it compered to the performance metric
- **II.4. Customer Satisfaction** assesses the degree to which the customers are satisfied with the end product and/or service developed in the program.

4.3 Financial and business success

Within the dimension Financial and Business Success the commercial success of the program is assessed. The following set of metrics comprises internal metrics as costs and external that represent the success in the marketplace.

- **III.1. Cost Effectiveness** measures the profitability over time and compares it to enterprise thresholds and the initial planning.
- **III.2. Cost** describes the whole costs incurred during the program. The metric compares the actual costs against the planned costs. If applicable to the program it can be meaningful to consider costs relative to the number of units.

III.3. **Market Success** reflects the market acceptance of the product or service. It comprises the following metrics:
   a. **Market Share** expresses the commercial success of the program by measuring the market share the product achieved in its respective segment.
   b. **Customer Loyalty** measures the retention rate of existing customers from predecessor products but also takes into account cross-selling rates.
   c. **Percentage of Sales by New Product** as a metric for innovativeness of an enterprise breaks down the composition of the enterprise's total sales volume and measures the proportion the program accounted for.

III.4. **Revenue** measures the total monetary sales volume of the program's end product.

III.5. **Profit** measures the profitability of the program as revenue in relation to costs.

III.6. **Shareholder Value** assesses the benefits the program achieves for the shareholders expressed through the impact the program has on the enterprise value or the stock value for market listed enterprises.

4.4 Learning and change

The dimension of Learning and Change assesses how much the enterprise changed itself and its surrounding environment through executing the program. It investigates the individual as well as the enterprise and ultimately societal level of learning and change with the following metrics:

IV.1. **Top Management Involvement,** as often mentioned crucial for program success as an enabler, can also be seen as an indicator for success in terms of increasing the bonding between management and lower level employees as an improved organizational asset for future programs.

IV.2. **Improved Collaboration and Communication** as an aspect of change within the enterprise measures the progress that was achieved in the collaboration within and across different divisions of the program enterprise.

IV.3. **Learning and Development** assesses learning and skill development throughout the program enterprise. Depending on the progress it can be measured on an individual skill level, behavior level or finally their impact on an organization wide level. It also comprises the success of knowledge management activities to foster knowledge sharing.

IV.4. **Employee Satisfaction** is measured through direct statement of the satisfaction level e.g. in employee surveys or through indirect measures such as the employee turnover rate

IV.5. **Preparation for the Future** is measuring to what extent the program contributed to make the enterprise future proof, may it be by developing a crucial technology or the establishment of new improved processes that will help the enterprise in the acquisition and execution of future programs.

4.5 Program management process quality and efficiency

The dimension Program Management Process Quality and Efficiency comprises all metrics directly related to the program management process. It expresses success in terms of managing the program in a way that the set objectives are met, but also in terms of process efficiency and resource utilization. The five metrics in this dimension are:

V.1. **Risk** assesses the uncertainty of negative impacts on the objectives of the program.

V.2. **Scope Evolution** assesses to what extent the program objectives have changed and how well the program enterprise coped with these changes.

V.3. **Objectives** measures the degree to which the set objectives throughout the program management process were met.

V.4. **Interdependencies** assesses how well interdependencies between projects within the program as well as dependencies with external programs and initiatives were managed.

V.5. **Time** compares the actual program length with the schedule.

V.6. **Process Efficiency** relates to the program management process. Efficiency measures the output related to the input, what was achieved in the program and what amount of resources had to be utilized.

Table 2. Example metrics

#	Metric Type (No. of Citations)	Example Metrics
I.	**Enterprise Strategy Alignment**	
I.1.	Social and Environmental Benefits (8)	quality of life, social and environmental impact
I.2.	Stakeholder Satisfaction (6)	managing stakeholders, steering group satisfaction
I.3.	Competitive Position (15)	image of the competitors' products, influence in the specific industry, market position, sales growth vs. five target competitors, competitive achievement, perceived superiority, profitability vs. competitors, competitive advantage, quality of the competitors' products, uniqueness of new product
I.4.	Reputation (6)	brand image, strength of the new product image, name and recognition
I.5.	Strategy Alignment (7)	better alignment with business drivers, business continuity, consistency of the product with the resources and capabilities of the company, strategic goals
II.	**Product and/or Service Performance and Quality**	
II.1.	Performance (9)	functionality, meets technical performance objectives, performance specs, system implementation met requirements, technical success rating
II.2.	Quality (12)	build standard, degree of quality orientation, maintainability, met quality guidelines, perceived quality, quality specs, reliability, service quality
II.3.	Technological Achievement (7)	innovativeness, new technology, science-technology development
II.4.	Customer Satisfaction (20)	degree of customer satisfaction, satisfaction rate, customer service rating, deliver customer needs
III.	**Financial and Business Success**	
III.1.	Cost Effectiveness (10)	break-even time, cost-benefit data, internal rate of return or return on investment, period of restitution, profitability relative to spending
III.2.	Cost (20)	average costs for the development of new products, development costs, cost per unit, investment costs, lowering product costs, meets cost objectives
III.3.	Market Success (13)	number of customers, increase in market share, met market share goals, customer retention rate, degree of customer loyalty, percentage of customer retention, percentage of turnover accounted for by products launched in last five years, percentage of sales by new products
III.4.	Revenue (14)	met sales objectives, met minimum revenue level by the end of year one, met revenue goals, potential sales volume, sales growth, sales growth vs. five target competitors/ industry average
III.5.	Profit (13)	attain margin goal, attain profitability goal, average profits, benefits margin, increased profits, meeting profit objectives, profit impact
III.6.	Shareholder Value (3)	benefits for shareholders, sponsor satisfaction
IV.	**Learning and Change**	
IV.1.	Top Management Involvement (3)	degree of high-management support for the development of innovation process, greater senior management visibility, increase confidence in leadership
IV.2.	Improved Collaboration and Communication (8)	degree of interfunctional coordination, degree of internal and external cooperation, good interaction, improved co-ordination, more coherent communication, more effective resource utilization, team building
IV.3.	Learning and Development (13)	degree of learning and innovation orientation, front-line personal capabilities, gaining experience, more effective knowledge transfer, organizational learning, percentage of training dollar compared to base salaries, career prospect
IV.4.	Employee Satisfaction (6)	degree of employee information, employee satisfaction index turnover rate, employee suggestion data, increase retention of high quality employees
IV.5.	Preparation for the Future (3)	opening new markets, platform for future
V.	**Program Management Process Quality and Efficiency**	
V.1.	Risk (5)	financial risk measurements, risk assessment
V.2.	Scope Evolution (2)	number of change requests
V.3.	Objectives (2)	met business objectives
V.4.	Interdependencies (Expert)	value of synergies realized
V.5.	Time (16)	cycle time, development process speed, launch on time, meets initial operational capability date, response time, schedule control, speed to market
V.6.	Process Efficiency (10)	development efficiency, hours saved, improved effectiveness, improved efficiency, operational excellence, productivity

5. Conclusion and outlook

5.1 Discussion

The presented framework for measuring success of large-scale engineering programs fills a gap in current literature. It overcomes the main shortcomings of current approaches to success measurement when applied to large-scale engineering programs.

The framework is tailored to the characteristics of large-scale engineering programs, it accounts for the increased complexity of programs as opposed to design projects. The framework not only incorporates the classic success dimensions of project management – cost, schedule and performance - moreover, its multidimensional approach allows placing significant emphasize on "softer" and leading factors such as learning and strategy. So the framework in addition to the technical perspective (primarily in II. Product and/or Service Performance and Quality) also addresses the inherent change (IV. Learning and Change) and public service aspect (primarily in I. Enterprise Strategy Alignment) of large-scale engineering programs as discussed.

However, despite being broad enough to cover the complexity of these programs we still designed it bearing in mind the needs of practitioners regarding usability. Whereas some of the reviewed approaches are fairly vague in their definition of success and consist only of broader categories we mention more detailed metrics assessing success within the five dimensions presented.

5.2 Applications, limitations and outlook

The framework for measuring success in engineering programs offers professionals a structure to reflect programs regarding their success. Its dimensions and metrics provide a basis for an individual assessment. Since the intended benefits are often unique to a single program we intentionally did not try to weigh and rank the dimensions and metrics. We believe that such customization can only be done on an individual program level. However, we do believe that the dimensions and metrics themselves are universally applicable. Tailoring the framework to the individual program will allow professional to set goals appropriate to the diversity of the program and prioritize them accordingly to support decision-making and performance measurement.

For academics the framework fills the gap in current literature of success measurement in engineering programs by presenting the state of the art in measuring success in the analysed disciplines and combining that body of knowledge for a new application. It provides the basis for further research in the field that may use the framework when developing a self-assessment or researching success enablers for engineering programs.

The framework as presented in this paper has not yet been applied. However, the design of the framework itself might serve as some sort of validation itself since it builds upon established frameworks. In addition we discussed and refined the framework with a focus group of experienced program management professionals.

To address this limitation we are currently conducting a follow-up study in which we use this framework in a survey to let program managers assess their programs in terms of success and share insights on enabling success factors.

Furthermore, the framework as presented in this paper takes an ex-post evaluation perspective on program success. It focuses on evaluating programs with regards to success after program completion. Another interesting aspect is to continuously track the path to success during the program lifecycle. Transforming this evaluation into a performance measurement framework appears as a promising addition to the work presented in this paper.

5.3 Summary

In this research we designed a framework for measuring success of large-scale engineering programs. Current approaches were reviewed identifying their limitations for the specific application. We then designed the framework based on an intersection of current approaches to success measurement in the adjacent disciplines. Before completion the framework was run through a review loop with an industrial focus group of program managers. The final result as presented in this paper is a balanced scorecard of program success consisting of five dimensions and 26 metrics.

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