DEFINING 'PROJECT SUCCESS' FOR A COMPLEX PROJECT – THE CASE OF A NUCLEAR ENGINEERING DEVELOPMENT

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ABSTRACT

The case of a nuclear engineering project was investigated to establish the relevant success criteria for the development of complex, high-technology systems. The project was first categorised according to an existing scheme, and the Delphi method was used to determine the criteria for project success that apply to this specific case. A framework of project success dimensions was extended to include criteria that are of specific importance for the project under consideration.

While project efficiency (delivery on time and within budget) obviously still needs to be controlled, the results provide empirical evidence for the notion that, for 'super high tech' projects, this is relatively less important. The relative importance of the dimensions of success was also evaluated and presented on a timeline stretching from project execution to 10 years after project completion. This provided empirical evidence for certain concepts in the literature.

OPSOMMING

Die geval van 'n kern-ingenieursprojek is ondersoek om die relevante kriteria vir sukses vir die ontwikkeling van komplekse hoë-tegnologiesisteme te bepaal. Die projek is eerstens geklassifiseer volgens 'n bestaande skema, en die Delphi-metode is vervolgens gebruik om die relevante kriteria vir projeksukses vir die betrokke geval te bepaal. 'n Bestaande raamwerk van dimensies vir projeksukses is uitgebrei om kriteria wat van spesifieke belang vir die betrokke geval in te sluit.

Terwyl tydige aflewering, binne begroting natuurlik steeds belangrik is, voorsien die resultate empiriese bewys vir die nosie in die literatuur dat hierdie aspekte van relatief minder belang is in die geval van 'super hoë-tegnologie'-projekte. Die relatiewe belangrikheid van die dimensies van sukses is ook evalueer, en aangedui op 'n tydlyn wat strek van projekuitvoering tot 10 jaar na die afhandeling van die projek. Dit lewer empiriese bewys vir sekere bewerings in die literatuur.

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1. INTRODUCTION

Much has been written about the factors that lead to project success by, among others, Pinto and Slevin [1] [2], Pinto and Mantel [3], Delone and Mclean [4], and Turner [5]. However, as described later in this paper, there is no clear cut definition of 'project success' that applies to all projects in all environments. Therefore, before an approach can be developed to manage a specific project, the criteria and metrics to judge whether the project would be 'successful' need to be defined for the specific project or type of project.

The Pebble Bed Modular Reactor (PBMR) nuclear power plant project is a long-term high technology project aimed at establishing from afresh almost all systems of a nuclear power plant (including the development of nuclear fuel, fuel production facilities, and a nuclear reactor) based on pioneering technologies. At the time of writing, the core team at the PBMR head office in Pretoria consisted of some 800 people. This team was supplemented by more than a thousand people at universities, private companies, and research institutes involved in the project, making it one of the largest nuclear development projects globally. In the USA, PBMR is a partner in an industrial alliance led by Westinghouse Electric Company, which was awarded a contract by the US Department of Energy (DOE) to consider the PBMR technology as a heat source for producing non-carbon derived hydrogen [6]. The technology has distinct advantages, including that the modular design enables the construction of much smaller nuclear reactors for certain niche applications. Furthermore, the design allows refuelling without shutting down the reactor. The project uses German technology that was acquired in the 1990s by the South African utility company Eskom. Following this acquisition, a small team of people started working fulltime on the Pebble Bed Modular Reactor (PBMR) project in 1995 to develop a modular nuclear fuel and power plant based on the German technology.

While the initial estimates were much more optimistic, it is now recognised that projects to develop a nuclear fuel typically take more than 20 years. At the time of writing, the planned date for completing the first power plant was 2018. As a result of slipping on previously planned dates, the project has been subject to some criticism. Some maintain, however, that the slippage and overspending on the initial cost estimates do not necessarily constitute a serious failure for such exploratory work. Complicating factors include the fact that the pool of resources available to the project is limited because the global nuclear industry is in a state of hibernation; rigorous regulations regarding nuclear power; and the uniqueness of the South African political situation - all of which need special consideration in the management of the project. The question arises: How should project success be defined for this project – and for other projects of similar novelty, technology, complexity, and pace?

To improve our understanding of what project management in this environment requires, and to lay the foundation for successful completion of the PBMR project and other similar projects and programmes, an unambiguous definition of the concept 'project success' is required for the type of project under consideration. This study indicates that a specific, tailored project management approach needs to be considered, instead of traditional procedures that are proven in other environments. Appropriate success measures for a project of this nature and in this environment are defined. The relative importance of each of the success dimensions, and changes in the relative importance of such dimensions over time, can also provide an important perspective.

2. CLASSIFICATION OF PROJECTS

The scope of this study was limited to a very specific type of project, exemplified by the PBMR. The project classification scheme developed by Shenhar and Dvir [7] was used to define the specific project type.

The development of the classification scheme stemmed from work on project success factors. In a study by Fortune and White [8], a list of 27 project success factors was identified from 63 articles. Three main critical success factors - support from senior management, clear and realistic objectives, and the development of an efficient plan - were identified. At least one of these three is cited in 81% of the publications, but only 17% of the publications cite all three factors. This clearly illustrates the lack of consensus on success factors.

To demonstrate that a project should be classified before drawing conclusions, Shenhar and Dvir [9] identified the level of technological uncertainty at the moment of project initiation as a major variable that differentiates projects. They clearly prove that different success factors influence the successful completion of each type of project.

Dvir et al. [10] subsequently identified success measures and factors associated with each kind of project. Their results clearly show that a different success "framework" was applicable to each type of project, supporting the premise that a typological approach to project management should be employed.

In an attempt to further prove that "one size does not fit" all projects when it comes to an approach towards management, Shenhar [11] evaluated more than 50 projects, based on the complexity of scope and technological uncertainty.

Shenhar et al. [12] proposed a project classification scheme based on the dimensions of *uncertainty*, *complexity*, and *pace* to define the type of project and its unique associated requirements. Shenhar and Dvir [7, p 47] developed the framework further to include *four* factors: novelty, complexity, technology, and pace – the NCTP scheme for project classification. The four dimensions of the scheme are defined as follows:

- Novelty. This relates to how *new* the product is *to the market*, customers, and potential users. Product novelty affects how easy it is to know what to do or what to build, and how to market a product to customers.
- Technology. This is defined as the knowledge, capability, and means needed to create, build, manufacture, and enable the use of the product. This measure is included to assess the extent to which the project is using *new* or *mature technology*. This can be a very subjective measure, but a well-proven approach is to base it on the share of new-to-the-company technology within the product.
- Complexity. With this dimension the focus is on the *intricacy of the project*, not of the product. But the complexity of a project often results directly from the complexity of the product.
- Pace. This refers to the urgency and criticality of meeting the project's time goals.

Shenhar et al. [11] used the NTCP model to begin the development of a framework for project management within NASA, while Sauser et al. [14] used the NTCP model in a separate study, and concluded that a specific approach needs to be considered for every separate situation, and that 'one size does not fit all' when it comes to project management practice.

From the above-mentioned work on project classification, it is clear that one should not plan a project or develop a project management methodology without due consideration of the unique characteristics of the specific project or type of project. It is also apparent that a typological approach should be the starting point when evaluating aspects of project success.

To provide insight into an appropriate approach for managing the PBMR project, the notion of 'project success' specific to the project had to be determined. As a prelude to assessing project success for the PBMR project, the project was classified as follows:

- Novelty: Breakthrough – it represents a radical innovation, often called 'new to the world' products. Market research is ineffective for such products, and product requirements will only stabilise after prototypes have been built and after intensive interaction with customers.

- Complexity: Array – a project dealing with a large, widely-dispersed collection of systems that function together to achieve a common purpose. (Other examples are national communication networks and regional power distribution networks.)
- Technology: Super high-tech – a project based on new technologies that do not exist at project initiation.
- Pace: Fast/competitive – a project carried out to address market opportunities.

This classification is illustrated in Figure 1.

Classifying the project also provides a reference for the work done in this study, relating the project under consideration to other projects that would have a similar NTCP classification. In other high technology environments, such as the defence industry, it is common practice *not* to develop new technology and a new, complex system based on the new technology simultaneously; proven technology is used in the development of complex new systems. The classification above clearly illustrates the high level of risk associated with the PBMR project.

3. MEASURES OF PROJECT SUCCESS

One of the most important aspects that influence the outcome of a project is the measures used to gauge its success. These are normally determined at the highest level of the organisation, and shape the actions of the entire project team from inception to close-out.

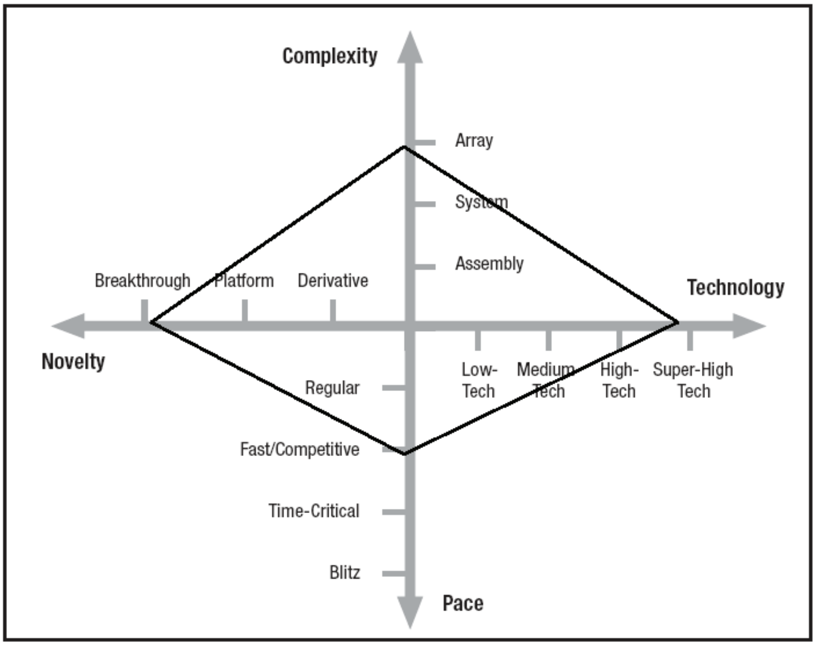

Figure 1: NTCP classification of the PBMR project
(Model by Shenhar & Dvir [7] applied to the PBMR)

Most project management texts link the measurement of project success directly to the so-called 'iron triangle' of time, money, and quality. For many years these factors were deemed the only ones to consider when measuring the success of a project. However, it makes sense also to include several other factors. As Freeman and Beale [15] put it: *"Success means different things to different people. An architect may consider success in terms of aesthetic appearance, an engineer in terms of technical competence, an* *accountant in terms of dollars spent under budget, a human resources manager in terms of employee satisfaction. Chief executive officers rate their success in the stock market.*"

Atkinson [16] questions the unconditional use of the 'iron triangle' to measure project success. He even suggests that this mindset might be the underlying cause of continual project failures in industry. As motivation he describes two stages in a project's life-cycle: the delivery stage and the post-delivery stage. During the delivery stage, standard measures can be applied, as a process is normally being followed for execution within set boundaries. Here the focus is naturally on "*doing* it right". In the post-delivery stage, customers, users, and the organisation itself are concerned; and the main question here is, "Did we *get* it right?" In other words, "Can appropriate benefits be reaped?" In the long run "*getting* it right" proves to be much more significant than "doing it right". Atkinson [16] builds on work done by Delone and Mclean [4] and develops what he calls a non-exhaustive list of success criteria, divided into four dimensions that he calls the "Square Route". In turn, Shenhar et al. [17] built on the work of Atkinson [16] and others to create a similar but refined model, also with four dimensions. These dimensions are:

- Project efficiency:
  - Meeting schedule goals
  - Meeting budget goals

- Impact on the customer:
  - Meeting functional performance
  - Meeting technical specifications
  - Fulfilling customer needs
  - Solving a customer's problem
  - The customer is using the product
  - Customer satisfaction

- Business success:
  - Commercial success
  - Creating large market share

- Preparing for the future:
  - Creating a new market
  - Creating a new product line
  - Developing new technology

This model was subsequently tested on 127 projects, classified into groups by technological uncertainty at project onset, to provide success measures applicable to each of the various project types. Shenhar et al. [17] indicate that the dimension of project efficiency would be relatively less important in super high-tech projects. They further argue that the relative importance of the dimensions would change over time, as illustrated in Figure 2.

Shenhar et al. [17] conclude that project success planning should become part of an organisation's strategic management process, and that project success dimensions should be determined prior to project initiation, as these criteria need to be considered in the staffing and planning of each project.

The question arose whether (a) the proposition of project efficiency would be relatively less important on super high-tech projects, and (b) the proposition illustrated in Figure 2 would be validated by the PBMR project.

A comprehensive framework for project success measures was created by Shenhar and Dvir [7, p 27]. Measures within this framework were expanded from the four dimensions of Shenhar et al. [17] to the following five dimensions:

- Efficiency;
- Impact on customer;
- Impact on team;
- Business and direct success;
- Preparation for the future.

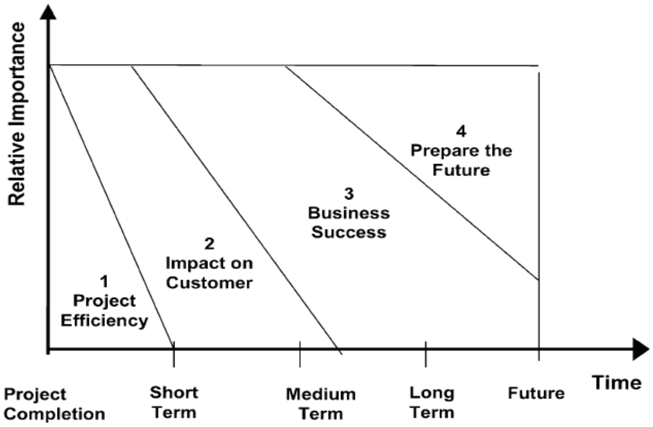

Figure 2: Relative importance of success dimensions is time dependent
(Shenhar et al. [17])

Criteria for success were also listed by Shenhar and Dvir [7, p 27] under each of the five dimensions. As discussed and illustrated later in this paper, this framework was extended for the project under consideration.

4. RESEARCH DESIGN AND METHOD

Included in the first set of objectives for this study is to determine whether:

- The importance of *project efficiency* for the PBMR project would differ from that for projects with other NTCP classifications;
- *Product effectiveness* would receive equal attention in the PBMR and in projects with other NTCP classifications;
- A *different* project management *style/approach* should be used in the PBMR project from that used in projects with other NTCP classifications.

Further objectives included:

- To determine criteria for project success applicable to this specific case;
- To verify the notion of Shenhar et al. [17] that, for 'super high-tech' projects, project efficiency would be relatively less important than other factors;
- To discover whether the relative importance of success dimensions would be time-dependent, as suggested by Shenhar et al. [17], and;
- To determine whether the relative importance of project efficiency would decline over time, as suggested by Shenhar et al. [17].

Achieving these objectives would be useful for future R&D projects similar to the PBMR.

The best source of information regarding the project is vested in experts who are familiar with the project under consideration and with the management of a variety of projects in other environments. The most suitable data-gathering technique for such an exploratory study in the specific environmental setting was considered to be the Delphi method.

5. THE DELPHI METHOD

This technique ensures that each member of a panel of experts first deals with the complex problem individually. After each round of the survey, their individual, anonymous judgments are collated by the facilitator and presented to the panel. During subsequent rounds panel members can reconsider their judgements in order to improve the quality of the information. This is especially useful when the problem does not lend itself to precise analytical techniques [18]. The validity of a Delphi study is based on reasoned argument, and can further be strengthened by involving participants who have knowledge and interest in the topic at hand [19].

The suggested process for application of the Delphi method in the engineering management environment, adapted from Barry et al. [20], is shown in Figure 3.

The following important aspects of the Delphi method are addressed on the basis of information provided by Mullen [21] to ensure proper research 'execution'.

5.1 Selection of the expert panel

The Delphi method relies on the opinion of a panel of experts. As they form the main source of data, it is obviously essential to pay special attention to the selection and composition of the panel.

To add value, experts need to have sufficient relevant knowledge and experience of the topic under consideration. Delphi studies should not be confused with conventional surveys, where statistically large numbers are required for validity [21]. Selection of the panel of experts is not aimed at obtaining a representative sample of any specific population; instead the specific problem within a specific environment, together with the exact definition of traits required from experts, provide sufficient qualification to indicate correct representation of panel members. The required size of a Delphi panel is a contentious issue in the literature [20]. For fear of losing data accuracy, Mullen [19] suggests not using a panel with fewer than seven members, while Delbecq et al. [22] suggest a panel of ten to fifteen. Delbecq et al. [22] are also of the opinion that no further new ideas would be generated once the panel exceeded thirty participants.

For this study the following conditions were set:

- In order to be able to judge the need for different approaches, members of the panel were required to have experience of working on both a nuclear development project and at least one other major project that did not specifically involve R&D (e.g. a major construction project);
- Panel members needed to have more than ten years' experience working on projects - most of the time in strategic leadership positions;
- Each panel member had to be an incumbent in a management position, and should have been in such a management position for at least for the previous two years.

Based on these conditions, thirteen experts were invited to take part in the Delphi survey.

Ten of the thirteen individuals opted to act as members of the panel. All ten had experience of other projects, and all were at some stage involved with the larger PBMR project team; all are considered as strategic leaders in their respective companies, and are often involved in strategic problem-solving sessions. All are registered professional engineers; one has a PhD; five have masters' degrees; three are registered project management professionals; and seven of the members are or have been in project management positions with more than 50 employees under their control. In total they have combined, relevant experience of about 178 years.

5.2 Level of consensus required

It is a common conception that the Delphi technique aims to obtain consensus between the members on the panel of experts. It is clear, however, that not all Delphi studies obtain, or seek to obtain, consensus. Whether or not consensus is important, it should be the aim to obtain the correct answer from the panel of experts. For this study a fair level of consensus was required before the loop illustrated in Figure 3 would be terminated.

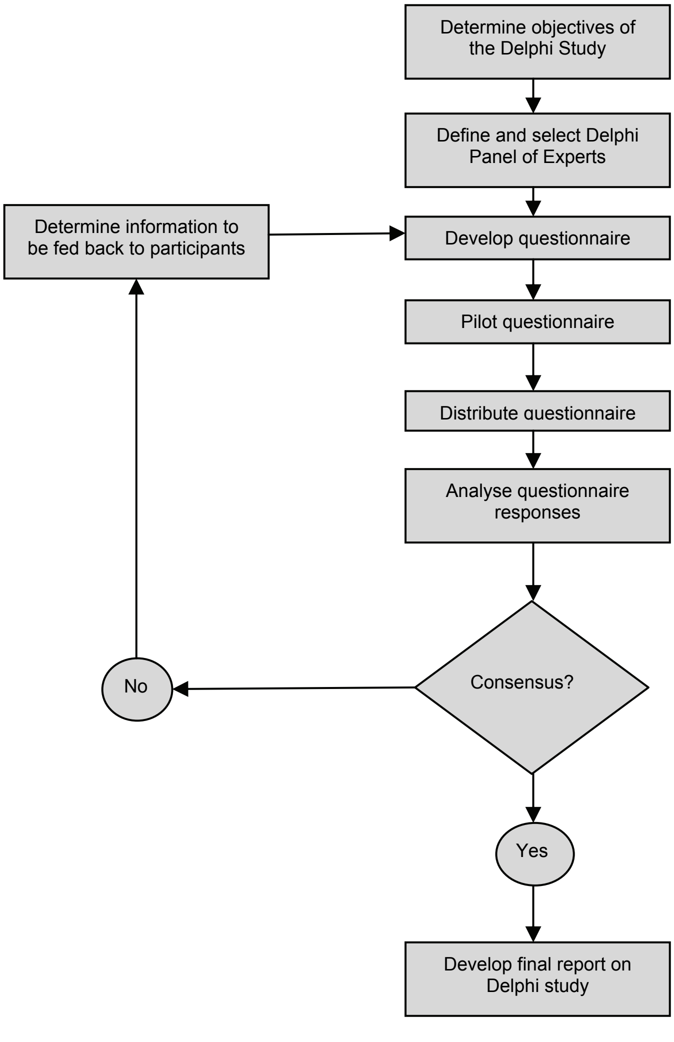

Figure 3: Suggested procedure for application of the Delphi method
(Adapted from Barry et al. [20])

5.3 The Delphi method

Mullen [21] indicates the importance of having a first round that includes open-ended questions. This can be achieved either by the inclusion of broad open-ended questions or by the use of a seed-list with the option to add additional items. Both approaches aim to obtain the opinion of the individual experts on the final basis that was used for further evaluation of the research problem. The first round of this study provided a seed-list of dimensions identified from the literature and the option to pick from this list, as well as the opportunity to add additional items where applicable.

Questionnaires were presented with the help of web-based software to provide an electronic, online questionnaire, designed to require the minimum amount of time from the respondents.

The results from the first round were collated by the facilitator and evaluated by the panel during the next round of the survey. As suggested by Mullen [21], the second round was performed soon after the first round in order to retain involvement of the panel members. For the second round, a five-point Likert scale (proposed by Barry et al. [20]) was used to rate the importance of project success dimensions. The survey was concluded after the second round.

The identities of the respondents were not hidden from the facilitator (to enable him to follow up with anyone who did not respond), but responses to other members of the panel were presented anonymously throughout the study.

6. RESULTS

6.1 Data gathered

As noted earlier, of the thirteen individuals who were invited to participate in the study, ten opted to do so (a 77% response rate). This was considered an acceptable response rate, since Walker and Selfe (as cited in Mullen [21]) recommend that, for rigour, a minimum response rate of 70% is required. (They grade response rates from 8% ['unacceptable'] to 100% ['excellent']).

6.1.1 Is one management approach appropriate for all projects?

The respondents reached consensus that the project management style required for a high technology, novel project should be different from that for a lower technology project with little product novelty. They also agreed that project efficiency is always an important factor to consider for both the PBMR project and for other projects they have been involved in, but that the product effectiveness would *not* receive equal attention in the different project types.

More specifically, the results were as follows:

- All of the respondents agreed that *project efficiency* is important on both a project such as the PBMR and other projects they have been involved in;
- Nine of the ten respondents agreed that *product effectiveness* would receive more attention on the PBMR than on other projects they have been involved in;
- Seven of the ten respondents agreed that the project management *style or approach* to be used on a project such as the PBMR *should differ* from the approaches employed on other projects that they have been involved in.

6.1.2 Extended framework of success criteria for this type of project

When the framework of Shenhar and Dvir [7, page 27] was applied to the PBMR project, two extra dimensions were added to the model. These were:

- Including a criterion of *regulatory approvals* to account for this important aspect in the nuclear industry; and
- Including the criterion of *impact on the country and community* to address specific requirements in the South African economic and development context. In South Africa requirements for employment equity, black economic empowerment (BEE), and localisation, to benefit the local economy, are considered very important.

The success criteria listed underneath each of the dimensions in Figure 4 were also slightly adapted to fit the specific scenario. The framework with these modifications is shown in Figure 4.

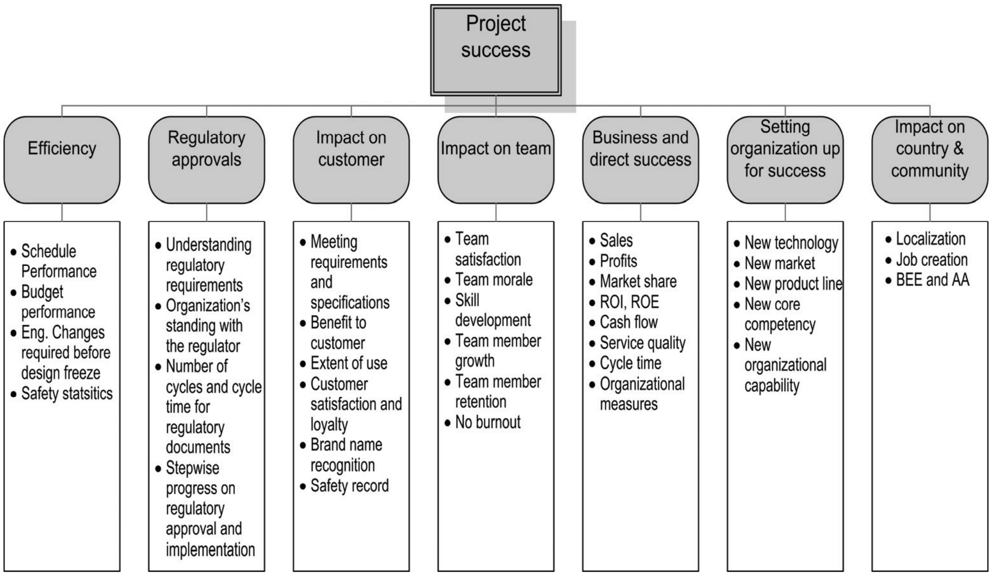

Figure 4: Success criteria basis for the research study
(Model by Shenhar & Dvir [7] applied to the PBMR)

6.1.3 Most applicable success dimensions

The framework in Figure 4 was presented to the respondents to identify the most important success dimensions for this type of project. Applicable success dimensions were scored on the basis of the percentage of respondents who reached consensus on the applicability of each dimension. The results were as follows:

- Efficiency of project execution - 40%
- Impact of the product on the customer - 80%
- Impact on the project team - 70%
- Business success - 40%
- Preparing for the future - 60%
- Impact on the country and the community - 80%
- Regulatory standing - 80%

The respondents suggested no additional success dimensions or criteria that could not be accommodated in the definition of one of the seven dimensions.

6.2 Success dimensions over the lifespan of the system

The relative importance of success dimensions can change over the lifespan of the system, and the relative importance of each of the seven success dimensions was determined for the following four phases of the system lifespan:

- During project execution – from inception to completion;
- Short term – first year after project completion, when the project team is demobilised and reviews of the work done are undertaken;
- Medium term – 1 to 5 years after completion, when the customer is most affected by the product;

Long term – 5 to 10 years after completion, when the organisation is supposed to reap increasingly direct benefits from the system.

6.2.1 Relative importance of success dimensions over time

The relative importance of the success dimensions was determined by the percentage of respondents who reached consensus, on a 5-point Likert scale, on the importance of each dimension. For the four dimensions with a 70% or higher level of consensus, the relative importance is illustrated as a function of time in Figure 5.

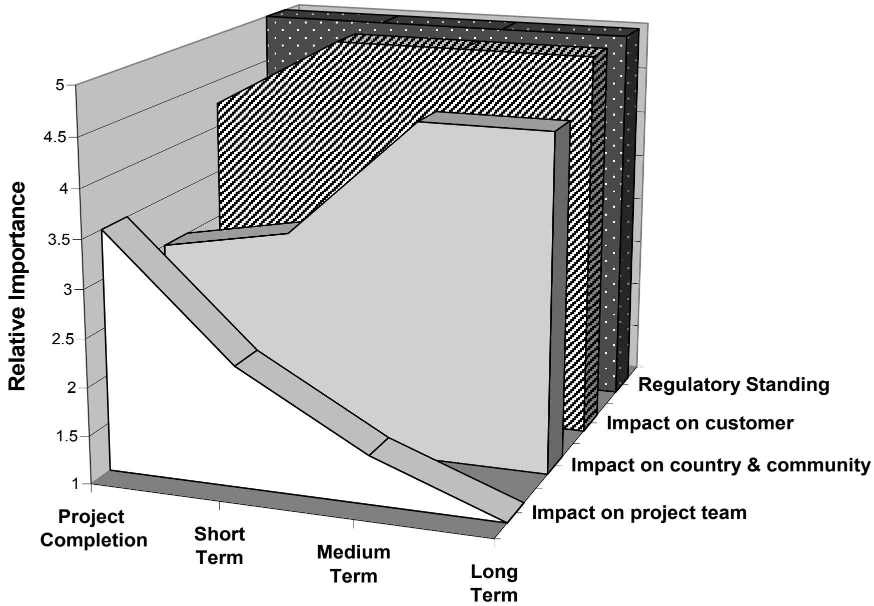

Figure 5: Relative importance of four central success dimensions over time

Although there was a lower level of consensus on three of the seven dimensions, all seven of the proposed success dimensions were measured for relative importance over time. This more comprehensive result is shown in Figure 6.

6.3 Discussion of results

6.3.1 Is one management approach appropriate for all projects?

It was confirmed that different project management approaches should be used in projects with dissimilar classifications. This supports the statement by Shenhar et al. [17] that one project management style does not fit all, and that project classification should be considered before establishing important project decisions associated with project initiation.

6.3.2 Specific project success dimensions for this type of project

The data confirm that specific success criteria should be determined for each type of project. This study validates the dimensions of project success proposed by Shenhar & Dvir [7], and also expands the framework of these authors. For this specific project, the panel of experts believed that four main success dimensions should be used to measure success, and that focusing on these four dimensions would ultimately lead to a successful system. The exclusion of *project efficiency* as one of the four main success dimensions should be noted. Project efficiency is obviously always of concern and, while all respondents did agree on the relevance of project efficiency management in the project in the first set of questions, they did not include this as one of the four main dimensions during the second round. The conclusion is that, in relation to the other aspects mentioned, respondents felt that project efficiency should receive less attention than the four dimensions that they identified as centrally important.

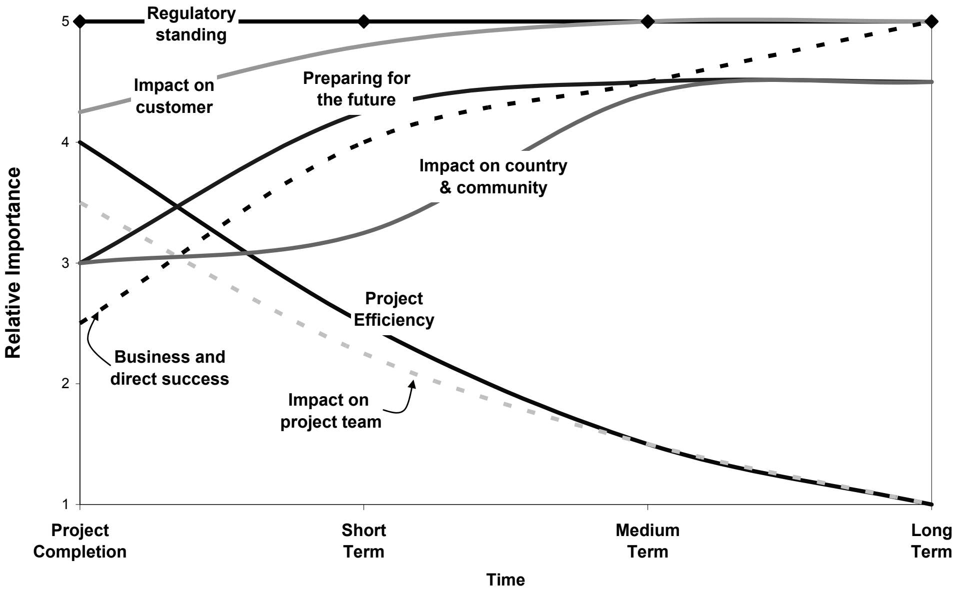

Figure 6: Relative importance of seven success dimensions over time

6.3.3 Relative importance of success dimensions over time

The rating of the relative importance of the four success criteria identified by the respondents provides a good indication of what can be expected after project completion. Shenhar et al. [17] provide a framework of success dimensions that indicates that 'project efficiency' is important in the short term, and that later on, 'impact on the customer', 'business success', and 'preparation for the future' become increasingly important. They also propose a generic diagram to illustrate this point. This study confirms the notion that different dimensions are more important at different times, provides empirical evidence, and refines the diagrams of Shenhar et al. [17] for a specific case.

The relative importance of project efficiency was seen as important during project execution and immediately thereafter. The fact that its importance rapidly reduces with time correlates well with the theory provided by Shenhar et al. [17].

The importance of *regulatory standing* as a success dimension should be noted. The success of a nuclear system is highly dependent on international regulatory approvals, and the respondents indicated this by rating this dimension as essential throughout the product lifecycle. The relation between this dimension and the dimension of *impact on customer* should also be noted. These are closely linked as, in the case of a nuclear installation, the nuclear regulator remains a stakeholder, and the company's regulatory standing will have an influence on any further business success.

The results draw attention to the notion that project efficiency, which is normally associated with successful project management (in other words, *doing* it right), should be distinguished from the success of the product or deliverable of the project (*getting* it right).

7. CONCLUSIONS AND RECOMMENDATIONS

This study confirms the well-established view that one project management approach does not fit all, and that it would be prudent for project managers to classify each major project and identify its unique characteristics during the early stages. Such classification would influence the way in which the project is managed, and improve its chances of success.

The classification of the PBMR project according to the NTPC model exemplifies the challenges associated with the project. A specific, tailored project management approach should indeed be considered for projects such as this one. The dominant success dimensions for this type of project in the specific setting of the South African nuclear industry were identified to be: *regulatory standing*, *impact on the customer*, *impact on the country and community*, and *impact on the project team*. It was also shown that project efficiency is not a sufficiently suitable success criterion in this situation, even though it needs to be maintained. This confirms the principles stated by Shenhar et al. [17] that project efficiency is relatively unimportant for super high-tech projects, and that its importance declines over time.

The relative importance of the success dimensions as a function of time after project completion was established, and this provides empirical confirmation of a diagram by Shenhar et al. [17]. For this specific case, a refined version of a diagram by Shenhar et al. [17] was developed. This diagram indicates that from one year after completion and onwards the impact on the country and community outweighs any other factor. Five years after completion, this factor far overshadows the other factors.

In order to develop a project management approach for a project such as the PBMR, the constructs of *regulatory standing* and *impact on the country and community* should be refined to meet the requirements for *metrics* described by Melnyk et al. [23]. This includes a numerical value that identifies the minimum threshold of performance that is considered acceptable to management, as well as a description of the environment or context within which the activity or person being measured operates.

The value of a typological approach when identifying metrics for success is underlined by this study. Suitable criteria in turn are useful in developing project management approaches and methodologies. Further research should be undertaken to identify the processes required for different types of project. This would supplement the processes described in the PMBOK [24] and add value to the available project management practices. Defining 'project success' for the project under consideration paves the way for the development of appropriate project management processes for other similar projects.

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