INVESTIGATING THE RISK MANAGEMENT POTENTIAL OF A STAGE/PHASE-GATE PROJECT MANAGEMENT APPROACH

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The paper investigates the potential of a stage/phase and gate process as a general approach to manage project risks. The use of stages/phases and gates as a project management approach is well established in literature and industry. However, the approach has primarily been used for product development projects, and opinions differ as to the number of stages/phases and what tasks should be completed in each stage/phase in general. Furthermore, the risk management potential of such an approach is not well established in literature. The risk managing potential that is considered in this investigation is both overall and within project phases by considering project lifecycle phases as stages. A case study is presented to illustrate this potential for progressively lowering risk through such a stage/phase-gate project management approach.

Key phrases: Project management, risk management, risk reduction, life cycle management, stage, phase, gate

INTRODUCTION

Various project management models, methodologies and standards have been developed since the middle of the 20th century and include, amongst others, PRINCE2 (OGC 2005) and PMBOK (PMI 2004), as well as a host of company-specific methodologies. There are large similarities amongst classical project management models and/or standards irrespective of which model and/or standard is used. The generalised project management sequence is depicted in Figure 1 (Openlearn 2007) that corresponds with the widely used Guide to Project Management Body of Knowledge (PMBOK) phases in a project lifecycle (PMI 2004). Figure 1 shows that it is commonly accepted that a project can be broken down into stages or phases. Each of these phases then has specific goals that must be achieved. Collectively, the identified phases are known as the project lifecycle (PMI 2004). A variety of different sets of phases that differ with respect to the number and nomenclature of the stages are being used. The PMBOK (PMI 2004) states that the phases in the project lifecycle generally define the following:

- Technical work to be accomplished during each phase;
- When deliverables are to be generated during each phase;
- How each deliverable is reviewed, verified and validated;
- What parties are involved during each phase; and
- How to control and evaluate each phase.

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Figure 1: Generalized project management sequence

Source: adapted from Openlearn 2007

A set of phases and gates adopted within a company often forms the basis of a comprehensive project management methodology of the company; policies and procedures relating to a variety of aspects such as cost management, risk management, environmental, safety and health, procurement, project communication, etc. are defined for each phase of a project. Criteria that need to be met regarding each of these aspects are defined for each project phase. Labuschagne (2005) and Brent & Petrick (2007) attempted to establish some conformity between various views regarding project management phases; sixteen different references that suggest various project lifecycle phases or stages are listed (Brent & Petrick 2007) (see Table 1).

Table 1: Phase in the project lifecycle

No.	Reference	No. of phases	Project phases									
1	Parker & Skitmore (2005)	4	Concept	Contract awarded	Execution phases							
					Design	Planning						
2	Labuschagne & Brent (2005)	7	Conceptual	Planning	Testing	Implementation		Closure				
3			Idea generation	Pre-feasibility	Feasibility	Development and execution	Commissioning	Launch	Post implementation review			
4	Pillai *et al* (2002)	9		Project selection phase			Project execution phase			Implementation		
			Screening	Evaluation	Selection	Technology development	Production development	Performance development	Production		Marketing	Sales
5	Kartam *et al* (2000)	6	Feasibility	Design	Procurement	Construction	Start-up	Operation				
6	Jaafari & Manivong (1998)	5	Planning	Design	Procurement	Construction management	Commissioning of facility					
7	Vanhoucke *et al* (2005)	6	Conception	Definition	Planning and schedule	Execution	Controlling (monitoring)	Termination of project				
8	Cleland (2004)	4	Definition	Planning	Execution/ control	Close-out						
9	X-PERT Academy (2005)	5	Initiation	Planning	Execution	Controlling	Close-out					
10	PMI (2002)	5	Initiation	Planning	Execution	Controlling	Closing					
11	Kerzner (2001)	5	Conceptual	Planning	Testing	Implementation	Closure					
12	Steyn *et al* (2003)	6-7	Clarifying need	Feasibility	Definition (design and development)	Implementation (project execution)	Hand over and project closure	Support and maintenance				
13			Pre-feasibility	Feasibility	Basic development		Execution		Start-up and hand-over		Evaluation and operation	
						Detailed design		Procurement	Construction			
14	Tarr (2003)	9	Pre-feasibility	Site selection	Feasibility	Feasibility report		Board decision	Detailed design	Construction	Operation	Closure
15	Buttrick (2000)	7	Proposal	Initial investigation	Detailed investigation	Develop and test		Trial	Launch/ close	Post implementation		
16	DANTES (2005)	6	Idea	Concept	Investigation	Development		Validation	Launch			

Source: adapted from Brent & Petrick (2007)

The risk management advantages of such a staged/phased project management approach are much neglected in literature. The objective of this paper is to illustrate how a staged/phased project management approach lowers project risks progressively through the lifecycle; risk reduction that results from the overall staged/phased approach is differentiated form risk reduction achieved by each of the embedded stages/phases.

PROJECT LIFECYCLE STAGES AND PHASES

Projects are, by definition, unique endeavours. This implies unknown factors, uncertainty and risks. The cumulative cost of a project typically follows an S-curve. Initially, during the early phases such as the idea and feasibility phases, costs rise gently. During the design or definition phases costs increase somewhat and as the implementation/construction/manufacturing phases are reached, costs, and therefore risk, often rise exponentially. Therefore, while relatively accurate, detailed plans for the immediate future are possible, only “broad-brush”, “rough-cut”, high-level plans are possible for the longer term. The use of phases and gates is based on a rolling-wave planning approach, which implies that, while overall, high-level plans should always exist, detailed plans are only developed for an imminent phase of a project.

Each phase has the objective of reducing the risk of subsequent phases in a cost-effective way; a relatively small amount of financial resources is spent on a phase to lower the risk of subsequent phases. If the risk of subsequent phases cannot be reduced sufficiently, the project can be terminated at the end of an early phase.

The end of a phase is an important milestone in the lifecycle of a project where the project team typically presents the work performed to a project review board that comprises of customers and other stakeholders. This point also serves as a gate that needs to be opened for work on the succeeding phase to be authorised.

The review board therefore has two functions to perform at the milestone: to look back to validate the work performed during the phase, and look ahead to evaluate detailed plans for the subsequent phase as well as updated high-level plans for the rest of the project. The function of looking ahead also involves assessment of risks and the authorisation of the next phase. Allocation of project funds for each phase is based on successful completion of the preceding phases and where a preceding phase does not succeed in reducing risk satisfactorily it can be addressed, e.g. additional work may be requested before authorization is given to proceed to the next phase.

Looking back should prove that the objectives of the phase and all criteria set for the phase have been met. The review board evaluates, validates and approves the work performed during the phase and formally accepts the deliverable or deliverables of the phase. Before the phase is formally closed out, it is confirmed that there are no outstanding issues. Payments are typically made following such formal approval.

As the work performed during a project phase typically provides more information, the overall plan for the rest of the project can be updated. Also, the completed phase typically provides inputs for detail planning of the succeeding phase.

Following the approval of a completed phase, the project team typically presents to the review board a proposal or tender for the next phase, based on the detailed planning that has been done for the imminent phase. The review board evaluates the sufficiency of the detailed planning for the next phase, availability of resources, risks involved and the feasibility of the rest of the project. If the review board is satisfied, the next phase of the project is authorized.

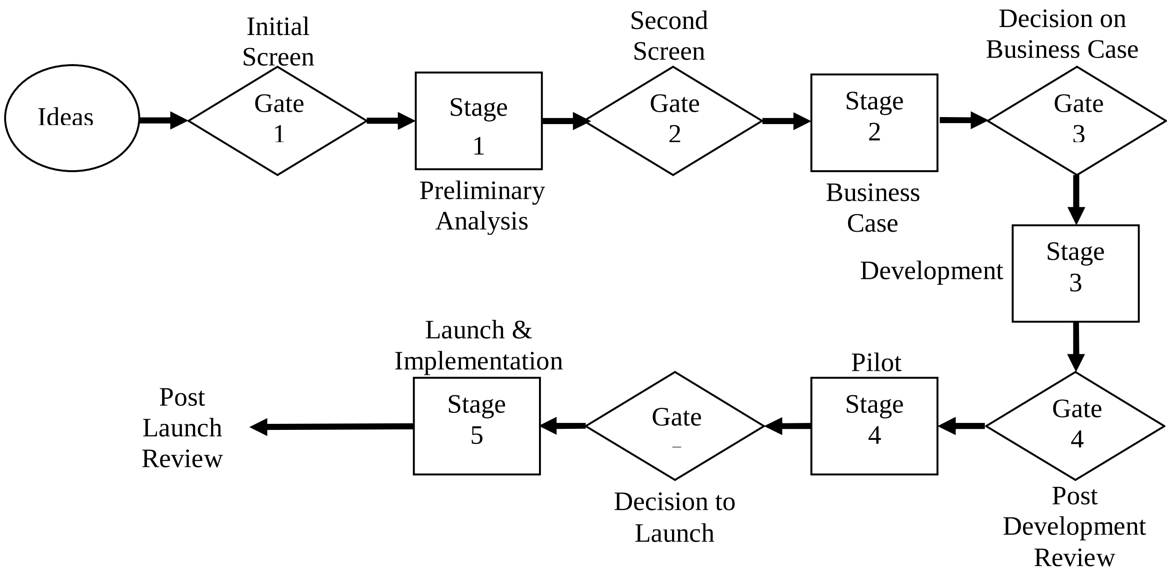
The stage-gate process of Cooper (2001) is considered a typical example of a project management approach with stages (phases) and gates that include pre-project phases such as Discovery and Idea Screening (see Appendix A). The National Renewable Energy Laboratory (NREL 2001) states that a stage/phase-gate management process is an approach for making disciplined decisions about research and development that lead to focused process and/or product development efforts. The purpose of such a project management approach is to reduce costs and time to market for product development (NREL 2001). A staged/phased-gate project management model is also used by companies in the process industry, e.g. Exxon and Rohm and Haas, system developers, utility companies, the construction industry, defence industry, and many others (Riley 2005).

COMPONENTS OF A STAGED/PHASED-GATE PROJECT MANAGEMENT MODEL

A table summarizing what ought to be achieved and verified at each stage and gate respectively is provided in Appendix B. The complete high-level five-stage process of Cooper 2001 that includes pre-project phases is illustrated in Figure 2. The project reviewing at a gate has the following objectives (NREL 2001):

- Proof that objectives of the previous gate and stage has been met;
- Proof that the objectives of the current gate has been met; and
- Set objectives for the following stage and formulate the next gate criteria.

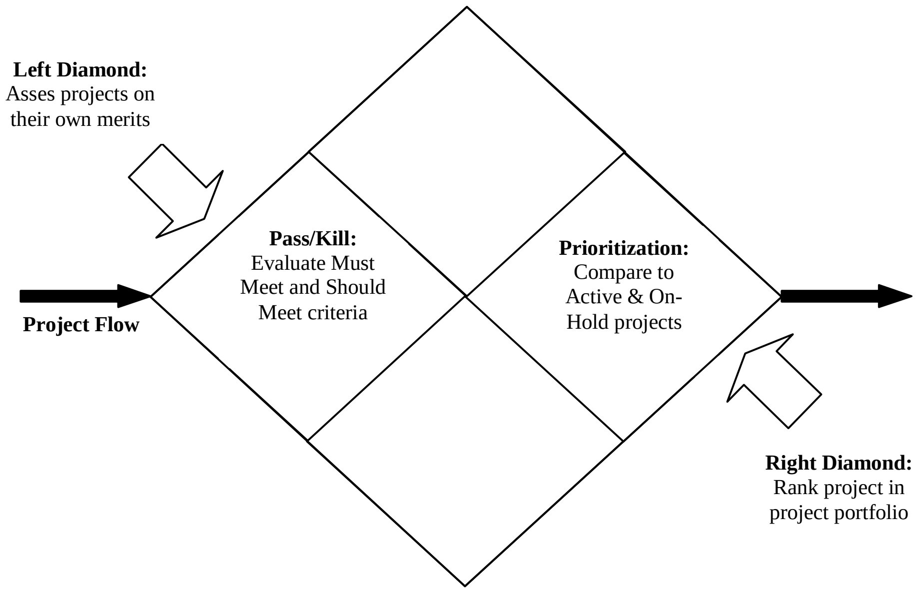
Figure 2: Comprehensive Stage Gate Project Management Model (SGPMM)



Source: adapted from Cooper (2001)

The gate evaluation process can also contribute to project portfolio management (Cooper 2001). To prioritize projects, as part of such a portfolio, a "right-hand side" was added to the block representing a gate, whereby the relative importance of the project is compared to projects that require the same limited amount of resources. Figure 3 illustrates the proposed dual-purpose gate structure.

Figure 3: The gate structure



Source: adapted from Cooper (2001)

Gate evaluations can have the following outcomes (Ayers 1999):

- Pass – the goals of the previous stage were met and it is decided to further pursue the specific project;
- Recycle – all goals are not met, the current stage needs further work/investigation;
- Hold – work on the project is suspended for various possible reasons; and
- Stop – the project is stopped permanently due to various possible reasons.

Cooper *et al* (2000) warn against having gates with poor decision criteria. A gate should predominantly result in a pass/stop decision and a prioritization process, rather than a simple checklist of tasks complete. They propose the use of a scorecard with "must meet" non-negotiable criteria and a "should meet" scoring system. Various other systems for scoring exist, e.g. a matrix approach. Table 2 illustrates the gate scorecard proposed by Cooper *et al* (2000).

Table 2: Proposed "must meet" and "should meet" gate decision structure

Must Meet Criteria	Should Meet Criteria
Evaluated as binary 'Yes'/'No' decision. Typical Must Meet criteria:	Evaluated using a scoring system (0 – 10 scale). Typical Should Meet criteria:
• Strategic alignment • Technical feasibility • Positive return Vs. Risk • Project killers	• Strategic fit • Product advantage • Market attractiveness • Business synergies • Technical feasibility • Risk vs. Return

Source: adapted from Cooper *et al* (2000)

ADVANTAGES AND DISADVANTAGES OF A STAGED/PHASED-GATE PROJECT MANAGEMENT APPROACH

It is argued that the advantages of a staged/phased-gate model include (Cooper 2001):

- Capital expenditure is controlled as an exit at every gate;
- Time spent on projects are controlled as an exit at every gate;
- Adding clarity and flexibility to project management, especially in research;
- Weak projects are ended sooner;
- Focus on quality of project execution, important project steps and completeness of the project;

- Allows for fast-paced, parallel processing with a multifunctional team approach;
- Cross departmental collaboration; and
- Strong customer/competition orientation.

In contrast to the foreseen advantages NREL (2001) notes that a staged/phased-gate process can lead to artificial gate decisions. The impression can be given that the gates represent a simple checklist of future events that are known for certain. Cooper (2001) argues that this is not the case since the resulting project plan of a staged/phased-gate process represents the best guess estimate of future events. The fact remains that all project planning is based on estimates; it is not unique to the staged/phased-gate process and this should obviously not prevent project planning. The guessing nature of the model will have to result in frequent updating of a project plan. The staged/phased-gate process should not be seen as a stagnant once-off model, but rather an evolving process with definite early termination possible at every gate; this aspect is addressed further on in this paper.

The linear appearance of a staged/phased-gate process might lead one to assume that, if all project stages are completed sequentially, the time and cost advantages of parallel stage execution can not be achieved. Overlapping of activities and of phases (fast tracking) is, however, commonly practised and a staged/phased-gate process does allow for parallel stage execution, but this has to be described explicitly in the staged/phased-gate process as the parallel execution of stages still requires authorization at relevant gates. It must also be noted that a project phase is typically performed by a multi-disciplinary, cross-functional team and could deliver multiple outputs, and concurrent engineering (Smith 1997) dictates that these multiple outputs should not be developed in series.

Sebell (2008) and Bessant *et al* (2005) raise various concerns regarding the rigidness and the innovation potential of a staged/phased-gate process. Their concerns, and arguments against such concerns, are summarised in Table 3.

Table 3: Addressing concerns raised by critics of a staged/phased-gate process

Critic source	Critic	Response
Sebell (2008) Bessant *et al* (2005)	A staged/phased-gate process is only applicable for incremental innovation and not breakthrough ideas or innovation. Breakthrough innovation requires a more dynamic model.	In a stage/phase-gate process time could be allocated to idea generation. Some ideas can be incremental advances and other ideas can lead to breakthrough innovation. The limit to the level of innovation is determined by the quality of the ideas and not by the stage/phase-gate process.
Sebell (2008)	Unanswered questions in the early stage will not let the truly breakthrough ideas to pass initial gates.	The objective of early project gates is to do early idea screening. It is accepted that early stages/phases will not deliver qualitative answers for gate appraisals.
	Backing from top management is necessary for innovative breakthroughs. A project team alone is not sufficient.	Idea generation can come from a top-down approach or a bottom-up approach. These ideas could be breakthrough ideas irrespective of the origin. After idea generation the project team has the authority and responsibility to be able to act autonomous to other company activities or projects.
	Staged/phased-gate processes are logic driven and resource allocation based. It is about consensus decision-making driven down into the organization.	

THE RISK MANAGEMENT POTENTIAL OF STAGE/PHASE-GATE MODELS

Risk mitigation that results form the overall approach includes doing the right project; it includes pre-project phases and forms part of a comprehensive project portfolio management process. In addition, each phase within a project contributes to doing the project right. In addition to mitigating risk, risk can also be eliminated by terminating the project; in the case of pre-project phases as well as in the case of within-project phases, the 'gate' at the end of a phase can lead to the termination of the project in order to eliminate risk.

Jaafari (2001) states that risk management is a fundamental characteristic of project management and backs this argument by indicating that risk management is one of the nine project management characteristics as described in the PMBOK (PMI 2004).

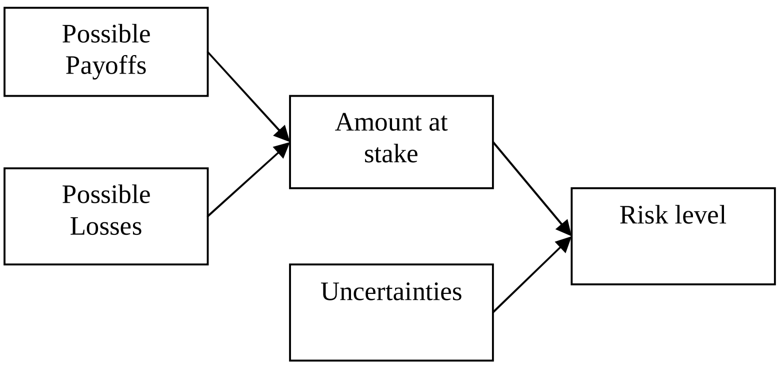
It can be argued that a stage/phase-gate process should aim to reduce the risk associated with projects. This is in agreement with Anderson (1996) who states that a phased approach provides a disciplined system for managing product development, ensuring that steps are not skipped, quality stays high, and technical and marketing risks are controlled by senior management.

Before risk can be managed it must be assessed. One way to quantify risk is to consider the impact (often the monetary value) of a risk event at stake and the uncertainties of events occurring. The relationship of the amount at stake, and the uncertainties of events, is illustrated in Figure 4. By combining possible monetary payoffs with possible monetary losses provides insight into the monetary value at stake. The uncertainties of the "amount at stake" monetary value must be ascertained to establish the level of risk of the project. This view on risk is similar to that of the PMBOK (PMI 2004) where risk is defined as the probability of an event occurring and consequence of such an event.

At a micro risk management level each phase/stage of a project should contribute to systematically reducing the risk associated with a project. This is briefly addressed by Anderson 1996 when he states that risk is managed by allocating development funds based on the successful completion of each phase/stage of development.

Despite the recognition of the contribution that phases/stages and gates make to empower senior management and other stakeholders to control the project, and despite the fact that the purpose of each phase should be to contribute to systematic risk reduction, the notion of risk management through phases/stages and gates is still much neglected in project management literature.

Figure 4: A structured view of risk



Source: adapted from Cooper (2001)

CASE STUDY

An illustrative case study, based on Lotz (2006), is used to demonstrate the risk management potential of a stage/phase-gate project management approach. In this case study steel plates were to be manufactured by a new facility. Some of these steel plates could have had defects and the steel plates made with defects had to be scrapped.

The first option that the designers of the new facility had, had been to use an existing control system on the market. This control system acted as a predictive model for identifying whether the steel plates were made to specification or not. The existing control system required twenty inputs to be measured from the manufacturing facility and had a guaranteed predictive performance of 73%.

The cost of the predictive control system available on the market was estimated at US$ 1,200,000. This included the installation and implementation of the complete control system as well as maintenance for three years.

The problem with the existing, available control system was that the predictive accuracy fell to zero if one of the required twenty inputs were not available to the control system. Ensuring that all twenty inputs from the manufacturing facility were available at all times was problematic. Furthermore, management, plant operators from similar facilities, and the design team of the new production facility had differing opinions regarding which variables had a larger impact.

It was known from other similar manufacturing plants that 5% of all steel plates manufactured had had defects. As stated, with the available predictive control system on the market 73% of all defects could be predicted. The result was that at least 1.35% of product with defects would be delivered to the clients as final product. Furthermore, if one also takes into account that the combined reliability of the twenty sensors required was 94.2% then the actual amount of defects passed on to the clients was 1.43%; the annual reliability of the twenty sensors was simply the product of the annual reliability to the power of the amount of sensors (see Appendix C for calculations).

The loss of revenue would have been the 1.43% of rejected product and as the annual revenue was estimated at US$100,000,000 then the loss of revenue would have been US$1,433,609.

The total three year cost would then have been the cost of the available predictive control system and the three year loss of revenue. The result was US$5,500,826 (see Appendix C). The cost of a newly developed predictive control system then had to be lower or at least had to be equal to this amount to be advantageous.

Management authorized a study to investigate whether the control system available on the market was the best possible solution or whether a new system should rather had been developed from a financial risk perspective. This beckoned the following technical questions:

- Was it necessary to measure all twenty variables?
- If not, which variables had to be measured?
- Could a more optimized model be developed?

A further prerequisite of management, for the possibility whether a new model had to be derived, was that the model had to be human interpretable. The current predictive control system available on the market, at that stage, was considered to be a black box model. Management deemed that the derivation of another black box predictive model would have added little understanding of underlying process fundamentals even if it used less than twenty input variables.

A process consisting of stages/phases and gates was applied. A cross-functional and diverse project team was assembled consisting of:

- Project manager – Acting as the leader of the project team;
- Plant operator(s) – These individuals worked with the steel plate manufacturing equipment on a daily basis. Valuable input was provided by them, although these individuals could not be dedicated to the project team on a full time basis;
- Process engineer(s) – These individuals had extensive knowledge of the design of the steel plate manufacturing equipment, operation and broader plant operation; and
- Computer programming and data mining expert(s) – These individuals had experience in extracting underlying fundamentals from data and how to program this.

Members of the project team had the opportunity to come up with innovative approaches and ideas during the Discovery Stage. The plant operators gave valuable input from their plant experience. The process engineering staff and programming experts formulated technical approaches based on these inputs. Some of these ideas were eliminated during the first gate due to technical difficulty and time restrictions.

The first stage focussed mostly on refining some of the technical aspects of the Discovery Stage as “market place merits” of this project were not an applicable stage objective (see Appendix D for details). A budget of US$ 40,000 was allocated to this stage, which had to be used to search for new technologies that could be used.

During the second gate emphasis was placed on the “must meet” and “should meet” criteria of the project. Preliminary ideas were discussed with management to refine the project objectives and technical feasible options.

The second stage focussed on improving the technical aspects of the project and refining the estimated costs. A business case was developed, which specified the project costs compared to the estimated increase of income due to project implementation.

In this case study the issue of marketing of the product/newly developed predictive control system is not applicable as it is a system specifically developed for this project.

The second stage had limited resources and time for development. A budget of US$ 85,000 was allocated to this stage.

The third gate was executed as another meeting with all related parties including top management. The project definition and outcomes were fixed. Managerial approval and backing were obtained even though the project team could operate autonomously.

A lab-tested model was derived as the outcome of the third stage. The model used fewer variables than the original predictive model. The plant operators, process engineers and data mining experts all provided inputs during the development process.

The incremental improvements from stages one and two, together with the options eliminated during previous stages, implied that third stage progressed quite quickly. Expensive modelling software had to be purchased, which made this stage run over the allocated budget. The stage was budgeted at US$ 190,000 and came in at US$ 210,000. The budget overrun could be approved by the project manager because of the autonomous nature of the project team.

This model was tested (gate four) on real time data, but still in a lab environment.

Parallel model implementation (stage four) was done on a similar plant so that the same input was sent to the predictive control system and the newly derived model. The new model used less input variables to deliver comparable predictive accuracy to that of the old model.

The cost of stage four was kept low because the predictive control system derived in the previous stage could be applied as is. Furthermore, the single input used by the new predictive control system was already available as it was measured as an input to the predictive control system already in use. The cost of stage four was US$ 80,000.

The loss of revenue of the newly developed predictive control system was determined in exactly the same manner as was done in the case of the existing predictive control system available on the market. The overall reliability of the newly developed control system is higher due to the fact that the new system only requires one input parameter from one sensor. This increased reliability directly results in fewer losses due to send backs of the steel plates by clients.

Approval was given to install the newly developed predictive control system in the new plant (gate five) after all parties (project team, management, etc.) came to the conclusion that the system was ready for launching.

Stage five was then the implementation of the new predictive control system in the new production facility. The single sensor that will act as input parameter was installed. The specialized sensor and controls cost US$ 440,000 for the complete installation.

The phased/staged approach also limited the expenditure of the complete project. The result is that the capital for development, implementation and maintenance of the newly developed system was less than that of the available control system on the market. The cost was again worked out for a period of three years (see Appendix C).

A post-launch review took place, during which certain perceptions and views were raised by the project team and management. These perceptions and views were discussed and resolved where needed.

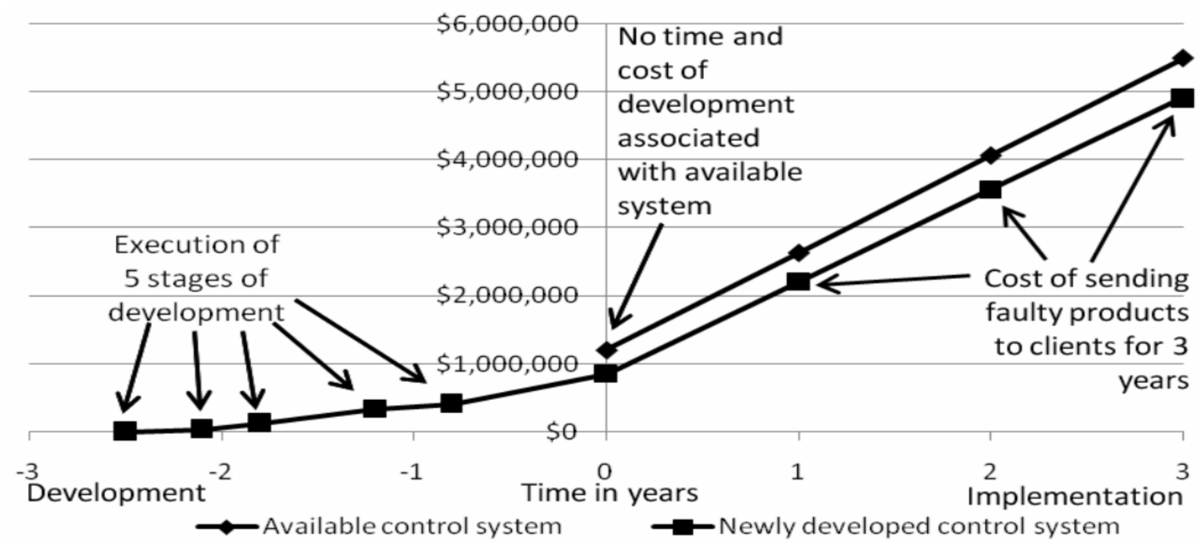
The results of the project were the following (Lotz 2006):

- An optimized predictive model was developed;
- This new predictive control system required only one input variable compared to the twenty variables of the old predictive model;
- The new predictive control system had comparable predictive accuracies to that of the old model;

- The singular model input resulted in a human interpretable model since it was known now that a specific variable had to be controlled precisely to ensure correct steel plate manufacturing; and
- The development and implementation of a new predictive control model cost came in 10.6% lower on a three-year payback basis as compared to the control system available on the market (the financial calculations are presented in Appendix C).

Figure 5 compares the financial implications of developing a newly developed control system with the application of the available control system. Figure 6 summarises the stage/phase-gate development of the case study as a binary decision tree.

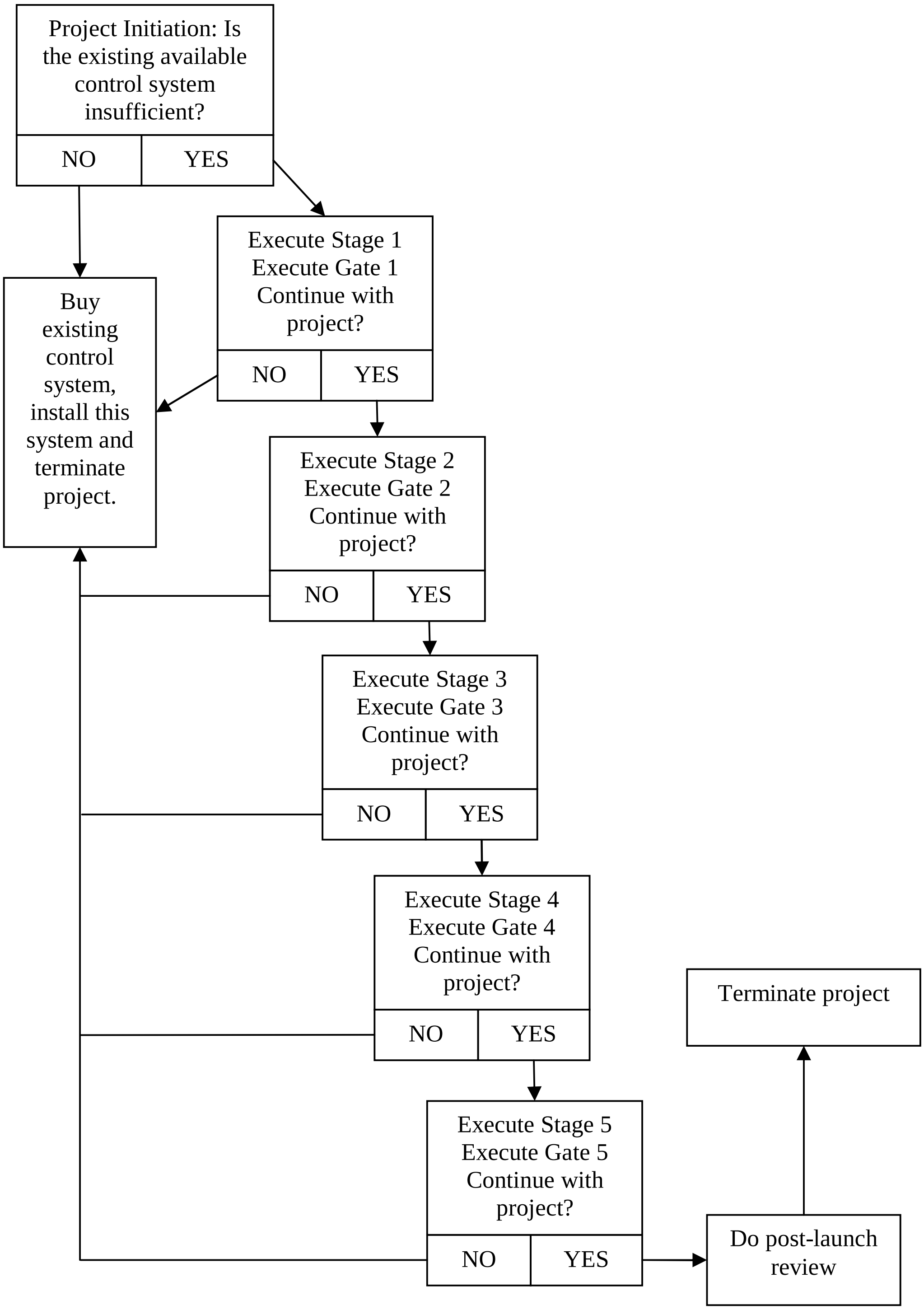
Figure 5: Comparing development and operational cost of a newly developed control system with the costs of an existing control system



The following advantages were observed in this project due to application of a stage/phase-gate project management model:

- The cross functional dedicated project team was completely responsible and empowered for the project - this lead to speedy project completion since separate departments did not have to wait for each other or miss-communicate requirements;
- The incremental addressing of all project aspects during each phase lead to the identification of wrong project options quicker; and
- Financial project risk was controlled well due to the incremental cost incurred in the stage/phase-gate process.

Figure 6: Binary decision tree representation of the case study



CONCLUSIONS

The use of phases (or stages) and gates is well established in literature and industry. Phased project management approaches are used because of the risk management potential that they offer; this potential was established from literature. This paper describes the relationship between risk management, project phases and rolling-wave planning. Risk management at the end of phases within a project is distinguished from the contribution that a phased approach can make to the management of a portfolio of projects if pre-project phases are included. The risk management potential of a stage/phase-gate project management approach was explored by means of an illustrative case study.

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APPENDIX A: THE STAGE-GATE PROCESS AND CONVENTIONAL PROJECT MANAGEMENT

Cooper differentiates between the stage-gate process and conventional project management practices by stating: "*stage-gate is a macro process – an overarching process. By contrast, project management is a micro process*". This is debatable as concurrent engineering can also be seen as a macro process, but is still a project management method. Cooper further states that project management remains applicable as part of more complex stages. The question then becomes what are the criteria that a process should satisfy to be considered project management. Various sources exist that provides information regarding the desired criteria of a project management approach. The following table evaluates the criteria of project management against the objectives of the stage-gate approach:

Project management criteria	Does the stage-gate process satisfy these?
The application of knowledge, skills, tools, and techniques to project activities to meet the project requirements.	Yes. The stage-gate is the application of knowledge proposed by Cooper 2001. It can be seen as a tool and/or technique to be used to achieve project requirements.
The planning, monitoring and control of all aspects of a project and the motivation of all those involved in it to achieve the project objectives on time and to specified cost, quality and performance.	Yes. The cross-functional team approach of the stage-gate process aims to "control … all aspects of a project." The stage-gate process furthermore addresses objectives of cost, quality and performance.

The conclusion drawn from the comparison between what is considered to be criteria for project management and what the stage-gate process aims to achieve is that the stage-gate process indeed aims to achieve project management. However, the project management characteristics of a stage/phase-gate process are not unique to the stage-gate process of Cooper. Any of the stage/phase-gate approaches presented in Table 1 will satisfy the criteria for project management. The conclusion is then expanded to state that all stage/phase-gate process can be viewed as project management models if they satisfy the criteria as stated in the table of this Appendix. Furthermore, the uniqueness of the parallel development process of the stage-gate process is highly debatable as parallel development forms the basis of concurrent engineering.

APPENDIX B: SUMMARY OF STAGES/PHASES AND GATES, THEIR PURPOSE AND ACTIVITIES TO BE COMPLETED DURING EACH

Component	Purpose	Activities
Discovery Stage	Towards a defined, proactive idea generation system.	• Technical research; • Search new technological possibilities; • Uncover unarticulated needs; and • Uncover market opportunities.
Gate 1: Idea Screen	First decision to commit resources to an idea.	• Decide on idea's strategic fit; • Evaluate market attractiveness; • Investigate technical feasibility; and • Investigate definite project stoppers.
Stage 1: Scoping	Determine project's technical and marketplace merits in short time with low cost.	• Do preliminary market assessment; • Do preliminary technical assessment; and • Deliver first pass business and financial analysis as input to Gate 2.
Gate 2: Second Screen	Re-apply the "must meet" and "should meet" criteria of Gate 1 more stringently considering the improved and additional information available. Additional criteria can be added.	• Similar as in Stage 1 with expansions.
Stage 2: Building the Business Case	Clearly define the product and verify market attractiveness.	• Define target market; • Delineation of product concept; • Specify product positioning and strategy; • Specify product benefits; and • Specify essential and desired product requirements.
Gate 3: Go to Development	To complete product definition and/or project definition.	• Review Stage 2 activities for completeness, quality of work and positive product outcome, and; and • Designate project team.
Stage 3: Development	To deliver a lab-tested product prototype.	• Do full scale technical design; • Advance the marketing of product; and • Resolve legal aspects of product.
Gate 4: Go to Testing	Check product development and continued product attractiveness.	• Review development work for completeness and quality; • Check consistency of Gate 3 product definition; and • Review product financials.
Stage 4: Testing and Validation	Test product viability. Negative results will send the product back to Stage 3.	• Do in-house product tests; • Execute user or field product trials; • Do pilot production; • (Pre)test market; and • Revise business and financial plan.
Gate 5: Go to Launch	A go-ahead will lead to full production and market launch.	• Determine quality of testing and validation; • Evaluate final financials; and • Evaluate start-up plans.

Stage 5: Launch	To implement marketing and production launch.	• Implement marketing and production launch.
Post-Launch review	Determine project's and product's strengths and weaknesses.	• Do post-project audit.

APPENDIX C: FINANCIAL CONSIDERATIONS OF ILLUSTRATIVE CASE STUDY

Summary of cost involved in implementing the existing predictive control system		
Description	**Cost**	**Symbol**
Cost of existing control system	$1,200,000	A1
Normal % defects	5%	B1
Accuracy of predictive control system available on the market	73%	C1
Expected annual reliability per sensor	99.7%	D1
Number of inputs required (one sensor per input)	20	E1
Plates with defects historically sent to clients	1.43%	F1
Total annual revenue	$100,000,000	G1
Loss in revenue per year	$1,433,609	H1
Allowable payback period (years)	3	I1
Cost associated with existing control system and loss of revenue for a 3 year period	$5,500,826	J1

Calculating the plates with defects historically sent to clients (F1):

$$F1 = \frac{B1 \times (1 - C1)}{D1^{E1}} \quad (1)$$

Calculating the loss in revenue per year (H1):

$$H1 = F1 \times G1 \quad (2)$$

Calculating the cost associated with existing control system and loss of revenue for a 3 year period (J1):

$$J1 = A1 + H1 \times I1 \quad (3)$$

Summary of cost involved in implementing the existing predictive control system		
Description	**Cost**	**Symbol**
Cost of newly developed predictive control system	$855,000	A2
Normal % defects	5%	B2
Accuracy of predictive control system developed	73%	C2
Expected annual reliability per sensor	99.7%	D2
Number of inputs required (one sensor per input)	1	E2
Plates with defects historically sent to clients	1.35%	F2
Total annual revenue	$100,000,000	G2
Loss in revenue per year	$1,354,062	H2
Allowable payback period (years)	3	I2
Cost associated with existing control system and loss of revenue for a 3 year period	$4,917,187	J2

Calculating the plates with defects historically sent to clients (F2):

$$F2 = \frac{B2 \times (1 - C2)}{D2^{E2}} \tag{4}$$

Calculating the loss in revenue per year (H2):

$$H2 = F2 \times G2 \tag{5}$$

Calculating the cost associated with existing control system and loss of revenue for a 3 year period (J2):

$$J2 = A2 + H2 \times I2 \tag{6}$$

Cost associated with developing and implementing a new predicative control system		
Description	**Cost**	**Symbol**
Stage 1	$40,000	A3
Stage 2	$85,000	B3
Stage 3	$210,000	C3
Stage 4	$80,000	D3
Stage 5	$440,000	E3
Total development and implementation cost	$855,000	F3

The total cost was determined by equation 7:

$$F3 = A3 + B3 + C3 + D3 + E3 \tag{7}$$

APPENDIX D: DETAILS OF THE CASE STUDY STAGE INVESTIGATIONS

During Stage 1 a principle component analysis (PCA) was performed on a data set consisting of the twenty inputs that the control system available on the market required. PCA is a vector space transformation often used in exploratory data analysis to lower the multidimensional space of data. Encouraging results were obtained in that a lower dimensional space, i.e. using less than the twenty input parameters, was obtainable that retained most of the higher dimensional space's information.

The PCA result indicated that it was probable that a predictive control system could be developed that needed less than twenty input parameters. Using less than twenty input parameters were listed as a "must meet" criterion. Options that produce models that were difficult to interpret, like artificial neural networks (ANNs), were eliminated. Developing human interpretable models was a "should meet" criterion. The encouraging results of the first stage lead to the successful passing of the second gate.

Computer programming and data mining experts further investigated the potential benefits of a newly developed predictive control system. Various modelling options, like support vector machines (SVM) and genetic programming (GP), was investigated.

On lab scale, during Gate 4, it was found that only one specific input parameter of the twenty measured was required to deliver the same predictive performance of the control system available on the market. The human interpretability of a predictive model based on the value of a single input parameter is trivial.

The added advantage of the new model was that it resulted in an explicit model that could be analysed. It must be remember that the predictive control system available on the market was a ‘black box’ system which gave the user no insight into the logic used during predictions.