An implementation strategy for Tecnomatix Plant Simulation software

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DECLARATION OF ORIGINALITY

I, the undersigned, hereby declare the following:

- This is my own unaided work unless specifically referenced as such in the text.
- That no work submitted here has previously been published.
- That all the information gained herein was whilst enrolled at the North-West University.

____________________ __2021/11/10__

Josua Olivier Wesch *Date*

ABSTRACT

Many companies are investigating on whether it would be beneficial (financially and operationally) to implement discrete-event simulation (DES) software in-house. Moreover, to what strategy can be followed in implementing and integrating the software within the business. These are some of the problems that are faced by many companies, looking into the use and incorporation of DES type software. This is particularly relevant in the 4th Industrial Revolution as companies strive to compete by continuously improving their business strategy.

The importance of this research topic is highlighted through a gap in literature relating to the topic. Literature on DES, dedicated to production process simulations – is mainly focused on project cases and not overall strategy development, subject to business capacity and requirements.

This research study focuses on the use and implementation of Tecnomatix Plant Simulation (TX) at a project and organisational level. This study aims to:

- Guide individuals and companies through the complexities of implementing TX software within organisational capacities;
- Illustrate the different project phases and steps, with regards to various input and output focal points; and
- Equip individuals and companies with the necessary points of value, to implement TX at a project and organisational level in a feasible manner.

This research study was based on an evaluative case study that follows the pre-requisite selection of TX, using a hybrid evaluation and selection methodology for DES (Wesch & Hattingh, 2021). The Action Design Research (ADR) method developed by Sein et al. (2011) was followed as part of developing a suitable strategy for implementing TX, from selection up to incorporation and integration within business systems.

The primary aim of this research study was to develop a referable and holistic implementation strategy to follow for TX software. This has been achieved and the compiled simulation strategy and summarised approach provide an easy and efficient reference to follow for any new DES user(s). This methodology thus achieves the purpose of the study to provide a useable and referable strategy that can be used in multiple ways.

Key words:

Discrete-Event Simulation; Tecnomatix Plant Simulation; Software Implementation Strategy

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My friends & family, for their love and support.

SOLI DEO GLORIA

A PERSONAL NARRATIVE

To give a personal perspective to the research topic and the importance thereof, it is important to include my personal narrative leading up to the research investigation.

It starts with the completion of both my mechanical and industrial engineering undergraduate degrees in the span of six years, at the North-West University. These degrees enabled me to learn both the fundamentals of engineering systems and the tools and skillsets to optimise these systems, at a technical and operational level. Thereafter, I started to work permanently at a large manufacturing/production company (Company A) – as the first and only industrial engineer within the associative division (Division A). The opportunities regarding implementing new IE tools and identifying areas of improvement in a cross-functional division and the flow-over to other departments were set out as my main responsibilities. The aim is to construct value-adding IE tools to form part of a developing organisational structure, in an industry that is mainly dependent on 'older' generational experience and knowledge.

Consequently, I decided that due to my position and responsibilities (to include IE practices within Division A), together with the responsibility of procuring and integrating Tecnomatix Plant Simulation (TX) within Company A – to develop a feasible and viable implementation strategy, for identified and potential projects.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

ADR	-	Action design research
BIE	-	Building, intervention, and evaluation
BOM	-	Bill of Materials
CFD	-	Computational-Fluid Dynamics
Company A	-	Company facilitating the case study
Division A	-	Division facilitating the case study
Division B	-	Process engineering division at Company A
DES	-	Discrete-Event Simulation
ECAD	-	Electrical Computer-Aided Design
ERP	-	Enterprise Resource Planning
FEA	-	Finite-Element Analysis
IE	-	Industrial Engineering
IT	-	Information Technology
MCAD	-	Mechanical Computer-Aided Design
PLM	-	Product Lifecycle Management
PMO	-	Project Management Office
Product A-E	-	Various product types manufactured by Company A
ROI	-	Return-on-Investment
SDN	-	Software Defined Networking
Site A/B/C/D	-	Various Company A operational sites
TRREE	-	Training and Resources in Research Ethics Evaluation
TX	-	Tecnomatix Plant Simulation
URS	-	User Requirements Specification
VDI	-	Verein Deutscher Ingenieure, Association of German Engineers

CHAPTER 1: INTRODUCTION

Chapter 1 provides the background and context for the research topic. It features the basis and the motivation for the investigation and illustrates its key features.

1.1 Background to the Research

The background to this research topic initiates from the selection of TX software (see 1.1.1 DES Software Evaluation & Selection), which is a discrete-event simulation (DES) software dedicated to production process simulations. DES software is used to model real-world systems that can be decomposed into a set of logically separate processes, which autonomously progress through time. TX software is developed by Siemens PLM Software and has been in the marketplace for almost two decades. TX is one of the major products that dominate the DES market space today (Wikipedia, 2021). The need for an integrated strategy for DES implementation follows on the requirement to implement this software efficiently and effectively with no formal DES structures or simulation team, dedicated to production process simulations, in place.

To provide further perspective, the evaluation and selection methodology that was used by Company A for the DES software is considered, followed by an exploration of TX software implementation strategies.

1.1.1 DES Software Evaluation & Selection

Many companies are looking to use and incorporate DES type software in the 4th Industrial Revolution to compete and continuously improve their business strategy (Siemens, 2009).

The first step required in evaluating and selecting software is the analysis of the possible value that discrete-event simulation software will add to the company. As with many software types, determining a direct return-on-investment (ROI) is very difficult, because of non-quantifiable inherent characteristics associated with simulations, as well as indirect cost effects that offer great value for various implementations. The main sources of ROI are typically provided by the software developers or are based on case-specific examples to provide a baseline reference.

The pre-requisite selection of TX was supported by utilising a hybrid evaluation and selection methodology for DES. This hybrid methodology is covered and referenced in more detail in a separate conference paper compiled in parallel to this study by the lead author, titled – A Case Study on a Hybrid Selection & Evaluation Strategy for DES Software (Wesch & Hattingh, 2021).

The hybrid methodology used was derived from an internal case scope of requirements, and a two-phase evaluation and selection methodology for DES software (Tewoldeberhan, et al. 2002). The base methodology followed is a reliable and well-referenced method, with this phase not requiring substantial research – due to the research already done on the evaluation of DES packages, including Hlupic (1997), Nikoukaran, Hlupic, and Paul (1999) – which aided as frameworks for the two-phased method developed by Tewolderberhan, et al. (2002). Tewolderberhan, et al. (2002) also stated that evaluating simulation packages, and selecting the best one for a large company, is a time-consuming task unless an efficient methodology is used. Usually, choosing from a list of alternatives requires detailed knowledge of the selection criteria, and on the score of the alternatives using these selection criteria. The evaluation and selection methodology follows the first phase in which simulation packages are selected based on the existence of the most important features and criteria. In the second phase, detailed evaluation and analysis are done for packages that satisfy the requirements of the first phase, and within this hybrid selection – the industry case scope of requirements and motivation. As indicated, this section is referenced in more detail in a separate conference paper (Wesch & Hattingh, 2021).

A selection of various simulation software, dedicated to production process simulations went through this evaluation and selection methodology, including Tecnomatix Plant Simulation. By using the compared software package analysis and filtered evaluation from phase one, a ranking table featuring the main requirements is compiled. Capabilities are ranked with the following symbols and highlighted colours: (A/green) – best in class; (B/orange) – average in class; (C/red) – worst in class.

Table 1: Software Capability Matrix, sources: Anylogic (2017) & Critical Manufact. (2014)

Capabilities	Package A	Package B	Package C	TX (Standard/ *Professional*)
Supported Operating System	Windows, Mac, Linux (A)	Windows (A)	Windows (A)	Windows (A)
Compatible Software	Excel, Access, SQL, OptQuest, Stat::Fit, Java (B)	Excel, SQL, Stat::Fit, OptQuest (B)	Excel, C++ (B)	Matlab, Excel, Simatic IT, Autocad, Microstation, *SAP, Teamcenter* (A)
Input Distribution Fitting	31 predefined dist, Stat::Fit, ExpertFit (A)	Stat::Fit (B)	ExpertFit (B)	22 predefined distributions (B)
Graphical Model Construction	Yes (A)	Yes (A)	Yes (A)	Yes (A)
Output Analysis Support	Reports, logs, charts, db output (B)	N/A (C)	Charts, graphs, dashboards, Excel (B)	Datafi, charts, Bottleneck/Energy analyzer, neural networks, reports (A)

Capabilities	Package A	Package B	Package C	TX (Standard/ *Professional*)
Optimisation	OptQuest (B)	OptQuest (B)	OptQuest (B)	Neural networks, Hill Climbing, Dynamic prog., Branch & Bound (A)
Run Time Debug & Code Reuse	Yes (A)	Yes (A)	Yes (A)	Yes (A)
Cost Allocation	Yes (A)	Yes (A)	Yes (A)	Yes (A)
Batch Run/Experimental Design	Parameter variation, run compares, Monte Carlo, Sensitivity analysis, calibration (B)	Multiple replications and scenario management (B)	Built-in experimentation engine (A)	Experiment Manager supporting distributed simulation (A)
Mixed Discrete/ Continuous Modelling	Yes (A)	No (C)	Yes (A)	Yes (A)
3D Animation Capability	Yes (A)	No (C)	Yes (A)	Yes (A)
CAD Drawings Import	Yes (A)	No (C)	Yes (A)	Yes (A)
Price Range (approximation)	R280 000 (B)	R110 000 (A)	R350 000 (C)	R350 000 / *R760 000* (C)
Future Integration Capabilities within Company A Systems	No (C)	No (C)	No (C)	Yes (A)

Based on the ranking and comparison evaluation between the identified software packages, TX was selected as the most suitable software. Wesch & Hattingh (2021) derived further motivation for the selected package into three main sections: software capability motivation, initial return-on-investment targets, and license motivation.

1.1.2 Motivation for the Study

An important point to note is that most research based on DES implementation and integration is either too generic **or** too case-dependent. Jägstam and Klingstam (2002) proposed a simulation handbook within their article, titled – a handbook for integrating discrete event simulation as an aid in conceptual design of manufacturing systems. Although the activities in the developed handbook are generic to suit different plants within a company, it is based only on DES implementation at a project level, **not** at a dedicated production process simulation and organisational level. Other related articles building on DES at a higher-level analysis, includes Kampa, et al. (2017) – DES Method as a Tool for Improvement of Manufacturing Systems.

The 'gap' in research and opportunity for this study falls in between similar research on DES implementation and integration methods as indicated, and on the selected simulation software (TX) – not providing a complete holistic implementation strategy at a project **and** organisational level. A strategy that can be followed to successfully implement and integrate TX within a company, will thus be the focus of this research study.

TX-based research is mainly focused on either case-by-case studies or a general overview, such as Fil'o, et al. (2013) article – PLM Systems and Tecnomatix Plant Simulation, a Description of the Environment, Control Elements, Creation Simulations, and Models. On an implementation and application level, research has been conducted in various industry-specific cases. Siderska (2016) is one of the more recognised articles, where the main objective was to present the possibilities and examples of using TX to simulate production and logistics processes. Various other researchers based in Europe, including Kikolski (2016), Musil, et al. (2016) and Kliment, et al. (2014) have also aided in the analysis of TX at a *project case*[1] basis, **but not** at a *strategy and organisational level*[2]. This is due to the research only revolving around the modelling and simulation requirements and capabilities per case, and not including overall business effects and strategy development.

There are very good sources to provide a base structure, with individuals such as Bangsow (2010 & 2015) who has made it his life's work to aid in the development and application of Siemens software packages, including TX. However, this does not incorporate strategies at a business level. Bangsow is also the author of two of the most important books for any TX simulation engineer to have, titled:

- Manufacturing Simulation with Plant Simulation and SimTalk, usage and programming with examples and solutions (Bangsow, 2010), and
- Tecnomatix Plant Simulation, modelling and programming by means of examples (Bangsow, 2015).

A TX organisational integration strategy is of the utmost importance at a practical level for multiple industries looking to potentially invest and implement simulation software, to cut costs between the concept and production/manufacturing phase. Companies are also interested in holistically simulating operations to improve planning, assist in root cause analysis and help with decision or design support, among other focus areas. Most research on Siemens software is focused on European industries – as seen with the reference cases in the previous sections. This implies that research, not only on the main problem statement but also on the research topic, as a whole will aid as a valuable contribution to potentially fill a knowledge gap and expand into a new contribution across industries.

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[1] ***Project cases*** *refer to modular facilities/processes that are modelled and simulated based on input and output requirements utilising TX software.*

[2] *References about* ***strategy*** *and* ***organisational level*** *application, includes the development and evaluation of the utilisation and incorporation of TX within company structures.*

1.2 Research Aim and Objectives

1.2.1 Research Aim

This research study holistically addresses an identified problem revolving around TX software implementation at a project and organisational level. The intended value is that the research meets the needs of not only researchers in the field of TX software, but also DES software dedicated to production process simulations as a whole. With a target audience of companies, simulation engineers, and other stakeholders looking into the potential implementation and incorporation of TX, from the selection phase, up to integration at a high level with other systems in a company. This study aims to:

- Guide individuals and companies through the complexities of implementing TX software within organisational capacities;
- Illustrate the different project phases and steps, with regards to various input and output focal points;
- Equip individuals and companies with the necessary points of value, to implement TX at a project and organisational level in a feasible manner.

The research will use a case study, with multiple samples at a project level to derive a holistic strategy revolving around multiple types of projects. Furthermore, a parallel leg will focus on the business case subjugated to all of the projects.

1.2.2 Primary Research Question and Objectives

The objectives provide a means to an end, and necessitate the answering of the primary research question – *what practical strategy can be followed for successful TX software implementation within a manufacturing/production industry at a project and organisational level?*

The focus will be at a case study level, incorporating multiple project types, business case implications and impact. This will be achieved by providing a substantial case study, facilitating a *broad enough*[3] spectrum to act as a generic strategy to follow for individuals and companies, which have an interest in implementing DES type software.

In order to answer the primary research question, the following objectives have been formulated:

i. Develop an implementation strategy for TX software, with initial design guided by theory and existing research.

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[3] *This is a statement subjugated to an inherent warrant as the strategy/method is being developed.*

ii. Quantify the feasibility of project cases and TX implementation, based on project input and output requirements.
iii. Provide guidelines to ensure sufficient TX utilisation and functionality as a company support tool.
iv. Verify/validate the modular project and organisational components with identified stakeholders, to ensure a practical and viable strategy is developed.

1.3 Importance of the Research

"$9 billion per year could be saved in Germany alone through the use of simulations. The plant is too expensive to be used as an experimental environment and time is too precious to be wasted. Therefore simulation is an efficient means for developing and testing new and innovative production concepts!"

- Dr. h.c. Dr.-Ing. E.h. Hans-Jürgen Warnecke, President of Fraunhofer-Gesellschaft, Germany via (Siemens, 2009).

The importance of this research is reflected in this thought-provoking quote. These substantial savings can however only be achieved if the simulation software is **successfully** implemented within the specific company.

Literature on the implementation of DES software dedicated to production process simulations is mainly focused on project cases and not overall strategy development, subject to business capacity and requirements. The potential deliverable from this study that will be of great benefit for multiple fields stems from a principle idea for an implementation strategy, similar to a proposal produced by Jägstam and Klingstam (2002). The research study will also look at **why** it is important to include an implementation strategy, at both an organisational and project level.

It should also be noted that this research dissertation was drafted during the National State-of-Disaster that was forced on all South Africans due to the global Coronavirus (Covid-19) epidemic. Through the lockdown, it became apparent that DES could be used as a main support tool at a business and operations level, with many more advantages going into an unknown economic and operational period. The research thus feels more pertinent and justifiable going into a period of disruption, where any form of viable support could be critical to the survival of many companies.

1.4 Overview for the Research Study

The overall aim of this research study is to develop a practical implementation strategy, focused at a project and organisational level for simulation software dedicated to production process simulations. There are a few important factors, however, that require evaluation concerning the main aim of this study. Firstly in general research, case implementation at a project level and business integration of software are mostly separated. This is mainly for qualitative research purposes on a modular level. Secondly focusing on a selected software type, within a company could create a constrained case study environment (Randell, 2002).

Based on the initial evidence and strategy requirements, this only holds true at a modular level. Following a holistic approach in creating an implementation strategy for TX, will ensure a practical solution from software rollout to day-to-day operational use, as well as providing a methodology that can be used as a reference for multiple types of DES software. With sufficient data and cross-analysis, this research will provide a platform that will incorporate both issues.

Figure 1 is a general overview of the research terrain and illustrates the research sections and topic points, which will be referenced in the succeeding chapters.

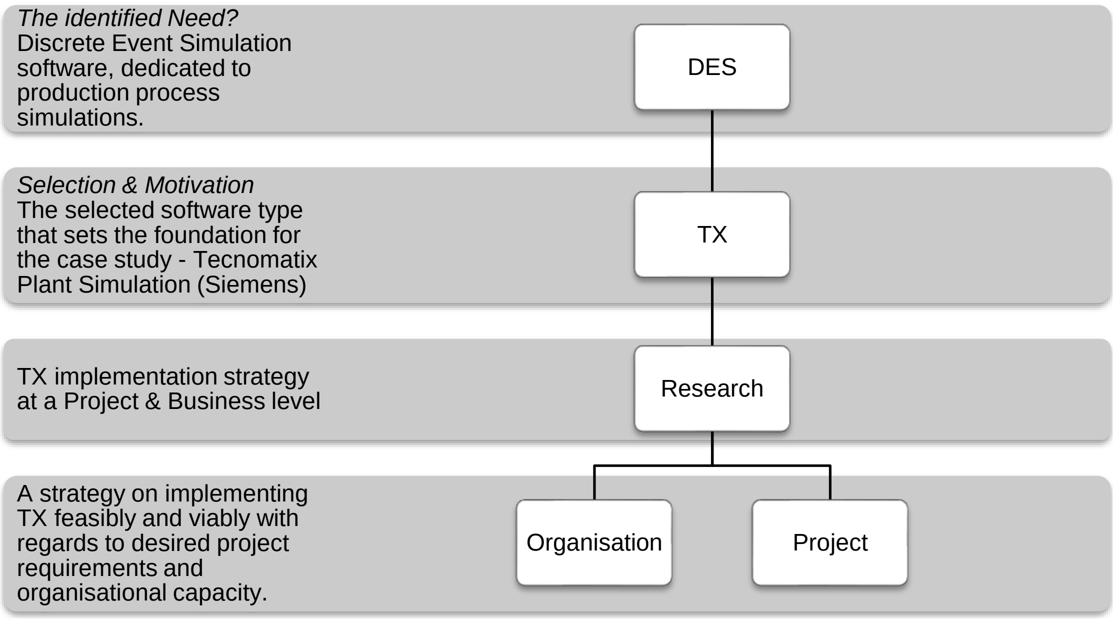

Figure 1: General overview for the research

Figure 1 illustrates the functional hierarchy of the selected software type (TX), following identifying the need for DES, based on selection and motivation criteria (Background). The implementation strategy is split into parallel modular functions at an organisational and project level.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The literature review discusses four aspects related to the research topic. These include discrete-event simulation (DES) software dedicated to production process simulations, strategies to implement other types of software/technology within a company at a project and organisational level, Tecnomatix Plant Simulation (software and strategy components), and feasibility models associated with software implementation and integration.

The review maintains a critical focus on TX and the implementation strategy requirements in particular. Insight is provided into the meaning of DES software implementation at a project and business level, and determining the feasibility surrounding both levels. The applicability of various strategy steps is analysed and the most appropriate practice is identified based on the relevant study.

2.2 Discrete-Event Simulations (DES)

According to Maidstone (2012), DES is one of the most widely used simulation techniques in operational research. As the name suggests it models a process as a series of discrete events. This means that entities (the general name for what is being considered, e.g. a part) are thought of as moving between different states as time passes. The entities enter the system and visit some of the states (not necessarily only once) before leaving the system. Typically, DES systems are thought of as networks of queues and processes, as depicted in the example in Figure 2.

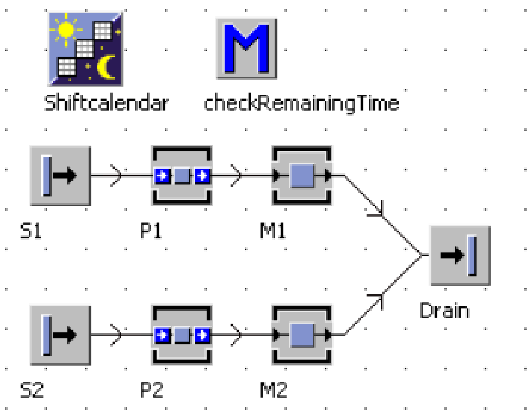

Figure 2: Basic DES model example, source: Bangsow (2010)

S1 and S2 are part sources from which an entity enters the model; P1 and P2 are buffers that hold parts until the connected processes, M1 and M2 are ready to receive them. The processed parts are then moved on, in this case to the associative drain. The example considered is a basic buffer-process simulation model. However, even a basic model such as this can prove to be insightful. Using a simulation such as this can help the modeller to identify possible areas in the system where problems may occur. DES techniques can especially be used to discover whether it would be advisable to add more processes, or even restructure the system far more radically.

DES represents the modelling, simulating, and systems utilising computational and mathematical techniques while creating a model construct of a conceptual framework of a defined system. The system is further simulated by performing experiments using computer implementation of the model and analysed to conclude the model outputs that can assist in the decision-making process. DES technologies have been extensively used by industry and academia to deal with various industrial problems (Babulak, 2010). According to Babulak (2010) by the late 1990s, DES was in the doldrums as global manufacturing industries went through radical changes, with the simulation software industry going through consolidation. He goes on by saying that these changes have created new problems, challenges, and opportunities within the field. DES remains one of the most effective decision support tools but much needs to be done to address new challenges (Babulak, 2010).

> *'Simulations are of great importance as they prevent the catastrophic failures in the system due to impact of a change.'* – Sharma (2015).

New changes, procedures, information flows, etc. can be examined without interrupting the smooth working of real systems. A simulation model is developed to study the working of a system as it evolves over time. A fully developed and validated model can answer a variety of questions about real systems (Sharma, 2015).

Gupta (2014) states that in a period of continuous change in the global business environment, organisations (large and small) are finding it increasingly difficult to deal with, and adjust to the demands of such change. He also states that simulation is a powerful tool for designers to imagine new systems and enable them to both quantify and observe behaviour. Currently, the market offers a variety of simulation software packages. Some are less expensive than others are. Some are generic and can be used in a wide variety of application areas while others are more specific. Some have powerful features for modelling while others provide only basic features. Modelling approaches and strategies are different for different packages. Companies are seeking advice about the desirable features of software for manufacturing simulation, depending on the purpose of its use. Because of this, the importance of an adequate approach for simulation software selection and integration is apparent (Gupta, 2014).

'Despite significant cost savings and the stride towards developing and implementing the Virtual Factory, few companies have managed to fully integrate simulation as a daily tool in their engineering processes.' – Jägstam & Klingstam (2002).

Jägstam and Klingstam (2002) explored the pre-requisites for this integration, using DES as an aid for high-quality decision making in early phases (conceptual design and pre-study). They looked at three aspects of the pre-requisites: technological, operational, and organisational – and summarised the main challenges connected to each one of the aspects. The main result presented in their paper was a proposal for a simulation handbook, to be used when integrating simulations into the engineering process. The strength of the handbook is the focus on operational and organisational issues, reflecting different roles with connection to simulation.

As stated, the DES software that will be focused on in this study is Tecnomatix Plant Simulation (TX). To ensure a holistic approach is taken in selecting and developing a suitable implementation strategy, other software/technology types are considered.

2.3 Software and Technology Integration Strategies

In order to scope the most suitable strategy development for TX, other software/technology type integration strategies were researched. This provides a reference point to work from concerning the overall research study.

2.3.1 Information Technology (IT)

Information systems play a critical role in today's manufacturing business, and the need for enterprise-wide integrated information systems has grown rapidly, as isolated information systems represent inadequate business solutions (Kuang & Gao, 2006). To successfully and profitably operate in rapidly changing markets, there is a need to integrate different information systems like enterprise resource planning system (ERP), supply chain management (SCM), and customer relationship management (CRM) in a company (Chang, 2000).

It has been an increasingly evident phenomenon that information technology often provides a manufacturing-based competitive advantage (Ho, 1993). Ho (1993) introduced an evolutionary process for implementing information technology in the manufacturing sector. The evolutionary process contains stages for which transformation to a world-class manufacturer is prescribed. The process draws upon a strategic alignment model of manufacturing management and IT. The model is defined in terms of four domains of strategic choice: the structure and infrastructure of manufacturing strategy, and the structure and infrastructure of information technology – each with its constituent dimensions. The model is conceptualised in terms of two fundamental characteristics of strategic management: strategic fit (i.e., integration between manufacturing and information technology functional domains) and functional integration (i.e., integration between manufacturing and information technology functional domains). The way that information technology is implemented is through cross-domain alignment via strategic fit and functional integration.

In Ho (1993)'s framework, integration is not treated as a combination of discrete techniques developed for a specific application, but as a new development process of information techniques for a specific business purpose. The framework focuses on data created in the business functions and the integration of information flow across the business functions. Hence, the main information functions were the basis of the description of the present business functions and the respective integration of these functions.

Kuang & Gao (2006) also introduced an integration framework with the aim of providing a methodology to integrate manufacturing information systems. The integration framework has been divided into five stages with fifteen steps to give a step-by-step procedure for the analysis and implementation. The stages should be followed sequentially, as each stage requires the information and analysis input from the stage that precedes it, as shown in Figure 3.

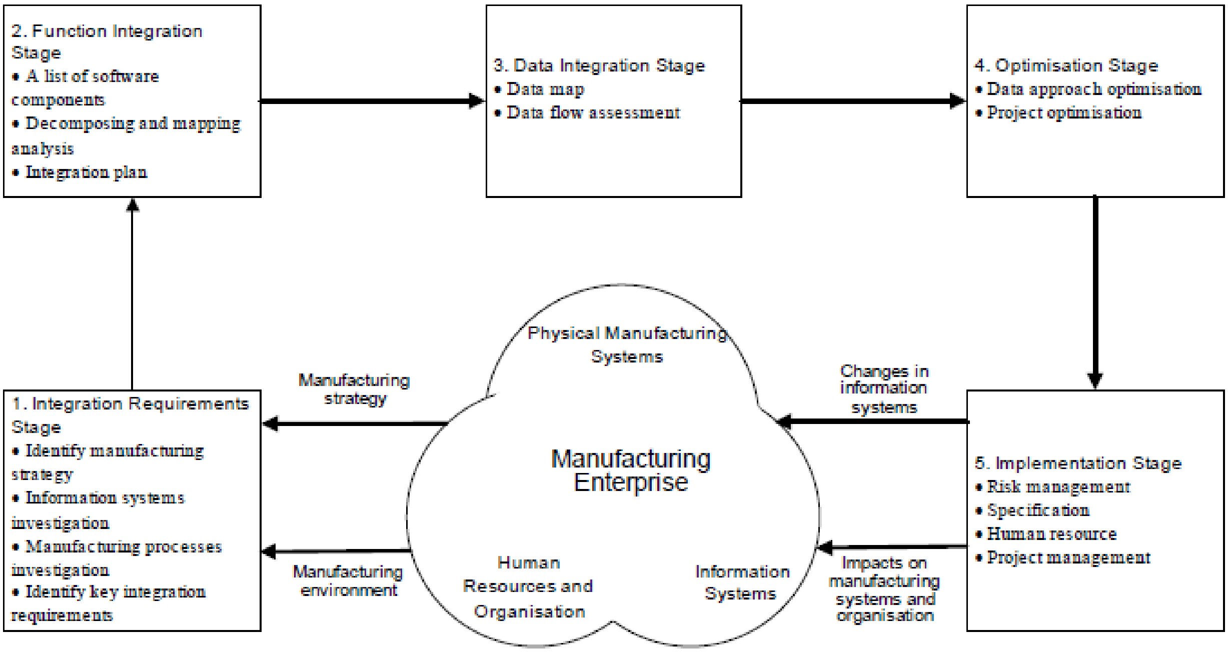

Figure 3: The proposed framework for IT systems integration, source: Kuang (2006)

This integration framework, however, does not include a functional strategy for the implementation of a selected software type at a project level.

2.3.2 Enterprise Resource Planning (ERP) Systems

Enterprise Resource Planning (ERP) is an information system that attempts to integrate all departments and functions across a company onto a single computer system. Bhatti (2009) introduced research to integrate a prominent model of information system implementation to develop a holistic approach to ERP implementation. Using an ERP implementation model and Critical Success Factors (CSFs), and an integrated ERP implementation framework was proposed. This framework comprises of two important phases of ERP systems in the organisations, namely implementation processes and CSFs. Each phase comprises of four stages in which the process follows and then the success of ERP implementation is measured by project outcomes and organisational impacts (Bhatti, 2009).

The main issue with the model that Bhatti (2009) introduced is that with the implementation of a new type of software (i.e. DES type software) within a company, the critical success factors (CSFs) are not known. For this study, the CSFs need to be introduced and evaluated concurrently with the implementation thereof.

2.3.3 Project Management Office (PMO)

One of the strategies for the successful implementation of large software projects is the establishment of a Project Management Office. PMO aids with continuous process improvement, identifies and mitigates risk early in the software development life cycle, and manages cost through the application of applied project management methodology. The implementation of best practices in project management has a greater impact on the project's success, to be on time and budget. The PMO Framework is proposed for the successful implementation of Information Technology projects (Kaufman, 2007).

Although PMO consists of well-established methods for project execution at a high level. It includes varying overhead costs and is very ambiguous about roles and responsibilities associated of the PMO, for software implementation projects (Sanchez Macias, 2006).

2.3.4 Software Defined Networking (SDN)

SDN is an emerging approach to handle data forwarding and control separately. The notion of programmability has a central importance in SDN. Two implementation strategies: proprietary and open source, are shaping the trends of the adoptability of SDN by major hardware manufacturers. A group of leading vendors believes that loose coupling between the logical and physical layers of a network hinders the proper provision of physical resources and suggests a proprietary fix to this problem. The other group regards the notion of openness as a key feature of SDN (Raza et al., 2014).

As with the case in PMO, SDN is also only applicable at a modular level regarding hardware and software integration management.

2.3.5 Overview of Strategies

A few of the main considerations that will add value to this research study will be provided in this overview section.

Firstly, the IT framework by Kuang & Gao (2006) illustrates the value of having a phased integration methodology. Phasing out an implementation or integration strategy in a modular approach provides a qualitative means to follow and apply the strategy more effectively.

The model that Bhatti (2009) introduced for ERP systems highlights the benefits of implementing a new software system based on identified critical success factors (CSFs). The return-on-investment for DES type software is a CSF that requires quantification in parallel with the implementation of the software.

The PMO (Kaufman, 2007) and SDN (Raza et al., 2014) strategies provide a good frame of reference for the implementation of software at a project level. Some of the PMO components will thus add benefit to the strategy development at a modular project level.

All of the components mentioned will contribute to provide a holistic approach to the strategy development, surrounding TX implementation at a project and business level.

2.4 Tecnomatix Plant Simulation (TX)

TX is an object-oriented 3D program used to simulate discrete events, which allows to quickly and intuitively create realistic, digital logistic systems (e.g. production) and thus test the properties of the systems and optimise their performance. The German company Siemens PLM Software manufactures the application, which is the leading global supplier of software for PLM (Product Life-cycle Management) and MOM (Manufacturing Operations Management). The solutions provided by Siemens as part of their Smart Innovation Portfolio help production companies optimise digital enterprises and implement innovations. Digital models make it possible to perform experiments and test “what-if” scenarios without disturbing the work of production systems or, in the case of the planning process, long before their assembly (Siemens, 2020). A preliminary definition of the libraries of factory and logistic facilities makes it possible to create simulation models interactively (see Siemens, 2020).

Advanced analytic tools, such as bottleneck analysis, statistics and charts, can be used to evaluate different production scenarios. The results ensure information necessary for making good decisions at the early stages of production planning. In addition, it is possible to optimise material flow, the use of resources, and logistics at each level of planning – beginning with global production facilities, through local enterprises, up to individual lines.

TX application is available in English, German, Japanese, Hungarian, Russian and Chinese. It is also possible to switch from one language to another. A very important feature of the program is the possibility to model and simulate processes following the paradigms of object-oriented programming. The following programming features need to be mentioned (Bangsow, 2010):

- Inheritance
- Polymorphism
- Hierarchy

TX also provides analytic tools, which allow the detection of bottlenecks (Bottleneck Analyzer), tracking material flow (Sankey Diagrams), and identification of resource excess (Chart Wizard). A very important advantage of this program according to Siderska (2016) is that it provides integrated optimisation tools. These include mainly:

- GA Wizard – an optimising simulation model using genetic algorithms;
- Layout Optimizer – which enables minimising transportation costs using genetic algorithms;
- Neural Network – which makes it possible to identify connections between input and output parameters and which provides projections with the use of artificial neural networks;
- Experiment Manager – used to create scenarios or evaluate relations between two input parameters.

TX also allows to perform statistical data analyses (e.g. studying dependence and independence, regression, data fitting, ANOVA, etc.). Furthermore, it is possible to import data from other systems, programs, or databases, e.g. Access, Oracle, Excel, SAP, and AutoCAD. Another very important advantage of the program is also the tool used for original algorithms and script programming (Method). The built-in language SimTalk, with the syntax based on BASIC, is used for this purpose (Siderska, 2016).

As referenced in Chapter 1, TX is comparable to other solutions such as FlexSim, Anylogic, and Simul8. For the purposes of this study, the project and business components are derived around TX implementation.

2.4.1 Project Components

Project components point to the procedural components regarding modelling and simulation, utilising TX.

According to VDI guideline 3633[4], the following approach is recommended:

i. Formulation of problems
ii. Test of simulation-worthiness
iii. Formulation of targets
iv. Data collection and data analysis
v. Modelling
vi. Execution of simulation runs
vii. Result analysis and result interpretation
viii. Documentation

Bangsow (2015) as follow interpreted these guidelines:

i. Formulation of Problems

Together with the customer of the simulation, the simulation expert must formulate the requirements for the simulation. The result of the formulated problem should be a written agreement (e.g. a technical specification), which contains concrete problems that will be studied using simulation.

ii. Test of Simulation-Worthiness

To assess simulation-worthiness you can examine:

- The lack of analytical mathematical models (for instance, many variables);
- High complexity, many factors to be considered;
- Inaccurate data;
- Gradual exploration of system limits;
- Lead time to provide results;
- Repeated use of the simulation model.

[4] *VDI 3633 is a standards guideline by Verein Deutsher Ingenieure e.V., titled: Simulation of systems in materials handling, logistics and production – Terms and definitions. This standard is intended for users of simulation technology who are involved in the preparation, execution and evaluation of simulation studies for examining systems in logistics, material flow, and production.*

iii. Formulation of Targets

Each company aims at a system of targets. It usually consists of a top target (such as profitability), which splits into a variety of sub-targets that interact with each other. The definition of the target system is an important preparatory step. Frequent targets for simulations are, for example:

- Minimise processing time
- Maximise utilisation
- Minimise inventory
- Increase in-time delivery

All defined targets must be collected and analysed statistically at the end of the simulation runs, which implies a certain required level of detail for the simulation model. Hence, they determine the range of the simulation study.

iv. Data Collection

The data required for the simulation study can be structured as follows:

- System load data
- Organisational data
- Technical data

The following is a small selection of data to be collected for simulation purposes:

Table 2: Simulation data collection example, source: Bangsow (2015)

Technical Data	
Factory Structural Data	Layout; means of production; transport functions; transport routes; areas; restrictions
Manufacturing Data	Use time; performance data; capacity
Material Flow Data	Topology; conveyors; capacities
Accident Data	Functional accidents; availability
Organisational Data	
Working Time Organisation	Break scheme; shift scheme
Resource allocation	Worker; machines; conveyors
Organisation	Strategy; restrictions; incident management
System Load Data	
Product Data	Working plans; Bill of Materials
Job Data	Production orders; transportation orders; volumes; dates

v. Modelling

The modelling phase includes building and testing the simulation model. Modelling usually consists of two stages:

First Modelling Stage:

First, you must develop a general understanding of the simulated system. Depending on the objectives to be tested, you have to make decisions about the accuracy of the simulation. Based on the accuracy of the simulation, necessary decisions are taken about which aspects to simplify. The first modelling stage covers two activities:

- Analysis (breakdown)
- Abstraction (generalisation)

Using the system analysis, the complexity of the system in accordance with the original investigation targets will be dissolved through meaningful dissection of the system into its components. Using abstraction, the amount of the specific system attributes will be decreased as far as it is practical to form a limited image of the original system. Typical methods of abstraction are reduction (elimination of irrelevant details) and generalisation (simplification of essential details).

Second Modelling Stage:

A simulation model will be built and tested. The result of modelling must be included in the model documentation to make further changes in the simulation model possible. In practice, this step is often neglected; hence, models cannot be used due to the lack of documentation of functionality. Therefore, there is a need for commenting on the models and the source code during programming. This ensures that the explanation of the functionality is still available after programming is complete.

vi. Executing Simulation Runs

Depending on the objectives of the simulation study, the experiments based on a test plan will be realised. In the test plan, the individual experiments on output data, arguments of the model, objectives, and expected results are determined. It is also important to define a period for the simulation experiments, based on the findings of the test runs. The computer runs spanning several hours or frequent repetitive experiments for statistical coverage are not uncommon. In these cases, it is helpful to check whether it is possible to control the experiments using a separate programmed object (batch runs). The realisation times for the experiments can be relocated partly at night so that the available computing capacity can be utilised optimally. Input and output data as well as the underlying parameters of the simulation model must be documented for each experiment.

vii. Result Analysis and Result Interpretation

The values, which will change in the modelled system, are derived from the simulation results. The correct interpretation of the simulation results significantly influences the success of a simulation study. If the results contradict the assumptions made, it is necessary to analyse what influences are responsible for the unexpected results. It is also important to realise that complex systems often have a ramp-up phase. This phase may run differently in reality and the simulation. Therefore, the results obtained during the ramp-up phase are often not transferable to the modelled system and may not influence the evaluation (Exception: The ramp-up phase of the original system has to be fully modelled).

viii. Documentation

For the documentation of a simulation study, the form of a project report is recommended. The documentation should provide an overview of the timing of the study and document the work conducted. The core of the project report should be a presentation of the simulation results based on the customer requirement specification. Resulting from the simulation study, it makes sense to include proposals for actions in the documentation. Finally, we recommend describing the simulation model in terms of its structure and functionality.

2.4.2 Organisational Components

Organisational components point to all other incorporated facets required for integrating and incorporating TX within a company effectively.

The following components have been derived from Siemens (2020):

i. Resource Capacity

Resource capacity indicates to the company's available resources and capital expenditure capabilities, concerning software application and development. This also includes skill capacity and project simulation maturity within company structures.

ii. Software Licensing

Licensing indicates to the strategy regarding TX license procurement and implementation. This includes the different license types and module capabilities, including TX Standard fixed/floating license, TX Professional fixed/floating license, subscription licenses, etc.

A fixed license can only be utilised by one specified user, with a floating or subscription license able to be utilised by multiple users (separately at a time). The Tecnomatix Plant Simulation license capabilities manual can be referred to for more detail.

iii. Training

Training indicates the targeted simulation training regarding various skill capacities and strategy requirements. This includes in-house and outsourced training, with variants on basic and advanced training.

iv. ROI

Companies' main measurement on successful software implementation within a company is based on the Return-on-Investment thereof (Siemens, 2020). This is however very difficult, due to the inherent nature of simulations not being easily quantifiable and measurable.

This study and Company A's focus surrounding this measurement is constructed utilising the TELOS Model (see 2.5 Feasibility Studies). Moreover, the study is subjected per project case sample to provide a holistic view of the value added by the software at various levels.

v. Organisational Integration

According to Robbins (2015), no other topic in management has undergone as much change in the past few years as that of organisational structure. Managers are questioning and re-evaluating traditional approaches to organising work in their search for organisational structures that can achieve efficiency but also have the flexibility necessary for success in today's dynamic environment. Robbins (2015) defines organising as the process of creating an organisation's structure. And states further that the challenge for managers is to design an organisational structure that allows employees to work effectively and efficiently. Organisational structure is how job tasks are formally divided, grouped, and coordinated within an organisation. Organisational design is a process that involves decisions about six key elements: work specialisation, departmentalisation, chain of command, span of control, centralisation and decentralisation, and formalisation (Robbins, 2015).

Organisational integration indicates the introduction of TX at various levels within the company, based on the phasing strategy (succeeding section). This is included within the strategy to integrate TX within the company more efficiently.

vi. Strategy Phasing

Phasing indicates to the phased strategy that is followed by Company A. This incorporates all of the other business components, to integrate TX more efficiently and successfully at a project and business level. This will form part of the strategy development, which forms part of the research study aim and objectives.

2.5 Feasibility Studies

A feasibility study in Software Engineering is a study to evaluate the feasibility of a proposed project or system. Feasibility studies are one of four important stages of the Software Project Management Process (Jena, 2020). As the name suggests feasibility studies are the feasibility analysis or measure of the software product, in terms of how beneficial the software development will be for the organisation from a practical point of view. Feasibility studies are carried out based on many purposes to analyse whether a software product will be right in terms of development, implementation, the contribution of a project to the organisation, etc. (Jena, 2020).

Multiple models are considered in order to identify the most suitable feasibility strategy for this research study.

2.5.1 Business Process Models

According to Issa (2007), Business Process Modelling (BPM) can be defined as the representation of one or more of the process perspectives to understand, analyse, and/or improve automated and/or non-automated business processes. Hence, the availability of business process models in any organisation is not tied to any corresponding software system. Rather, they may exist much before the automation of the business of any organisation. However, business process modelling can be used to contribute positively to the software development process (Issa, 2007).

Karner (1993) developed a use case points method that utilises the identified actors, uses cases to size the software project, and consequently estimates the predicted effort and time required to deliver an operational system. In addition, Issa et al. (2006) developed three use case-based software estimation methods regardless of the use-cases levels of detail. These cases include use-case rough estimation, use-case patterns catalogue estimation, and object points extraction using the anticipated system’s use-case model. The initial investigation for the results of these new methods showed promising signs on the applicability of employing use case models for software cost estimation purposes (Issa, 2007).

Although performing early feasibility studies of software development projects using BPM provides a holistic overview, depending on the candidate use cases. It does not include project implementation components, where requirement engineering comes in.

2.5.2 Traditional Requirements Engineering (RE)

The scoping factors involved when creating bespoke software and therefore conducting traditional RE are; budget constraints, timeline issues and constraints, technical issues, and development issues. Analysts conducting traditional RE will consider whether the timeline and budget that have been set are feasible, and must ensure that the proposed software can meet the organisation's objectives. Their main concern is whether the system that is developed will be 'worthy' for use (Jebreen, 2013).

Traditional RE and pre-implementation packaged software share similarities as both can be seen as comprised of the same kinds of elements, and as, to some degree the sharing of similar objectives and being influenced by similar business concerns and technical concerns.

2.5.3 Pre-implementation Packaged Software (PS)

Analysts engaging in pre-implementation RE must think about specific issues and decide whether any existing packages offered by their company can offer a solution. They will need to consider the time and cost involved with implementing a particular package and with making requested changes to that package, and they may well decide to refuse a request for a particular solution if that solution falls outside the scope of the company or the scope of their current products (Jebreen, 2013).

In this regard, pre-implementation PS RE differs strongly from traditional RE, as analysts practising traditional RE do not need to consider how to deal with requests for modifications to existing functions.

The critical requirement that is not covered in both cases is the components relative to business strategy development. With RE feasibility studies only focusing on the project implementation using the identified software. This requirement is identified by breaking up the feasibility components that will affect implementation strategy development.

2.5.4 TELOS

Sometimes a feasibility study is done as part of a systems development lifecycle, in order to drive precision for the implementation of technologies (Techopedia, 2020). Engineers might look at a five-point model called TELOS – this includes the following components:

i. Technical
ii. Economic
iii. Legal
iv. Operational
v. Schedule

James A. Hall first presented the TELOS model in 2007 in his book, “Accounting Information Systems.” It has been adopted across a huge range of settings since then, because it offers a simple way to consider the most important issues related to feasibility, whether a multi-national pipeline or small business project is considered (Rudy, 2014).

The following components have been derived from Jena (2020):

i. Technical Feasibility

In technical feasibility, current resources both hardware and software, along with required technology are analysed/assessed to develop a project. This technical feasibility study reports on whether there exists correct required resources and technologies, which will be used for project development. Along with this, this study also analyses the technical skills and capabilities of the technical team, whether existing technology can be used or not, maintenance, and up-gradation viability for chosen technology, to name among a few aspects.

ii. Economic Feasibility

In economic feasibility studies, the cost and benefits of the project are analysed. This includes a detailed analysis of the related cost of the project development. This includes all required costs for final development like hardware and software resources, design and development cost, and operational cost. An economic feasibility study is a means for an organisation, to analyse whether a project will be financially beneficial for the said company.

iii. Legal Feasibility

In legal feasibility studies, a project is analysed from a legality point of view. This includes analysing barriers to the legal implementation of a project, data protection acts, project certificate, license, copyright, etc. Overall, it can be said that a legal feasibility study is an analysis, to know whether a proposed project conforms to legal and ethical requirements within a company.

iv. Operational Feasibility

In operational feasibility studies, the ease of product operability and maintenance is analysed after deployment. Along with this, other operational scopes include determining the usability of the product, determining whether the suggested solution by the software development team is acceptable or not, etc.

v. Schedule Feasibility

In schedule feasibility studies, timelines/deadlines are mainly analysed for a proposed project. This includes how much time teams will take to complete a final project, which might have a great impact on the organisation, as the purpose of the project may fail if it cannot be completed on time.

2.5.5 Feasibility Study Process

The steps below are carried out during the entire feasibility analysis.

i. Information collection
ii. Information assessment
iii. Report writing
iv. General information

2.5.6 Need for Feasibility Studies

Feasibility studies are an important stage of the Software Project Management Process, because it gives a conclusion of whether to go ahead with a proposed project (Jena, 2020). It provides a means to measure whether a project is practically feasible or to stop a proposed project as it is not feasible to develop.

Along with this, feasibility studies help in identifying risk factors involved in developing and deploying systems. Planning for risk analysis also narrows the business alternatives and enhances success rates, analysing different parameters associated with proposed project development.

2.6 Theoretical Framework Development

The chosen project and business components relative to TX implementation strategy development are concluded within this section.

2.6.1 Project Components

The associative steps that will be included for the development of sample projects have been derived following VDI guideline 3633[4] and Bangsow (2015)'s interpretation:

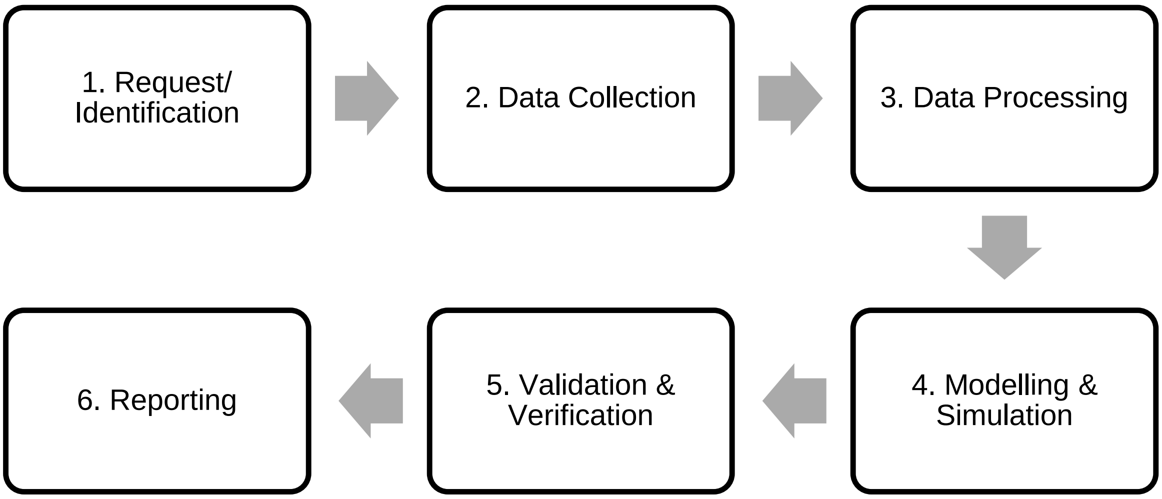

Figure 4: DES project components (Bangsow, 2015)

The project level entails a strategy to build and model various types of processes/facilities/operations, including various input and output requirements. The diagram illustrates the main steps that form part of the whole project requirement.

The first component includes the project request/identification process, which includes the formulation of problems, testing/analysis of simulation-worthiness and formulation of targets. These steps are combined within one component since these requirements are parallel functions to the project initiation phase.

The second and third component consists of data collection and analysis of the identified project. These steps are separated into two components because data processing follows on data collection, and in some instances reverts to data collection based on analysis/reviews.

The fourth component includes the modelling and simulation process. These steps are combined within one component, because of the inherent modelling environment of DES software (particularly TX), where simulation programming and debugging are concurrently developed within the model itself.

The fifth component incorporates the validation and verification aspects of the simulated projects. Validation in the project sense refers to the assurance that the model simulation meets the needs of the identified stakeholders. Verification is the evaluation of whether the simulated model complies with the requirement or imposed conditions. This includes result analysis and result interpretation, together with validation and verification in the form of project stakeholder reviews, and reference production data.

The last component consists of the reporting of these components and project closeout, in an attempt to communicate boundary conditions, parameters, construction and results.

2.6.2 Organisational Components

The organisational components includes all other parts required to incorporate the software within company structures, including software selection criteria (Background) and the overall simulation strategy (Case Study). The components included within the project and feasibility strategy development illustrated in Figure 5, are derived from Siemens (2020).

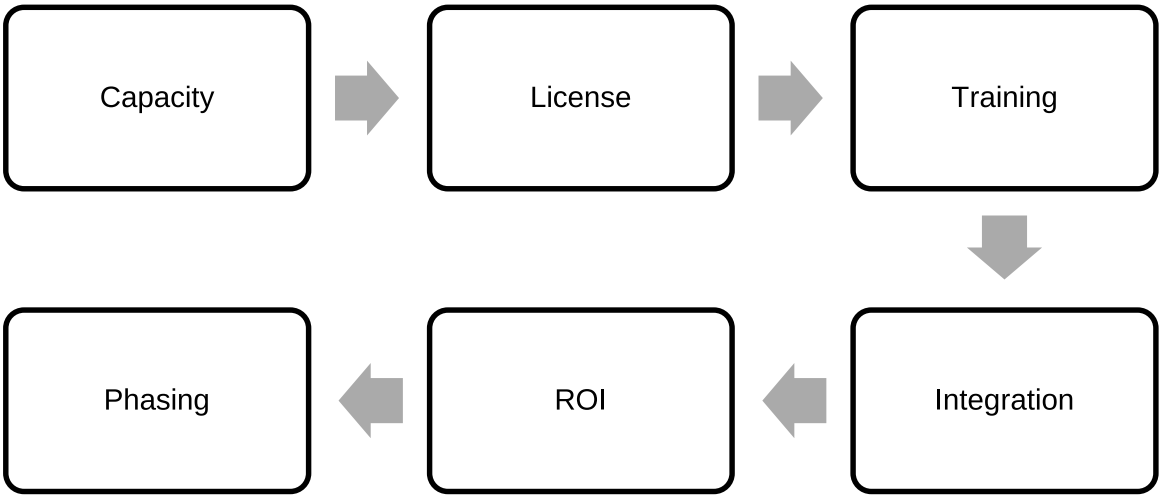

Figure 5: DES organisational components

The first component includes the analysis and evaluation of the company's resource capacity and maturity regarding DES simulation software/hardware/skills/structure/etc.

The second component consists of the analysis and evaluation of the preferred licensing strategy. The first and second components also form part of the initial DES software evaluation and selection methodology (Background).

The third component consists of the required training to comply with resource capacity and project requirements.

The fourth component includes the organisational integration of software within set working structures, as well as the evaluation of integration with other resources, hardware, and software.

The fifth component is determining and evaluating the return-on-investment (ROI) for the implementation of the software, at a project and organisational level. Every company's main criteria focus concerning an operational asset is feasibility and ROI orientated at a project and overall business level (Siemens, 2009).

The last component consists of a phasing strategy as part of the overall strategy development, to achieve the most feasible and viable results. It should be noted that all of these components, as well as the project-level components, will inherently form part of the overall strategy development.

2.6.3 Feasibility Model

The TELOS model is identified as the most suitable feasibility model to incorporate all of the various project-level and organisational facets, which might be relevant to the overall strategy development requirements.

The main motivation behind utilising the TELOS model is due to the generic component breakdown thereof, incorporating all of the main feasibility components. The other factor is that it is a widely popular and well-referenced model, which is used in many different companies.

2.6.4 Strategy Development

The derived strategy facilitates all of the project and business components, whilst providing a foundation to develop an appropriate TX implementation strategy. The initial phases introduced, include:

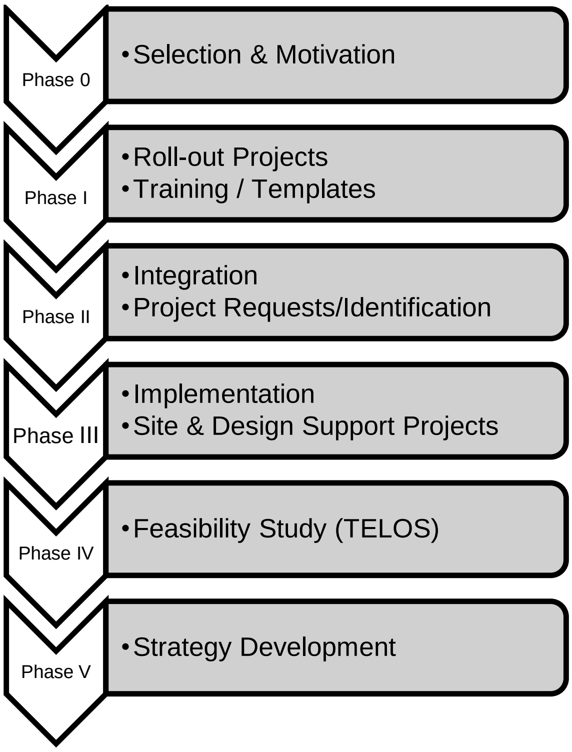

Figure 6: Strategy Development Phases

Phase 0 formed part of the procurement process of identifying and motivating TX as the preferred software for DES capabilities within Division A, and Company A as a whole. As referenced, a hybrid evaluation and selection methodology was followed in parallel with internal company procurement procedures.

Phase I incorporated identified training requirements, in parallel with identified 'roll-out' projects as part of resource capability evaluation.

Phase II includes the integration of the proposed project request/identification procedure within Division A, to identify initial sample projects.

Phase III introduces requested projects for design and site support type projects, to implement the software as a support tool.

Phase IV incorporates feasibility studies done on sample projects, to try and 'quantify' these projects.

Phase V concludes the strategy development as a whole on which this research study will focus.

2.7 Conclusion

The literature begins with an examination of DES software dedicated to production process simulations as a whole. It is noted that there is a requirement for compatible implementation strategies with variants of the software, implemented in different industries. The review maintains a critical focus on TX and the implementation strategy requirements in particular.

A general overview of DES implementation strategy components is investigated, with a focus on TX requirements at a project and organisational level. It should however be noted at this stage of the research study, that this review only provides an outline structure for the development of a specified TX implementation strategy for this case study. The review of implementation strategies with other types of software/technology is therefore included, to aid in the conceptualisation of an appropriate method and approach thereof.

The link between the project and organisational level components lies in the feasibility strategy for the implemented software. Thus, the variant feasibility strategies and components thereof are of utmost importance, to incorporate the modular blocks successfully. This is very important for the development of a successful and viable implementation strategy for DES-type software, due to the inherent and somewhat unquantifiable nature of simulation projects.

In conclusion, the review suggests the importance of simulation software implementation at both a project and organisational level and provides a basis and context for further exploration and development. Literature on the implementation of TX, incorporating both levels is scarce and a clear gap in current literature is evident.

The literature presented in this chapter consequently forms the foundation on which the succeeding chapters and dissertation are based. Most notably the three key elements of TX implementation strategy requirements provide a strong theoretical framework, for the development of the method section and research instruments.

CHAPTER 3: METHOD

3.1 Introduction

This chapter focuses on two topics that are often mistaken to have the same meaning namely methodology and method. According to Raciti (2016), the methodology of a research paper examines the frameworks around which the research is based. The research type dictates the choice of framework. The method, however, is the actual process undertaken by the researcher to obtain the desired results. These two areas are discussed in depth in the following sections.

3.2 Methodology

This section explores the differences between the various approaches to research design by looking at quantitative, qualitative, and mixed methods strategies. It also explores the concepts of reliability and validity and concludes with a summary of the approaches towards sampling and informant selection (Raciti, 2016). The section aims to highlight the frameworks and theory most suited to the study at hand and offers a basis for the research method that follows in Section 3.3.

3.2.1 Study Design

Following Kumar (2011), Creswell (2014) and Booth, et al. (2008), the research methodology is divided into the following three phases:

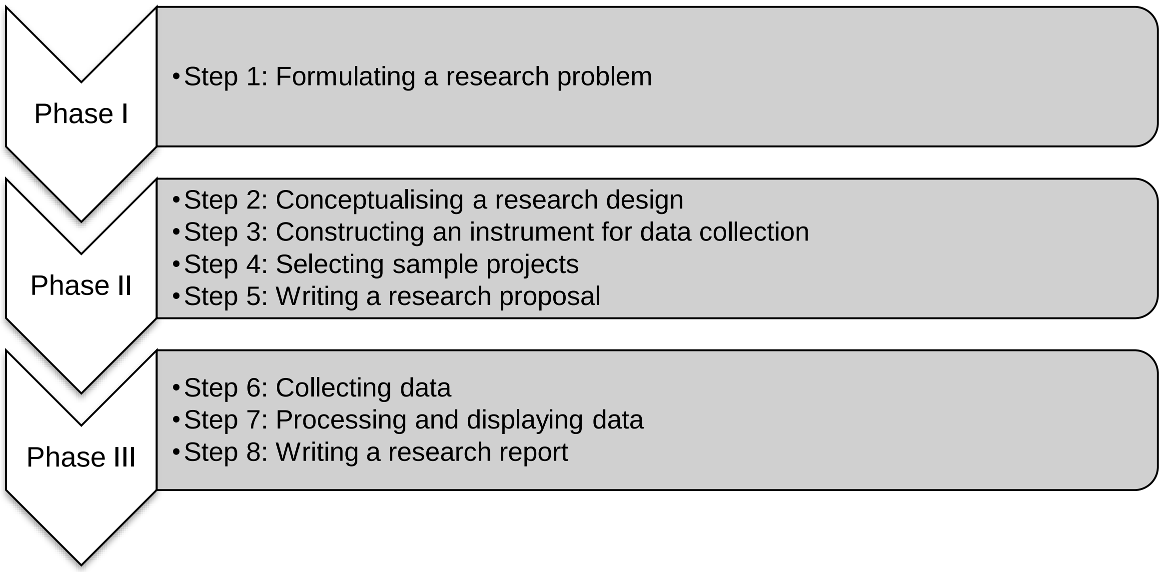

Figure 7: Study design phases

Phase I entails deciding what to research, with Phase II involving the planning of the research study, and Phase III is where the research study is conducted.

The design approach is covered in more detail in the succeeding sections.

3.2.2 Research Approach

There is a broad consensus that research regarding Information Systems must respond to two requirements, this includes making theoretical contributions and assist in solving the current and anticipated problems of practitioners (Rosemann and Vessey, 2008). Sein et al. (2011) proposed **Action Design Research (ADR)** as a method, in which an IT artefact emerges from interaction with the organisational context even when its initial design is guided by the researchers' intent.

Sein et al. (2011) describes ADR as a research method for generating prescriptive design knowledge through building and evaluating IT artefacts in an organisational setting. Two seemingly disparate challenges are dealt with: (1) addressing a problem situation encountered in a specific organisational setting by intervening and evaluating, and (2) constructing and evaluating an IT artefact that addresses the class of problems typified by the encountered situation **(case study)**. The responses demanded by these two challenges result in a method that focuses on the building, intervention, and evaluation of an artefact that reflects not only the theoretical precursors and intent of the researchers but also the influence of users and ongoing use in context (Sein et al. 2011).

Kumar (2011) defined that in a case study design the 'case' you select becomes the basis of a thorough, holistic, and in-depth exploration of the aspect(s) that you want to analyse. It is an approach 'in which a particular instance or a few carefully selected cases are studied intensively' (Gilbert, 2008). According to Burns (1997), 'to qualify as a case study, it must be a bounded system, an entity in itself. A case study should focus on a bounded subject/unit that is either very representative or extremely atypical.' A case study according to Grinnell (1981) is characterised by a very flexible and open-ended technique of data collection and analysis.

Within the set manufacturing/production environment based in the selected company (Company A) and the lead author's key responsibilities and functionalities as a support simulations engineer, a bounded case is formed as per these definitions. This case is also representative of multiple industries, with a very flexible and open-ended platform to collect data and analyse experiments/tests.

Case studies are also prevalent in qualitative research, although they are predominantly a qualitative study design. In Kumar's opinion, 'the qualitative-quantitative-qualitative approach to research is comprehensive and worth consideration'. This involves starting with a qualitative approach to identify important modular parts of the research, using a quantitative approach to quantify these parts, and then going back to qualitative to explain the observed patterns (Kumar, 2011). This will be a valid approach, based on the structure around which this research topic is introduced throughout the first sections of this study.

Zainal (2007) noted that there are several categories of case studies. He referenced Yin (1984) that notes ‘three categories, namely exploratory, descriptive and explanatory case studies’, with definitions and examples on all three. Researchers in other fields also mention other categories of case studies. For instance, according to McDonough and McDonough (1997), other categories include interpretive and evaluative case studies. They indicate that through interpretive case studies, the researcher aims to interpret the data by developing conceptual categories, supporting or challenging the assumptions made regarding them. In evaluative case studies, the researcher goes further by adding their judgment to the phenomena found in the data. This research study falls into an **evaluative case study**, considering the initial research aim and objectives.

Advantages of the case study methodology, as derived from Zainal (2007), include the examination of data being conducted within the context of its use (Yin, 1984). This allows for both quantitative and qualitative analyses of data and a case study helps to explore or describe the data in a real-life environment.

Disadvantages also derived from Zainal (2007), include that case studies lack rigour and provide very little basis for scientific generalisation if a small number of subjects are used. Case studies are also often labelled as being too long if an unstructured methodology is followed (Yin, 1984). Another common criticism of a case study method is its dependency on a single case exploration making it difficult to reach a generalising conclusion (Tellis, 1997). Yin (1994) considered case methodology ‘microscopic’ because of the limited sampling cases. To Hamel, et al. (1993) and Yin (1994), however, parameter establishment and objective setting of the research are far more important in the case study method than a big sample size.

Case studies, however, have often been viewed as a useful tool for the preliminary, exploratory stage of a research project, as a basis for the development of the ‘more structured’ tools that are necessary for surveys and experiments (Rowley, 2002).

This study makes use of a mixed-methods approach incorporating qualitative and quantitative elements. From the introduction and literature review, the research forms part of a case study, with the selection of TX software being covered as part of a hybrid methodology based on Tewoldeberhan, et al. (2002) and industry case scope of requirement and motivation procedures (refer to 1.1.1 DES Software Evaluation & Selection). The research study follows the selection methodology at a case level and forms part of a generalised case study on the development of an implementation strategy of TX following the ADR approach.

This strategy will be developed and evaluated, subjected to multiple projects in parallel to business case development. The software supplier's (Siemens) ROIs and case studies will be utilised as a base reference to facilitate strategy evaluation.

3.2.3 Study Context

The setting for this research study is the lead author's place of employment (Company A), which is a private manufacturing company. The company comprises of a division (hereafter referred to as Division A), dedicated to the design and manufacture of operational plants/facilities, as well as engineering support for the relevant sites – who all have different main responsibilities.

TX was implemented within this Division A, to act as a design and site support tool. The division's functionalities range from the design of new manufacturing facilities around the world, including mechanical, chemical, and electrical systems – to site support of production facilities across the various sites, including logistics, operations, and material handling aspects.

The selected software that acts as the main study focus is TX, which is a DES type software, dedicated to production process simulations. This is the first of its type that was introduced within the company, thus the implementation thereof is on a clean canvas – with no formal simulation structures and team in place. This provides an excellent platform for this study, which will facilitate a practical and overall well-suited environment to incorporate research strategies and methodologies in the form of an evaluative case study.

Siemens Digital Solutions (software supplier and support), will also be included within the research approach, due to TX being a Siemens-based software. This is to ensure validity and reliability on data analysis/reviews and to form part of certain data collection functionalities.

The envisaged project cases include a variety of modelling and simulation projects completed or currently in development in Division A. These include design and site support projects with varying complexity and detail. These projects are initiated from the project request and data input/capturing phase to deliverable reports and output analysis. The organisational elements will include all of the other requirements for developing and evaluating the utilisation and incorporation of TX and structures within the company, in a feasible and viable manner.

3.3 Method

The research method provides an overview regarding details, on the suggested study sampling techniques and analysis guidelines. The selected ADR method, developed by Sein et al. (2011), contains stages and principles that address these issues. The ADR stages and principles are described in the following sections (see Figure 8), together with the implementation components of the method regarding this research case study.

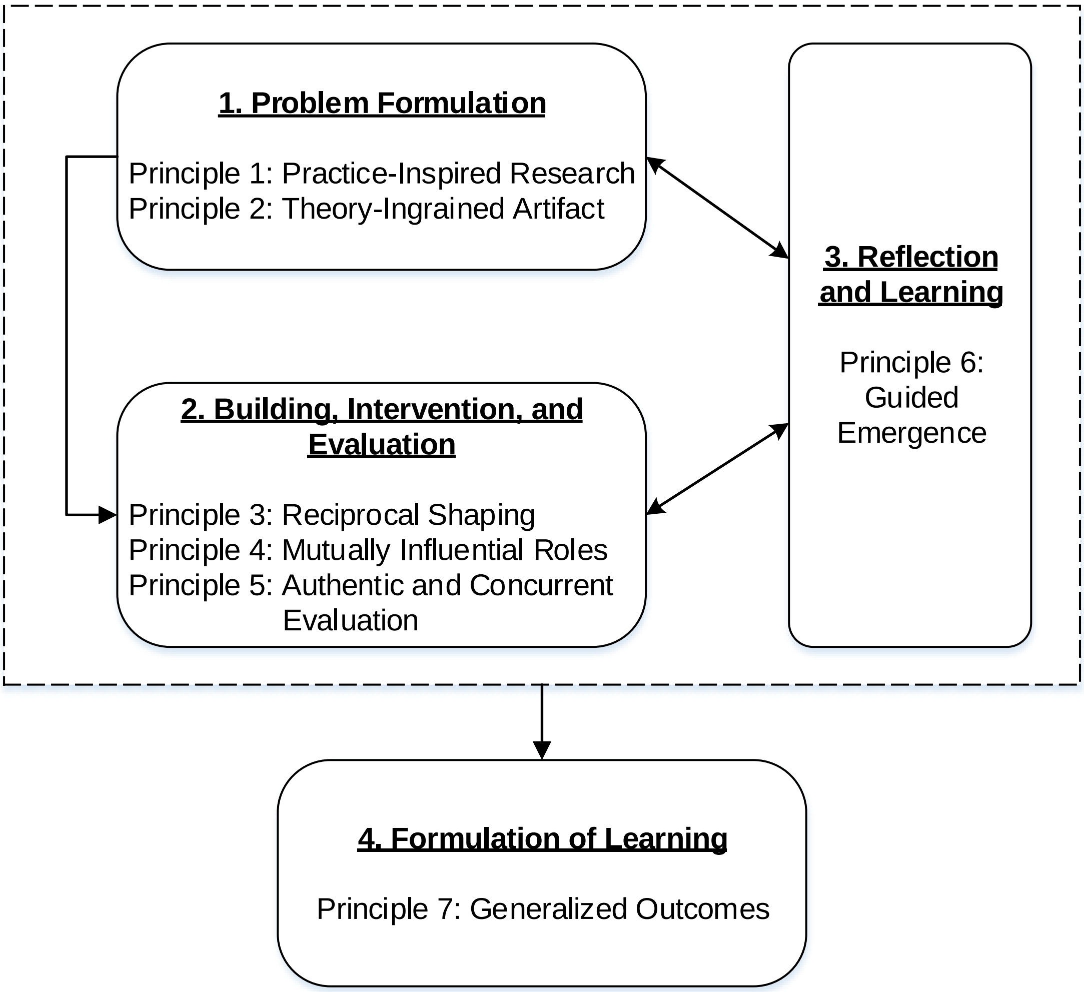

Figure 8: ADR Method Stages and Principles, source: Sein et al. (2011)

3.3.1 Stage 1: Problem Formulation

The problem formulation stage identifies and conceptualises a research opportunity based on existing theories and technologies (see Hevner et al. 2004). Sein et al. (2011) derived the stage into two principles: practice-inspired research and theory-ingrained artefact.

Principle 1: Practice-Inspired Research

This principle emphasises viewing field problems (as opposed to theoretical puzzles) as knowledge-creation opportunities. The action design researcher should generate knowledge that can be applied to the class of problems that the specific problem exemplifies. As a result, the research activity is problem-inspired (Markus et al. 2002).

Principle 1 is covered within the research aim and objectives (Chapter 2), and the identified study context is described in the preceding section.

Principle 2: Theory-Ingrained Artefact

This principle emphasises that the artefacts created and evaluated via ADR are informed by theories. This principle suggests that, as technology designers will inscribe in the artefact theoretical traces that reflect the socio-political context of the design situation (Hanseth and Monteiro, 1997), the action design researcher actively inscribes theoretical elements in the artefact, thus manifesting the theory "in a socially recognisable form" (Orlikowski and Iacono, 2001). This act of inscribing, however, results in only the initial design of the theory-ingrained artefact. It is then subjected to organisational practice, providing the basis for cycles of intervention, evaluation, and further reshaping (Sein et al. 2011).

Principle 2 is covered within the literature study on the project and organisational components (Chapter 2), and the preliminary design artefact developed revolving around the project and business cases compiled in Chapter 4.

The artefact will be comprised of practical TX software implementation guidelines; developed templates and secondary sources; and referable project samples that are evaluated concurrently as part of the ADR approach. The artefact details for this research study are divided into three categories, which are interdependent on one another in certain aspects. These categories include project case, organisational components, and strategy development components.

Project case components include the following:

i. <u>Project Request/Identification:</u>

An initial project request form was compiled (template attached to Appendix B), which forms part of the preliminary design artefact created by the lead author as action researcher. The following elements are included in the initial template form:

- Project – This is to provide a project reference, which this request will potentially support.
- Requestor – This is to provide a reference to the project requestor.
- Department – This is to provide a reference to the requestor's department.
- Line Manager – This is to provide a reference to the requestor's line manager.
- Project Background – The requestor must give a brief description of the project, to provide a relative idea of the project as a whole.

- Support Request – The requestor must give a brief description of the simulation requirement, and potential deliverables that they would like to see.
- Priority – The priority from the requestor's side should be indicated (low/average/high), to provide additional input for project planning.
- Lead Time – Similarly, the basic lead-time for a solution should be provided, to identify the viability of requirements and for project planning.
- Signatures – The requestor and their line manager are required to sign and approve the form. This is to provide an additional review step, to increase the credibility of the request.

The initial project request template provides editable space, for a requestor to provide basic project and departmental reference information. Space for a brief description of the requested project and support requirement will provide the simulation engineer with an overview of the problem. An indication of the priority and lead-time required from the project requestor's perspective will potentially provide relevant information for planning purposes. Lastly, a space for the requestor and their line manager provides a formal sign-off for the submitted request.

ii. Project Data Collection:

Similarly, an initial process data input form was compiled (see Appendix C), which forms part of the preliminary design artefact created by the lead author as action researcher.

The developed template was derived following Bangsow (2015)'s VDI implementation guidelines (described in 2.4.1 Project Components). This document is to be used by the process/simulations engineer in an attempt to collect suitable data sets in line with project request requirements. Project requestors are required to aid in indicating data available as well as relevant references to aid with the data collection process. The required sections are divided into four sections: *Technical, Operational, System Load, and Human Resource* data sets.

Technical Data (T) - This is all of the relevant technical data regarding the facility/processes requiring simulations:

1. Factory Structural Data - Includes production process layouts and equipment/flow information.
2. Manufacturing Data - Includes process data and operational information.
3. Material Flow Data - Includes material flow and material handling information.
4. Failure Data - Includes any process/product/equipment failure data.

Operational Data (O) - This is all of the relevant operational data including shift schedules and production strategies:

5. Work Time Organisation - Includes shift schedules and requirements.
6. Resource Allocation - Includes worker and equipment requirements.
7. Organisation/Facility Strategy - Includes production and maintenance strategies.

System Load Data (S) - This is all of the relevant product and job data included in the process/facility:

8. Product Data - Includes product specifications and BOMs.
9. Job Data - Includes product and transportation orders, with schedules and volumes.

Human Resource Data (H) - Includes input personnel relevant to project/facility/process, and any other additional information regarding data requirements:

10. Input Contact Personnel - Includes project stakeholders and contacts.

iii. Project Data Processing:

Project data processing is an important part of constructing an accurate and/or acceptable simulation model, depending on requirements. A conformance table was developed to identify the data available from the data collection phase; internal data reviews on the processed data sets, as well as potential inclusions; and data obtained on design reviews on developed simulation models, which also affects data processing in certain cases. Table 3 is an illustration of the developed conformance table:

Table 3: Data conformance table (empty)

Data Step		Data Available	Data Review	Design Reviews
Technical Data	1. Factory Structural Data			
	2. Manufacturing Data			
	3. Material Flow Data			
	4. Failure Data			
Organisation Data	5. Working Time Organisation			
	6. Resource Allocation			
	7. Organisation/Facility Strategy			
System Load Data	8. Product Data			
	9. Job Data			
Resources	10. Input Contact Personnel			

iv. Project Modelling & Simulation:

The model and simulations referenced are constructed following the preceding steps. These files are stored based on revisions constructed by the simulation engineer as the project progresses.

A revision control log is developed for each project sample, to provide a basic description of the modelled revisions.

v. Project Validation & Verification:

Validation refers to the assurance that the model simulation meets the needs of the identified stakeholders. Verification is the evaluation of whether the simulated model complies with the requirement or imposed conditions. This includes result analysis and result interpretation, together with validation and verification in the form of project stakeholder reviews, and reference production data.

vi. Project Reporting:

On completion of a project or project phase, it is important to document simulated results and project progress. This is to ensure clear communication of deliverables and recommendations to act as an effective decision support tool. Summarised project portfolio samples were compiled for all the project samples, to provide a quick reference per project.

The *organisational components* are relevant to the individual project cases, and strategy development as a whole. The lead author acting as participant-observer logged all the applicable organisational components. The components addressed include the following:

- Resource capacity
- Software licensing
- Training
- Feasibility studies
- Integration (company and software)
- Strategy phasing

The lead author acting as participant-observer also logged the overall strategy development.

3.3.2 Stage 2: Building, Intervention, and Evaluation

The second stage of ADR uses the problem framing and theoretical premises adopted in stage one. These premises provide a platform for generating the initial design of the IT artefact, which is further shaped by organisational use and subsequent design cycles. Carried out as an iterative process in a target environment (case study), this phase interweaves the *building* of the IT artefact, *intervention* in the organisation, and *evaluation* (BIE).

Sein et al. (2011) identify two end points for the research design continuum: IT-dominant BIE and organisation-dominant BIE.

IT-Dominant BIE: At one end of the continuum, the BIE may be IT-dominant. This approach suits ADR efforts that emphasise creating an innovative technological design at the outset.

Organisation-Dominant BIE: At the other end of the continuum is organisation-dominant BIE, suited for ADR efforts to generate design knowledge where the primary source of innovation is organisational intervention. See Figure 9 for a generic overview of this continuum:

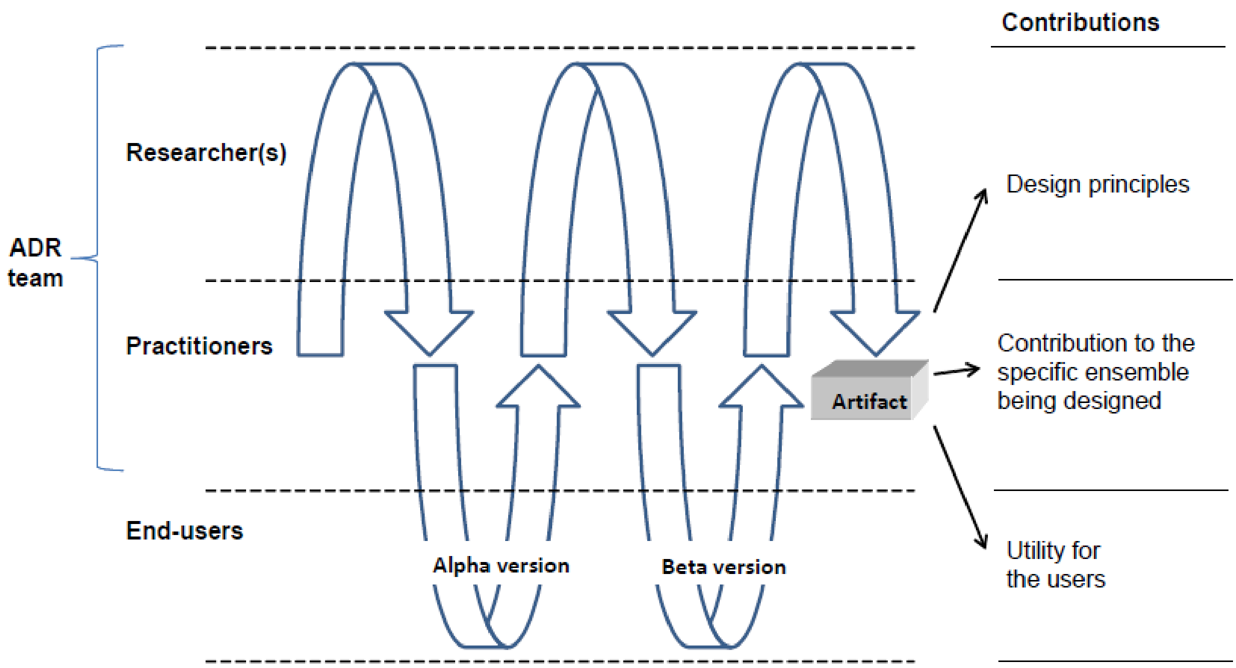

Figure 9: The Generic Schema for Organisation-Dominant BIE, source: Sein et al. (2011)

The organisation-dominant BIE is more prevalent in the evaluative case study identified in this research paper. The preliminary implementation strategy (alpha version) is developed at this stage and the effects are captured, to analyse and further develop the strategy – to construct the most feasible and appropriate strategy concerning this research study. This stage draws on three principles: reciprocal shaping, mutually influential roles, and authentic and concurrent evaluation (Sein et al. 2011). Together, these principles emphasise the inseparability of the domains that influence the ADR case study.

Principle 3: Reciprocal Shaping

According to Sein et al. (2011), this principle emphasises the inseparable influences mutually exerted by the two domains: the IT artefact and the organisational context. The ADR researcher may engage in recursive cycles of decisions at finer levels of detail in each domain.

A very important point is that this research case study predominantly follows a qualitative approach. Data is collected until a point of data saturation is reached (Kumar, 2011), **or** until sufficient data is collected to develop an implementation strategy, that is well defined and incorporates all the relevant project and business aspects. Five project cases are initially considered, but more project cases will be considered if there is not sufficient data to ensure valid conclusions.

The projects were sampled from TX implemented projects at Division A. Sample selection depended on the varying input/output requirements and capacity of these projects on a case-by-case basis, which formed part of a holistic or general structure. The project samples vary with regards to implementation and deliverable requirements, as well as having different functionalities, e.g. storage facilities, chemical facilities, semi-automated and automated systems, fluid systems, etc.

Initial considerations for project samples include:

<u>Project#1:</u> This is a *large*[5] design support project consisting of the modelling and simulation of a complete loading, assembly, and packaging facility.

This project was selected because it was one of the initial projects as part of the rollout phase of the software, and is a large design support project that is continuously developing based on requirements.

<u>Project#2:</u> This is a *medium*[5] design support project consisting of the modelling and simulation of an asphalt lining facility, including preparation, pre-heating ovens, cooling racks, finishing, and gantry hoists for material handling.

This project was selected because it was a medium design support project that was completed to utilise the software to support and motivate a potential concept.

<u>Project#3:</u> This is a *small*[5] design support project consisting of the modelling and simulation of a filling process upgrade concept.

[5] *Note that the terms small/medium/large referred to about the project samples, relate to the complexity and development time associated with the relevant project, as determined by the researcher acting as participant-observer.*

This project was selected because it was a small design support project that was completed to utilise the software to motivate a potential concept.

Project#4: This is a *medium*[5] site support project consisting of the modelling and simulation of an automated gantry line in the company's CNC manufacturing area.

This project was selected because it was one of the initial projects as part of the rollout phase of the software, and is a support project for another site in parallel with an upgrading project, to analyse and motivate various scenarios.

Project#5: This is a *small*[5] site support project consisting of the modelling and simulation of an updated phosphating line in the company's existing Paint shop.

This project was selected because it was a motivation support request to analyse and identify the most suitable design parameters.

Principle 4: Mutually Influential Roles

This principle points to the importance of mutual learning among the different project participants. Action design researchers bring their knowledge of theory and technological advances, while the practitioners bring practical hypotheses and knowledge of organisational work practices. These perspectives and contributions may compete with one another or be complementary (Mathiassen, 2002).

As mentioned, the population and sampling concerning this research study are confined in a case study form that is based in the selected company department as the main stakeholder. With active participation and support from Siemens Digital Solutions as a reference stakeholder. The research population includes:

a) The identified company department (Division A):

Active project participants of identified sample projects that revolve around the implementation and utilisation of TX at a project and business level. The lead author is an active participant-observer and action researcher.

b) Siemens Digital Solutions:

Support at an analytical level, identified as the 'experts' in aiding with reviews and evaluation of the project process reports and strategy development. This is to increase the validity and reliability of the research analysis and decrease any potential industry bias. Siemens will potentially bring their own bias based on the software because naturally, they want to promote their product. This is however not perceived as a major risk regarding this study, due to the fact that the research will focus primarily on the implementation of TX (selected software) at a project and business level – and not a comparison study between different software types.

Principle 5: Authentic and Concurrent Evaluation

This principle emphasises a key characteristic of ADR, in that evaluation is not a separate stage of the research process that follows building. Instead, decisions about designing, shaping, and reshaping the artefact and intervening in organisational work practices should be interwoven with ongoing evaluation (Sein et al. 2011).

The evaluation cycle for the alpha version is formative, contributing to the refinement of the artefact (Remenyi and Sherwood-Smith, 1999) and surfacing anticipated, as well as unanticipated consequences. Later evaluation of the beta versions is summative, assessing value and utility outcomes.

An important aspect of a case study is the use of multiple methods to collect data, namely in-depth interviewing, obtaining information from secondary records, and gathering data through observations (Kumar, 2011). Based upon the broad approaches to information gathering, data can be categorised as primary and secondary data. Figure 10 illustrates these two branches of data collection.

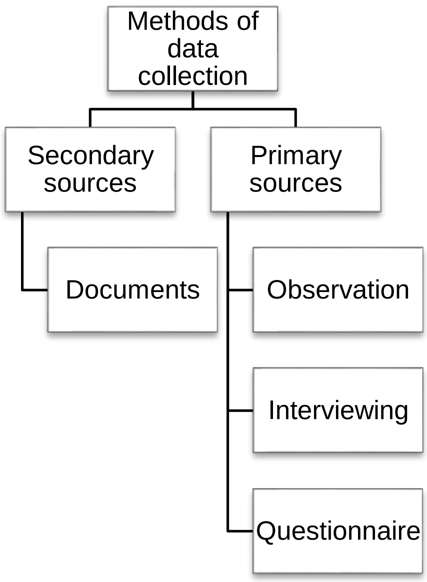

Figure 10: Methods of data collection, source: Kumar (2011)

Rowley (2002) states that data collection, and in general the execution of a good case study, depend crucially upon the competence of the researcher. The evidence to be gathered is defined as it is collected, and the researcher is an active agent in the process. This involves having a sound grasp of the questions and propositions of the case study and being able to approach the study in an unbiased and flexible manner.

Data collection should be guided by a case study protocol. This protocol needs to include the following sections:

- An overview of the case study project.
- Procedures, such as the use of different sources of information, and access arrangements to these sources.
- Case study questions, or the questions that the case study researcher needs to keep in mind when collecting data.

**Note: A vital source of data and testing will be obtained from the primary case study, following in parallel with the lead author being in a unique position of being able to implement and test methodologies within a manufacturing/production industry environment.*

Data Collection Tool:

Typically, case studies draw on multiple sources of evidence. These include **unstructured interviews, participant observations,** and **secondary sources**. Rowley (2002) suggests that whichever sources of evidence are used, three key principles of data collection need to be observed:

- Triangulation
- Case Study Database
- Chain of Evidence

The gathering of data is done per project sample, with parallel reviewing done at an organisational level. The following diagram gives an overview of the planned data collection tool, including **triangulation**:

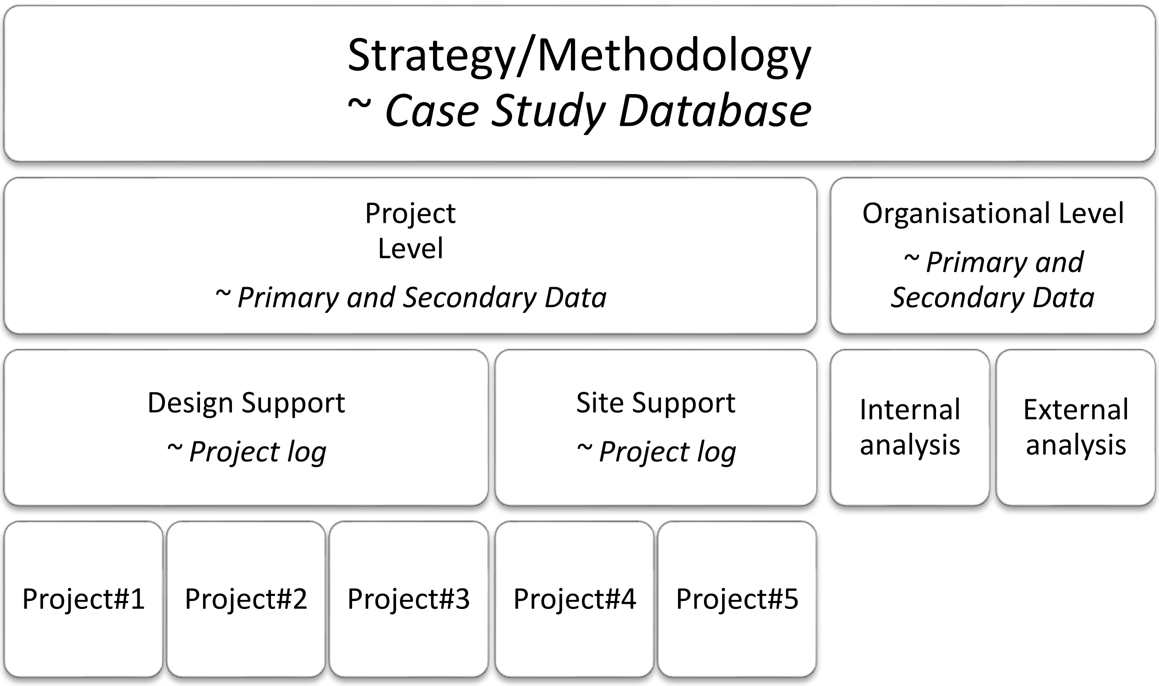

Figure 11: Overview of data collection tool

Figure 11 provides a basic structure from which the overall strategy and database development will be derived. This is a top-down approach, including triangulation using either multiple sample cases or variant data sources. A basic breakdown for the research study is into two modular blocks for project and organisational level data. The project level is compiled from multiple sample cases to saturate the project related data sufficiently. The organisational data is collected in parallel with project samples and subjected to internal and external analysis, to limit any company bias, as well as triangulate data collection.

The following protocol was developed to collect data in a standardised format, to enable sufficient control and improve the quality of project sampling for ADR requirements. The following points will be included as part of the data collection strategy.

Ethical Approval:

Ethical approval forms part of the research process, to comply with international research standards set out by the NWU. The three main components include ENG-REC; research gatekeeper; and documentation requirements.

a) ENG-REC

The North-West University Engineering Research Ethics Committee (NWU-ENG-REC) on 11/23/2020, approved the research study indicated in the research proposal titled: An implementation strategy for Tecnomatix Plant Simulation software at a project and business level.

The letter of approval (ethics number: NWU-00124-20-A1), regarding the proposed research study as well as all the relevant TRREE ethics module certifications, are configured for future reference.

b) Gatekeeper

As part of the case study requirement, an organisation gatekeeper was identified to accept the provided letter of goodwill permission and grant consent to partake in the research study.

c) Documents

The following approved documents will form part of the data collection protocol:

- Letter of Goodwill Permission (Company A & Siemens)
- Informed Consent Form (Research Participants)

Database Construction:

The **case study database** is constructed as part of the chain of evidence required based on the research study. This database was compiled as the data collection and analysis phase progressed within an internally identified encrypted server. All the data and information underwent internal reviews to ensure no propriety information was issued (part of ethical and industry requirements), before being exported to an open-access database with the development of the research dissertation. The initial modular data blocks include:

i. Secondary Sources

The secondary sources include all documentation and resources developed or used as part of this research study.

ii. Project Level (samples)

The identified project samples and project data is compiled per project case, including the alpha version implementation components. These project-level components include documents and notes based on **participant observations**. Project templates and reports conforming to secondary sources are also included as part of project development. The project data sets (also referred to as project logs) are not the same for each project sample and differ based on project requirements and deliverables.

**Note that the project level components were subjected to internal reviews and questionnaires.*

iii. Organisational Components

The applicable organisational components are compiled as the implementation strategy was developed. This includes the background requirements as well as the referenced implementation components.

**Note that the organisational components were subjected to external reviews and questionnaires.*

iv. Internal Reviews

Internal reviews consist of unstructured interviews, with baseline questions and guidelines (see Appendix A2). The interviews were done through an in-person conference-type meeting (recorded with permission). This was done with voluntary project participants regarding the overall development and project phases, with a focus surrounding project requests, model/simulation development, and deliverables. Unstructured interviews were selected due to the variant nature of the project samples and to be able to gain a broader perspective for better strategy conceptualisation.

Internal template/report questionnaires (derived from Appendix A1) based on recommendations provide valuable feedback on developed templates, including project request forms, data input templates, and project reporting.

v. External Reviews

External reviews consist of unstructured interviews, with baseline questions and guidelines (see Appendix A3). The interviews were done through a virtual online meeting (transcribed with permission). This was done with voluntary participants from Siemens regarding the overall development and organisational components, with a focus surrounding feasibility study reviews and strategy development analysis. As in the case of the internal reviews, unstructured interviews were selected due to the variant nature of the project samples and to be able to gain a broader perspective for better strategy conceptualisation.

External template questionnaires (derived from Appendix A1) based on recommendations provide valuable feedback on developed templates, including project feasibility studies.

vi. Strategy Development

The overall strategy development was logged by the lead author acting as participant-observer and was subjected to internal analysis, including relevant project participants and external analysis, by Siemens Digital Solutions (see Appendix A4 & A5). This section includes the developed alpha and beta version artefacts, including the implementation strategy development as part of this research study.

vii. Overview

The following diagram provides an overview of the proposed data collection strategy:

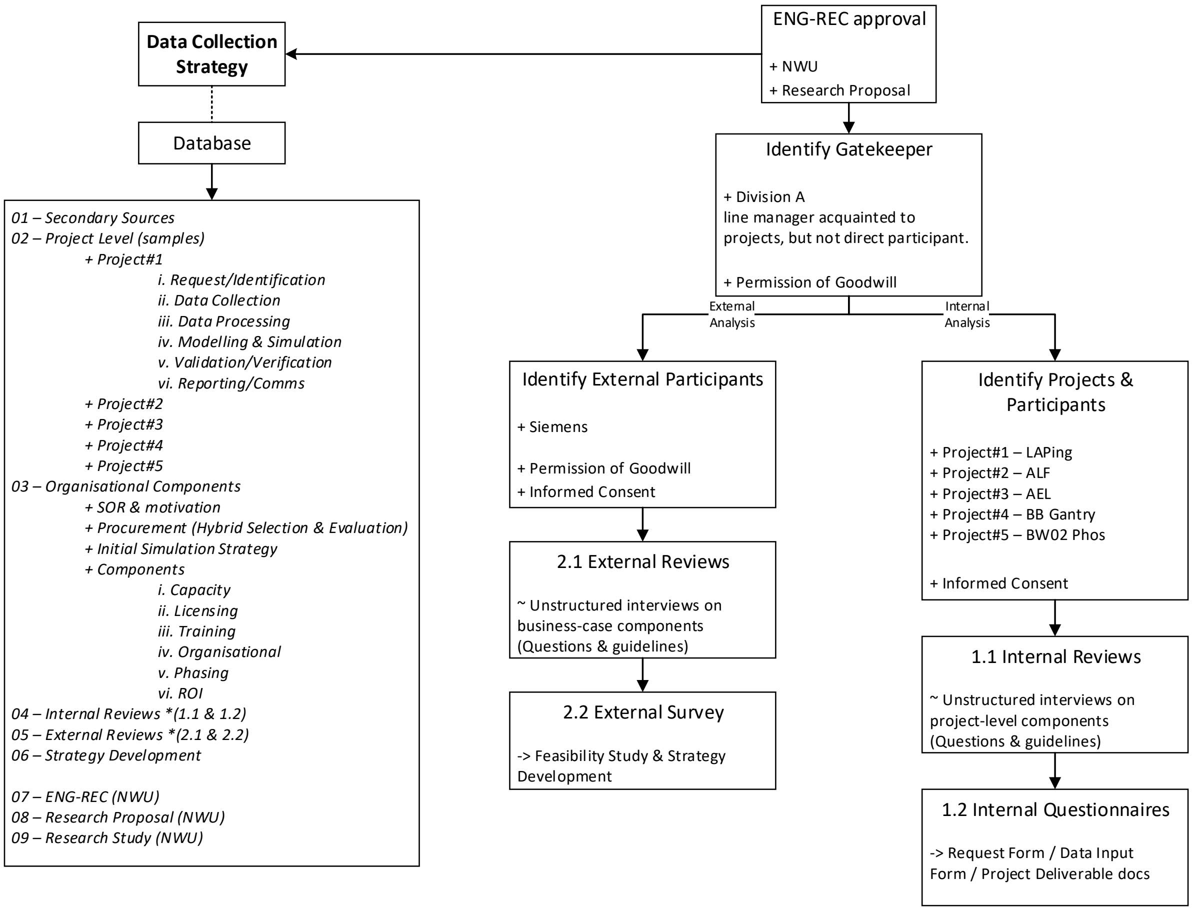

Figure 12: Data Collection Overview

Figure 12 is an overview to illustrate the primary sources and steps to obtain data on project and organisational components. The database block provides the initial layout of all the relevant primary, secondary and case study data sets as part of the research study.

The **chain of evidence** includes appropriate citation of documents, with accessibility of evidence in the shared database. The link between the protocol questions and the propositions should be transparent.

<u>Data Storage:</u>

As inclusion for the chain of evidence regarding data capturing, the following approach was followed:

i. All project and business case components regarding project samples were captured and filtered on an identified encrypted internal company server.
ii. Following review and analysis, the data was encrypted and exported to an accessible (to NWU and Company A) server.

All documentation and data were encrypted and exported in the preferred capacity, before authorisation by all participants involved.

Questionnaires Coding:

Coding is the process of labelling and organising qualitative data to identify different themes and the relationships between them. Due to the questionnaires applying to specific form templates (Appendix D to G), a basic coding system based on logical interpretation was implemented to obtain relevant results.

A rating scale is used from very poor (0) to very good (4), in order to calculate statistical values for multiple samples.

Direct feedback/response sections will be summarised, with important (and recurring) themes being labelled accordingly. The lead researcher will be the primary judge and transcriber to have some continuity revolving around internal/external input, subject to overall strategy development.

Data Analysis:

Data analysis was predominantly done by the lead researcher at a project input and output level, with quantification of project deliverables at an organisational level following the selected *feasibility methodology*, as well as all other evaluation parts of the strategy being developed and implemented.

Internal analysis was done at a project level within Division A, including project reviews, unstructured interviews, and template/report questionnaires. Siemens Digital Solutions did the external analysis on reviewed project feasibility studies and strategy evaluation. This is to ensure triangulation is introduced within the data analysis of the overall strategy development, as well as increase validity based on reviewed projects (see Appendix A for template and guidelines reference).

The initial consideration for the *feasibility model* based on the previously referenced TELOS model includes the following components:

- Technical (Technology – hardware/software)
- Economic (Costs & Benefits)
- Legal (Legal implementation)
- Operational (Maintenance)
- Schedule (Chronology)

Each project underwent a feasibility review based on various phases. This was done by utilising the selected TELOS model; the reviews differ based on various project requirements and development phases.

3.3.3 Stage 3: Reflection and Learning

The stage recognises that the research process involves more than simply solving a problem. Conscious reflection on the problem framing, the theories chosen, and the emerging is critical to ensure that contributions to knowledge are identified (Sein et al. 2011). This stage draws on one principle: guided emergence.

Principle 6: Guided Emergence

This principle emphasises that the artefact will reflect not only the preliminary design (see Principle 2) created by the researchers but also its ongoing shaping by organisational use, perspectives, and participants (see Principles 3 and 4 respectively), and by outcomes of authentic, concurrent evaluation (see Principle 5). These refinements include not only trivial fixes but also substantial changes to the design, meta-design, and meta-requirements (Walls et al. 1992) that culminate in changes to the artefact, similar to the idea of mutations described by Gregor and Iivari (2007).

Principle 6 is covered in the analysis part of Chapter 4 and the discussions thereon in Chapter 5.

3.3.4 Stage 4: Formalisation of Learning

Researchers outline the accomplishments realised in the IT artefact and describe the organisational outcomes to formalise the learning (Sein et al. 2011). The outcomes can be characterised as design principles and with further reflection, as refinements to theories that contributed to the initial design (see Principle 2). This stage draws on one principle: generalised outcomes.

Principle 7: Generalised Outcomes

Generalisation is challenging because of the highly situated nature of ADR outcomes that include organisational change along with the implementation of an IT artefact. The resulting outcome is defined as a bundle of properties in different domains. This represents a solution that addresses a problem. Both can be generalised. This move from the specific-and-unique to generic-and-abstract is a critical component of ADR. Sein et al. (2011) suggest three levels for this conceptual move: (1) generalisation of the problem instance, (2) generalisation of the solution instance, and (3) derivation of design principles from the design research outcomes.

The succeeding section on case study generalisation, rigour/validity and reliability describes the associated tests that will be subjected to this research case study.

3.4 Case Study Generalisation, Rigour / Validity & Reliability

Rowley (2002) states that the generalisation of the case study so that it contributes to theory is important. Generalisation can only be performed if the case study design has been appropriately informed by theory, and can therefore be seen to add to the established theory. The method of generalisation for case studies is not statistical generalisation, but analytical generalisation in which a previously developed theory is used as a template with which to compare the empirical results of the case study. The greater the number of case studies that show replication the greater the rigour with which a theory has been established.

Rowley (2002) also summarises four tests that have been widely used to establish the quality of empirical research:

i. Construct validity – establishing correct operational measures of the concepts being studied. This is concerned with exposing and reducing subjectivity, by linking data collection questions and measures to research questions and propositions.

ii. Internal validity – establishing a causal methodology whereby certain conditions are shown to lead to other conditions.

iii. External validity – establishing the domain to which a study's findings can be generalised. Generalisation is based on replicating logic as discussed above.

iv. Reliability – demonstrating that the operations of a study, such as the data collection produced can be repeated with the same results. This is achieved through thorough documentation of procedures and appropriate recording keeping.

The approaches for ensuring validity and reliability are discussed further below in Table 4.

Table 4: Checking Case Study Design, source: Rowley (2002)

Tests	**Case Study Tactic**	**Phase of research in which tactic occurs**
Construct validity	Use multiple sources of evidence. Establish chain of evidence. Have key informants review draft case study reports.	Data Collection Data Collection Composition
Internal validity	Do pattern matching. Do explanation building. Do time series analysis.	Data analysis Data analysis Data analysis
External validity	Use replication logic in multiple case studies. Use case study protocol.	Research design Data collection
Reliability	Develop a case study database.	Data collection

These components are covered in the following research sections:

- Construct validity – As part of data collection with multiple sources and chain of evidence.
- Internal validity – As part of the internal analysis and review process.
- External validity – Covered in the replication of the methodology in project samples, external reviews, and case study protocol.
- Reliability – As part of the developed case study database.

3.5 Conclusion

This chapter provided the choice of framework for the research study, i.e. methodology, as well as the method (process) undertaken by the researcher to obtain the desired results. These two areas are discussed in depth in the preceding sections, with an overview concluded in this section.

The framework methodology consists of a phased study design following input reference from Kumar (2011), Cresswell (2014), and Booth, et al. (2008). The research approach selected is the Action Design Research (ADR) method developed by Sein et al. (2011). This research method is implemented following an evaluative case study, based on the research environment and identified requirements. The researcher acted as the main participant-observer and action design researcher within the study context. This included observations and data collection revolving around TX software implementation at Company A. The implementation of which was done on a 'clean canvas', with no formal DES simulation structures in place.

The selected ADR method contains stages and principles that are described in the chapter (see Figure 8 for an overview), together with the implementation components of the method regarding this research case study. The developed artefact is comprised of practical guidelines; developed templates and secondary sources; and referable project samples. The method followed included the identification of the research setting and sampling requirements, data collection and analysis, as well as case study observations.

The research population included Division A as the main stakeholder and Siemens Digital Solutions as external reference stakeholders. The research study consisted of five varying project samples, including small, medium and large design/site support type projects. The data collection includes secondary sources (reference documents and templates), and primary sources (observations, interviews, questionnaires). Three key principles of data collection were included within the research protocol, including triangulation, construction of a case study database, and a chain of evidence. The lead researcher, acting as participant-observer, predominantly did data analysis. Together with internal project sample reviews with Division A participants, and external expert reviews with participants from Siemens. The collected and analysed data was stored on an internal company server, then encrypted and exported in an open-access file folder format based on internal company reviews and research conclusions.

To comply with case study generalisation, rigour/validity and reliability requirements, the following components formed part of the research method. In terms of construct validity, multiple project samples were generated with the researcher acting as the main participant-observer, including a chain of evidence. Internal validity was achieved through internal project sample reviews, including unstructured project participant interviews and questionnaires. External validity was achieved through a constructed case study protocol and external feasibility and strategy reviews, including unstructured expert participant interviews and questionnaires. The reliability of the research was achieved through constructing a reviewed case study database, which can be accessed on request.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents the developed and compiled components, with processed results of the whole study, along with an analysis of the findings. As in the case of research done by Raciti (2016), the two sections are presented together in this chapter to benefit the reader. It is believed that combining them allows the reader to construct a more cohesive picture of the findings and what they represent.

This chapter will follow the same sequence as the database configuration, referenced in the preceding chapter. This is to allow a modular review on results based on relevant project and business components, captured and analysed as building blocks for the strategy development as a whole. Figure 13 provides an overarching results presentation roadmap, to aid the reader for ease of navigation and understanding the rest of the chapter.

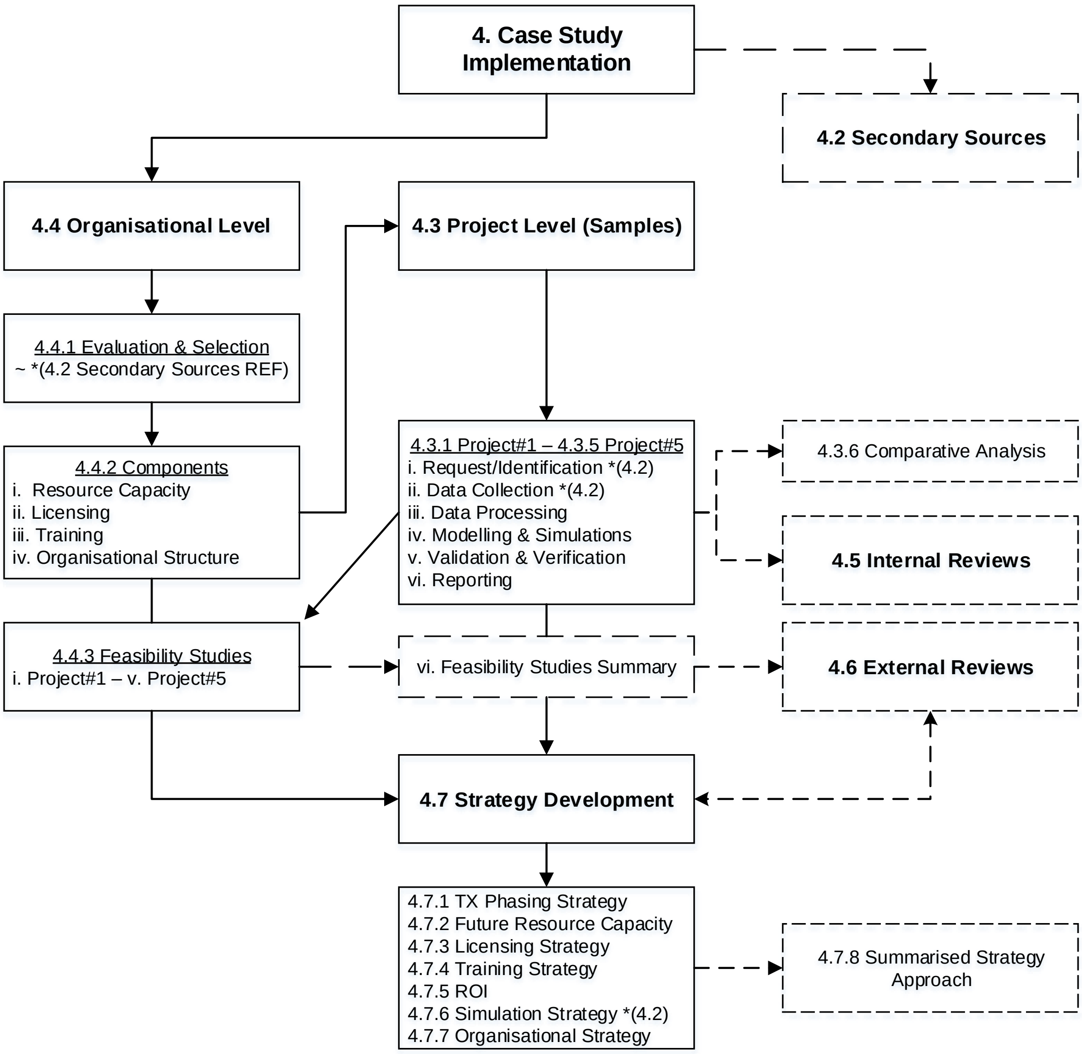

Figure 13: Results & Analysis Roadmap Overview

4.2 Secondary Sources

All of the secondary sources used as part of this research study have been configured within the research database and are referenced accordingly throughout the succeeding sections. A detailed summary of all the relevant secondary sources is included in Chapter 5.

4.3 Project Level (Samples)

The project samples are constructed within the identified project case components. This is done to provide uniformity in project data collection and comparative analysis, to ensure a structured approach for overall strategy development. The project level samples were also submitted as part of a commercial case study, for the proceedings of the 2021 Winter Simulation Conference (Wesch, 2021). A summarised comparison of quantified and compiled results follows at the end of this section (see 4.3.6 Comparative Analysis).

It is important to note that the project level samples only include analytical generalisation points, with sampled project feasibility studies and comparative analysis compiled in-line with theory references to previous case studies done by Siemens (2009).

4.3.1 Project#1

This is a large design support project consisting of the modelling and simulation of a complete loading, assembly, and packaging facility.

i. Request / Identification:

As part of the project level strategy development, a project request template was developed subjected to all of the project samples (see Appendix B). The request submitted is summarised as follows:

'Requirement to optimise LAPing facility design for Project#1. The focus should be around layout design, bottleneck identification, material flow, throughput analysis and overall model development.'

The project participants were then asked to complete a questionnaire (see Appendix D) to develop the most appropriate and value-adding template.

ii. Data Collection:

As part of the project level strategy development, a process data input form was developed subjected to all of the project samples (see Appendix C). The available data sets are identified in Table 5. The project participants were then asked to complete a questionnaire (see Appendix E) to develop the most appropriate and value-adding template.

iii. Data Processing:

Data processing is an important part of constructing an accurate and/or acceptable simulation model, depending on requirements. A conformance table was developed to identify the data available from the data collection phase; internal data reviews on the processed data sets, as well as potential inclusions; and design reviews on developed simulation models, which also affects data processing in certain cases.

Table 5: Project#1 Data Processing Log

Data Step		Data Available	Data Review	Design Reviews
Technical Data	1. Factory Structural Data	X	X	X
	2. Manufacturing Data	X	X	X
	3. Material Flow Data	X	X	X
	4. Failure Data			
Organisation Data	5. Working Time Organisation		X	
	6. Resource Allocation		X	X
	7. Organisation/Facility Strategy		X	X
System Load Data	8. Product Data	X	X	
	9. Job Data			
Resources	10. Input Contact Personnel	X	X	X

The sections logged indicate the data available and collected, in accordance with the project phases. Table 5 illustrates that the data available at project initiation included the technical data sets, product data, and the resources available. Organisation data sets were obtained based on historical process data set reviews, in addition to further processing of available data sets. The design reviews, in this case, provided verification and validation of the referred data sets.

iv. Modelling & Simulations:

The model and simulations referenced are constructed following the preceding steps. These files are stored based on revisions constructed by the simulation engineer as the project progresses. A revision control log is developed for each project sample, to provide a basic description of the modelled revisions.

Table 6: Project#1 Revision Control

Excel	Notes	Model	Reference	Error/Debug Notes
V0.1	Baseline frames created, including Preparation; Filling; Raw Material store; Probing and Finishing	Rev01	Initial basic model	
	Assembly of frames created as Model frame linking all the frames with interfaces	Rev02	Base model frame assembly	Operations call-up error due to Filling model in the z-direction (with footpaths) and other frames open (free movement) - multiple worker pools BUT DOES NOT AFFECT SIMULATION RUN OUTPUT
	First review updates/changes with project participants; inclusion of prod B-E and Thermal Cycling for prod A	Rev03	First review updates	Logical flow errors with the inclusion of Thermo-cycling plus (rev02 error)
	Logical flow of Thermo-cycling and buffers updated and final assembly plus NDT rigour	Rev04	Finishing frame debugging	Flow dependent on buffer layout and specification inputs plus (rev02 error)
	Second review updates/changes with project participants	Rev05	Second review updates	Thermo-cycling finished pallets build-up (Finishing interim buffer cap, based on flow) plus (rev02 error)
	Model refinement and clean-up; inclusion of other raw materials and extra interim buffer at finishing; first scenario simulation output sheet created	Rev06	Prelim model with sim output requiring validation	Simulation runs and scenarios require validation upon prelim review plus (rev02 error)
	Filling module update and hopper feeding scenario runs	Rev07	Filling module update	The filling module and hopper feeding scenario runs, based around OH conveyor use.

The Excel column indicates the data workbook version that is incorporated in the model simulation. Project#1 is developed utilising a single data workbook version, with multiple model/simulation revisions. The notes provide an overview of the version and revision constructed. The error/debug notes are subjected to each model revision, to provide some additional model/simulation information.

v. <u>Validation & Verification:</u>

As referenced in 3.3.1 Stage 1: Problem Formulation Part (v), validation refers to the assurance that the model simulation meets the needs of the identified stakeholders. Table 7 illustrates the applicable validation and/or verification referrals applied to Project#1 processed and simulated data sets.

Table 7: Project#1 Validation & Verification Referral

Analysis Referral	Validation	Verification

Historical Data (Reference)		X
Project Stakeholders	X	
Expert Review	X	
Process Data (Implemented)		

vi. Reporting:

On completion of a project or project phase, it is important to document simulated results and project progress. This is to ensure clear communication of deliverables and recommendations to act as an effective decision support tool. Summarised project portfolio samples were compiled for all the project samples, to provide a quick reference per project.

Project Scope:

The LAPing facility consists of four modules for the Loading, Assembly and Packing of Product A and Product B-E. These modules include Preparation, Filling, Probing and Finishing. An extra process requirement is the Thermal Cycling of Product A together with the Finishing module.

The simulation requirement is to optimise the LAPing facility design for the project. The focus should be around layout design, bottleneck identification, material flow, throughput analysis and overall model development.

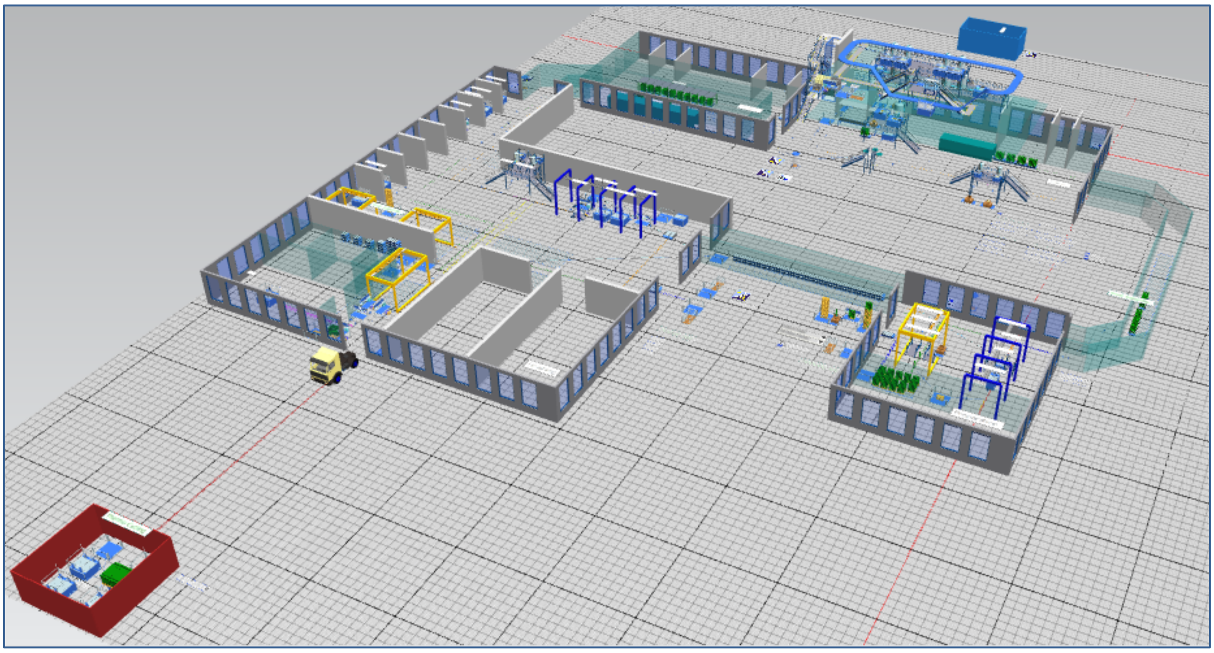

Figure 14: Project#1 model view, source: Tecnomatix Plant Simulation (2020)

Cost Reduction & Optimisation:

The following scenarios were simulated to potentially reduce operational costs or increasing production throughput/shift:

Scenario	Throughput / Shift					Points of Value
	A	B	C	D	E	
REFERENCE	198	34	21	8	5	*30 A trolleys | 10 B-E trolleys | 26 ops*
Trolleys (i)	198	33	21	11	7	*40 A trolleys | 20 B-E trolleys*
Operators (ii)	198	34	21	8	5	*21 operators*
Probing/Turntable (iii)	233	43	29	13	8	*+2 probing sta. | + Turntable*
Probing/Turntable+ (iv)	253	43	31	14	8	*+5 probing sta.| + Turntable + 20 trolleys*

Conclusion & Recommendations:

It can be concluded that the reference simulation produces results, related to that of the design capacity. The various scenarios produce varying results as seen above:

i. Product D & E throughput increases (20-30%), by an increasing amount of trolleys.
ii. The same throughput is obtained with setup, by decreasing to 21 ops (±R1.6m p.a. savings).
iii. 15% Product A throughput increase adding 2 probing stations | 30% B-E throughput increase adding Turntable.
iv. 22% Product A throughput increase adding 5 probing stations | 32% B-E throughput increase adding trolleys.

4.3.2 Project#2

This is a medium design support project consisting of the modelling and simulation of an external asphalt lining facility, including preparation, pre-heating ovens, cooling racks, finishing, and gantry hoists for material handling.

i. <u>Request / Identification:</u>

The same project request template was subjected to all project samples (refer to Appendix B). The request submitted is summarised as follow:

'A DES has been requested to ensure design capacity is met and to enable concurrent simulation analysis in-line with concept design, to potentially optimise operational requirements.'

Project participants completed the questionnaire to develop the most appropriate and value-adding template (Appendix D).

ii. <u>Data Collection:</u>

The same data input form was subjected to all project samples (refer to Appendix D). The data sets available are identified in Table 8. Project participants completed the questionnaire to develop the most appropriate and value-adding template (Appendix E).

iii. Data Processing:

A conformance table was developed for all project samples to identify the data available from the data collection phase; internal data reviews on the processed data sets, as well as potential inclusions; and design reviews on developed simulation models, which also affects data processing in certain cases.

Table 8: Project#2 Data Processing Log

Data Step		Data Available	Data Reviews	Design Reviews
Technical Data	1. Factory Structural Data	X	X	X
	2. Manufacturing Data			X
	3. Material Flow Data			X
	4. Failure Data			
Organisation Data	5. Working Time Organization		X	X
	6. Resource Allocation			X
	7. Organization/Facility Strategy	X	X	X
System Load Data	8. Product Data	X	X	X
	9. Job Data			
Resources	10. Input Contact Personnel	X	X	X

Table 8 illustrates that the data available on project initiation only included the factory structural data, facility and product data, and the resources available. Additional organisation data sets were obtained upon other historical process data set reviews, in addition to further processing of available data sets. The design reviews provided additional technical and organisation data sets, as well as providing verification and validation on the referred data sets.

iv. Modelling & Simulations:

The model and simulations referenced are constructed following the preceding steps. These files are stored based on revisions constructed by the simulation engineer as the project progresses. A revision control log is developed for each project sample, to provide a basic description of the modelled revisions.

Table 9: Project#2 Revision Control

Excel	Notes	Model	Reference	Error/Debug Notes
V0.1	Baseline model created based on concept process layout design.	Rev01	Base model, excl. gantries	Baseline model, excluding gantry (built-in recovery times).
	Gantries inclusion	Rev02	Incl. gantries	Gantry method execution bugging (part/process blocking)
	Baseline model with updated oven, lining and cooling processing.	Rev03A	Incl. gantries	Processing methods included for process flow requirements.
V0.2	Analysis model excluding gantry handling (built-in recovery times).	Rev03B	Excl. gantries	Processing is not accurate, with no gantry inclusion.
V0.3	Analysis model including power analyzer.	Rev03C	Excl. gantries	Processing is not accurate, with no gantry inclusion.
V0.4	Marketing model including non-blocking gantry handling and process flow (stats not accurate)	Rev03D	Incl. gantries (no restrictions)	Material handling times are not accurate.
V0.5	Updated model with gantry inclusion.	Rev04A	Incl. gantries (collision control)	Processing and material handling times are not accurate (rev03A update).
V0.6	Updated model with gantry processing inclusion; and operational, throughput and power analysis.	Rev04B	Incl. gantries (processes)	Processing and material handling times accurate, with no gantry animation (rev03B update).

Project#2 is developed utilising multiple data workbook versions, subject to different model/simulation revisions. This indicates that various data sets were included, based on the model/simulation revision and analysis requirements.

v. <u>Validation & Verification:</u>

Table 10 illustrates the applicable validation and/or verification referrals applied to Project#2 processed and simulated data sets, refer to 3.3.1 Stage 1: Problem Formulation Part (v).

Table 10: Project#2 Validation & Verification Referral

Analysis Referral	Validation	Verification
Historical Data (Reference)		X
Project Stakeholders	X	
Expert Review		
Process Data (Implemented)		

vi. <u>Reporting:</u>

Summarised project portfolio samples were compiled for all the project samples, to provide a quick reference per project.

Project Scope:

The Asphalt Lining Facility is a proposed concept consisting of asphalt lining of Products B-E, including preparation, pre-heating ovens, lining devices, cooling racks, finishing and gantry hoists for product handling.

The simulation requirement is to ensure design capacity is met and to enable concurrent simulation analysis in line with concept design, to potentially optimise operational requirements.

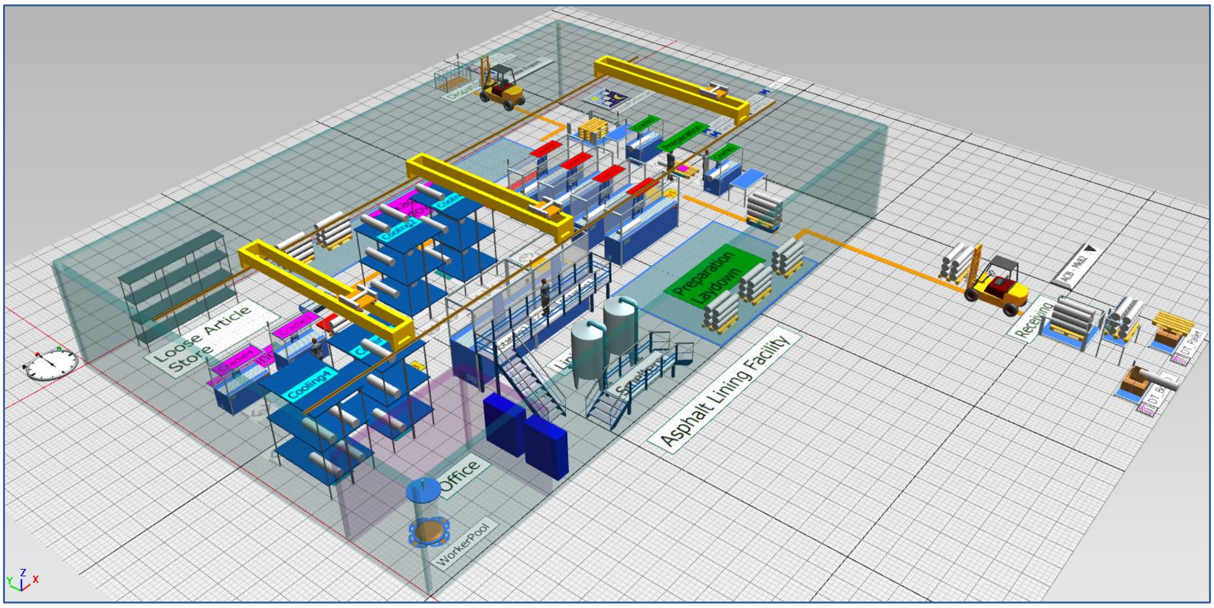

Figure 15: Project#2 model view, source: Tecnomatix Plant Simulation (2020)

Cost Reduction & Optimisation:

A baseline reference simulation was compiled focusing on the pre-heating and lining processing times (worst case), as well as the addition of an additional lining machine:

Scenario	Throughput per Shift			
	B	C	D	E
#0 (Baseline)	21	18	16	14
#1 (Reduced Pre-heating times)	22	19	16	14
#2 (Reduced Lining times)	24	21	18	16
#3 (Scenario #1 + #2)	24	22	18	16
#4 (Additional Lining machine)	26	24	22	18

Conclusion & Recommendations:

The results above conclude that the lining process within the initial setup – is the major constraint within the facility. Reducing the lining processing time produces an increase in throughput (10% avg. increase), with the addition of a lining machine – increasing the overall throughput capacity for all product types (>20% increase ~ the viability of this has not been investigated). Reducing pre-heating times for the ovens does not affect the overall production – since they can be heated and soaked during non-operational times (automatic process cycles ~ as well as the cooling racks).

4.3.3 Project#3

This is a small design support project consisting of the modelling and simulation of a potential internal filling process facility upgrade concept.

i. Request / Identification:

The same project request template was subjected to all project samples (refer to Appendix B). The request submitted is summarised as follow:

'A DES has been requested to analyse the proposed and operational concepts. As well, as to validate operational costing, based on throughput including labour, utilities, and overheads. The layout and overall concept design are also to be investigated.'

Project participants completed the questionnaire to develop the most appropriate and value-adding template (Appendix D).

ii. Data Collection:

The same data input form was subjected to all project samples (refer to Appendix C). The data sets available are identified in Table 11. Project participants completed the questionnaire to develop the most appropriate and value-adding template (Appendix E).

iii. Data Processing:

A conformance table was developed to identify the data available from the data collection phase; internal data reviews on the processed data sets, as well as potential inclusions; and design reviews on developed simulation models, which also affects data processing in certain cases.

Table 11: Project#3 Data Processing Log

Data Step		Data Available	Data Reviews	Design Reviews
Technical Data	1. Factory Structural Data	X	X	X
	2. Manufacturing Data		X	X
	3. Material Flow Data			X
	4. Failure Data			

Organisation Data	5. Working Time Organization	X		
	6. Resource Allocation			X
	7. Organization/Facility Strategy		X	X
System Load Data	8. Product Data	X	X	
	9. Job Data		X	X
Resources	10. Input Contact Personnel	X	X	X

Table 11 illustrates that the data available on project initiation only included the factory structural data, shift schedules, product data, and the resources available. Additional manufacturing data and job data was obtained upon other historical process data set reviews, in addition to further processing of available data sets. The design reviews provided additional technical and organisation data sets, as well as providing verification and validation on the referred data sets.

iv. <u>Modelling & Simulations:</u>

The model and simulations referenced are constructed following the preceding steps. These files are stored based on revisions constructed by the simulation engineer as the project progresses. A revision control log is developed for each project sample, to provide a basic description of the modelled revisions.

Table 12: Project#3 Revision Control

Excel	Notes	Model	Reference	Error/Debug Notes
V0.1	Baseline frames were created, including A03D - Filling processes as a starting point.	Rev01	Initial basic model	Process/concept review required.
	2 Frames were created, 1 for cleaning ops done at A03 and another at A02 (current ops); Also Including Input and Output tables and stat variables.	Rev02	CA03 & CA02 frames	Process/concept review required. Semi-validated values via process sheets and assumptions.
	Programmed automatic input and data export buttons, for quick scenario testing/evaluation.	Rev03A	Input & Output Methods	Process/concept review required. Semi-validated values via process sheets and assumptions.
V0.2	Updated concept, utilizing baseline modules.	UCRev01	Updated concept	Process/concept review required. Semi-validated values via process sheets and assumptions.

Project#3 was developed utilising two workbook versions, subject to and initial and updated concept model/simulation revisions. This indicates that various data sets were included, based on the model/simulation revision and analysis requirements.

v. <u>Validation & Verification:</u>

Table 13 illustrates the applicable validation and/or verification referrals applied to Project#3 processed and simulated data sets, refer to 3.3.1 Stage 1: Problem Formulation Part (v).

Table 13: Project#3 Validation & Verification Referral

Analysis Referral	Validation	Verification
Historical Data (Reference)		
Project Stakeholders	X	
Expert Review		
Process Data (Implemented)		

vi. <u>Reporting:</u>

On completion of a project or project phase, it is important to document simulated results and project progress. This is to ensure clear communication of deliverables and recommendations to act as an effective decision support tool. Summarised project portfolio samples were compiled for all the project samples, to provide a quick reference per project.

Project Scope:

A client approached Company A with the potential requirement to product variants at one of Company A's sites. The requirement is to fill three different product sizes. The identified facility for this operation is Site A-03, which is used for existing high-volume product filling.

The simulation requirement is to analyse the proposed process and operational concepts, as well as validate operational costing, based on throughput.

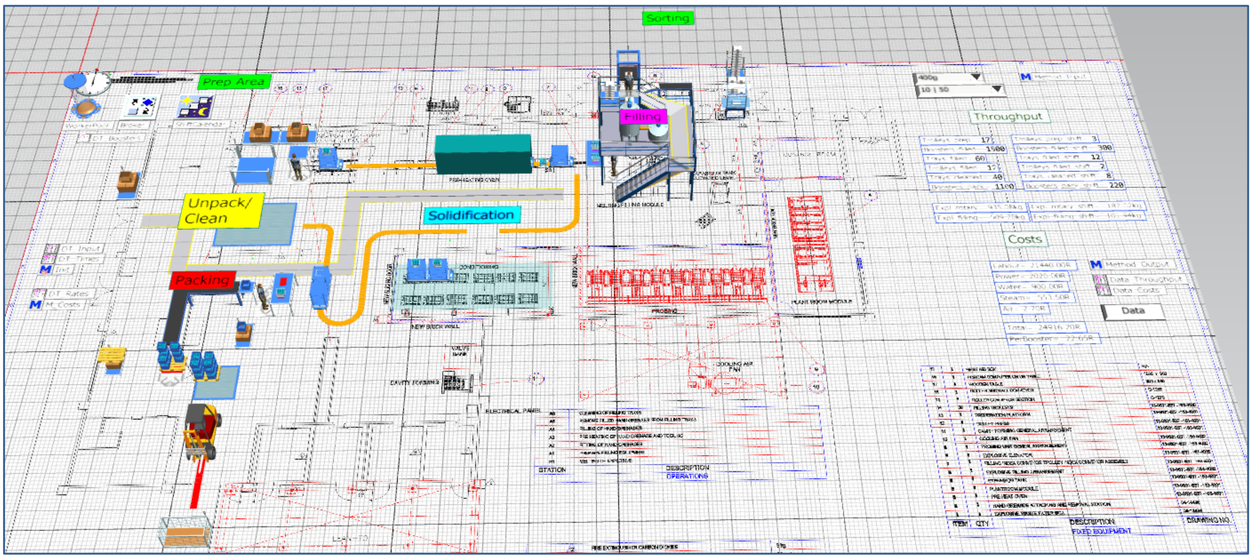

Figure 16: Project#3 Model View, source: Tecnomatix Plant Simulation (2020)

Cost Reduction & Optimisation:

A baseline reference simulation was compiled focusing on the trolley and tray quantities, together with operational cost per product:

Scenario	Product F		Product G		Product H	
	TP/shift	Cost/prod	TP/shift	Cost/prod	TP/shift	Cost/prod
5 trolleys | 22 trays	1450	R 3.44	1170	R 4.26	900	R 5.54
10 trolleys | 50 trays	1855	R 2.69	1450	R 3.44	1050	R 4.75
15 trolleys | 75 trays	1855	R 2.69	1450	R 3.44	1050	R 4.75

Conclusion & Recommendations:

The results above conclude a baseline reference that can be used with the development of the project. The most beneficial scenario perceived is increasing the amount of trolleys = 10 and trays = 50, leading to throughput per shift increase and operational cost reduction:

- 22% increase in Product F production | R0.75 operational cost reduction per product
- 19% increase in Product G production | R0.82 operational cost reduction per product
- 14% increase in Product H production | R0.79 operational cost reduction per product

4.3.4 Project#4

This is a medium site support project consisting of the modelling and simulation of an automated gantry line in one of the company's CNC manufacturing areas.

i. <u>Request / Identification:</u>

The same project request template was subjected to all project samples (refer to Appendix B). The request submitted is summarised as follow:

'Requirement to analyse and provide supportive simulations for the gantry lines, based on operational requirements. This is to provide motivational support and potential effects for the upgrading of the line and optimising the potential throughput and utilisation.'

Project participants completed the questionnaire to develop the most appropriate and value-adding template (Appendix D).

ii. <u>Data Collection:</u>

The same data input form was subjected to all project samples (refer to Appendix C). The data sets available are identified in Table 14. Project participants completing the questionnaire to develop the most appropriate and value-adding template (Appendix E).

iii. <u>Data Processing:</u>

A conformance table was developed to identify the data available from the data collection phase; internal data reviews on the processed data sets, as well as potential inclusions; and design reviews on developed simulation models, which also affects data processing in certain cases.

Table 14: Project#4 Data Processing Log

Data Step		Data Available	Data Reviews	Design Reviews
Technical Data	1. Factory Structural Data	X	X	
	2. Manufacturing Data	X	X	X
	3. Material Flow Data			X
	4. Failure Data			X
Organisation Data	5. Working Time Organization	X		
	6. Resource Allocation			X
	7. Organization/Facility Strategy		X	X
System Load Data	8. Product Data		X	
	9. Job Data		X	X
Resources	10. Input Contact Personnel	X	X	X

Table 14 illustrates that the data available on project initiation only included some technical data, shift schedules, and the resources available. Additional organisation data and system load data sets were obtained upon other historical process data set reviews, in addition to further processing of available data sets. The design reviews provided additional technical and organisation data sets, as well as providing verification and validation on the referred data sets.

iv. Modelling & Simulations:

The model and simulations referenced are constructed following the preceding steps. These files are stored based on revisions constructed by the simulation engineer as the project progresses. A revision control log is developed for each project sample, to provide a basic description of the modelled revisions.

Table 15: Project#4 Revision Control

Excel	Notes	Model	Reference	Error/Debug Notes
V0.1	Baseline frames created, including current Cell2 operations - OD, IM and BR stations.	Rev00	Initial basic model	Process/concept review required.
	Current state gantry lines and process setups created.	Rev01	G11 - G31 frames	Process/concept review required. Semi-validated values via process sheets and assumptions.

	Current state and scenario gantry lines and process setups developed.	Rev02	G11 - G31 frames updated	Process/concept review required. Semi-validated values via process sheets and assumptions.

Project#4 is developed utilising one data workbook, subject to and initial and updated concept model/simulation revisions. This indicates that an initial data set was included, subject to the model/simulation revision and analysis requirements.

v. <u>Validation & Verification:</u>

Table 16 illustrates the applicable validation and/or verification referrals applied to Project#4 processed and simulated data sets, refer to 3.3.1 Stage 1: Problem Formulation Part (v).

Table 16: Project#4 Validation & Verification Referral

Analysis Referral	**Validation**	**Verification**
Historical Data (Reference)		X
Project Stakeholders	X	
Expert Review		
Process Data (Implemented)		

vi. <u>Reporting:</u>

On completion of a project or project phase, it is important to document simulated results and project progress. This is to ensure clear communication of deliverables and recommendations to act as an effective decision support tool. Summarised project portfolio samples were compiled for all the project samples, to provide a quick reference per project.

Project Scope:
Cell2 is a machining station consisting of multiple CNC machines, capable of various operations for multiple products at Site A. Division A is currently busy with renovations and upgrading of the Gantry Line, with a new transporter to be included. The focus product is Product A, which requires Outer-diameter machining (OD) -> Internal machining (IM) -> Base recess machining (BR).

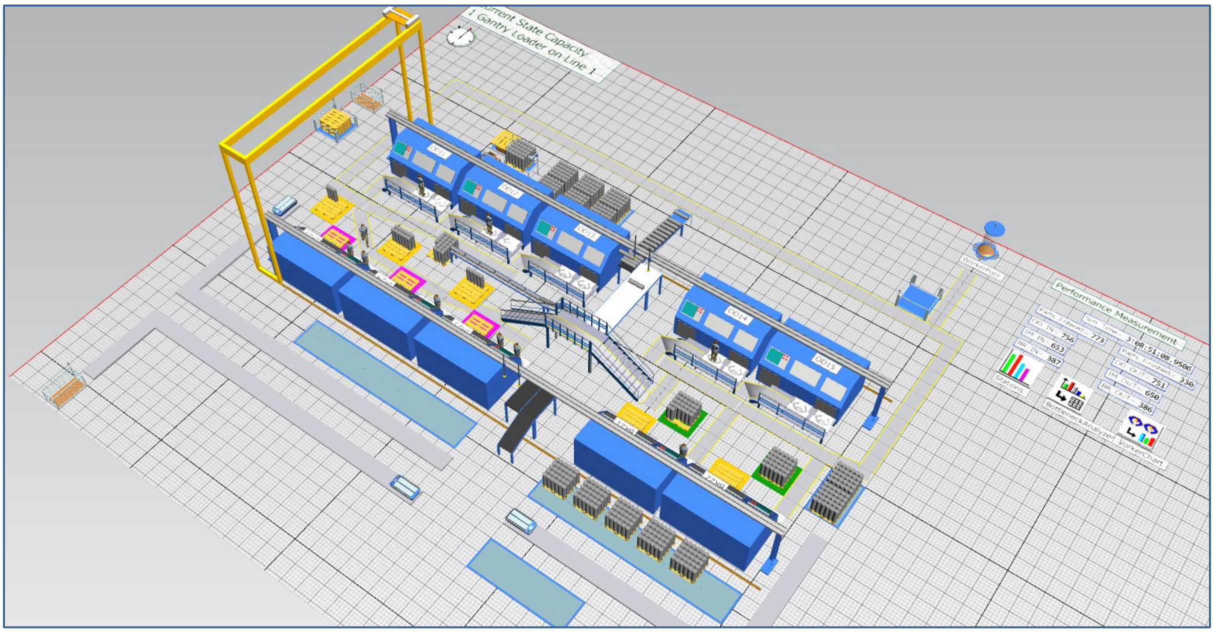

Figure 17: Project#4 Model View, source: Tecnomatix Plant Simulation (2019)

Cost Reduction & Optimisation:

The following baseline scenarios and frames were utilised to simulate the various process and operational parameters, focusing on Product A:

Frame	OD Stations	IM Stations	BR Stations
F1	5	3	2
F2	4	3	2
F3	5	2	3
F4	4	2	3

Scenario	1 Gantry Loader – Avg. Throughput/day			2 Gantry Loaders – Avg. Throughput/day		
	OD	IM	BR	OD	IM	BR
Frame 1	264	261	218	286	282	239
Frame 2	251	248	236	261	257	237
Frame 3	236	233	218	244	241	237
Frame 4	248	245	237	249	246	237

Conclusion & Recommendations:

It can be concluded that F1 is a buffer-producing model for the IM and BR stations. F2 consolidates a balance in total throughput to that of F1, with one OD station kept available. F4 is similar to F2, with the main difference being that the base BR stations are increased to 3 with 2 non-main IM stations, on line 2 (opposite to that of F1 and F2).

4.3.5 Project#5

This is a small site support project consisting of the modelling and simulation of an updated phosphating line in the company's existing Paint shop.

i. Request / Identification:

The same project request template was subjected to all project samples (refer to Appendix B). The request submitted is summarised as follow:

'Requirement to analyse various effects for transporter upgrading and basket quantities. Also to analyse transporter sequencing and handling requirements.'

Project participants completing the questionnaire to develop the most appropriate and value-adding template (Appendix D).

ii. Data Collection:

The same data input form was subjected to all project samples (refer to Appendix C). The data sets available are identified in Table 17. Project participants completed the questionnaire to develop the most appropriate and value-adding template (Appendix E).

iii. Data Processing:

A conformance table was developed to identify the data available from the data collection phase; internal data reviews on the collected and processed data sets, as well as potential inclusions; and design reviews on developed models, which affects data processing in certain cases.

Table 17: Project#5 Data Processing Log

Data Step		Data Available	Data Reviews	Design Reviews
Technical Data	1. Factory Structural Data	X	X	
	2. Manufacturing Data	X		X
	3. Material Flow Data	X		X
	4. Failure Data			
Organisation Data	5. Working Time Organization	X		
	6. Resource Allocation	X		X
	7. Organization/Facility Strategy	X		X
System Load Data	8. Product Data	X	X	
	9. Job Data	X		X
Resources	10. Input Contact Personnel	X	X	X

Table 17 illustrates that the data available on project initiation included almost all of the data sets. Additional factory and product data were obtained upon other historical process data set reviews, in addition to further processing of available data sets. The design reviews provided verification and validation on the referred data sets.

iv. Modelling & Simulations:

The model and simulations referenced are constructed following the preceding steps. These files are stored based on revisions constructed by the simulation engineer as the project progresses. A revision control log is developed for each project sample, to provide a basic description of the modelled revisions.

Table 18: Project#5 Revision Control

Excel	Notes	Model	Reference	Error/Debug Notes
V0.1	Baseline model created, including Baths and Transporter.	Test01	Multiportalcrane	Initial basic model transporter movement test with multiple running methods. 1 Flightbar/basket
	Refined baseline model created.	Rev01	Multiportalcrane	Initial basic model with single call method. 1 Flightbar/basket
	Added flight bars/baskets to model.	Rev02	Transporter + Baskets	Initial basic model with single call method. Multiple Flightbars/baskets
V0.2	Created 4 frames, including Fixed/Open Transporter and with added Soakbath in Fixed/Open T scenario.	Rev03	4 Frames	4 Frames based on Fixed/Open Transporter scenario, including/excluding Soak bath.
V0.3	Created 4 more frames, including sequence algorithm for Transport movement.	Rev04	8 Frames + Stats	Initial models for reference analysis and scenario simulations.

Project#5 is developed utilising multiple workbook versions, subject to various model/simulation revisions. This indicates that various data sets were included, based on the model/simulation revision and analysis requirements.

v. Validation & Verification:

Table 19 illustrates the applicable validation and/or verification referrals applied to Project#5 processed and simulated data sets, refer to 3.3.1 Stage 1: Problem Formulation Part (v).

Table 19: Project#5 Validation & Verification Referral

Analysis Referral	Validation	Verification
Historical Data (Reference)		X

Project Stakeholders	X	
Expert Review		
Process Data (Implemented)		X

vi. <u>Reporting:</u>

On completion of a project or project phase, it is important to document simulated results and project progress. This is to ensure clear communication of deliverables and recommendations to act as an effective decision support tool. Summarised project portfolio samples were compiled for all the project samples, to provide a quick reference per project.

Project Scope:

Project#5 is an operational process for the phosphating of Product A at the Paint shop. The line was upgraded with the inclusion of new transporter and basket operations – to include rotational handling and better processing of new product types.

The simulation requirement is to analyse various effects for transporter upgrading and basket quantities. As well as to analyse transporter sequencing and handling.

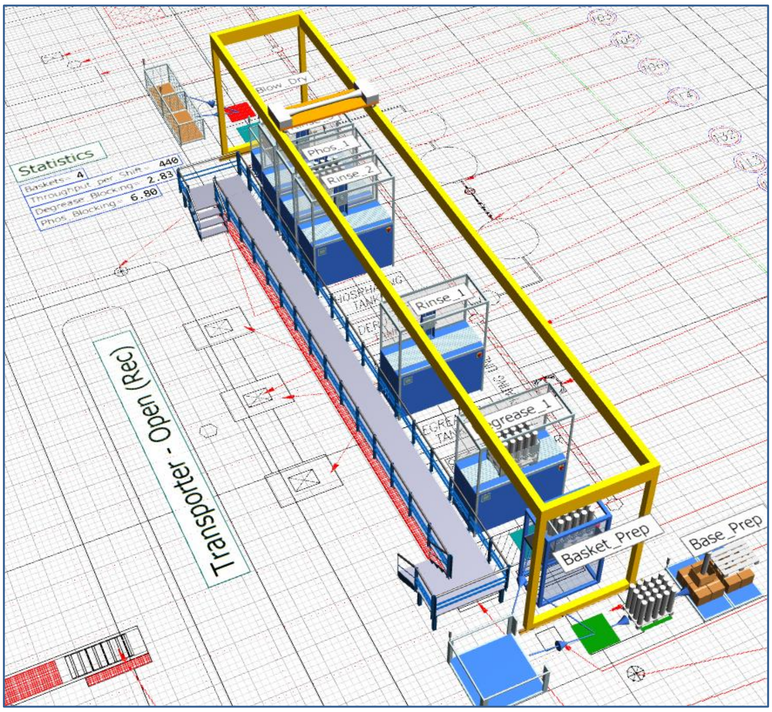

Figure 18: Project#5 Model View, source: Tecnomatix Plant Simulation (2020)

Cost Reduction & Optimisation:

The transporter was simulated with various scenarios, including fixed at blow-dry and open to moving between all stations; as well as the inclusion of a soak bath; with varying basket quantities (1-4):

Scenario	Throughput / Shift			
	1 basket	2 baskets	3 baskets	4 baskets
Transporter Fixed	140	280	320	360
Transporter Open	140	280	380	440
Soak Bath (Fixed)	140	280	320	360
Soak Bath (Open)	140	280	380	480

Conclusion & Recommendations:

The results conclude that the major constraint for the transporter setup is the number of baskets. Opening the transporter up after moving a basket to the blow-dry station, increases the throughput per shift between 15-20% (4 baskets). Adding another soak bath increases the throughput per shift by another 8%, only with the open transporter scenario with four baskets.

4.3.6 Comparative Analysis

The comparative analysis between project samples provides a means of summarising important data and evaluating project-level components holistically. This is done for each project level component, to analyse all project samples collectively as part of the strategy development as a whole.

i. <u>Request / Identification:</u>

As indicated, the same project request template was subjected to all project samples (refer to Appendix B). Project participants completed the questionnaire to develop the most appropriate and value-adding template (Appendix D). Scoring by the relevant participants is summarised in Figure 19. These questions relate to the format and content of the template:

a) *Question 1 – Is the form readable/understandable?*
b) *Question 2 – Is there sufficient writing/editing space?*
c) *Question 3 – Are the sections well defined/described?*
d) *Question 4 – Is the purpose/reason for completing the form understood?*
e) *Question 5 – Are the sections elaborate enough, without being overly complicated?*
f) *Question 6 – Are the sections relevant and applicable, with regards to project requesting?*

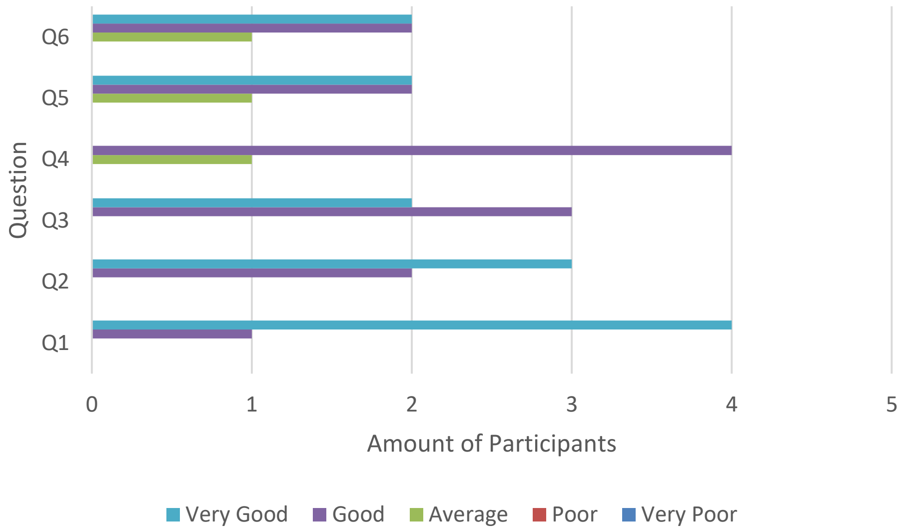

Figure 19: Initial Project Request Template Scoring Feedback

Additional personal feedback was also summarised, to obtain qualitative responses regarding the structure and content of the initial project request template.

Feedback regarding the format and structure of the template document:

- Fields that require input should be indicated by a (*).
- It would be beneficial to convert the document to a digital format.
- A document number should be added in line with company policy.

Feedback regarding the content of the template document:

- Include a DES deliverable requirement checklist.
- Requestors should be able to indicate expected/required simulation accuracy.
- Include an option for indicating an existing or new facility/process.
- Possibly replace priority with "Business Impact" and include business cost indication.
- Possibly include a timeline for request and completion of the project.

ii. Data Collection:

Similarly to project requesting, the same data input form was subjected to all project samples (refer to Appendix C). Project participants completed the questionnaire to develop the most appropriate and value-adding template (Appendix E). Scoring by the relevant participants is summarised in Figure 20. The questions relate to the format and content of the form:

a) Question 1 – Is the form readable/understandable?

b) *Question 2 – Is there sufficient writing/editing space?*

c) *Question 3 – Are the sections well defined/described?*

d) *Question 4 – Is the purpose/reason for completing the form understood?*

e) *Question 5 – Are the sections elaborate enough, without being overly complicated?*

f) *Question 6 – Are the sections relevant, with regards to the process data required?*

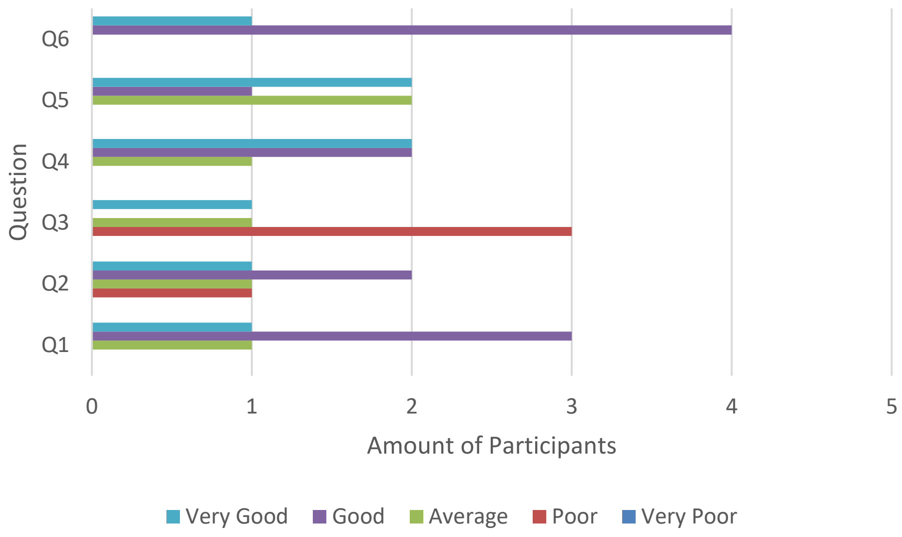

Figure 20: Initial Data Input Template Form Scoring Feedback

Additional personal feedback was also summarised, to obtain qualitative responses regarding the structure and content of the initial project request template.

Feedback regarding the format and structure of the template document:

- Include a more descriptive section on the use of the document, and indicate responsibility regarding data input by the requestor and simulation engineer.
- Add document number in line with company policy.
- Use different sheets for each data section.

Feedback regarding the content of the template document:

- Describe and define sections in simpler terms and with detailed example references.
- Required information needs to be grouped according to simulation type, and responsibilities should be indicated with regard to data provision.
- Include the desired outputs (measurable variables) section at the start of the document.

iii. <u>Data Processing:</u>

The project samples are compared based on the defined and allocated degree of project complexity and categorised as design support (DS) or site support (SS) type projects. The data sets are separated into three sections:

a) Data available on project request/initiation;
b) Data reviews on data collected and processed; and
c) Data obtained on design reviews.

Table 20: Comparison Table for Data Collection & Processing

(a) Data Available on Project Request/Initiation						
Data Step		**Project#1 (Large DS)**	**Project#2 (Medium DS)**	**Project#3 (Small DS)**	**Project#4 (Medium SS)**	**Project#5 (Small SS)**
Technical Data	1. Factory Structural Data	x	x	x	x	x
	2. Manufacturing Data	x			x	x
	3. Material Flow Data	x				x
	4. Failure Data					
Organisation Data	5. Working Time Organisation			x	x	x
	6. Resource Allocation					x
	7. Organisation/Facility Strategy		x			x
System Load Data	8. Product Data	x	x	x		x
	9. Job Data	x				x
Human Resources	10. Input Contact Personnel	x	x	x	x	x

(b) Reviews on Data Collected & Processed						
Data Step		**Project#1 (Large DS)**	**Project#2 (Medium DS)**	**Project#3 (Medium DS)**	**Project#4 (Medium SS)**	**Project#5 (Small SS)**
Technical Data	1. Factory Structural Data	x	x	x	x	x
	2. Manufacturing Data	x		x	x	
	3. Material Flow Data	x				
	4. Failure Data					
Organisation Data	5. Working Time Organisation	x	x			
	6. Resource Allocation	x				
	7. Organisation/Facility Strategy	x	x	x	x	
System Load Data	8. Product Data	x	x	x	x	x
	9. Job Data			x	x	
Human Resources	10. Input Contact Personnel	x	x	x	x	x

(c) Data Obtained on Design Reviews						
Data Step		**Project#1 (Large DS)**	**Project#2 (Medium DS)**	**Project#3 (Medium DS)**	**Project#4 (Medium SS)**	**Project#5 (Small SS)**
Technical Data	1. Factory Structural Data	x	x	x		
	2. Manufacturing Data	x	x	x	x	x

	3. Material Flow Data	x	x	x	x	x
	4. Failure Data				x	
Organisation Data	5. Working Time Organisation		x			
	6. Resource Allocation	x	x	x	x	x
	7. Organisation/Facility Strategy	x	x	x	x	x
System Load Data	8. Product Data		x			
	9. Job Data			x	x	x
Human Resources	10. Input Contact Personnel	x	x	x	x	x

**The results compiled in Table 20 (a) – (c) are discussed and summarised in Chapter 5.*

iv. Modelling & Simulations:

A revision control log was developed for each project sample, to provide a basic description of the modelled revisions. The TX model revisions and the simulated and processed data worksheet revisions are compared in Figure 21 based on project complexity and type.

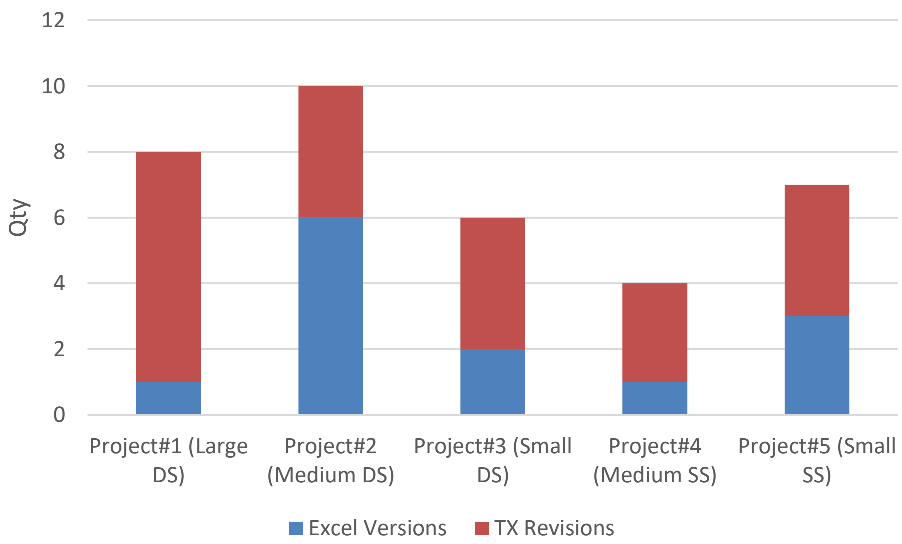

Figure 21: Comparison Graph for Revision Control Requirements per Project

v. Validation / Verification:

Table 21 summarises the associative analysis types complied with the various project samples, refer to 3.3.1 Stage 1: Problem Formulation Part (v).

Table 21: Comparison Table for Validation & Verification Referral per Project

	Analysis Referral			
Project Sample	**Historical Data (Reference)**	**Project Stakeholders**	**Expert Review**	**Process Data (Implemented)**

Project#1 (Large DS)	x	x	x	
Project#2 (Medium DS)	x	x		
Project#3 (Small DS)		x		
Project#4 (Medium SS)	x	x		
Project#5 (Small SS)	x	x		x

**The results compiled in Table 21 are discussed and summarised in Chapter 5.*

vi. Reporting:

As indicated, varying project reporting methods were used for the varying project requirements. The main project deliverables were summarised in an internal portfolio, conforming to a similar structure. Project participants completed a questionnaire based on the relevant project reports, to develop the most appropriate and value-adding template (Appendix F). Scoring by the relevant participants is summarised in Figure 22. The questions relate to the format and content of the template:

a) *Question 1 – Is the document readable/understandable?*
b) *Question 2 – Is there sufficient information relative to project requirements?*
c) *Question 3 – Are the sections well defined/described?*
d) *Question 4 – Is the purpose/reason of the document understood and does it add value?*
e) *Question 5 – Are the sections elaborate enough, without being overly complicated?*
f) *Question 6 – Are the sections relevant, with regards to project requirements?*

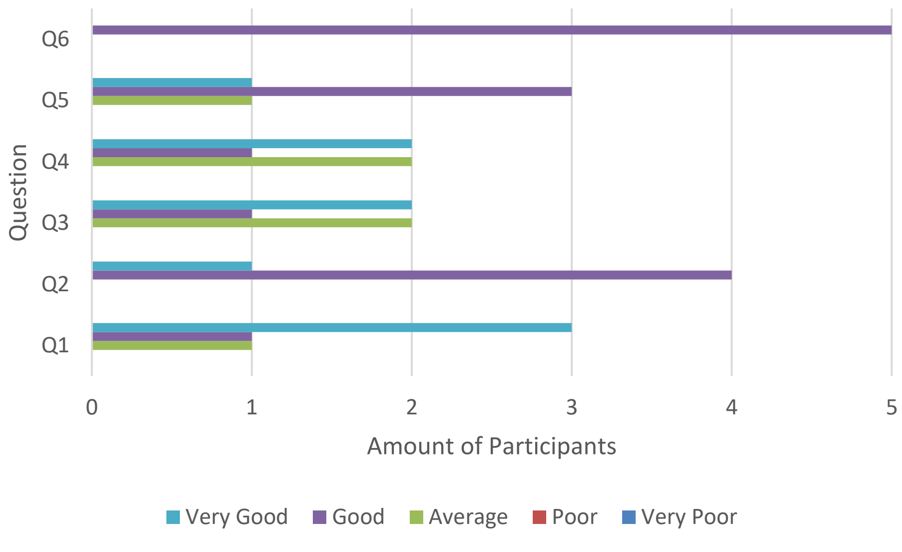

Figure 22: Deliverables Reporting Scoring Feedback

Additional personal feedback was also summarised, to obtain qualitative responses regarding the structure and content of the initial project request template.

Feedback regarding the format and structure of the reporting documents:

- Documents (even as an interim report), should be structured in a formal company FEA/CFD-style document template.

Feedback regarding the content of the reporting documents:

- Tables, diagrams and sections should be described in more detail.
- Included additional IE conclusion/recommendations section.
- Include a model build summary.
- Worksheets should be included with the report and/or a summary.

4.4 Organisational Level

4.4.1 Selection & Evaluation

Only references to applicable documents and papers are made for this section since it is covered in detail as part of the background study. The following documents cover the fundamental construction of this section:

i. Company A: DES Software Scope of Requirement (CompanyA-SOR-001, 2018)
ii. A hybrid selection and evaluation methodology for DES software (Wesch & Hattingh, 2021)
iii. TX motivation summary (CompanyA-MS-002, 2018)

4.4.2 Components

The organisational components consist of all the other relevant data sets that apply to the overall strategy requirements and business development. The lead author as participant-observer primarily compiles the collected datasets. It should be noted that these data sets formed part of external reviews by Siemens participants, to ensure triangulation and limit any company related bias.

It should be noted that this section does not conform to the complete generalisation requirements as stated previously, with the external reviews only supplementary to the rigour and validity of the research case study as a whole. The organisational level was only abstracted and compiled from Company A, as reference component, as part of the development of the implementation strategy as a whole.

i. <u>Initial Resource Capacity:</u>

The initial resource capacity is one simulations engineer, who is accountable for the implementation of TX at a project and business level in a phased approach.

The identified initial user and developer is the lead author (participant-observer), acting as a sole license holder to develop an acceptable implementation strategy and software utilisation.

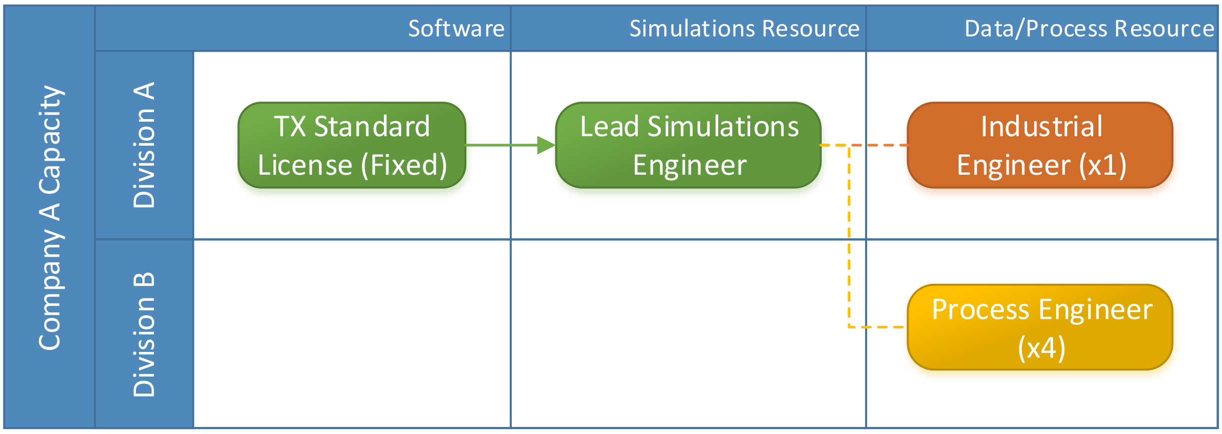

Figure 23: Initial Company A Resource Capacity

ii. Initial Licensing:

The license files created by Siemens PLM Software can specify any of the following license types (Siemens PLM Software Inc., 2012):

Floating / Concurrent	Anyone on the network can use the licensed module, up to the limit specified in the license file.
Node-locked (Perpetual)	The licensed module can be used only on one node.
Mixed	Mixes node-locked and floating licenses in the same license file.
Subscription	Annual subscription floating license (*new)

TX Standard Perpetual License is the current software license used to set up a baseline modelling and simulation structure within Company A. This license is only useable by a single identified user. A 2-3 year rollout and implementation phase will be used to complete identified projects, from where evaluation on ROI and implementation strategy development be completed.

iii. Initial Training:

The training strategy forms part of the overall implementation strategy and identified requirements, identified by Division A. The training is separated into two sections:

a) In-House Training (Division A)

b) Outsourced Training (Siemens)

As part of the training and rollout phase for this research study, basic informal training was incorporated in parallel with identified 'roll-out' projects and advanced outsourced training as part of the resource capability evaluation.

The 'informal' in-house training was done utilising the following sources:

- Plant Simulation Step-By-Step ENU (Siemens PLM Software Inc., 2017),
- Manufacturing Simulation with Plant Simulation and SimTalk, usage and programming with examples and solutions (Bangsow, 2010), and
- Tecnomatix Plant Simulation, modelling and programming by means of examples (Bangsow, 2015).

The advanced outsourced training was done by Siemens Digital Solutions as per the initial standard license agreement with Company A on license purchase.

iv. <u>Organisational Structure:</u>

The following figure provides a basic organisational structure for Company A, associated with the initial implementation of TX at Division A.

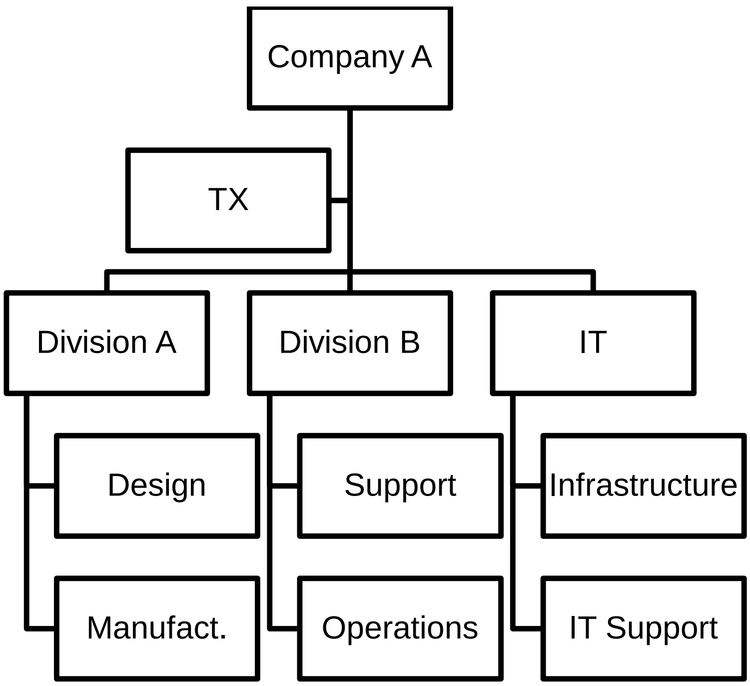

Figure 24: Organisational Structure (Company A)

Figure 24 illustrates the effective organisational resources involved with the implementation of TX. Division A is the functioning resource, where the software is implemented and utilised within a design support functionality. Division B is a subsidiary resource, benefiting from the site support and data provision functionality. The IT department provides the infrastructure used on a software/hardware level, as well as functional support.

Phasing is covered and developed in more detail in the strategy development section.

4.4.3 Feasibility Studies

This section provides a basic feasibility study performed utilising an initially developed template form. The results obtained and compiled for the various samples are compiled in the following sections. Completed template questionnaires, attached in Appendix G were used to develop the most appropriate and value-adding template.

i. <u>Project#1 – Feasibility Study:</u>

Project:	LAPing
Background:	
The LAPing facility consists of 4 modules for the Loading, Assembly and Packing for Product A and Product B-E. These modules include Preparation, Filling, Probing and Finishing. An extra process requirement is the Thermal Cycling of Product A together with the Finishing Module.	
Technical:	
Request	The requirement to optimise LAPing facility design for project#1. The focus should be around layout design, bottleneck identification, material flow, throughput analysis and overall model development.
Hardware	PC capable of running selected DES software
Software	Tecnomatix Plant Simulation (DES)
Skill/capability	Simulations engineer with advanced TX skills.
Economic:	
Cost	Labour hours for simulations engineer.
Benefits	In-line design support
	Bottleneck analysis and potential throughput increase (>10%)
	Potential cost reduction
	Layout optimisation
	Material requirements analysis
Legal:	
IP	Company sensitive data
Compliance	Internal reviews
Research	NDA; Internally reviewed and filtered data
Operational:	
Utilisation	Continuous; baseline model
Maintenance	Manual model updates; TX updates
Change Management	Revision control (TX); Internal reviews (Utilization)
Schedule:	
Timeline	This is a concurrent project, with development and analysis requirements continuously updated. An initial lead-time of 6 months for a complete baseline model and basic analysis (as part of TX rollout phase).

Simulation Summary:

Scenario	**Throughput / Shift**					**Points of Value**
	A	**B**	**C**	**D**	**E**	

REFERENCE	198	34	21	8	5	Baseline reference
Trolleys (i)	198	33	21	11	7	D/E throughput increases by (20-30%)
Operators (ii)	198	34	21	8	5	Similar results as REF, +/-R1.6m p.a. savings
Probing/Turntable (iii)	233	43	29	13	8	15% A TP | 30% B-E TP increase
Probing/Turntable+ (iv)	253	43	31	14	8	22% A TP | 32% B-E TP increase
Note: *The simulation results are based on constructed scenarios, requiring viability investigation and systems/design analysis.*						

ii. Project#2 – Feasibility Study:

Project:	ALF
Background:	
The Asphalt Lining Facility is a proposed concept consisting of asphalt lining of Product B-E, including preparation, pre-heating ovens, lining devices, cooling racks, finishing and gantry hoists for product handling.	
Technical:	
Request	A DES has been requested in order to ensure design capacity is met and to enable concurrent simulation analysis in line with concept design, to potentially optimise operational requirements.
Hardware	PC capable of running selected DES software
Software	Tecnomatix Plant Simulation (DES)
Skill/capability	Simulations engineer with basic TX skills.
Economic:	
Cost	Labour hours for simulations engineer.
Benefits	In-line design support
	Bottleneck analysis and potential throughput increase (>10%)
	Layout optimisation
Legal:	
IP	Company sensitive data
Compliance	Internal reviews
Research	NDA; Internally reviewed and filtered data
Operational:	
Utilisation	Once-off; plug-and-play
Maintenance	Process data updates; TX updates
Change Management	Revision control (TX); Internal reviews (Utilization)
Schedule:	
Timeline	This is a development and analysis requirement project, with inline design updates. An initial lead-time of 4 weeks for a baseline model and basic analysis.

Simulation Summary:

Scenario	**Throughput / Shift**				**Change**
	B	**C**	**D**	**E**	
#0 (REFERENCE)	21	18	16	14	Reference
#1 (Reduced Pre-heating times)	22	19	16	14	No
#2 (Reduced Lining times)	24	21	18	16	10% avg. increase
#3 (Scenario #1 + #2)	24	22	18	16	10% avg. increase
#4 (Additional Lining machine)	26	24	22	18	>20% increase
Note: *The results conclude that the lining process within the initial setup - is the major constraint within the facility. Reducing the lining processing time produces an increase in throughput (10% avg. increase),*					

with the addition of a lining machine - increasing the overall throughput capacity for all product types (>20% increase ~ the viability of this has not been investigated). Reducing pre-heating times for the ovens does not affect the overall production - since they can be heated and soaked during non-operational times (Automatic process cycles ~ as well as the cooling racks). *The simulation results are based on constructed scenarios, requiring viability investigation and systems/design analysis.*

iii. Project#3 – Feasibility Study:

Project:	Product F-G Filling
Background:	
A client approached Company A with the potential requirement to fill product variants at Site A. The requirement is to fill three different sizes of products. The identified facility for this operation is A03D, which is used for other high-volume filling products.	
Technical:	
Request	A DES has been requested in order to analyse the proposed process and operational concepts. As well, as to validate operational costing, based on throughput including labour, utilities and overheads. The layout and overall concept design are also to be investigated.
Hardware	PC capable of running selected DES software
Software	Tecnomatix Plant Simulation (DES)
Skill/capability	Simulations engineer with advanced TX skills.
Economic:	
Cost	Labour hours for simulations engineer.
Benefits	In-line design support
	Bottleneck analysis and potential throughput increase (>10%)
	Potential cost reduction
	Layout optimisation
Legal:	
IP	Company sensitive data
Compliance	Internal reviews
Research	NDA; Internally reviewed and filtered data
Operational:	
Utilisation	Developmental; plug-and-play
Maintenance	Process data & layout updates; TX updates
Change Management	Revision control (TX); Internal reviews (Utilization)
Schedule:	
Timeline	An initial lead-time of 2 weeks for a baseline model and basic analysis.

Simulation Summary:

Scenario	**Product F**		**Product G**		**Product H**		**Rating**
	TP/shift	**Cost/prod**	**TP/shift**	**Cost/prod**	**TP/shift**	**Cost/prod**	
5 trolleys | 22 trays	1450	R 3.44	1170	R 4.26	900	R 5.54	Worst
10 trolleys | 50 trays	1855	R 2.69	1450	R 3.44	1050	R 4.75	Best
15 trolleys | 75 trays	1855	R 2.69	1450	R 3.44	1050	R 4.75	Average

Note:

The simulation results are based on constructed scenarios, requiring viability investigation and systems/design analysis.

iv. <u>Project#4 – Feasibility Study:</u>

Project:	Site B Gantry Line Cell2
Background:	
Cell2 is a machining station consisting of multiple CNC machines, capable of various operations for multiple products at Site B. Division A is currently busy with renovations and upgrading of the Gantry Line, with a new transporter to be included.	
Technical:	
Request	The requirement to analyse and provide supportive simulations for the gantry lines, based on operational requirements. This is to provide motivational support and potential effects for the upgrading of the line and optimising the potential throughput and utilisation.
Hardware	PC capable of running selected DES software
Software	Tecnomatix Plant Simulation (DES)
Skill/capability	Simulations engineer with advanced TX skills.
Economic:	
Cost	Labour hours for simulations engineer.
Benefits	Site support
	Bottleneck analysis and potential throughput increase (>10%)
	Equipment utilisation/availability
Legal:	
IP	Company sensitive data
Compliance	Internal reviews
Research	NDA; Internally reviewed and filtered data
Operational:	
Utilisation	Analytical
Maintenance	Process data; sequencing updates; TX updates
Change Management	Revision control (TX); Internal reviews (Utilization)
Schedule:	
Timeline	Part of the PE Gantry line-upgrading project, utilized as TX rollout project. A lead-time of 8 weeks for basic analysis.

Simulation Summary:

Scenario	**1 Gantry Loader - Avg. TP/day**			**2 Gantry Loaders - Avg. TP/day**			**Material Flow**
	OD	**IM**	**BR**	**OD**	**IM**	**BR**	
Frame 1	264	261	218	286	282	239	Buffer
Frame 2	251	248	236	261	257	237	Balanced
Frame 3	236	233	218	244	241	237	Balanced
Frame 4	248	245	237	249	246	237	Balanced

<u>Note:</u>

It can be concluded that F1 is a buffer-producing model for the IM and BR stations. F2 consolidates a balance in total throughput to that of F1, with 1 OD station kept available. F4 is similar to F2, with the main difference being that the base BR stations are increased to 3 with 2 non-main IM stations, on line 2 (opposite to that of F1 and F2). The simulation results are based on constructed scenarios, requiring viability investigation and process analysis.

v. Project#5 – Feasibility Study:

Project:	Phosphating Line
Background:	
Phosphating Line is a Site A operational process for the phosphating of Product A at the Paint shop. The line was upgraded with the inclusion of new transporter and basket operations. To include rotational handling and better processing of new product types.	
Technical:	
Request	The requirement to analyse various effects for transporter upgrading and basket quantities. Also to analyse transporter sequencing and handling requirements.
Hardware	PC capable of running selected DES software
Software	Tecnomatix Plant Simulation (DES)
Skill/capability	Simulations engineer with advanced TX skills.
Economic:	
Cost	Labour hours for simulations engineer.
Benefits	In-line design/site support
	Bottleneck analysis and potential throughput increase (>10%)
	Equipment optimisation
	Sequencing optimisation
Legal:	
IP	Company sensitive data
Compliance	Internal reviews
Research	NDA; Internally reviewed and filtered data
Operational:	
Utilisation	Analytical; plug-and-play
Maintenance	Process data; sequencing updates; TX updates
Change Management	Revision control (TX); Internal reviews (Utilization)
Schedule:	
Timeline	An initial lead-time of 2-4 weeks for a baseline model and basic analysis.

Simulation Summary:

Scenario	**Throughput / Shift**				**Points of Value**
	1 basket	**2 baskets**	**3 baskets**	**4 baskets**	
Transporter Fixed	140	280	320	360	Reference model
Transporter Open	140	280	380	440	15-20% TP increase (4 baskets)
Soak Bath (Fixed)	140	280	320	360	No change
Soak Bath (Open)	140	280	380	480	25-30% TP increase (4 baskets)

Note:

The results conclude that the major constraint for the transporter setup is the number of baskets. Opening the transporter up after moving a basket to the blow-dry station, increases the throughput per shift between 15-20% (4 baskets). Adding another soak bath increases the throughput per shift by another 8%, only with the open transporter scenario with 4 baskets. The simulation results are based on constructed scenarios, requiring viability investigation and process analysis.

vi. Summarised Feasibility Studies:

The cost savings and optimisation points are summarised in the following table, for the different project samples.

Table 22: Summarised Feasibility Study Analysis

Project Sample	Avg. Throughput Increase [%]	Avg. Cost Savings [R]	Other Value Adding outputs
Project#1 (Large DS)	20-30 %	R1.6m p.a.	Layout development in line with design work.
Project#2 (Medium DS)	10-20 %	-	Provided graphical aid and simulated reference data for material handling and operational throughput concept to the client.
Project#3 (Small DS)	15-20 %	R0.75 per product	Layout development concept based on existing facility layout.
Project#4 (Medium SS)	5%	-	Line balancing development.
Project#5 (Small SS)	15-20 %	-	Basket quantity effects and operational buffer analysis.

Project participants completed a questionnaire regarding the feasibility study reports, to develop the most appropriate and value-adding template (Appendix E). Scoring by the relevant participants is summarised in Figure 25. The questions relate to the format and content of the form:

a) *Question 1 – Is the form readable/understandable?*
b) *Question 2 – Is there sufficient information relative to project requirements?*
c) *Question 3 – Are the sections well defined/described?*
d) *Question 4 – Is the purpose/reason of the document understood and does it add value?*
e) *Question 5 – Are the sections elaborate enough, without being overly complicated?*
f) *Question 6 – Are the sections relevant, with regards to the feasibility requirements?*

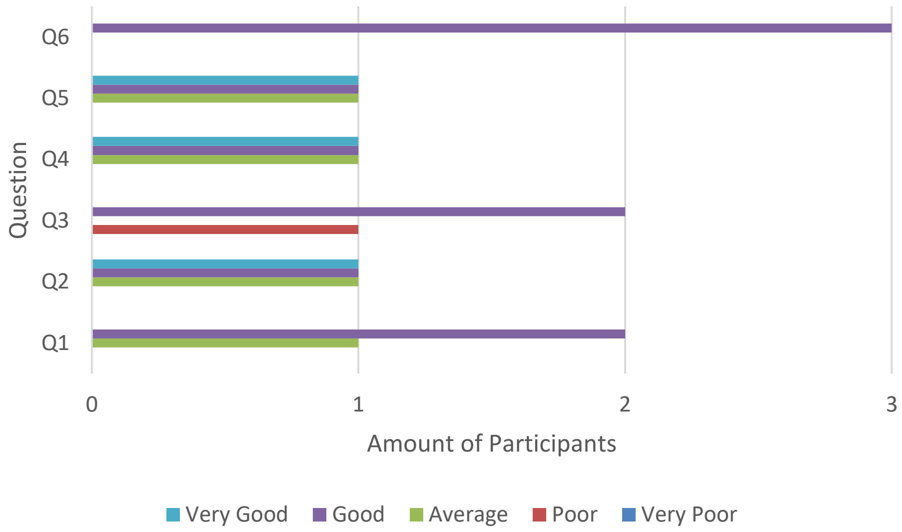

Figure 25: Feasibility Study Template Scoring Feedback

Additional personal feedback was also summarised, to obtain qualitative responses regarding the structure and content of the relevant feasibility study forms.

Feedback regarding the content and structure of the template:

- Include notes to describe sections and abbreviations.
- Include a flow diagram as well as a graphical display of comparing scenario results.
- Provide notes on detail costing breakdown.

4.5 Internal Reviews

The internal reviews were conducted on all the project samples and with voluntary identified participants. This was done in the form of an unstructured interview, following the guidelines set out in Annex A2. The survey questionnaires applicable, have been referenced in the preceding sections based on the relevant subject matter.

4.5.1 Unstructured Interview

The internal review process was completed following an unstructured interview with project participants. The transcribed interview and details are attached to Appendix H. Participant recommendation and feedback regarding relevant project level concepts are summarised, and categorised into relative study sections:

- Project
- Organisational

- Strategy
- TX/DES
- Template
- General

Table 23: Summarised Internal Interviews

Participant	Category	Recommendation/Feedback
Benefits of TX at a project level		
Participant E	TX/DES	Provides an overview of the production process and throughput analysis.
Participant D	TX/DES	Provides a means for concept analysis, operational analysis, bottleneck identification and analysis, and provides a visual aid for clients of facilities.
Participant B	TX/DES	Aids in bottleneck and operator analysis, production order analysis, and overall system integration analysis.
Participant C	TX/DES	TX at a project level provides output to design as a verification tool, concept evaluation as a decision support tool, and scenario analysis.
Participant D	TX/DES	Presentation of value-adding benefits, case study examples, and key features of TX should be compiled for potential requestors.
Input on the project requesting strategy		
Participant E	Project	Simulations engineers should specify data input requirements and deliverables with the project engineer during the project request phase.
Participant D	Template	Include simulation requirement checklist.
	Strategy	It would benefit design engineers to have sessions with regards to TX to discuss case studies and receive training on data input requirements and potential DES value-adding deliverables.
Feedback on the project reporting template developed		
Participant C	Template	Reporting similar to company FEA/CFD report structure should be followed, including boundary conditions, methods and relevant requirements.
Participant D	Template	The outcome of requirements should drive template reporting.
Feedback on the project deliverables/outcomes provided		
Participant E	Project	Adds value as motivation/support tool.
Participant D	Project	Adds value with detailed production analysis
	General	Of the opinion that Division A is not utilising TX to its full capability yet.
Participant C	Project	ROI/feasibility of concept designs should be included.
Input on the TX strategy development		
Participant C	Strategy	Implementation strategy should be incorporated within the existing design methodology in Division A. Initial implementation phases should include: i. Input and analysis of user specification requirements (URS). ii. Concept design + TX model iii. Detail design (verification) iv. Official working simulation model (digital twin)
	Strategy	TX must be incorporated before the concept design phase, to aid in design input.

	Organisational	The organisational strategy should be linked and developed with ROIs at a project level.
	Strategy	The licensing strategy must continuously be evaluated on company capacity and requirements.
Participant D	Strategy	Should be used as a proactive design support tool, rather than a reactive analysis tool.
	Strategy	ROI examples per case study should be compiled to quantify where the value lies for TX at project level.

4.6 External Reviews

The external reviews were done on the organisational level and strategy development, subjected to all the project samples and voluntary identified participants. This was done in an unstructured interview, following the guidelines set out in Appendix A3. The applicable questionnaires have been referenced in the preceding sections based on the relevant subject matter.

4.6.1 Unstructured Interview

The external review process was also completed following an unstructured interview with external experts. The transcribed interview and details are attached to Appendix I. Participant recommendations and feedback regarding relevant project level concepts are summarised and categorised into relative study sections:

- Project
- Organisational
- Strategy
- TX/DES
- Template
- General

Table 24: Summarised External Interviews

Participant	Category	Recommendation/Feedback
Overview on TX and DES		
Participant F	TX/DES	The biggest factor regarding DES software implementation for any company relates directly to the maturity of the business. Based on the entry of technology at hardware and software level.
	General	After the Covid pandemic, it has become clear to almost all industries that virtual is key to ensure future success and profitability. In the next 10-15 years, most production companies should have virtual modelling/simulation capabilities.
	TX/DES	DES should be used as a proactive strategic tool and not as a reactive tool, to add the most value.

Participant G	TX/DES	TX is utilised more as a gateway and support tool, with the biggest ROI perceived from quick prototyping and greenfield projects, with the following focus points: - Increasing production throughput - Cost reduction - Equipment/process flow analysis - Dynamic variation (scenario) analysis
	Strategy	DES implementation is focused on ROI.
	Project	DES projects benefit design and production-type projects. Design project simulations provide the following benefits: - Material handling analysis and optimisation - Logistics management support - Operational management support - Testing of scenarios for motivation/support - Layout changes
	TX/DES	Another important benefit that DES can provide companies, is a means to simulate extreme measures, e.g. impact of Covid on operations, strikes, export restrictions, etc.
	General	TX provides value to management, operations, logistics and design departments.
	TX/DES	Virtual commissioning escalated the use of this technology with the last year.
TX/DES business requirements		
Participant G	Organisational	The most important factor to keep in mind is the People-Process-Technology barrier. The following aspects are required for DES implementation: - People: Technically proficient people should be in place or available, with a cross-functional team. - Process: Simulation steps and procedures as part of functional operations should be incorporated. - Technology: Hardware/software requirements.
	Strategy	The best practice is to ensure strategic decisions are included as a process from implementation to integration. Change management is of utmost importance regarding new software implementation within companies.
Participant F	Organisational	Identified resource requirement for TX implementation at a company is at least one simulations engineer, who will be a dedicated individual implementing the software at a project level. Preferably an industrial engineer with coding experience.
	Organisational	Mature companies with an implementation strategy in place can benefit from having a 2-5 man simulations team.
	Strategy	Initially, the standard TX license capabilities are sufficient, with development and maturity professional integration can be incorporated.
Strategy development input		
Participant G	Project	The primary data requirement and value-adding simulation are a continuous back-and-forth process.
	Strategy	The best software strategy to follow is with a top-down initiative for production and design support, with quantification of simulations to review the potential measurable success of projects.
	Strategy	With DES, maturity companies should move to simulate closed-loop models and integrate with other PLM systems.

	TX/DES	A standardised modelling approach for TX implementation is the best practice.
Participant F	Strategy	Knowledge transfer is the most important aspect of an implementation strategy.
	Strategy	Building a library of models and incorporating a modular design approach, with object templates will provide the most efficient working practice as more projects are completed. This will lead to reusable models for new projects (automation).
	Strategy	Following a top-down approach, the following implementation method for TX is recommended: i. Start small with a few identified small projects. ii. Prove that the simulations are accurate. iii. Roll out the software within the company. iv. Implement a broad spectrum of project types. v. Construct a blueprint methodology to follow. vi. Implement methodology concurrently and evaluate continuously.
	Project	All simulation projects require data, models, and simulation reviewing.
	TX/DES	Siemens has started providing subscription level licensing support.

4.7 Strategy Development

This section reports on the initial strategy developed and implemented by Division A. The resource capacity, licensing-, training-, phasing-, ROI- and plant simulation strategy to be followed by Division A and project requesting parties follow.

4.7.1 TX Phasing Strategy

The motivation in phasing the overall strategy is to ensure that Company A gets the most out of the solutions and can set up integrated structures, with a staggered licensing adoption. The reason for this is that Company A will not be able to fully utilise the extra integration functions, without setting up the PLM and simulation modelling structures in parallel. The initial TX phasing strategy will be described in the subsequent sections.

<u>Phase 0: Selection & Motivation</u>

This phase formed part of the procurement process of identifying and motivating TX as the preferred software for DES capabilities within Division A and Company A as a whole. A hybrid selection and evaluation methodology were followed in parallel with internal company procurement procedures (Wesch & Hattingh, 2021).

<u>Phase 1: Training & Roll-Out</u>

As mentioned in the preceding chapter, this phase incorporated basic informal training in parallel with identified 'roll-out' projects and advanced outsourced training as part of resource capability evaluation.

Phase 2: Implementation

This phase introduces requested/identified projects and overall implementation strategy development.

**Note that this is the current phase implemented, and is the focus of this research study.*

Phase 3: Resource Integration

This phase will potentially introduce further resource capacity, based on licensing upgrades or procurement of additional licenses within Company A.

Phase 4: PLM Integration

This phase will include the direct integration and development of database link-up with Company A's other PLM systems (Teamcenter and SAP) – based on the successful completion and evaluation of the implementation phase as a separate project when systems are fully set up and operations with the software more experienced.

4.7.2 Future Resource Capacity

The initial resource capacity is outlined in the previous business case section. The future options as part of the strategy development provide potential avenues for Company A to expand and develop capacity further.

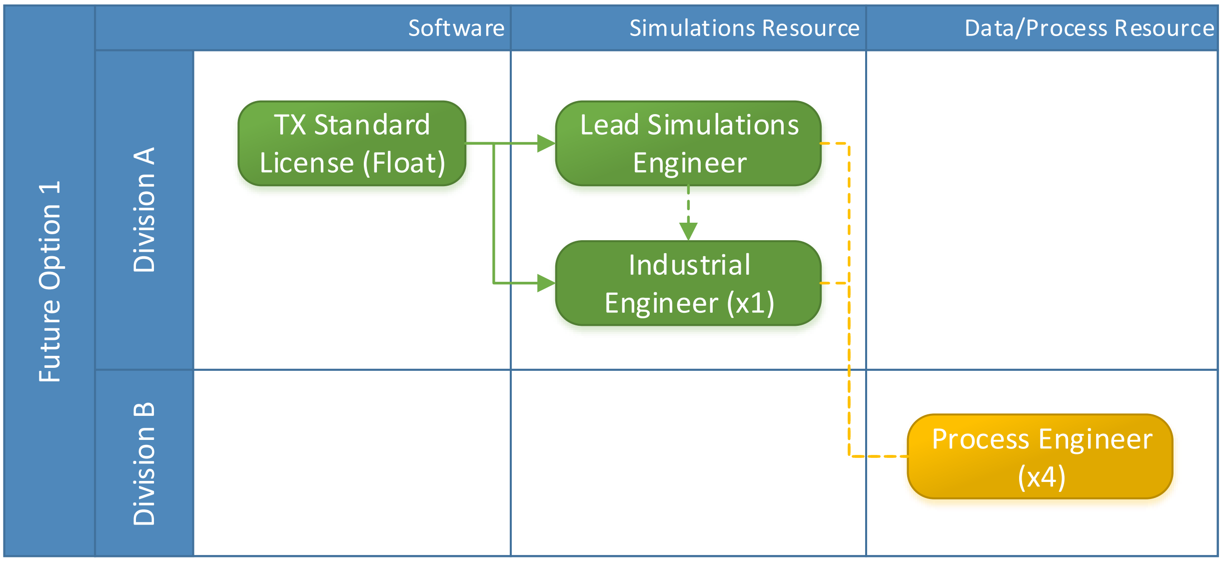

Figure 26: Future resource capacity option #1

The first option as seen in Figure 26 is to potentially upgrade the initial lone fixed license to a floating license. An additional industrial engineer can then be trained and be an additional simulations resource for Division A, reporting to the advanced lead engineer. This option is a relatively low-cost option, with Division A being able to provide design support and production support by Division B.

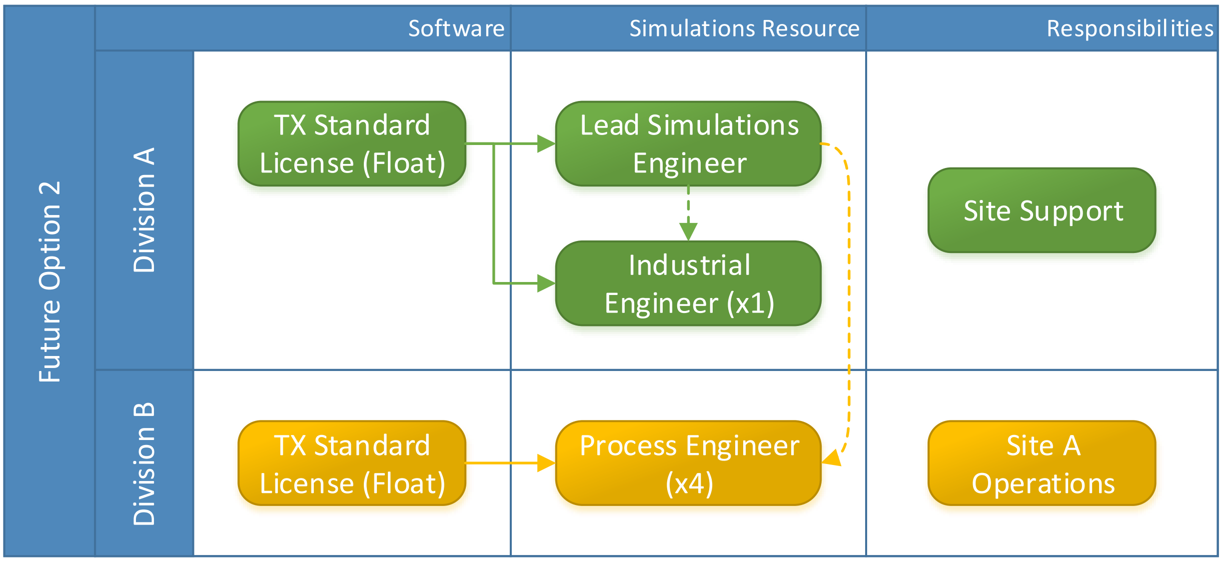

Figure 27: Future resource capacity option #2

The second option as seen in Figure 27 is to potentially upgrade the initial lone fixed license to a floating license and procuring an additional license for Division B (directly responsible for site operations). An additional industrial engineer (Division A) and process engineers (Division B) can then be trained and supported by the advanced lead engineer. This option requires the additional license requirement for Division B but provides a significant increase in simulation resource capacity.

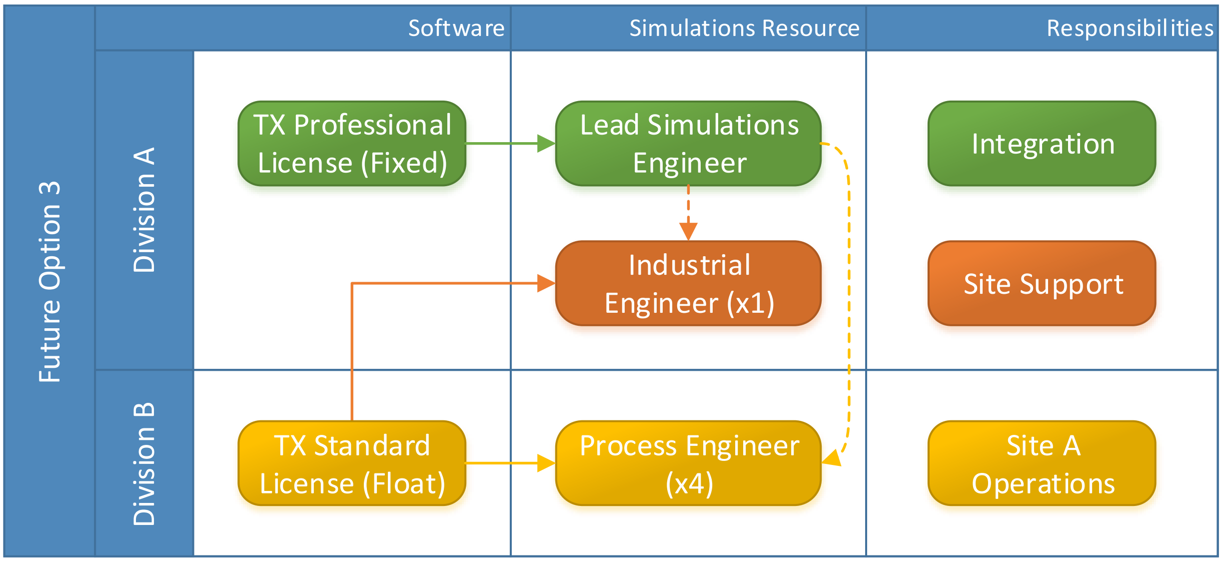

Figure 28: Future resource capacity option #3

The third option as seen in Figure 28 is to potentially upgrade the initial fixed standard license to a professional license for use by the lead simulations engineer, and procuring an additional standard floating license to be utilised between Division A and B. This option is a more high-cost investment requirement than the preceding options, but it does provide further simulations resource capabilities and opens up further capacity, with the lead engineer still acting as a main support thread.

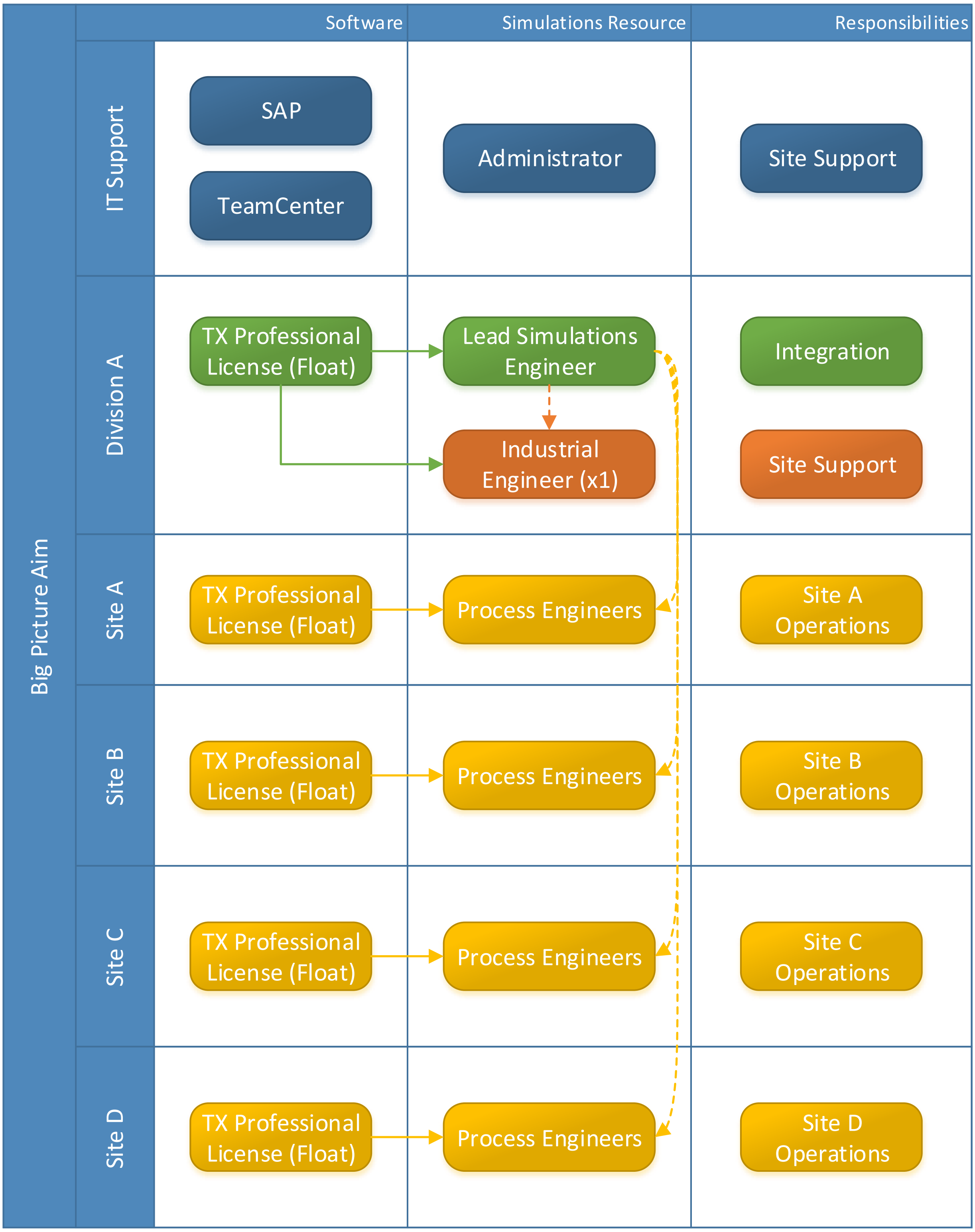

Figure 29: Future resource capacity big picture aim

An additional big picture aim is represented in Figure 29. This option is based on the successful implementation and integration of TX software within Company A, together with other PLM software capabilities. The thinking is that each site within the company should have at least one dedicated simulations engineer, with process engineers utilising the software for production support, with Division A providing additional site support with a focus on design support internally, as well as further integration requirements. Lastly, an IT infrastructure with a dedicated administrator for all PLM software and site support will be a requirement, to ensure effective resource integration.

4.7.3 Software Licensing Strategy

i. Initial Implementation Development:

As indicated in previous sections, a perpetual license is the current TX software license used to set up a baseline modelling and simulation structure within RDM. A 2-3 year rollout and implementation phase will be used to complete identified projects, from where evaluation on ROI and implementation strategy development be completed.

ii. Resource Capacity Integration:

TX license upgrading or additional license subscriptions can potentially benefit the overall phasing strategy, based on resource capacity and requirements.

The perpetual license can be changed to a floating license, to include an additional user (or two) to increase the utilization of the license, based on training and resource capacity identified by Division A.

iii. PLM Integration & Database Development:

Tecnomatix Plant Simulation Professional License will be required for the direct integration and development of database link-up with Company A's PLM system (Teamcenter and SAP).

This will be introduced after successful completion and evaluation of the implementation phase as a separate project when systems are fully set up and operations with the software more experienced. An approximate 3-5 year lead-time is planned to upgrade licensing (trade-in value on Standard License) OR purchase a separate Professional license and keep the Standard license as support, with software suppliers on as phase rollout support. The introduction of annual subscription licensing provides additional potential benefits.

4.7.4 Training Strategy

The training strategy will form part of the overall implementation strategy and identified requirements, identified by Division A.

a) In-House Training:

As part of the Division A support function, basic TX training will be provided to potential users based on licensing and phasing strategy. This training can be done utilising TX trial versions to identify and analyse resource capabilities before further development, without procuring additional licenses.

b) Outsourced Training:

Advanced TX training will be outsourced to Siemens based on requirements and further development of identified users. Note that Siemens is Company A's approved consulting and support supplier and are included as part of the TX implementation strategy.

4.7.5 Return-on-Investment

Division A's expected initial result/outcomes regarding implementation of software, derived from the various project sample feasibility studies, include:

- 2-3 Large modelling projects in the first 12 months with cost planning savings from direct/indirect simulated decision support of 10%, which will be determined on the balance of total project cost and/or 20-30% reduction in planned throughput times and material handling and transport.
- 3-5 Small/Medium projects in the first 12 months with a focus on immediate material/product flow optimisation with aim of 10-20% increase in productivity and utilisation and/or cost reduction planning from reduced waste streams and inventories of 10-20%.
- Other goals include model support for sales/marketing purposes of plant layouts and production simulation; decision support based on simulated analysis with what-if/as-is scenarios; concept and detail design support to analyse the integration of process and systems.
- The confidence on return of initial capital investment on the software is initially set at 12 – 24 months. With ROI on simulation projects being done directly after each project, as well as follow up after 3-6 months to potentially capture indirect impact results.

**Note that with simulation software determining ROI is not always directly quantifiable, with indirect factors being of major value within a whole of a project/process start-to-end phase.*

4.7.6 Plant Simulation Strategy

Division A will follow the following strategy in project acceptance and initiation.

Project Request:

Potential projects can be identified by any individual at any site (with a particular focus on operations and process departments). Project requests require approval by line managers before being requested. The project request must include the following:

i. Background/Problem

A brief description of the subject requiring modelling, problem statement can be included. Any related information to aid in scoping the project as a whole.

ii. Data Inputs

Information that can be provided by the 'requestor' including: processes (including process time; setup times; cycle times; MTTR; OEE; etc.), layouts, CAD models, operators (shifts, responsibilities, etc.), product/part compositions, etc.

'Requestor' should also identify information gaps/constraints known, if possible.

iii. Provisions

Operational provisions that can be made for the simulations engineer, for further data collection (e.g. time studies, Gemba ~ operational tour, etc.)

iv. Outputs/Solution Requirements

The *'answers'* that are required by the 'requestor' including (but are not limited to):

- Process fly-through
- Bottleneck analysis
- Material flow
- Logistical flow
- Utilization & Efficiency

- As-is/What-if scenarios
- Transportation & Material Handling flow/requirements
- Process/Layout/Model Optimization

**Output requirements mainly provide filtered focus on simulating for particular solutions.*

v. Basic Schedule

A basic project timeline requirement needs to be identified – this might be negotiated with project initiation.

**The refined Project Request template is attached to Annex J.*

Project Initiation:

On processing the project request, the project will be filtered and approved by Division A and prioritized and logged with a forecasted lead-time. The 'requestor' will be contacted on lead-time and receive feedback concurrently on project progress.

Thereafter the project will be initiated and the 'requestor' directly contacted to set up a project initiation meeting, from which all of the requirements, inputs and outputs be consolidated.

Project management will be set up by the simulations engineer and will require approval by Division A management, the 'requestor' and line manager of the 'requestor'. This will include provisional requirements, schedule and targets.

Data Collection / Processing:

If required data will be collected statically (existing documents – e.g. daily's; layouts; timesheets) AND/OR dynamically (time studies, Gemba, etc.). Provision needs to be made if on-site collection is required.

Processing of data will also be included in provision to ensure integral data/information on project initiation.

**The refined Plant Simulation Data Input template is attached to Annex K.*

Model Validation & Verification:

i. Current State vs. Static Data

Validation will be done based on a statistical comparison between current state model simulations vs. static collected/processed data with pre-set parameters.

ii. As-is/What-if Scenarios

Models will be simulated in accordance with requirements using pre-set parameters with scenarios being modelled and defined.

iii. Model and Simulation Review & Evaluation

Internal reviews & evaluation on multiple phases of the modelling and simulation process will follow with 'requestor' and/or persons associated with the project.

Project Results:

On approval and acceptance of model in the model validation and verification phase, the results will be provided in the following manner:

Report on output/solution requirements, including diagrams, charts, figures, motivations, etc.

Results meeting – a meeting between stakeholders involved can be scheduled to discuss findings and model in detail.

On completion and acceptance of the results, the Project must be signed-off by Division A management, the 'requestor' and line manager of the 'requestor'.

4.7.7 Organisational Strategy

The organisational strategy provides the integration functionality within the company structure. The following diagram illustrates the initial organisational strategy, for the implementation of TX:

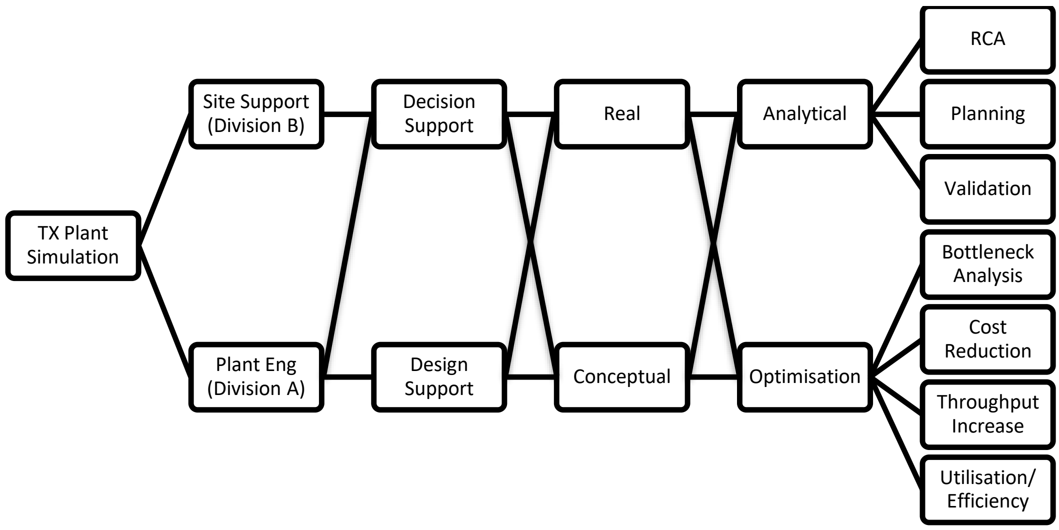

Figure 30: TX Organisational Strategy (Company A)

Figure 30 illustrates the functional support provided to the various organisational sections and the relevant simulation approaches. Initially, TX is supportive of two sections (Division A and B), due to the fact that Division A provides the initial simulation resource to supporting projects. TX is utilised as a decision and design support tool for Division A projects, that have a make-up of Greenfields and Brownfields type projects. Division B, predominantly benefits of site support (decision support) type projects, due to it being projects on existing Company A site facilities/processes. The simulation approaches depend on the project requirements, and is further divided into real (existing) or conceptual type models. Depending on the outcome/objective requirements for the projects, an analytical and/or an optimisation approach can be selected.

The analytical approach typically involves the following scope requirements:

- Root Cause Analysis (RCA)
- Planning (Logistical)
- Validation (Scenarios).

With the optimisation approach typically involving, the following points of value:

- Bottleneck Analysis
- Cost Reduction
- Throughput Increase
- Utilisation/Efficiency Analysis.

4.7.8 Strategy Validation

Final validation of the strategy was obtained by applying the strategy and abstracting relevant project and business case data, which will fit specific company models as limited by the case study.

A summarised strategy approach was developed, due to the sheer volume of information that has been collected. The strategic approach is summarised via a phased flow diagram (Figure 31), to provide a holistic overview of the research case study.

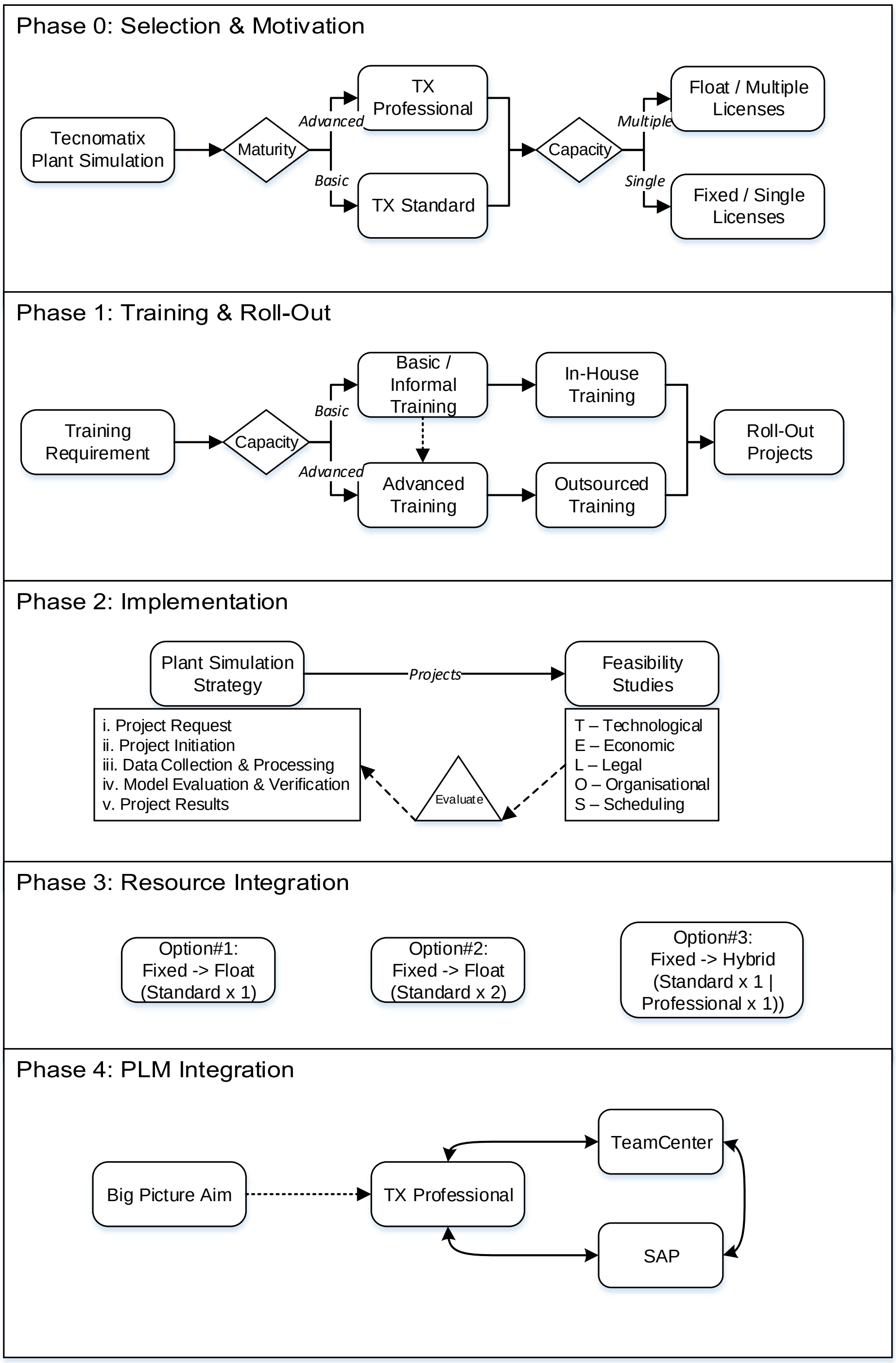

Figure 31: Implementation Approach Overview Process Flow Diagram

Phase 0 initiates from the hybrid evaluation and selection methodology (Wesch & Hattingh, 2021) as background to the strategy. The selection and motivation on the selected software and license type are based on the company maturity concerning hardware, software and resource capacity.

Phase 1 includes the training requirements for the identified software user(s) and rollout projects, to aid with a more structured implementation plan. Training is subject to the user(s) programming and simulations capacity and development requirements. Rollout projects are project types, which is not in line with critical company requirements and that aid in user development and training with the software.

Phase 2 introduces the implementation of TX at a project level. The projects are requested/identified as potential value-adding type projects, with a focus on varying deliverable requirements to build an initial modelling library. These projects are evaluated in parallel following detailed feasibility studies, to quantify and identify value implemented through simulations.

Phase 3 will introduce the next facet of the implementation strategy, to further develop simulation structures within the company. Multiple initial options are identified in this research case but will be dependent on varying company capacity and requirements.

Phase 4 is the big picture aim, which is to develop simulation structures that can be integrated with other existing company PLM systems. This includes TeamCenter and SAP that is also implemented at Company A, in parallel with the implementation of TX. The simulation team and operational user(s) will then be identified, trained and assisted within a structured manner, including templates, initial libraries, and methodologies/procedures to follow.

CHAPTER 5: DISCUSSION

This chapter not only discusses the content presented in Chapter 4 but also considers the research in its entirety. The discussion uses the results from the preceding chapter as a starting point for further exploration into the implications of the results and the overall value of the research. The chapter is divided into 6 sections, which explore different elements of the dissertation to reduce confusion and increase ease of reading. The sections cover the critical components of the research study and provide a holistic overview of the case study as a whole.

5.1 Research Question & Objectives Alignment

This section references the objectives achieved in this case study, based on the results compiled and analysed in the previous Chapter. As well as the answering of the primary research question – *what practical strategy can be followed for successful TX software implementation within a manufacturing/production industry at a project and organisational level?*

The primary objective was to develop an implementation strategy, with an initial design guided by theory. This was achieved by developing initial project and organisational components, based on existing research and frameworks. The project level was developed based on VDI-3633 guidelines; following Bangsow (2010 & 2015) derived components. The organisational level was developed and divided into three sections, including the evaluation and selection of the software (Wesch & Hattingh, 2021), the organisational components (derived from Siemens' approach), and the relating project feasibility studies. The strategy was developed concurrently following the ADR approach. With the artefact comprising of practical TX software implementation guidelines; developed templates and secondary sources; and referable project case samples.

The second objective was to quantify the feasibility of the project cases and TX implementation, based on project input and output requirements. This was achieved by following the TELOS model for each project sample, from which a reusable template was developed (see 4.4.3 Feasibility Studies). Initial ROI targets were also compiled based on the project samples and other referenced case studies, compiled by Siemens (2009).

The third objective was to provide guidelines to ensure sufficient TX utilisation and functionality as a company support tool. This was achieved by compiling project implementation guidelines (see 4.7.6 Plant Simulation Strategy), as well as a phased business approach (see 4.7.7 Summarised Strategy Approach).

The final objective is to verify/validate the modular project and organisational components with identified stakeholders, to ensure a practical and viable strategy was developed. This was achieved through internal and external reviews, subject to all phases of the implemented strategy.

**Alignment of the research objectives and developed artefact is also referred to in the artefact review section.*

5.2 Literature Review

As referenced in Chapter 2, the literature review suggests the importance of simulation software implementation at both a project and organisational level, and provides a basis and context for further exploration and development. Literature on the implementation of TX, incorporating both levels is scarce and a clear gap in current literature is evident. This converges with the selected ADR method's first stage: problem formulation, where a research opportunity based on existing theories and technologies was identified and conceptualised. This stage comprises of two principles: practice-inspired research and theory-ingrained artefact, which is referenced in more detail in Chapter 3.

5.3 Significance & Implications of the Study

The significance of this study is in its effort to bridge the identified 'gap' in research. Providing a developed artefact, comprising a holistic implementation strategy at a project and organisational level. The referenced project samples provide evidence on the viability of the implemented strategy, as well as providing a baseline for further evaluation and development.

The research study also looks at why it is important to include an implementation strategy, at both an organisational and project level. This is covered in the first two chapters, in which it is evident that the ROI for DES type software can only be achieved by successfully implementing the software within the specific company.

The implications of this research study will be of benefit to multiple individuals and companies looking into the potential implementation and incorporation of TX, from the selection phase, up to integration at a high level with other systems in a company. This case study lends itself as not only a practical solution to follow from software roll-out to day-to-day operational use, but also as a holistic strategy that can be used as a reference for further research for multiple types of DES software.

5.4 Limitations of the Study

The limitations of the study revolve around the organisational components. This is primarily due to the development and implementation of the strategy being completed at one company (Company A). The implications thereof were that the phased strategy developed in this study, was implemented in a constrained company environment. Further limitations included the verification and reliability analysis of the organisational options referenced in Chapter 4. This was however not within the research scope identified for study, but included to provide a holistic strategy for further development.

5.5 Validity, Reliability & Verification of the Study

In order to comply with case study generalisation, rigour/validity and reliability requirements, the following components were covered as part of the research method (refer to section 3.4). In terms of construct validity, multiple project samples were compiled with the researcher acting as the main participant-observer, including a chain of evidence. Internal validity was achieved through internal project sample reviews, including unstructured project participant interviews and questionnaires. External validity was achieved through a constructed case study protocol (referenced in Chapter 3), and external feasibility and strategy reviews, including unstructured expert participant interviews and questionnaires. The reliability of the research was achieved through constructing a reviewed case study database, which can be accessed on request.

5.6 Artefact Review

5.6.1 Secondary Sources

The relevant developed and referenced secondary sources are compiled in this section. *This is done to develop an implementation strategy from interaction with the organisational context, with an initial design guided by theory.*

The research regarding the implementation of TX software was developed in parallel with referenced secondary sources. The training and strategy development at project level was completed by following Bangsow's books, relating to TX modelling and simulating techniques, titled:

- Manufacturing Simulation with Plant Simulation and SimTalk, usage and programming with examples and solutions (Bangsow, 2010), and
- Tecnomatix Plant Simulation, modelling and programming by means of examples (Bangsow, 2015).

These two secondary sources are very important regarding the research because it provides a source of reference for informal software training, which individuals can follow to be able to complete a basic level of training in TX. It also provided the guideline reference for the project component requirements, in line with strategy development for this research study as a whole.

The case study background covers the fundamental construction on the evaluation and selection of TX, as the motivated and selected DES software. The following reference documents provide a research outline:

- Company A: DES Software Scope of Requirement (CompanyA-SOR-001, 2018).
- A hybrid selection and evaluation methodology for DES software (Wesch & Hattingh, 2021).
- TX motivation summary (CompanyA-MS-002, 2018).

These secondary sources provide the initial stepping-stone to the research and provide a baseline from where the implementation strategy is based on. The methodology and criteria covered in these documents also aid as a valuable reference, for the selection and evaluation of other DES software types for varying environments.

The implementation strategy developed as part of this research was compiled within an internal company reference document. This document provides a means to communicate the developed strategy components in a formal document, as part of change management requirements. The developed strategy is referenced within the following document:

- Division A Plant Simulation Strategy (CompanyA-PSS-003, 2021).

The developed simulation project request and data input templates are also important value-adding secondary sources to the research, at a project level. The refined request form template is attached as Appendix J, with the refined process data input form template attached as Appendix K.

5.6.2 Project Samples

The project samples provided valuable comparative analysis for the research at a project level. The project components are divided into 6 sections, with varying results obtained and analysed for each section.

i. <u>Request / Identification:</u>

The questionnaire regarding the project request template form provided valuable feedback in an attempt to develop an effective and understandable template. The average feedback scoring on the content and format of the initial compiled template was good to very good. This meant that the initial document was understandable and effective in its purpose. Additional feedback however provided points of value for additional inclusions, to further develop and refine the request template. This included the addition of a DES deliverable requirement checklist, existing/new facility/process selection box, business impact and business cost indication sections, and timeline inclusion from request to completion.

ii. Data Collection:

The survey regarding the data input template form also provided valuable feedback in an attempt to develop an effective and understandable template. The average feedback scoring on the content and format of the initial compiled template was average. This meant that the initial document was an acceptable baseline to work from, but that there were some shortcomings requiring addressing. Inclusions and changes were made to the initial template, based on the feedback provided. This included a more descriptive section on the use of the document and an indication of the responsibility regarding data input by the requestor and simulation engineer. The varying data sections were also converted into separate sheets, for ease of use and readability.

iii. Data Processing:

The processing of the data was divided into 3 sections, in an attempt to identify where value is added for varying model and simulation project data requirements. The first section logged includes the data available on Project Request/Initiation. The main takeaway analysed is that failure data and resource allocation data was not available, with material flow data, facility strategy, and job data being rarely available on initiation.

The second section indicates the data obtained via processing and reviewing of raw data sets or via collection methods, by the simulation engineer. Here the most data were obtained with design support type projects. This lends to the fact that design support type projects are on new facility designs, which do not have existing datasets. Thus, reviewing datasets of similar facilities/processes by the simulation engineer tends to provide baseline datasets to be used for modelling and simulating the projects.

The third section included provides the most interesting takeaway for data processing requirements. This included data obtained on design reviews of varying model/simulation revisions, with assumption datasets included at points not known. This technique provided the most effective means of obtaining and identifying datasets for all the project types. This is because the simulation engineer not only identifies the main data requirements as the model/simulation is built, but it also provides an easier and more intuitive mean of illustrating data requirements to project stakeholders.

iv. Modelling & Simulations:

The modelling and simulating of the varying projects provided little trend regarding the number of simulated data outputs and model revisions. The amount of TX revisions is directly proportional to the complexity of the project, the number of design reviews, and overall simulation deliverable requirements. The most value retrieved from this section is regarding the example modelling structures and building blocks, which aids in internal library construction and the simulation methodology published per sample case. These sample sets can be utilised as sub-set case study references at a project level per type and constructed components.

v. Validation / Verification:

The project sample validation and verification per model/simulation and the relevant datasets provide an analytical reference per project requirement. This can be seen in the fact that almost all of the project samples were verified using historical data sets as a reference, and validated by project stakeholders based on design reviews per project. The only exception was with the large design support project (Project #1); an additional expert review was required to validate certain data sets and programming requirements. Project #5 was the only project sample that could be validated in line with concurrent process data with the implementation of the real system. There is thus no trend to analyse or discuss regarding these analysis types.

vi. Reporting:

Although the reporting regarding the required simulation deliverables/outputs vary per project sample, some important results provide a good reference for future project types. The average feedback scoring regarding the reporting of the various samples was good to very good. This indicates that the reporting structure and format was effective for the purpose based on the different project requirements. Valuable feedback from project participants did however point out that worksheets and model build history would be an additional contribution as part of a formal company structure document. This will provide a standard mean of simulation reporting, irrespective of the requirements.

5.6.3 Organisational Components

As referenced earlier in the study, the organisational components are relevant to the individual project cases, and strategy development as a whole, and logged by the lead author as a participant-observer. *This is to provide guidelines to ensure sufficient TX utilisation and functionality as a company support tool.* This section is divided into three sections, including the selection and evaluation of the software, the organisational components, and the relating project feasibility studies.

The important variant that will affect different companies is based on the background evaluation and selection of DES type software. Although the implementation strategy will still provide a good reference to work from, this research case study revolves around TX. The referred hybrid selection and evaluation methodology followed by Wesch & Hattingh (2021), will be a great starting point for any new company or user looking at potentially procuring DES software, dedicated to production process simulations.

The resulting organisational components provide substantial reference data, which will be beneficial for all simulation users. The content and processing of these components might differ depending on the case study, but it will provide a baseline reference for future research or implementation of the developed strategy.

The most critical organisational component relating to DES implementation revolves around the feasibility studies per project sample. This is a very important evaluator tool in order to analyse benefits and ROI concurrently per project type, as part of the implementation strategy going forward.

The feasibility studies concluded in Chapter 4 for this case study provided valuable insight and references in line with the strategy development. *This is done to quantify the feasibility of project cases and TX implementation, based on project input and output requirements.* Project #1, which was the large design support type project, provided the biggest average throughput increase (20-30%) and average cost savings (R1.6m p.a. for a specific scenario). This was however achieved due to the complexity and size of Project#1, and the fact that the most time was also spent in the modelling/simulation phase in relation to the other medium and small type projects. The interesting statistic that can be observed from the other small and medium type projects is that the analysed average throughput increase was between 10-20%. The main advantage with smaller type projects (not as complex and timeous as large types), provide relatively good results and is completed in a shorter time. It should however be noted that Project#1 provided a lot of input to the modelling/simulating library, as well as acting as a roll-out project utilised as training in the software. This in turn provided inherent benefits to the other projects. The other value-added outputs achieved included:

- Layout development in line with design work.

- Graphical aid and simulated reference data for material handling and operational throughput concept to the client.
- Line balancing development.
- Equipment quantity effects and operational buffer analysis.

The compiled feasibility study template was also scored by an external reviewing panel, to develop a suitable and effective template. The average feedback scoring regarding the initial feasibility study template was good. This meant that the template achieved its purpose and was acceptable, but that there was room for improvement. The most value-adding feedback, that was retrieved to include in the project feasibility studies, included the addition of a flow diagram as well as a graphical display of comparing scenario results. The other inclusion is to add notes in the worksheets to describe sections and abbreviations to the readers.

5.6.4 Internal Reviews

The internal review process was completed following an unstructured interview with project participants. The interviews provided valuable data on feedback from project participants. This not only aided in the strategy development as part of this case study but also provides very valuable raw data and references for future research on the topic.

5.6.5 External Reviews

The external review process was similarly completed by following an unstructured interview with external experts. This provided outsider analysis to the case study, which was a vital contribution to data triangulation and research analysis. The interviews also provided valuable raw data and feedback from software experts, which will benefit future research on the topic.

5.6.6 Strategy Development

The funnelling point of this research study was to develop an overall methodology, including a holistic organisational strategy and project guidelines on implementing TX software within a company. This was achieved through providing an initial resource capacity, licensing-, training-, phasing-, ROI- and plant simulation strategy to be followed by Division A and project requesting parties. This methodology provides the most valuable reference to potential new user(s) of TX, as well as provide a stepping-stone for companies looking to potentially incorporate DES type software in the future.

CHAPTER 6: CONCLUSION, RECOMMENDATIONS AND GENERAL OBSERVATIONS

This chapter presents the conclusions of the research as well as general observations and recommendations for future research. The conclusions compiled is in line with the overall research aims.

6.1 Conclusion

In light of the results presented in the preceding chapter, the following conclusions can be made:

1. The secondary sources referenced in this research study provide a valuable role by adding value and creating base platforms for the following:
   - Evaluation & Selection methodology to select the most appropriate DES type software (three internal documents compiled).
   - TX handbooks for informal software training and project rollout support (two handbooks by Steffen Bangsow).
   - Developed implementation strategy reference based on a case study, including project request and data input form templates (three internal documents compiled).
2. The project samples provide valuable reference results regarding the implementation of TX at a project level, for various site and design support type projects. The following are some of the main conclusions regarding the various project steps:
   - Request/Identification – A project request template together with data collection requirements were developed based on feedback and reviews.
   - Data Collection – This is one of the most important, but inherently difficult steps regarding successful simulation project implementation. The most important conclusion made is that data should be processed according to requirements and collection, prior to constructing the model/simulation. However, a lot of value and verification on data processing lies in concurrent data and design reviews with project stakeholders. This is done to obtain additional data and aid with further project scoping, to get the most value out of the simulations.
   - Modelling & Simulations – This step is very dependent on the capacity and preference of the simulation engineer in charge of developing and analysing the simulation model. The most value is retrieved after a few different projects have been developed, in terms of model library building and development.
   - Validation/Verification – It was notable that almost all project samples were validated using historical data sets and validated by project stakeholders based on

design reviews. This is an important step in simulation type projects, to ensure validity and be able to identify value in project samples.

  - Reporting – This is also a very important step, which is sometimes ignored by simulation engineers. It is vital to develop set standards for documentation for varying simulation requirements. This is to ensure that future project referencing and development will be possible.

3. The resulting organisational components provide substantial reference data, in the form of feasibility studies per project sample and company case component development. The content and processing of these components might differ depending on the case study environment and requirements, but it will provide a baseline reference for future implementation research on the developed strategy for most simulation users.
4. It can also be concluded from the summarised project sample feasibility studies, that irrespective of the project type or complexity – that there is a relative throughput increase and cost savings resulting from various scenario simulations. With an average of 10-20% throughput increase and in some cases, savings calculated of more than 20% in relation to budgeted costing. This is on top of other inherent benefits resulting in parallel, following the developed methodology.
5. The internal project participant and external 'expert' reviews provided valuable data in developing and analysing the implementation strategy at both a project and organisational level.
6. The primary aim of this research study was to develop a referable and holistic implementation strategy to follow for DES type software, and in this case study – Tecnomatix Plant Simulation. This has been achieved and the compiled simulation strategy and summarised approach provide an easy and efficient reference to follow for any new DES user(s). This methodology thus achieves the purpose of the study to provide a useable and referencing strategy that can be used in multiple ways.

6.2 Recommendations & General Observations

It is suggested that in order to further the results of the study the following aspects should be considered regarding the design of the study:

1. Due to the non-probabilistic sampling method used in acquiring the internal and external interview data, there is no true way of identifying the extent to which the sample represents the most valuable or important references. Therefore, the conclusions made in this study cannot be directly applied to all companies and more research should be conducted into identifying samples that more accurately represents the population.

2. Another concern is the fact that the project samples selected in this research study, are too varying in type and more representations of the case study environment and effects, than the project steps applied through the implementation methodology. It is suggested for future studies, that multiple of the same type of project requirements are implemented. This will potentially eliminate variation and allow for a clearer view of the project steps implications and comparable value.
3. Due to the scale and size of the research study, and with the focus surrounding developing an appropriate and effective implementation strategy. It is recommended that the case study be replicated to a degree using the strategy developed in this study as a primary reference.
4. It is also recommended that the number of project samples be increased, for further data collection to verify and validate the research samples.
5. Organisational components will vary case-by-case and it would benefit future research in the field to obtain further data based on different case studies following a similar implementation approach.
6. It is recommended that the evaluation and selection phase be incorporated with the implementation strategy, seeing as this has an influential effect on the organisational strategy as a whole.
7. It is lastly suggested that further exploration be conducted into the impact of different company capacities and maturity levels, on implementing DES type software using a similar implementation strategy.

REFERENCES

Anylogic. (2017). Simulation Software Comparison. *The Biannual Survey*. OR/MS Today Magazine.

Babulak, E., & Wang, M. (2010). Discrete Event Simulation: State of the Art. In A. Goti, *Discrete Event Simulations.* InTech.

Bangsow, S. (2010). *Manufacturing Simulation with Plant Simulation and SimTalk.* Berlin: Springer.

Bangsow, S. (2015). *Tecnomatix Plant Simulation.* Switzerland: Springer.

Bhatti, T. (2009). An Integrated Model For The Implementation of ERP. *CONF-IRM Proceedings 48.* AISeL.

Booth, W. C., Colomb, G. G., & Williams, J. M. (2003). *The Craft of Research (2nd edition).* Chicago: The University of Chicago Press.

Burns, R. B. (1997). *Introduction to Research Methods (2nd edition).* Melbourne: Longman Cheshire.

Chang, H. H. (2000). The Implementation and Integration of Information Systems for Production Management in Manufacturing: an Empirical Study. *International Journal of Computer Integrated Manufacturing, Vol. 13*, 369-387.

Creswell, J. W. (2014). *Research Design, Qualitative, Quantitative, and Mixed Methods Approaches (4th ed).* California, US: Sage Publications.

Critical Manufacturing. (2014). Simulators Comparison. *Critical Manufacturing, Simulators Comparison*. South Africa: Critical Manufacturing.

Fil'o, Markovic, Kliment, & Trebuna. (2013). PLM systems and Tecnomatix Plant Simulation, a description of the environment, control elements, creation simulations and models. *American Journal of Mechanical Engineering*, 165-168.

Gilbert, N. (2008). *Researching Social Life (3rd edition).* London: SAGE Publications.

Gregor, S., & Iivari, J. (2007). Designing for Mutability in Information Systems Artifacts. In D. Hart, & G. S. (eds.), *Information Systems Foundations: Theory, Representation and Reliability* (pp. 13-24). Canberra: ANU Press.

Grinnell, R. J. (1981). *Social Work Research and Evaluation.* Itasca, IL: F.E. Peacock.

Gupta, A. D. (2014). How to Select A Simulation Software. *International Journal of Engineering Research and Development*, 35-41.

Hall, J. A. (2008). *Accounting Information Systems, 6th Edition.* Mason, OH: Rob Dewey.

Hamel, J., Dufour, S., & and Fortin, D. (1993). *Case Study Methods.* Newbury Park, CA: Sage Publications.

Hanseth, O., & Monteiro, E. (1997). Inscribing Behavior in Information Infrastructure Standards. *Accounting, Management & Information Technologies Vol. 7 no. 4*, 193-211.

Hevner, A., March, S., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly Vol. 28 No. 1*, 75-105.

Hlupic, V. (1997). *Simulation Selection Using SimSelect.* Uxbridge, U.K.: Brunell University.

Ho, C.-F. (1993). Information Technology Implementation Strategies for Manufacturing Organizations: A Strategic Alignment Approach. *PACIS Proceedings 40* (pp. 219-226). AISeL.

Issa, A., & Abu Rub, F. (2007). Performing Early Feasibility Studies of Software Development Projects Using Business Process Models. *Proceedings of the World Congress on Engineering 2007 Vol I.* London, UK: WCE.

Issa, A., Odeh, M., & Coward, D. (2006). Software Cost Estimation Using Use-Case Models. *Proceedings of the 2nd IEEE International Conference on Information and Communication Technology* (pp. 1-6). Damascus, Syria: From Theory To Applications.

Jägstam, & Klingstam. (2002). A handbook for integrating discrete event simulation as an aid in conceptual design of manufacturing systems. *Winter Simulation Conference* (pp. 1940-1944). ResearchGate.

Jebreen, I., Wellington, R., & MacDonell, S. (2013). Understanding Feasibility Study Approach for Packaged Software Implementation by SMEs. *22nd International Conference on Information System Development.* Seville, Spain: AUT University.

Jena, S. (2020, June 26). *Types of Feasibility Study in Software Project Development.* Retrieved from GeeksforGeeks: https://www.geeksforgeeks.org/types-of-feasibility-study-in-software-project-development/

Kampa, Golda, & Paprocka. (2017). Discrete event simulation method as a tool for improvement of manufacturing systems. *MDPI Computers*, 1-12.

Karner, G. (1993). *Resource Estimation for Objectory Projects.* Objectory Systems.

Kaufman, C. (2007). A Project Management Office (PMO) Framework for Successful Implementation of Information Technology Projects. *Proceedings of the Academy of Information and Management Sciences, Vol. 11.* Jacksonville.

Kikolski, M. (2016). Identification of production bottlenecks with the use of Plant Simulation software. *Economics and Management*, 103-112.

Kliment, Popovic, & Janek. (2014). Analysis of the production process in the selected company and proposal of a possible model optimization through PLM software module Tecnomatix Plant Simulation. *Procedia Engineering 96*, 221-226.

Kuang, L., & Gao, J. (2006). Development of An Information System Integration Framework for the Manufacturing Business. *Proceedings of the 6th WSEAS International Conference on Robotics, Control and Manufacturing Technology* (pp. 119-124). Hangzhou, China: ResearchGate.

Kumar, R. (2011). *Research Methodology, a step-by-step guide for beginners (3rd edition).* London: SAGE Publications.

Maidstone, R. (2012, March). *Discrete Event Simulation, System Dynamics and Agent Based Simulation: Discussion and Comparison.* The University of Manchester: ResearchGate.

Markus, M., Majchrzak, A., & Gasser, L. (2002). A Design Theory for Systems That Support Emergent Knowledge Processes. *MIS Quarterly Vol. 26 No. 3*, 179-212.

Mathiassen, L. (2002). Collaborative Practice Research. *Information Technology & People Vol. 15 No. 4*, 321-345.

McDonough, J. a. (1997). *Research Methods for English Language Teachers.* London: Arnold.

Musil, Laskovsky, & Fialek. (2016). Analysis of logistic processes using the software Tecnomatix Plant Simulation. *International Conference of Industrial Logistics*, (pp. 195-200). Zakopane, Poland.

Nikoukaran, J., Hlupic, V., & Paul, R. (1999). *A hierarchical framework for evaluating simulation software, Department of Infromation SYstems and Computing.* Uxbridge, U.K.: Brunel University.

Orlikowski, W., & Iacono, C. (2001). Research Commentary: Desperately Seeking the 'IT' in IT Research - A Call to Theorising the IT Artifact. *Information Systems Research Vol. 12 No. 2*, 121-134.

Participant_A, Participant_B, Participant_C, Participant_D, & Participant_E. (2021, March 5). Internal Reviews - Project Samples. (J. Wesch, Interviewer)

Participant_F, & Participant_G. (2021, March 10). External Review - Siemens. (J. Wesch, Interviewer)

Raciti, A. (2016). *Is there a relationship between TQM practices and service quality in the restaurant industry?* Johannesburg: University of the Witwatersrand.

Randell, L. (2002). *On Discrete-Event Simulation and Integration in the Manufacturing System Development Process.* Lund, Sweden: Lund University.

Raza, M., Sivakumar, S., Nafarieh, A., & Robertson, B. (2014). A Comparison of Software Defined Network (SDN) Implementation Strategies. *Procedia Computer Science 32* (pp. 1050-1055). Elsevier B.V.

Remenyi, D., & Sherwood-Smith, M. (1999). Maximize Information Systems Value by Continuous Participative Evaluation. *Logistics Information Management Vol. 12 No. 1*, 14-31.

Rosemann, M., & Vessey, I. (2008). Toward Improving the Relevance of Information Systems Research to Practice: The Role of Applicability Checks. *MIS Quarterly Vol. 32 No. 1*, 1-22.

Rowley, J. (2002). Using Case Studies in Research. *Management Research News (vol.25 no.1)*, 16-27.

Rudy, L. J. (2014, June 25). *Can We Really Do It? How to Conduct a TELOS Feasibility Study.* Retrieved from Envato Tuts+: https://business.tutsplus.com/articles/can-we-really-do-it-how-to-conduct-a-telos-feasibility-study--cms-21442

Sein, M., Henfridsson, O., Purao, S., Rossi, M., & Lindgren, R. (2011). Action Design Research. *MIS Quarterly Vol. 35 No. 1*, 37-55.

Sharma, P. (2015). Discrete-Event Simulation. *International Journal of Scientific & Technology Research Volume 4, Issue 04*, 136-140.

Siderska, J. (2016). Application of Tecnomatix Plant Simulation for modeling production and logistics processes. *Business, Management and Education*, 64-73.

Siemens. (2009). Plant Simulation ROI. Siemens Product Lifecycle Management Software Inc.

Siemens. (2020, July 28). *Products: Tecnomatix*. Retrieved from Siemens PLM Automation: https://www.plm.automation.siemens.com/global/en/products/tecnomatix/#lightview-closes/

Siemens PLM Software Inc. (2012). *Siemens PLM Licensing User Guide.* Siemens AG.

Siemens PLM Software Inc. (2017). *Plant Simulation Step-By-Step ENU.* Siemens.

Techopedia. (2020). *Techopedia, Feasibility Study*. Retrieved from Techopedia: https://www.techopedia.com/definition/19297/feasibility-study

Tellis, W. (1997). Introduction to Case Study. *The Qualitative Report. Retrieved from https://nsuworks.nova.edu/tqr/vol3/iss2/4*, 3(2), 1-14. Retrieved from The Qualitative Report, 3(2).

Tewoldeberhan, Verbraeck, Valentin, & Bardonnet. (2002). An evaluation and selection methodology for discrete-event simulation. *Winter Simulation Conference* (pp. 67-75). ResearchGate.

VDI-Richtlininie 3633 Blatt 1. (2000). *Simulation von Logistik-, Materialfluss- und Produktionssystemen, Grundlagen.* Grundruck Beuth, Berlin: VDI-Handbuch Materialfluss und Fordertechnick.

Walls, J., Widmeyer, G., & El Sawy, O. (1992). Building and Information Systems Design Theory for Vigilant EIS. *Information Systems Research Vol. 3 No. 1*, 36-59.

Wesch, J. O. (2021). A case study on an implementation strategy for Tecnomatix Plant Simulation software. *Submitted to the 2021 Winter Simulation Conference.* Phoenix, AZ: WSC.

Wesch, J. O., & Hattingh, T. S. (2021). A Case Study on a Hybrid Selection & Evaluation Strategy for DES Software. *Submitted to SAIIE32 Conference.* RSA: SAIIE.

Wikipedia. (2021, June 25). *Plant Simulation*. Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Plant_Simulation

Yin, R. (1984). *Case Study Research: Design and Methods.* Beverly Hills: Sage Publications.

Yin, R. (1994). *Case Study Research: Design and Methods (2nd ed.).* Beverly Hills: Sage Publishing.

Zainal, Z. (2007). Case study as a research method. *Jurnal Kemanusiaan bil.9*.

APPENDIX A: DATA COLLECTION TOOL

A1 – Template Questionnaire

Project Request Form | Data Input Form | Project Report | Feasibility Study:

1. The form was readable/understandable.

Very Poor	Poor	Average	Good	Very Good

2. There was sufficient writing/editing space.

Very Poor	Poor	Average	Good	Very Good

3. Sections were well defined/described.

Very Poor	Poor	Average	Good	Very Good

4. The purpose/reason for completing the form was understood.

Very Poor	Poor	Average	Good	Very Good

5. The number of sections was elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good	Very Good

6. The relevancy of the sections applied to the project.

Very Poor	Poor	Average	Good	Very Good

7. Please provide any feedback concerning the structure of the form (editing).

____

____

____

8. Please provide any feedback concerning the content of the form (structure).

____

____

____

9. Please provide any general feedback/notes regarding the form.

____

____

____

A2 – Unstructured Project Interview guidelines for Internal Reviews

**This will be done with project participants (RDM) in order to gain qualitative information regarding the Tecnomatix Plant Simulation Project strategy.*

The following guideline points will be followed as a baseline for the unstructured interviews for internal reviews based on the selected project samples:

1. Feedback/response regarding overall strategy and project development.
2. Feedback/response regarding project request strategy.
3. Feedback/response regarding project data collection & processing strategy.
4. Feedback/response regarding model & simulation development process.
5. Feedback/response regarding project validation/verification process.
6. Feedback/response regarding project reporting and deliverables/outputs.
7. Personal feedback/response regarding TX implementation at a project level.

A3 – Unstructured Project Interview guidelines for External Reviews

**This section will be completed by a simulation engineer (lead author as participant-observer), with external software support (Siemens) review.*

The organisational level analysis is based on project feasibility studies and organisational components. The following guideline points will be followed as a baseline for the unstructured interviews for external review:

1. Feedback/response regarding overall strategy development.
2. Feedback/response regarding current simulations capacity and future requirements (based on TX simulation capabilities and resources).
3. Feedback/response regarding current software licensing and future requirements (based on company requirements and development).
4. Feedback/response regarding training on TX and future requirements (based on capacity and development).
5. Feedback/response regarding phasing of organisational and project components relative to TX implementation strategy development.
6. Feedback/response regarding perceived ROI per project (based on feasibility studies).
7. Personal feedback/response regarding TX implementation strategy at an organisational level.

A4 – Preliminary Project level analysis guidelines

**This will be done by a simulation engineer (lead author) per project, with internal project participant reviews.*

The project level analysis is based on all components/factors as part of the overall project strategy development, important factors to focus on include:

- Project scheduling and prioritisation
- Accuracy and sufficiency of data
- Data gathering methods (input, time studies, historical, etc.)
- Output/deliverables achieved
- Validity/verification process
- General feedback concerning the strategy as a whole.

A5 – Preliminary Organisational level analysis guidelines

**This section will be completed by a simulation engineer (lead author) per project, with external software support (Siemens Digital Solutions) review.*

The organisational level analysis is based on project output/deliverable processing and business strategy, important factors to focus on include:

- Project deliverables/output analysis
- Quantification (throughput, utilization, flow, costs, etc.)
- Project ROI calculation
- Organisational capacity, licensing, training strategy

General feedback concerning the strategy as a whole.

APPENDIX B: INITIAL PROJECT REQUEST TEMPLATE

Project: ______________________________

Requestor: ______________________________

Department: ______________________________

Line Manager: ______________________________

Project Background (Give a brief description of the project):

____

____

____

____

____

Support Request (Brief description of requirement.):

____

____

____

____

____

Priority:

LOW	*AVG*	*HIGH*

Lead Time (e.g. 1 week/ 2 weeks/ 1 month/ etc.):

____

______________________ ______________________

(Requestor) *(Line Manager)*

APPENDIX C: INITIAL PROCESS DATA INPUT FORM

<table>
<tr><th colspan="2">Process/System Data Input Form</th><th rowspan="2">Company A</th></tr>
<tr><td colspan="2">This form is a tool for collecting data concerning specific processes to be modelled and simulated using Plant Simulation.</td></tr>
<tr><td>Site/Facility:</td><td></td><td>Page 1 of 6</td></tr>
<tr><td>Process/System:</td><td></td><td rowspan="2">Date:</td></tr>
<tr><td>Author:</td><td></td></tr>
<tr><td colspan="2">Step</td><td>Data Available(Y/N)</td></tr>
<tr><td rowspan="4">T</td><td>1. Factory Structural Data</td><td></td></tr>
<tr><td>2. Manufacturing Data</td><td></td></tr>
<tr><td>3. Material Flow Data</td><td></td></tr>
<tr><td>4. Failure Data</td><td></td></tr>
<tr><td rowspan="3">O</td><td>5. Working Time Organization</td><td></td></tr>
<tr><td>6. Resource Allocation</td><td></td></tr>
<tr><td>7. Organization/Facility Strategy</td><td></td></tr>
<tr><td rowspan="2">S</td><td>8. Product Data</td><td></td></tr>
<tr><td>9. Job Data</td><td></td></tr>
<tr><td>H</td><td>10. Input Contact Personnel</td><td></td></tr>
<tr><td colspan="2">Technical Data</td><td>T</td></tr>
<tr><td colspan="3">1. Factory Structural Data</td></tr>
<tr><td colspan="2">*Attach any related documents and add a reference.</td><td>Ref</td></tr>
<tr><td colspan="2">i. Layout Drawings (floor plan layout; process flow lines)</td><td></td></tr>
<tr><td colspan="2">ii. Production (process description; photos/videos)</td><td></td></tr>
<tr><td colspan="2">iii. Transport (functions; routes)</td><td></td></tr>
</table>

iv. Restrictions (process/transport/facility)	
2. Manufacturing Data	*Page 2 of 6*
**Attach any related documents and add a reference.*	*Ref*
i. Time Studies/Data (process; cycle; takt; recovery; setup times)	
ii. Performance data (utilization; efficiency; throughput)	
iii. Capacity (processing; energy requirement; operational)	

iv. Restrictions (process; capacity; operational)	
3. Material Flow Data	*Page 3 of 6*
**Attach any related documents and add a reference.*	*Ref*
i. Topology (dimensional changes through processing; assemblies; parts; containers)	
ii. Conveyors (flow line)	
iii. Capacity (processing; operational)	

iv. Material Handling (equipment; utilization; flow line)	
4. Failure Data	*Page 4 of 6*
**Attach any related documents and add a reference.*	*Ref*
i. Process Related (failure rate; MTTR)	
ii. Product Related (defects; quality; material)	

Organizational Data	*O*
5. Working Time Organization	
**Attach any related documents and add a reference.*	*Ref*
i. Shift Schedule (operating times; breaks; planning)	
6. Resource Allocation	
**Attach any related documents and add a reference.*	*Ref*
i. Worker	
ii. Machines	
7. Organization/Facility Strategy	*Page 5 of 6*
**Attach any related documents and add a reference.*	*Ref*
i. Production Strategy (throughput aim; cost savings; time reduction)	
ii. Maintenance Strategy (schedule; requirements)	
ii. Incident Management (procedure; operational effects)	

System Load Data	*S*
8. Product Data	
**Attach any related documents and add a reference.*	*Ref*
i. Working Plan (specifications; deliverables)	
ii. BOMs (parts; assemblies)	
9. Job Data	
**Attach any related documents and add a reference.*	*Ref*
i. Production Orders	
ii. Transportation Orders	
iii. Volumes	
iv. Dates	
10. Input Contact Personnel	*Page 6 of 6*
**Attach any related documents and add a reference.*	*Ref*
Project Manager:	
Plant Manager:	
Plant Supervisor:	

Process Engineer:	
Additional Contacts:	
***Additional Information**	

APPENDIX D: PROJECT REQUEST TEMPLATE SURVEYS

D1 – Project Request Template Form Questionnaire (Participant A)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good (x)	Very Good

2. There is sufficient writing/editing space.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average	Good (x)	Very Good

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average (x)	Good	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good (x)	Very Good

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the form (format).

   Could include notes which indicate all the required fields to include e.g. with a (*).

8. Please provide any feedback concerning the content of the form (information).

   Include DES deliverable requirement checklist.

9. Please provide any general feedback/notes regarding the form.

   This form alone does not make a lot of sense, but with formal communication or strategy documents (as received); it works well as an attachment request file.

D2 – Project Request Template Form Questionnaire (Participant C)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good	Very Good (x)

2. There is sufficient writing/editing space.

Very Poor	Poor	Average	Good	Very Good (x)

3. Sections are well defined/described.

Very Poor	Poor	Average	Good (x)	Very Good

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average	Good (x)	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average (x)	Good	Very Good

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average (x)	Good	Very Good

7. Please provide any feedback concerning the structure of the form (format).
   I think that the traditional approach of filling out a request form must be scrapped completely. Some kind of digital (perhaps digital survey format/style) format should be considered, as a shift towards digital documentation is evident in all other facets of company documentation.

8. Please provide any feedback concerning the content of the form (information).
   I would like to see an indication of expected/required accuracy (which indicates model complexity) as a separate input field on the form. In addition, the requestor for example optimisation /financial feasibility study/digital twinning/verification of throughput /required process times for specified throughput/etc. must list the main goal of the simulation.

9. Please provide any general feedback/notes regarding the form.

   Everything I would like to add is discussed above.

D3 – Project Request Template Form Questionnaire (Participant E)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good	Very Good (x)

2. There is sufficient writing/editing space.

Very Poor	Poor	Average	Good	Very Good (x)

3. Sections are well defined/described.

Very Poor	Poor	Average	Good	Very Good (x)

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average	Good (x)	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good	Very Good (x)

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the form (format).

   You could add a document number to the footer for traceability and filing purposes, which is the standard with all our work documentation.

8. Please provide any feedback concerning the content of the form (information).

   The form is sufficient in capturing the information that is needed.

9. Please provide any general feedback/notes regarding the form.

   The form has a good layout; you may want to add a space to capture the requested date on the form to give a timeline from the request date to simulation completion.

D4 – Project Request Template Form Questionnaire (Participant F)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good	Very Good (x)

2. There is sufficient writing/editing space.

Very Poor	Poor	Average	Good	Very Good (x)

3. Sections are well defined/described.

Very Poor	Poor	Average	Good	Very Good (x)

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average	Good (x)	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good	Very Good (x)

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good	Very Good (x)

7. Please provide any feedback concerning the structure of the form (format).
   It is nice and short and makes it easier to request a simulation project internally. Individuals also do not need to know how a model works to still request this, but it does force the requestor to think through carefully on why they want a model. It helps individuals to think in terms of what problem or opportunity they are facing and want help with.

8. Please provide any feedback concerning the content of the form (information).
   I think with Company A having existing plants and Division A manufacturing new plants, maybe have a section indicating whether this is a new or an existing facility.

9. Please provide any general feedback/notes regarding the form.

   I like it, keep it as short as possible.

D5 – Project Request Template Form Questionnaire (Participant G)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good	Very Good (x)

2. There is sufficient writing/editing space.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average	Good (x)	Very Good

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average	Good (x)	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good (x)	Very Good

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good	Very Good (x)

7. Please provide any feedback concerning the structure of the form (format).

   Good initial and official (sign and approve requirement) step to start the process. If there are internal business costs, they will need to be noted here.

8. Please provide any feedback concerning the content of the form (information).

   The priority and lead-time are up to the requestor's discretion. For small projects priority about how priority and lead-time translate to your process. Priority could be replaced with "Business Impact".

9. Please provide any general feedback/notes regarding the form.

   Overall a good idea and form to have.

APPENDIX E: DATA INPUT TEMPLATE FORM SURVEYS

E1 – Project Data Input Template Form Questionnaire (Participant A)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average (x)	Good	Very Good

2. There is sufficient writing/editing space.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average (x)	Good	Very Good

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average	Good (x)	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average (x)	Good	Very Good

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the form (format).

   A more descriptive section on the use of the document and responsibility will aid in understanding the form.

8. Please provide any feedback concerning the content of the form (information).

   Some of the sections can be described in a bit simpler terms.

9. Please provide any general feedback/notes regarding the form.

   The form is well thought out, but it can be constructed more user-friendly if other individuals need to provide info.

E2 – Project Data Input Template Form Questionnaire (Participant C)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good (x)	Very Good

2. There is sufficient writing/editing space.

Very Poor	Poor	Average	Good	Very Good (x)

3. Sections are well defined/described.

Very Poor	Poor (x)	Average	Good	Very Good

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average (x)	Good	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average (x)	Good	Very Good

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the form (format).
   The format is workable and can be completed digitally, which is a requirement.

8. Please provide any feedback concerning the content of the form (information).
   I personally did not understand which information is required throughout much of the document. I think the form attempts to be relevant to all model types/simulation goals. The required information should be grouped according to the simulation type (throughput verification/ design optimisation/ financial feasibility model, etc.). If this can be achieved, the required information will have a higher probability of being available and it would be easier to relate the questions/section headings in the form to the information in the requestor's possession.

9. Please provide any general feedback/notes regarding the form.
   A technical proposal or contract on which plant designs will be based may be a good bit of information to request for certain applications of a simulation.

E3 – Project Data Input Template Form Questionnaire (Participant E)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good	Very Good (x)

2. There is sufficient writing/editing space.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average	Good	Very Good (x)

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average	Good	Very Good (x)

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good	Very Good (x)

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good	Very Good (x)

7. Please provide any feedback concerning the structure of the form (format).
   You could add a document number to the form, for filing/Teamcenter storage purposes.

8. Please provide any feedback concerning the content of the form (information).
   The inputs the document requests are good and gives a type of build history for the process/product. It would be a good document to add as a summary to a report.

9. Please provide any general feedback/notes regarding the form.

   Good for capturing all the information and I like that it includes the responsible contact personnel.

E4 – Project Data Input Template Form Questionnaire (Participant F)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good (x)	Very Good

2. There is sufficient writing/editing space.

Very Poor	Poor	Average (x)	Good	Very Good

3. Sections are well defined/described.

Very Poor	Poor (x)	Average	Good	Very Good

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average	Good	Very Good (x)

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good	Very Good (x)

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the form (format).

   I like that it is very simple and organised, with a basic structure to follow. It is also easy to update in the future if need be.

8. Please provide any feedback concerning the content of the form (information).

   I think it would be better to have a section at the top before technical data, which allows you to capture the desired outputs (measurable variables) of the model. It will help guide the user on what is useful data to collect and what not. E.g., model outputs: throughput, buffer capacity, on-time deliveries, utilisation, etc.

9. Please provide any general feedback/notes regarding the form.

   I assume the use of this form is for the modeller and not the person requesting the model. In that case, I think it would be good to have a key section. I also think it would be good to leave notes on the cells to give a brief description of technical words. It might be redundant, but when you hand over or train others to model in your place, that it will help them understand the original idea behind the technical terms. Lastly, I suggest you have a folder named data dump and documents/media, and in the process, data be referenced in this document.

E5 – Project Data Input Template Form Questionnaire (Participant G)

Project Request Form | Data Input Form ~ (mark applicable form):

1. The form is readable/understandable.

Very Poor	Poor	Average	Good (x)	Very Good

2. There is sufficient writing/editing space.

Very Poor	Poor (x)	Average	Good	Very Good

3. Sections are well defined/described.

Very Poor	Poor (x)	Average	Good	Very Good

4. The purpose/reason for completing the form is understood.

Very Poor	Poor	Average	Good (x)	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good (x)	Very Good

6. The relevancy of the sections is applicable, to request the project.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the form (format).
   A clean, simple format that should be easy to understand. If the form will be shared using Excel, I suggest using different sheets per (T, O, S, H) section and describing appropriately.

8. Please provide any feedback concerning the content of the form (information).
   More detailed examples of information (and format/type of info) required might be needed to easier communicate the required info. The current setup does not guide someone with no simulation background enough to provide sufficient data without direct support. Note: Never use an abbreviation in a form before explicitly defining what it is.

9. Please provide any general feedback/notes regarding the form.

   For our models, we use a windows file structure (pre-defined) that we just copy and paste for every new project and data given in excel is copied into the same excel file, like the one imported into PlantSim. Makes finding things easier.

APPENDIX F: DELIVERABLES REPORTING SURVEYS

F1 – Project#1 Deliverables Documentation Questionnaire (Participant A)

Project Report | Work Sheet | Feasibility Study ~ (mark applicable document):

1. The document is readable/understandable.

Very Poor	Poor	Average (x)	Good	Very Good

2. There is sufficient information relative to the project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average (x)	Good	Very Good

4. The purpose/reason of the document is understood and adds value.

Very Poor	Poor	Average (x)	Good	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average (x)	Good	Very Good

6. The relevancy of the sections is applicable, concerning project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the document (format).
   The document (even as an interim report) should be structured in a formal format with a table of content and description details.

8. Please provide any feedback concerning the content of the document (info).
   Tables, diagrams and sections should be described in more detail.

9. Please provide any general feedback/notes regarding the document.

   Good 'informal' document to provide interim debriefing.

F2 – Project#2 Deliverables Documentation Questionnaire (Participant E)

Project Report | Work Sheet | Feasibility Study ~ (mark applicable document):

1. The document is readable/understandable.

Very Poor	Poor	Average	Good	Very Good (x)

2. There is sufficient information relative to the project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average	Good	Very Good (x)

4. The purpose/reason of the document is understood and adds value.

Very Poor	Poor	Average	Good	Very Good (x)

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good	Very Good (x)

6. The relevancy of the sections is applicable, concerning project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the document (format).

   The document is well laid out systematically introducing the inputs first and then proceeding to the results. Very concise.

8. Please provide any feedback concerning the content of the document (info).

   The content is presented well in the form of tables and graphs to illustrate the data obtained. The results with their explanation below their tables/graphs also work well and allow the reader to follow easily.

9. Please provide any general feedback/notes regarding the document.

   Overall, a very well planned and written document.

F3 – Project#2 Deliverables Documentation Questionnaire (Participant C)

Project Report | Work Sheet | Feasibility Study ~ (mark applicable document):

1. The document is readable/understandable.

Very Poor	Poor	Average	Good	Very Good (x)

2. There is sufficient information relative to the project requirements.

Very Poor	Poor	Average	Good	Very Good (x)

3. Sections are well defined/described.

Very Poor	Poor	Average	Good	Very Good (x)

4. The purpose/reason of the document is understood and adds value.

Very Poor	Poor	Average	Good	Very Good (x)

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good (x)	Very Good

6. The relevancy of the sections is applicable, concerning project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the document (format).
   The structure should be similar to that of an engineering design/simulation report, which it currently satisfies.

8. Please provide any feedback concerning the content of the document (info).
   The content is relevant and appropriately uncomplicated. I would like an additional conclusion to be added for this type of report (operations simulation for a concept plant): the estimated bottleneck in the concept must be included in such a report.

9. Please provide any general feedback/notes regarding the document.
   If possible, a model build summary or model code must be included in this report if it is not included in another document. It should allow the same model to be built from scratch. This will be useful for keeping a record of the model (in case of loss of the actual model) and providing quick access for other personnel without requiring Tecnomatix access.

F4 – Project#3 Deliverables Documentation Questionnaire (Participant C)

Project Report | Work Sheet | Feasibility Study ~ (mark applicable document):

1. The document is readable/understandable.

Very Poor	Poor	Average	Good (x)	Very Good

2. There is sufficient information relative to the project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average (x)	Good	Very Good

4. The purpose/reason of the document is understood and adds value.

Very Poor	Poor	Average (x)	Good	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good (x)	Very Good

6. The relevancy of the sections is applicable, concerning project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the document (format).

   The structure is adequate for the purposes of this document.

8. Please provide any feedback concerning the content of the document (info).

   The content is directly related to the project as variables and parameters, which drive financial feasibility in this case.

9. Please provide any general feedback/notes regarding the document.

   This document would be the best read in conjunction with something like a simulation report/design report. It is confusing to read on its own (or when no information about the simulation is available). Additionally, it might be a good idea to include a sheet containing a summary of the simulation problem, which would eliminate the need to read two documents at the same time.

F5 – Project#4 Deliverables Documentation Questionnaire (Participant E)

Project Report | Work Sheet | Feasibility Study ~ (mark applicable document):

1. The document is readable/understandable.

Very Poor	Poor	Average	Good	Very Good (x)

2. There is sufficient information relative to the project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average	Good (x)	Very Good

4. The purpose/reason of the document is understood and adds value.

Very Poor	Poor	Average	Good (x)	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good (x)	Very Good

6. The relevancy of the sections is applicable, concerning project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the document (format).
   The structure and layout of the document are good.

8. Please provide any feedback concerning the content of the document (info).
   Good illustrations and comparison between simulation frames. I also found it very informative and useful that the simulation can identify where the bottlenecks are and how many more billets can be processed by using two Gantry loaders. Good comparison.

9. Please provide any general feedback/notes regarding the document.

   A good baseline document based on the limited information provided.

APPENDIX G: FEASIBILITY STUDY TEMPLATE SURVEYS

G1 – Feasibility Template Review (Participant F)

Project Report | Work Sheet | Feasibility Study ~ (mark applicable document):

1. The document is readable/understandable.

Very Poor	Poor	Average	Good (x)	Very Good

2. There is sufficient information relative to the project requirements.

Very Poor	Poor	Average	Good	Very Good (x)

3. Sections are well defined/described.

Very Poor	Poor	Average	Good (x)	Very Good

4. The purpose/reason of the document is understood and adds value.

Very Poor	Poor	Average	Good	Very Good (x)

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good	Very Good (x)

6. The relevancy of the sections is applicable, concerning project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the document (format).

   Very simple and easy to update.

8. Please provide any feedback concerning the content of the document (info).

   Makes it easier to know what you are aiming at when you simulate, also helps to provide a cost-benefit reason as to why the model is run.

9. Please provide any general feedback/notes regarding the document.

   It might benefit to have a short note and sections to describe sections and abbreviations.

G2 – Feasibility Template Review (Participant G)

Project Report | Work Sheet | Feasibility Study ~ (mark applicable document):

1. The document is readable/understandable.

Very Poor	Poor	Average	Good (x)	Very Good

2. There is sufficient information relative to the project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

3. Sections are well defined/described.

Very Poor	Poor	Average	Good (x)	Very Good

4. The purpose/reason of the document is understood and adds value.

Very Poor	Poor	Average	Good (x)	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average	Good (x)	Very Good

6. The relevancy of the sections is applicable, concerning project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the document (format).

   Simple and concise format. Easy to understand.

8. Please provide any feedback concerning the content of the document (info).

   I would include a flow diagram (even if very simple) as well as a graphical display comparing the results of scenarios. Also, add a "KEY" or abbreviation sheet summarising all abbreviations used.

9. Please provide any general feedback/notes regarding the document.

   A good summary of the study to accompany the full project document.

G3 – Feasibility Template Review (Participant A)

Project Report | Work Sheet | Feasibility Study ~ (mark applicable document):

1. The document is readable/understandable.

Very Poor	Poor	Average (x)	Good	Very Good

2. There is sufficient information relative to the project requirements.

Very Poor	Poor	Average (x)	Good	Very Good

3. Sections are well defined/described.

Very Poor	Poor (x)	Average	Good	Very Good

4. The purpose/reason of the document is understood and adds value.

Very Poor	Poor	Average (x)	Good	Very Good

5. The number of sections is elaborate enough, without being overly complicated.

Very Poor	Poor	Average (x)	Good	Very Good

6. The relevancy of the sections is applicable, concerning project requirements.

Very Poor	Poor	Average	Good (x)	Very Good

7. Please provide any feedback concerning the structure of the document (format).

   Provide form notes and descriptive purpose of project components.

8. Please provide any feedback concerning the content of the document (info).

   Provide descriptive notes on detail costing breakdown.

9. Please provide any general feedback/notes regarding the document.

   The overall structure is good, but from a modular perspective, it provides restricted information.

APPENDIX H: UNSTRUCTURED INTERVIEW (INTERNAL REVIEW)

Interview: Internal Reviews – Project Samples (Participant_A, Participant_B, Participant_C, Participant_D, & Participant_E, 2021)

Interviewer: Josua O. Wesch

Interviewees: The interviewees will be referred to as Participant A to E for anonymity on feedback.

Date: 5 March 2021 (13h00 – 15h00) at Company A.

The unstructured interview is transcribed and edited to provide a more structured review, which can be analysed and referenced more easily.

i. Introduction & Informed Consent:

The participants were introduced to the research study and the informed consent forms were reviewed and signed before the start of the interview. All participants approved that they were well informed and gave consent to partake in the data collection for this research study.

ii. Data Collection Protocol:

The data collection protocol – constructed by the interviewer with ethical approval was briefly explained, with a focus on the background to the study and the importance/value to add from the internal reviews. The researcher, supervisor and gatekeeper to the research study were pointed out if there would be any questions or feedback required after the interview. Lastly, the database construction and purpose of the relevant follow-up survey/questionnaire forms were explained. The edited interview points follow from point (iii) to (vii).

iii. Feedback/response on benefits of TX at project level:

The initial question asked for opening remarks was to provide initial feedback on the perceived benefits of TX for the relevant project samples, from each participant.

Participant E: TX helped analyse the production times for [Project#2].

TX provided a good overview of the production process and throughput analysis for [Project#4].

Participant D: TX provided scenario simulations between varying concepts (concept analysis) for [Project#5].

Some of the benefits for [Project#2] included the gauging of production processes and times; bottleneck identification and analysis; and provided a visual aid for clients at the concept design phase.

TX provides the benefit of simulating scenarios on input variants and operational capacity. Identifying the impact of process/equipment changes efficiently and accurately [Overall].

Participant B: TX adds value with time studies, to identify upstream and downstream impact for [Project#5].

TX benefits include bottleneck and operator utilisation analysis; orders in/out analysis; and overall system integration analysis [Overall].

Participant C: The participant most exposed to TX as the client, participating in three of the project samples.

TX provided output to design as a verification tool for [Project#2].

TX provided concept evaluation as a decision support tool for [Project#3].

TX provided scenario simulations for [Project#5].

iv. <u>Feedback/response on TX value and project input</u>

Following a question by Participant D on what can TX do, and where can it add value? The question was derived to open up the discussion on how a TX simulation engineer can provide better input on TX capabilities and value to be added for Division A.

Participant D: Presentation with bullet points to illustrate value-adding benefits of TX, case study examples, and key features of TX for Division A and Company A.

TX team members should be included at the start of identified projects.

Participant C: An outcome of the study should be provided with main tools for which TX can be used, and provide benefit points for varying projects.

Participant E: TX team members should sit with the project engineer and spec user requirements. E.g. to identify where it will benefit on downtime effect and maintenance planning (motivation tool).

v. Feedback/response on TX project request and reporting:

It was then followed on by inquiring on the TX project request procedure and potential inclusions.

Participant C: Formalise requirements for model/design for data input requirements (e.g. part of URS). Define project requestor and input requirements, similar to MCAD/ECAD approach.

Simulation should be a project on its own, and aid in parameter development and concept design input.

Participant D: Include requirement checklist, e.g. 3D cad incorporation requirements.

It would benefit design engineers in having sessions about TX benefits/value-adding case studies and training on data input, e.g. process data requirements, 3D model translation, etc.

Feedback concerning project reporting for the varying samples was discussed.

Participant C: Reporting similar to Division A's FEA/CFD report structure should be followed, including boundary conditions, methods and all relevant requirements.

Participant E: Feels it is client and project dependent.

Participant D: Outcome of requirements should drive template reporting.

Participant C: Having a formal template with scope and parameters is necessary, to be able to replicate models/simulations in the future.

vi. Personal feedback regarding deliverables/outcome on TX projects:

Participant E: TX adds value as a motivation/support tool.

Participant D: Production environment benefits because a few aspects can be calculated in Excel, but analysing scenario changes and other operational effects is not easy. Thus, the ease-of-use and scenario calculations separate it from Excel.

Adds value, but believes that Division A is not utilising TX to its full capability yet.

Participant C: The 3D environment and inclusion of material handling and operations are of great benefit at a project level.

Participant B: Sees value in production (internally for Company A) as a support function by Division A.

Noted that TX should be utilised more proficiently.

TX is value adding as referencing and motivation tool, not sure on the exact value for Division A.

Participant D: Adds value with design concept illustration to clients and convey design function and decision support/motivation to clients, as well as the design team, especially at an operational level.

Participant A: TX value at the end lies as a support/motivation tool for design support and production (site) support.

Participant C: The ROI/feasibility of concept designs is also a valuable point that should be included.

Participant D: Added on the difficulty to quantify ROI and value-added by TX at the infancy level.

vii. Feedback/response on TX strategy development:

This section was to include project participant feedback on the overall phasing and initial strategy development of TX at a project and business level.

Participant C: The implementation strategy should be incorporated within the existing design methodology in Division A.

It should be included within each design input and model based on requirements. Initial implementation phases should include:

1. Input and analysis of user specification requirements (URS).
2. Concept design + TX model
3. Detail design (verification)
4. An official model with working simulation with a direct data link, similar to a digital twin.

It is especially important that TX be incorporated earlier within certain identified Technical Proposals for clients, as design input, before concept design (step 1).

Participant D: Would aid with design input and support for concept designs.

Should be used as a proactive design approach, rather than a reactive tool. We are only identifying production requirements and dependency requirements (interface) with the design concept. TX would mitigate a lot of unforeseen production requirements and scenarios that affect concept/process design downstream.

Participant C: The business strategy should be linked and developed with ROIs at a project level.

It is also dependent on the functions of the company and department (production vs. design). Maybe it would benefit to develop separate methods, which are well defined.

The licensing strategy must continuously be evaluated on company capacity and requirements.

Participant D: Focus and motivation should be on TX requirements/utilisation/capacity, depending on project loading.

The business level should be incorporated with the project level, including the use and input with an evaluation of TX requirements.

ROI examples per case study to quantify where the value lies for TX at project level.

Participant E: Pointed to the potential inclusion of outsourcing consultancy as a separate selling environment or service on modelled facilities for Division A to clients.

Participant C: In approval of idea indicating utilising TX similarly as other CAD software models for selling facilities or marketing purposes.

Participant A: Utilising TX as a marketing tool will inherently become a potential service based on model/simulation project development.

The legality of ‘consultancy’ using TX outside of an identified Siemens partner entity is not known.

APPENDIX I: UNSTRUCTURED INTERVIEW (EXTERNAL REVIEW)

Interview: External Review – Siemens (Participant_F & Participant_G, 2021)

Interviewer: Josua O. Wesch

Interviewees: The interviewees will be referred to as Participant F and G for anonymity on feedback.

Date: 10 March 2021 (10h00 – 12h00) via virtual online platform.

The unstructured interview is transcribed and edited to provide a more structured review, which can be analysed and referenced more easily.

i. Overview on TX and DES:

The initial opening for discussions was around an overview of TX and DES implementation strategy.

Participant F: The biggest factor regarding DES software implementation for any company, relates directly to the maturity of the business. Based on the entry of technology at hardware and software level.

DES mainly utilises perceptive modelling techniques.

It is important to note that DES-type software is not used every single day, and is mainly dependent on project requirements and resource availability.

After Covid, it has become clear to almost all industries, that virtual is key to ensure future success and profitability. In the next 10-15 years, most production companies should have virtual models/simulation capabilities.

DES should be used as a proactive strategic tool and not as a reactive tool, in order to add the most value.

The automotive industry is the leading industry with plant simulation utilisation and implementation.

Participant G: Baseline for maturity can be followed on existing company models, for example, ERP systems in place, IT infrastructure, etc.

TX is utilised more as a gateway and support tool, this can be seen from the fact that the biggest ROI can be perceived from quick prototyping projects, where focus points include:

- Increasing production throughput,
- Cost reduction,
- Equipment/process flow analysis,
- Dynamic variation (scenario) analysis.

TX pays back 1000-fold for Greenfield projects. DES is also very effective in simulating Kaizen-type projects.

Brownfield project needs benefit on backend requirements, and aid to developing Greenfield projects.

DES implementation is focused on ROI.

DES projects benefit design and production-type projects. Design project simulations provide the following benefits:

- Material handling analysis and optimisation;
- Logistics management support;
- Operational management support;
- Testing of scenarios for motivation/support;
- Layout changes.

The next level is on production simulations, which provide benefits regarding resource capacity and utilisation analysis for equipment, personnel, investigations, maintenance/failures, etc.

DES incorporates three functions: Time, logic, and behaviour.

Another important benefit that DES can provide companies, is a means to simulate extreme measures, e.g. impact of Covid on operations, strikes, export restrictions, etc. – this is however not utilised a lot.

TX provides value to management, operations, logistics and design departments.

Virtual commissioning escalated the use of this technology within the last year.

ii. <u>TX/DES Business Requirements:</u>

The identified business component requirements and points of value are compiled in this section.

Participant G: The most important factor to keep in mind is the People-Process-Technology barrier. The following aspects are required for DES implementation:

- People: Technically proficient people should be in place or available, with a cross-functional team.
- Process: Simulation steps and procedures as part of functional operations should be incorporated.
- Technology: Hardware/Software requirements.

The best practice is to ensure that strategic decisions are included as a process from implementation to integration. Change management is also of utmost importance regarding new software implementation within companies.

Participant F: The best-identified resource requirement for TX at a company is having at least one simulations engineer, who will be a dedicated individual implementing the software at a project level. Preferably, an industrial engineer with coding experience, and for simulation teams, it aids in having a cross-functional team including statisticians and process engineers with coding skills (this is a primary requirement).

Mature companies with an implementation strategy in place can benefit from having a 2-5 man simulations team. An important skill required is an engineering mindset and being able to quantify input requirements.

Initially, the standard TX license capabilities are sufficient, with development and maturity professional integration can be incorporated.

iii. <u>Strategy Development Input</u>

Feedback and input regarding overall strategy development are compiled separately in this section.

Participant G: TX value to operations lies with the simulations team and successful project-level implementation. The primary data requirement and value-adding simulation are a continuous back-and-forth process.

The best software strategy to follow is with a top-down initiative for production and design support, with quantification of simulations to review the potential measurable success of projects.

With maturity, companies should move to simulate closed-loop models and integrate with other PLM systems.

A standardised modelling approach for TX implementation is the best practice.

Participant F: Knowledge transfer is the most important aspect regarding an implementation strategy.

Building a library of models and incorporating a modular design approach, with object templates will provide the most efficient working practice as more projects are completed. This will lead to reusable models for new projects (automation).

Following a top-down approach, the following implementation method for TX is recommended:

i. Start small with a few identified small projects.
ii. Prove that the simulations are accurate.
iii. Roll out the software within the company.
iv. Implement a broad spectrum of project types.
v. Construct a blueprint methodology to follow.
vi. Use concurrently and evaluate continuously.

An important aspect that must be included in all simulation projects is the reviewing of data, models, and simulations.

Additional value for production and design support simulation projects lie in having building models, which can be maintained and used for future decision support.

Siemens bought out Mendex, and is becoming a cloud-based operation and started providing subscription level licensing support.

APPENDIX J: REFINED PROJECT REQUEST TEMPLATE

Project/Process/Facility: ______________________ *Facility/process history:*

Existing	*New*

Requestor: ____

Department: ____

Line Manager: ____

Project Background (Give a brief description of the project):

____

____

____

____

____

Support Request (Brief description of requirement):

____

____

____

DES Deliverables Requirement (Mark or highlight block):

Process fly-through	*Bottleneck analysis*	*Material flow analysis*	*Logistical flow analysis*
Operational Utilisation & Efficiency analysis	*As-is/What-if scenario simulations*	*Transportation & Material Handling analysis*	*Process/Layout/Model optimisation*

Business Impact:

LOW	*AVG*	*HIGH*

Business Cost (if applicable): __________________

Approximate Lead Time (From request to project completion requirement):

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(Requestor) *(Line Manager)*

APPENDIX K: REFINED PROCESS DATA INPUT FORM

**Overview inclusion and sheet separation (content the same as in Appendix C).*

Process/System Data Input Form		Company A
This form is a tool for collecting data concerning specific processes to be modelled and simulated using Plant Simulation.		
Site/Facility:		
Process/System:		*Date:*
Author:		

This document is to be used by the process/simulations engineer in an attempt to collect suitable data sets in line with project request requirements. Project requestors are required to aid in indicating data available as well as relevant references to help with the data collection process.

Data Step		Data Available(Y/N)
Technical Data (T)	*1. Factory Structural Data*	
	2. Manufacturing Data	
	3. Material Flow Data	
	4. Failure Data	
Operational Data (O)	*5. Working Time Organization*	
	6. Resource Allocation	
	7. Organization/Facility Strategy	
System Load Data (S)	*8. Product Data*	
	9. Job Data	
HR Data (H)	*10. Input Contact Personnel*	

Technical Data (T) - This is all of the relevant technical data regarding the facility/processes requiring simulations.

1. Factory Structural Data - Includes production process layouts and equipment/flow info.

2. Manufacturing Data - Includes process data and operational information.

3. Material Flow Data - Includes material flow and material handling information.

4. Failure Data - Includes any process/product/equipment failure data.

Operational Data (O) - This is all of the relevant operational data including shift schedules and production strategies.

5. Work Time Organization - Includes shift schedules and requirements.

6. Resource Allocation - Includes worker and equipment requirements.

7. Organization/Facility Strategy - Includes production and maintenance strategies.

System Load Data (S) - This is all of the relevant product and job data included in the process/facility.

8. Product Data - Includes product specifications and BOMs.

9. Job Data - Includes product and transportation orders, with schedules and volumes.

Human Resource Data (H) - Includes input personnel relevant to project/facility/process, and any other additional information regarding data requirements.

10. Input Contact Personnel - Includes project stakeholders and contacts.