THE DEVELOPMENT OF COMPLEX SYSTEMS: AN INTEGRATED APPROACH TO DESIGN INFLUENCING

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ABSTRACT

The aim of this research is to identify and analyze the impact of design changes to a system in a concurrent engineering environment and the development project, and to make proposals how to minimize the impact on the development project performance. A further objective is also to determine the effect of design changes as a result of design influencing. In a concurrent engineering environment system components are being developed in parallel. Any change to one component of the system may impact on other system components under development.

Design as part of the systems engineering process is an iterative and dynamic process. Although the systems engineering process has been very well structured and refined over the years, it still remains to a certain extent an unpredictable process. A consequence of this is that changes to a design of a subsystem or component comprising the system can occur at any stage of the process.

The systems engineering process is a "***static***" process since there are no time constraints or management of consumption of resources on the different systems engineering processes and steps. As such system engineering cannot function in isolation. To bring a system into being, systems engineering must function within a project management environment to provide the management of schedule and the consumption of resources. The interaction between project management and system engineering processes can have a distinct influence on the systems engineering process and must be taken into account when studying the performance of system development projects. This research investigates the project management/systems engineering interface with specific focus on cost and schedule.

Since project management is the encompassing process wherein a system is being developed, its influence on the system engineering process will also be investigated. This research has the following research objectives:

- Optimization of design influencing by dividing the design teams into two different complementary but opposing mindset groups.

- Evaluate the impact of design changes in terms of cost and schedule overruns in a concurrent engineering development environment.

A comprehensive development project was used as a case-study. A Narrative Inquiry comprising the main system development project players investigated the problems experienced on the project and found that management was the major cause for the project cost and schedule overruns. The principal finding of this research showed, that unplanned, unexpected and forced design changes was the primary

area of conflict between systems engineering and project management, leading to development project cost and schedule overruns. The Narrative Inquiry findings were actually the symptoms of a deeper underlying problem. Root Cause analysis identified the fundamental mechanisms of design change and the influence of management on the process.

This research identifies the fundamental mechanisms that result in design iterations and the influence that management has on this process. An improved "***Effect-to-Cause***" design influencing model is proposed to reduce the risk of design changes during system integration. A mathematical model has been developed to quantify the impact of a design change on a multi-layer, multi-component system. This model confirms that the system hierarchy design is very important to minimize the impact and consequential development project risk should a design change be required for one of the system components. By means of the mathematical model, a proposed system's architecture can be modelled. The model quantifies the impact of a system component design change on the rest of the system development project. This model will facilitate the optimization of system architecture to reduce development project cost and schedule risks. The system architecture model will also enable design review boards to make informed decisions when considering options for a system component design change.

This research also found that the Systems Engineering process must function harmoniously within the larger Project Management environment for the optimum performance of a development project. The road forward to achieve this goal is for the systems engineering and design processes to become more structured and the removal of the unpredictability in the processes so far as the number of design iterations is concerned. This will enable the systems engineering processes to be more easily accommodated within the structured project management processes to the benefit of the overall development project performance. A structured "***Cause-to-Effect***" design influencing methodology has been investigated. Indications are that this may be the road forward for systems engineering process development to even further reduce the risk of a design change during system integration and consequential detrimental impact on the development project performance.

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Abbreviations

AD	Axiomatic Design
ADM	Advanced Development Model
ADM	Arrow Diagramming Method
ARRL	American Radio Relay League
ATGM	Anti-tank guided missile
BIT	Built-in Test
BITE	Built-in Test Equipment
BOM	Bill of Materials
CDR	Critical Design Review
CI	Configuration Item
CFE	Customer Furnished Equipment
CM	Configuration Management
DoD	Department of Defence (USA)
DRB	Design Review Board
DSM	Design Structure Matrix
DSR	Design Science Research
ECP	Engineering Change Proposal
EDM	Engineering Development Model
ERA	Explosive Reactive Armour
ESEE	Early Systems Engineering Effort
ET&E	Engineering Test and Evaluation
FBS	Functional Breakdown Structure
FD	Failure Domain
FFF	Form, Fit and Function
FMECA	Failure Mode, Effects and Criticality Analysis
FRB	Failure Review Board
FTA	Fault Tree Analysis
GERT	Graphical Evaluation and Review Technique
Hdbk	Handbook
HEAT	High Explosive Anti-Tank
IEEE	International Electronics and Electrical Engineering
ILSP	Integrated Logistics Support Plan
INCOSE	International Council on Systems Engineering
IPC	Illustrated Parts Catalogue
IPS	Integrated Product Support
IPT	Integrated Project team
ISP	Integrated Support Plan
ITAR	International Traffic in Arms Regulations
LAN	Local Area Network
LCC	Life Cycle Cost
LORA	Level of Repair Analysis
LSA	Logistic Support Analysis
LSAP	Logistics Support Analysis Plan
LSAR	Logistic Support Analysis Record
MCLOS	Manual Command to Line of Sight
Mil	Military
MIS	Management Information System
MIT	Massachusetts Institute of Technology

MRV	Maintenance Recovery Vehicle
NASA	National Aeronautics and Space Administration (USA
NAVSO	Navy Standard Order (USA)
OT&E	Operational Test and Evaluation
PBS	Product Breakdown Structure
PC	Personal Computer
PCMB	Project Configuration Management Board
PDM	Precedence Diagramming Method
PDR	Preliminary Design Review
PM	Project Management
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PPM	Pre-Production Development Model
PRACAS	Problem Reporting and Corrective Action system
PSP	Product Support Plan
QA	Quality Assurance
RBD	Reliability Block Diagram
RBDO	Reliability Based Design Optimization
RCA	Root Cause Analysis
RCM	Reliability Centered Maintenance
SACLOS	Semi-Automatic Command to Line of Sight
SANDF	South African National Defence Force (SANDF
SD	Success Domain
SDD	Software Design Document
SE	Systems Engineering
SEMP	Systems Engineering Management Plan
SRD	Software Requirements Document
Std	Standard
TAAF	Test Analyse and Fix
TEMP	Test Engineering Management Plan
TRAMP	Testability, Reliability, Affordability, Maintainability and Produceability
URS	User Requirements Statement
XDM	Experimental Development Model