Powertrain and Test Development Process Optimisation

Methodology for Powertrain Product Development process optimization and waste reduction

by

Antonio O.R. Ciriello

B430725

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I dedicate this work to my wife Jeanie

Whom I love dearly and afforded me throughout this thesis immense support and patience

Abstract

The origins of this thesis stem from empirical observations made in several business environments which appeared contradictory, certainly interesting, challenging to understand and perhaps unique to the respective area of business. Typically, symptoms would reveal the underlying pattern only when encountered in stressed situations and with no obvious root cause. Symptoms could manifest as either total breakdown of output without any visible or intended change of the system, or adequate performance was reached only when the right person was brought in. It was further observed that qualified teams arrived at different solutions and output level when faced with the same technical problem. A hypothesis was constructed to explain in a qualitative way what was observed and to present a possible avenue for process performance optimisation.

This work explores key factors that may facilitate or inhibit the application of lean manufacturing (or *factory*) principles coupled with the very high *professional* skills needed in powertrain product development. Hence two distinct modes of delivery are introduced; namely Professional Handover and Factory Handover. Advantages and disadvantages of both modes are presented as well as their identifying characteristics. Two case studies were carried out in two environments to verify the hypothesis; (1) an automotive OEM test organization and (2) an engineering organisation. Design of questionnaires to underpin the two case studies and a structured analysis of the working environment is included. This resulted in two key findings i.e. evidence of both working modes, and employees are aware of the conditions and symptoms that support these modes. A multi-criterion decision making using Analytical Hierarchical Process used to implement the optimization.

This thesis concludes with strong evidence that awareness of, and process optimisation based on Factory and Professional handover can be used to deliver tangible productivity improvements in an engineering product development environment.

Keywords: *powertrain, product development, lean, waste reduction, optimization product, process improvement, testing*

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List of Publications and Presentations:

Papers:

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A. Ciriello, R. Osborne, W. Graupner, A. Pezouvanis, K. Ebrahimi, **A Classification Concept for Optimisation of Powertrain Product Development Productivity,** 3rd Biennial International Conference on Powertrain Modelling and Control Testing, Mapping and Calibration, Loughborough, 7th-9th Sep. 2016. See attached N57 for PDF of paper.

P. Lawson, J. Houldcroft, A. Neil, A. Balcombe, R. Osborne, A. Ciriello and W. Graupner, **Capability Assessment Process for the Optimisation of Testing Facilities for Powertrain Development,** SAE International Journal of Engines, Vol. 9, No. 3 (September 2016), pp. 1751-1762.

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A. Ciriello, R. Osborne, W. Graupner, **The Seven Habits of Highly Effective Test Facilities**, Product Development in Motion, Chalmers University – Nov. 2014.

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W. Graupner, A. Ciriello, R. Osborne, Andrea Balcombe, **Testfield Efficiency – How Many Ways to Rome?**, Product Development in Motion, Calmers University, 30th Nov. 2017.

W. Graupner, A. Ciriello, R. Osborne, K. Düring, **Lab. Management Challenges – How to Set Targets in Dynamic Environments?** Product Development in Motion, Chalmers University, 29th Nov. 2018.

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Abbreviations

AFR	Air-Fuel Ratio
AHP	Analytical Hierarchy Process
CAFE	Corporate Average Fuel Economy
CI	Compression Ignition
CO_2	Carbon Dioxide
COP	Conformity of Production
CPP	Constant Power Performance
CVT	Continuously Variable Transmission
DCT	Dual Clutch Transmission
DOH	Degree of Hybridization
ECU	Engine Control Unit
EFCC	Efficient Fuel Consumption Curve
EGR	Exhaust Gas Recirculation
EMS	Engine Management System
EOP	Engine Operating Point
EPA	Environmental Protection Agency
EUDC	Extra-Urban European Driving Cycle
EV	Electric Vehicle
FH	Factory Handover
FTP	Federal Test Procedure
FTP	Fixed Throttle Performance
GDI	Gasoline Direct Injection
HC	Hydrocarbons
IC	Internal Combustion
ICE	Internal Combustion Engine
IMEP	Indicated Mean Effective Pressure

ISG	Integrated Starter-Generator
ISO	International Standard Organization
IVT	Infinitely Variable Transmission
JIT	Just in Time
KPI	Key Performance Indicators
LCV	Low Carbon Vehicle
MAF	Mass Air Flow
MAP	Manifold Absoute Pressure
MPI	Multipoint (Port) Injection
NEDC	New European Driving Cycle
NO_x	Oxides of Nitrogen
PD	Powertrain Development
PH	Professional Handover
PiL	Powertrain in the loop
PO	Productive Output
PEMS	Portable Emission Measurement System
PCDC	Powertrain Controller Development Cycle
RDE	Real Drive Emission
SI	Spark-Ignition
SuT	System under Test
TA	Type Approval
TDC	Top Dead Centre
TPS	Toyota Production System
VVT	Variable Valve Timing
WOT	Wide-Open Throttle

Chapter 1 Introduction

Powertrain development is driven by a “product planning process” which results in a timeline from which all actions required to develop new product are triggered. Traditionally the primary goal is delivery of verified new product designs on time and quality, within the resource constraints of the organisation and available skills. Arrangement of resource for minimum wastage and highest utilisation of manpower and facility is often of secondary importance. This is in stark contrast to a typical manufacturing facility where concepts such as ‘Lean’ are routinely applied to seek out and minimise any unnecessary action and resource expended to produce the product. To many, the reason for this is down to the fundamental differences between the function and goals of product development and manufacturing. Although product development organisations often track certain elements such as facility and/or manpower utilisation they are often unable to formulate and apply solutions for fundamental waste reduction. The reasons for this are extremely complex in nature but include existing organisational structures, processes, task execution and working practices that effectively block productivity improvement. For this study powertrain product development is considered to include both development engineering and testing functions.

New product is typically delivered by periods of engineering design, prototype build and test. Testing is often supported by a distinct department within the organisation and is often considered highly resource intensive. Because of this it is also the area that often gets much attention for cost reduction.

1.1 Automotive Powertrain

Automotive powertrain can be defined as a group of components that generate power and deliver it to the road surface, water or air, including the engine (and/or electric motor), transmission, drive-shafts, differentials, and the final drive wheels. The vehicle powertrain typically consists of the internal combustion engine typically petrol or diesel, the transmission including a manual or automatic gearbox and driveline as shown in figure 1.1. This traditional arrangement is now being increasingly displaced by pure electric and hybrid concepts driven by a global desire to reduce the environmental impact of mobility. In recent years powertrains are almost exclusively monitored and controlled by electronic means.

Typical input and output signals for petrol engine electronic control units are presented in figure 1.2.

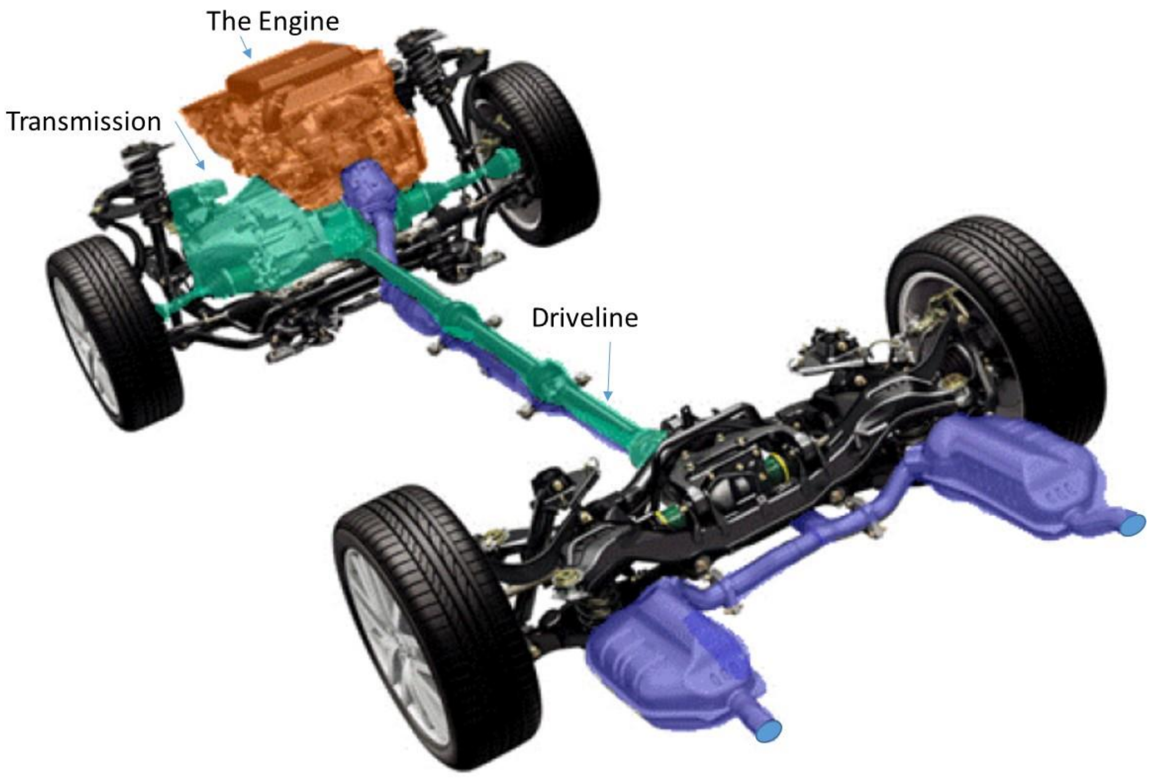


Figure 1.1 Vehicle Powertrain system [60]

Figure 1.2 Electronic Control - Inputs and Outputs to the Engine [60]

1.2 Powertrain Development Process

The powertrain development process (PDP) refers to the overall activities for the selection and integration of components and sub-systems and the verification of the propulsion system. It is highly dependent on test and measurement equipment used for evaluation of the powertrain output parameters such speed, torque and exhaust gas emissions. These parameters are directly related to vehicle performance, economy, drivability and environmental impact.

Typical powertrain development activity in the automotive industry can be categorised in the following way:

1. Hardware development and component selection
2. Electronic Control Unit (ECU) algorithm development
3. Engine Mapping and ECU calibration
4. Design/System verification

Although all four activities are markedly different in the skills, processes and tools required for delivery, they all share a common working pattern of periods of testing, analysis and decision making.

Everything being well this leads to a product delivery into the market place that meets corporate expectations of function, reliability, time to market and cost. Legislative requirements and market expectation have driven a many fold increase in powertrain complexity in recent years. This has put extreme pressure on product development organisations to contain the ever-increasing workload subject to investment, skills and operational costs within a shortening time line. It has become apparent that simply scaling current typical product development practices to meet demand is rapidly becoming untenable.

1.3 Powertrain Testing

Powertrain tests are an essential part of product development in the automotive industry. Many test facilities have been installed worldwide in order to manage the increasing complexity in the product. Annual investments accumulate to large sums of money every year including operating costs for personnel, fuel, prototypes, facilities etc. Bearing these sums in mind, it is obvious that effective test facility operations are of economic interest as is the optimisation of engineering development.

Figure 1.3 shows a typical engine testing environment. Engine development work is possible with the engine installed in a vehicle but is typically more convenient, accurate and repeatable with the engine installed on a test system.

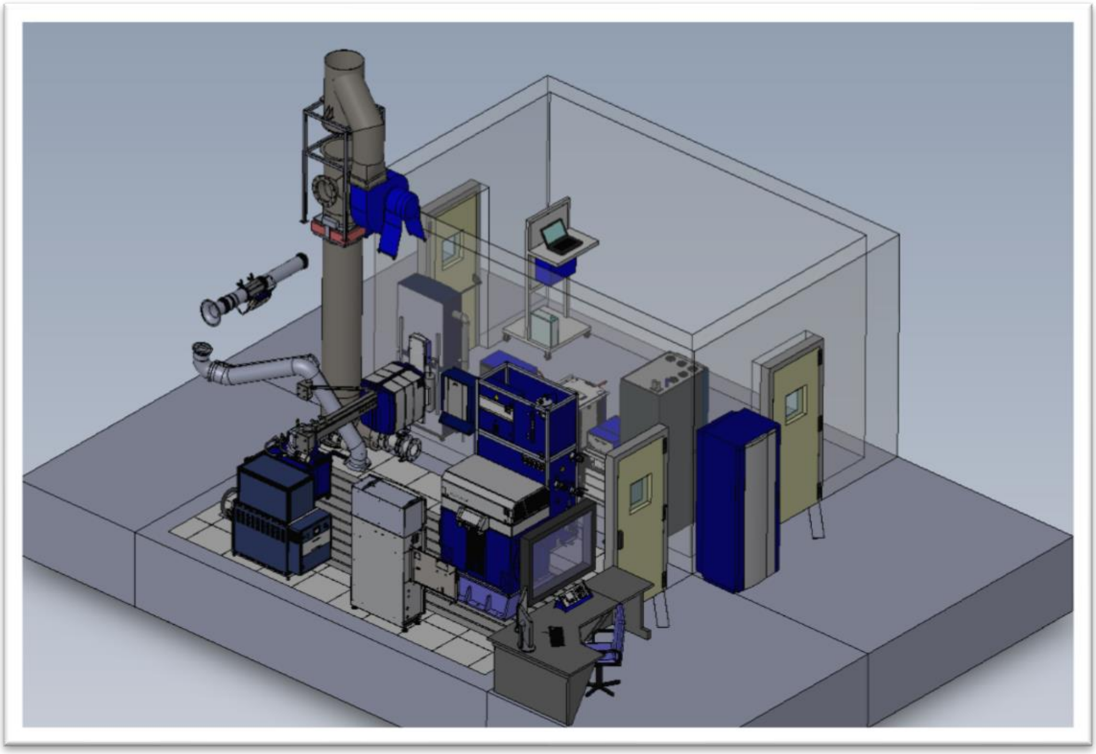


Fig. 1.3 Engine Test Environment [59]

Engine testing typically involves the application of braking resistance to motor rotation, and the measurement of torque and other quantities at various speeds and power levels.

Such a test system, capable of loading the engine as if it were being run installed in a driving vehicle is called an engine dynamometer. The engine dynamometer usually measures power at the flywheel of the engine for highest accuracy: no transmission or driveline losses influence the results. It is possible to have very good control over all test parameters and test conditions for best repeatability.

The validated data from testing is a most important part of the powertrain control development cycle (PCDC). If the data is not available in time, the launch of the product on the market will be delayed. Therefore, faster and predictable testing attains higher economical value than its mere costs.

Many development managers, driven to reduce testing costs and increase testing speed, replace complicated and expensive manual tests with automated testing or endeavour to replace them entirely with computational modelling and simulation.

Ultimately it is the responsibility of product development engineering to determine the type and amount of testing to verify the function and durability of a powertrain with acceptable confidence. It is therefore usual that what to test and how to test is defined by engineering. This definition is then passed to testing in the form of a specification. Refinement and standardisation of testing processes is typically both an engineering and test responsibility.

The people responsible for test facilities are hence under pressure to:

1. Deliver in the most efficient manner possible.
2. Achieve timely and predictable delivery.
3. Support the simplification, automation and rationalisation of tests.
4. Reduce effort in core activity – use less testing in development programmes.

The output of test facilities can be described as data of predefined quality that is delivered on time and with the least effort possible. In addition, test facilities require the flexibility to constantly adjust test-configurations within a very short space of time in order to react to the changing demands of internal customers within product development. It is suggested in [1] that highly effective test facilities across the world have the same common habits. In this paper seven habits are described qualitatively and support the quantitative data, or common key performance indicators (KPIs), that allow measurement of testing productivity.

It is further stated [1] that in powertrain testing productivity optimisation, the organisation change cannot be ignored. This key point is supported by experience with the lean manufacturing (as presented later in chapter 2).

Testing today in value chain terms is considered very wasteful yet perception in the industry is that more testing capability and capacity will be required to support future product development. A paradigm shift would be to engage testing to deliver clear tasks in the leanest possible way.

In powertrain product development it is a challenge to test efficiently and to deliver predictably. To date product development and testing were considered as only partially predictable processes since the results from today influence the plan for tomorrow. This approach may work for individual researchers in the laboratory, but as soon as several teams and test environments are obliged to work together, disproportionately high resources are required, because most staff and test infrastructure are in wait states. In these states, they are unused and hindered in their progress along their critical path. Hence the implementation of a just-in-time concept with short lead times to schedule testing capacity is highly desirable to maximise the ability to react and minimise capital employed.

Figure 1.4 demonstrates the difference between optimised (new method) and non-optimised (existing method) testing. The time per measuring point needed in a gasoline engine characterisation exercise is shown. Top and lower values are the upper and lower ranges respectively. The central value is the median for the population of measurements. By means of intelligent automation performed over months in a measurement campaign, the time per measuring point was reduced by approximately 3-fold, which led to reduction in the duration of the whole measurement campaign of 70% [1].

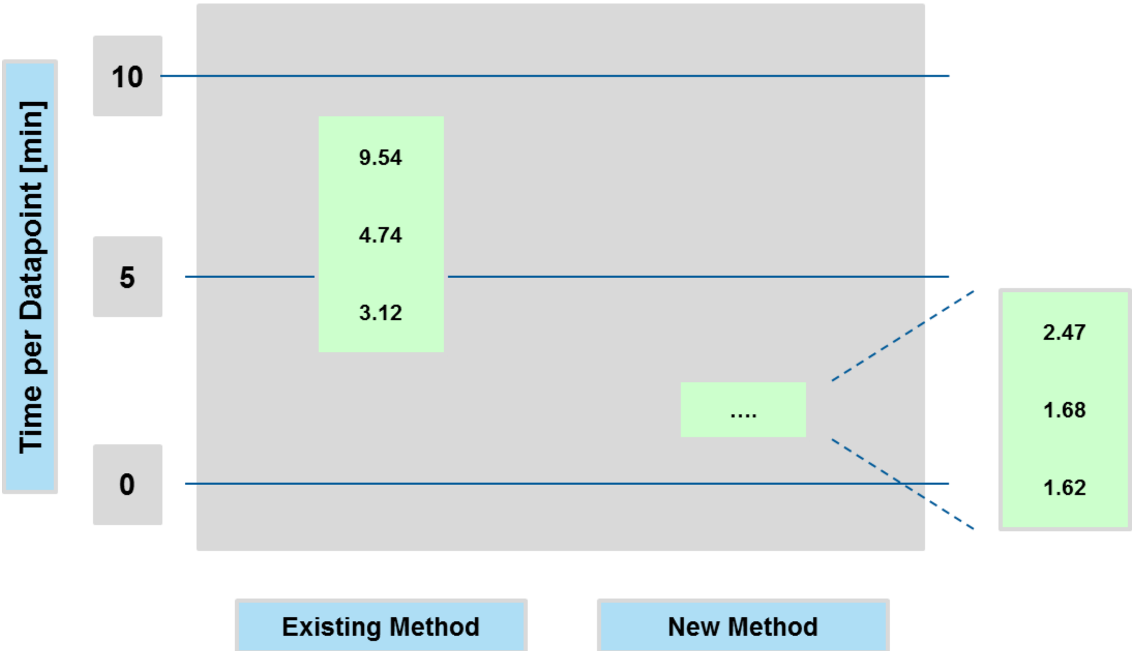


Figure 1.4 Difference between optimised and non-optimised testing [1]

The framework published by Stephen Covey in his book “The Seven Habits of Highly Effective People” [2] is a blueprint for personal development but as presented in [1] it also has relevance in organizational development. This is particularly true when an organisation (i.e. product development) has two departments (i.e. engineering and test) which are heavily dependent on one another.

Covey describes three states: Dependence, Independence and Interdependence. Figure 1.5 illustrates the philosophy in context of powertrain testing. The transition from Dependence to Independence is made with the first three habits: Proactivity, End in Mind and First Things First. Covey's world of private success shows how private victory can be achieved through optimising one's behavioural patterns. For an organisation this means the following: In order to achieve public victory, one needs to optimise interaction patterns as described by habits four to six: Think Win-Win, First Understand Then Be Understood and Synergize. This way, one will transit from independence to mutual dependence, namely interdependence.

Despite seeming like a step into the opposite direction, stronger interdependence is compensated by high performance. These patterns are identical between interacting departments as well as between people. They minimise sub-optimisation for the benefit of overall optimisation.

The ideas presented in [1] give insight into the importance of relationships and communication between departments in product development. This is however only part of the story i.e. the specific change actions needed to gain tangible productivity improvement in real organisations were not provided.

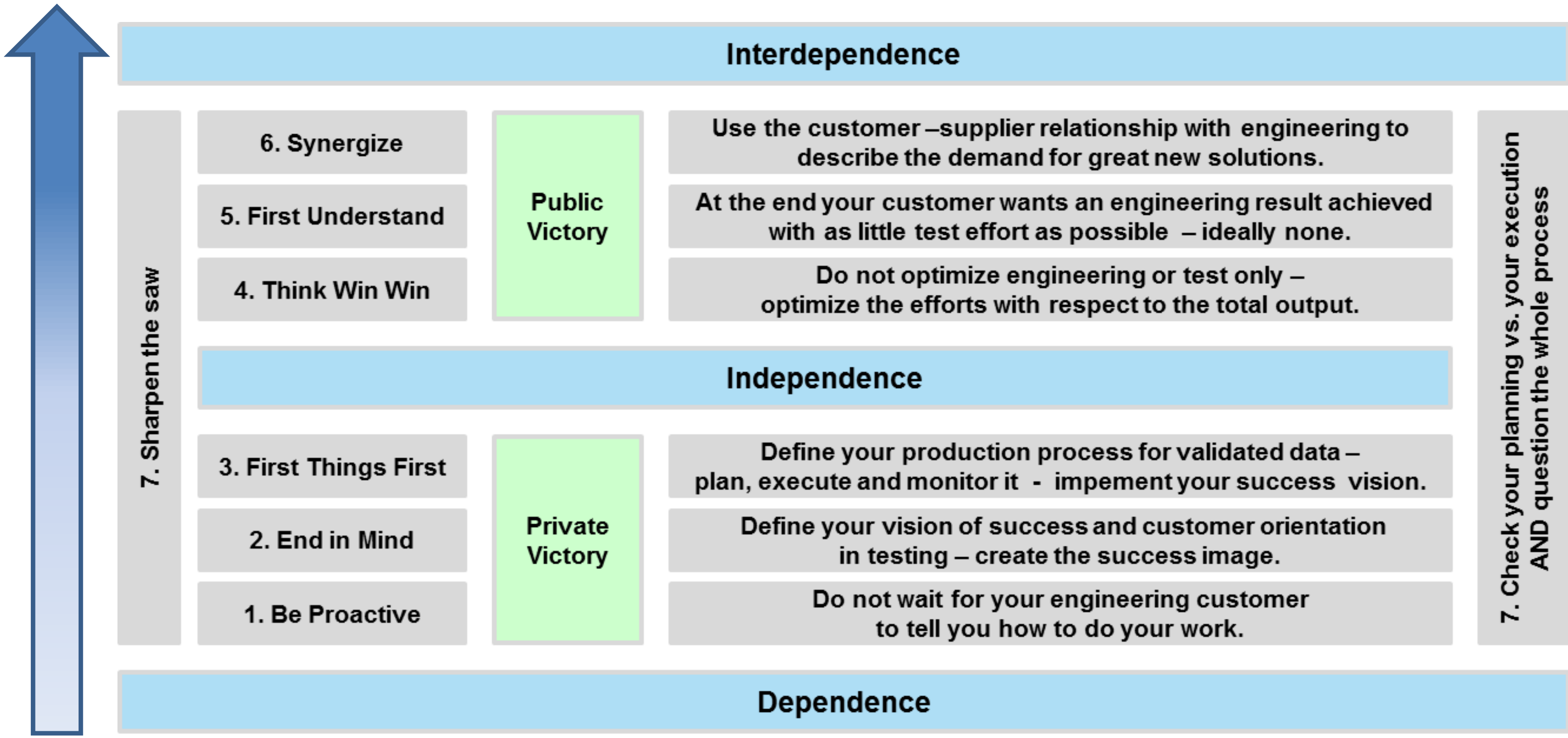


Figure 1.5 Mapping the seven habits in the world of powertrain testing [1]

1.4 Problem Statement and Contributions

At the outset of the work leading to this thesis it became clear that the real underlying reasons why product development organisations struggle to improve productivity were not fully understood. This was also supported by the author's own experience based on observations of real testing organisations in OEMs. Consequently, this research effort has focused on current and new methods to increase productivity (and minimise waste) in powertrain development and testing.

The contributions of this research are as follows:

1. A review of existing published work and experience with application of Lean principles in automotive manufacturing and product development.
2. A new concept is presented in which two operational delivery modes are defined: 'Professional Handover' PH and 'Factory Handover' FH.
3. A hypothesis is put forward that these two delivery modes are present in real world product development organisations and operate with a quantifiable proportion of Professional Handover and Factory Handover.
4. In addition, it is also put forward that there is an optimum proportion of Professional Handover and Factory Handover where productivity is maximised and/or waste (in Lean terms) is minimised.
5. The hypothesis (if proven valid) could be used as a tool for productivity improvement and waste reduction in Powertrain Product Development.
6. A case study design is presented. The aim is to prove/disprove the above by obtaining the relevant information from subject organisations using a pre-defined series of questions asked under interview conditions with key members of staff.
7. Two Case Studies were completed. To test the hypothesis' ability to differentiate between employee behaviours and organisational practices it was deemed that the two subject organisations should be fundamentally different in their business, organisation and processes. The first organisation was the testing department of a large automotive OEM, the second an engineering department a global supplier of powertrain test solutions. The engineering department was a mature organisation consisting of a small number of employees used to low volume and bespoke system deliveries. This was clearly highly different to the large

OEM with their large number of employees and volume manufacturing objective.

8. The results from the case studies are presented and are subjected to qualitative analysis.
9. In order to improve and automate future applications a prototype software is presented using and Analytic Hierarchy Process (AHP) approach.
10. The software was tested in the engineering department using process and design data in a specific application.

1.5 Thesis Outline

The structure of this thesis is shown in figure 1.6. Chapter 2 is an overview of past literature dealing with of the history of manufacturing process improvement in the automotive industry. A major focus is placed on the series of events that led to modern ‘lean’ manufacturing.

A description of a generic automotive product development process is described in chapter 3. This is followed by insight into the application of lean principles in product development based on the current literature available.

Chapter 4 covers a means of measurement of Test and Development Productivity that has been used in real improvement programmes applied in the automotive powertrain sector.

Chapter 5 specifically addresses current practices for decision-making processes used in industry to allocate resources for powertrain development programmes. The chapter is supplemented by personal experience of the author from direct interaction with the automotive industry.

Chapter 6 covers the methodology behind the case study design and actual examples of questionnaires used during the research are provided.

Chapter 7 is a description of how the interviews were carried out including in-depth descriptions of the two subject organisations that were studied. The results from two case studies including qualitative analysis follows in Chapter 8. The formulation and testing of an algorithm to aid and automate decision and provide recommendations for organisational improvement is presented in chapter 9. The thesis is then closed with final discussion and conclusions in chapter 10.

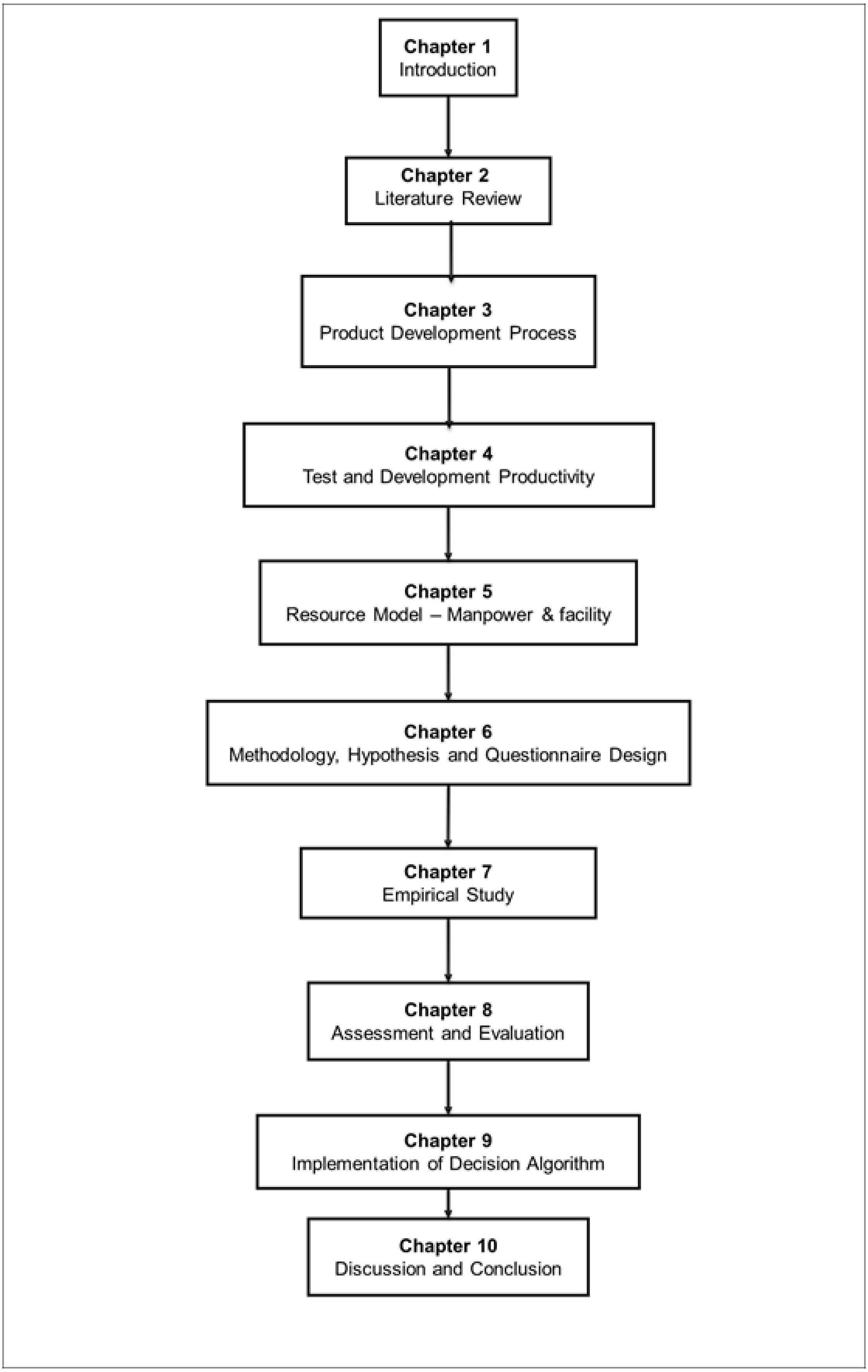


Figure 1.6 Structure of the Thesis

Chapter 2 Literature Review – Manufacturing Processes

This chapter will introduce the methodologies, theories and applications found in the literature covering automotive manufacturing processes and associated methods applied to its improvement. It begins by charting the beginning of mass production in the motor industry, ending with the latest application of ‘lean’ principles.

2.1 The Advent of Mass Production in the Automotive Industry

It is really interesting to trace back the UK history of automotive manufacturing to Evelyn Henry Ellis (1843-1913) [3]. The honourable ordered his vehicle from the Panhard et Levasson (P&L) factory where he specified engine control, transmission and with the curiosity for the brake to be on the left rather than the right. All the hundreds of parts were made by artisans in different shops in Paris using different gauges. This resulted in no two parts actually fitting together, the final assembly at P&L would entail of filing the two parts so that they would fit and then continue with the rest of the assembly. It was no surprise that the final vehicle was not the same as ordered as dimensions were not as per design.

The vehicle was imported to the UK and Ellis drove from Southampton to his ministerial seat, “the Brighton run” in five hours and thirty-two minutes to cover 56 miles. He averaged a speed of circa 10 mph breaking the speed limit set by the Red Flag law. He fought for a change in law and he won and a new highway speed of 14mph was set.

Just within a decade from this Henry Ford of Dearborn Michigan was starting a series of industrial innovations, which would transform the automotive manufacturing.

His first car was built in 1896 but he established his company “Ford Motor Company” in 1903 and 1908 he introduced the famous Model-T, this was to become the first vehicle for the masses. From the beginning he recognised the need to make standard parts “armoury practice”. He also introduced a flow process which was continuous rather than batches. Ford brought into his factory the work efficiencies concepts, which soon was acknowledged as the Fredrick Winslow Taylor system.

Frederick Winslow Taylor (1856-1915) [4] was the first efficiency expert, the original time-and-motion man -- the father of scientific management, the inventor of a system that became known, inevitably enough, as Taylorism. "In the past the man has been first. In the future the System will be first," he predicted boldly, and accurately. Taylor bequeathed to us, writes Robert Kanigel [4] in this definitive biography, a clockwork world of tasks timed to the hundredth of a minute. Taylor helped instil in us the obsession with time, order, productivity, and efficiency that marks our age.

For this reference is right to only bring forward in its historical context the father of efficiency. In Ford Motor Company during the first year produced one car for every 12 workers. This ratio was not achieved until 1934 at the Morris works. Ford wanted to achieve a mass production to feed the US market, hence he introduced single standard gauge hence standardizing specification of parts. Finally using the concept from slaughter houses cars were assembled as they went along. The efficiency of the manufacturing lines achieved massive gains for small cost. In 1913 a car was put together in 2 hours and 40 minutes rather than 12 hours and 30 minutes. This speed improvement achieved a commercial and time improvement dropping the sales price from $950 to $360. By the end of 1920 Ford has achieved a vertically integrated organisation bringing together its own iron mines, lumber mills, coal mines, glass plants and rubber plantation [4].

Going back to Taylor in the Ford factory whilst the machinery was well planned the workforce was a different challenge and growing in complexity. The whole concept was to transfer the skills to management, efficiency engineers were employed to time the work process and then recreate an efficient process reorganized scientifically to maximise efficiency. This method transferred individual skills to rules, methodologies. What is not clear how much of Taylor’s ideas where incorporated in Ford.

Up to 1955 the big three automotive industry in the US namely Ford, GM and Chrysler had enjoyed market domination, this was not being contested until other manufactures gained the knowledge of mass production. It is noted that Giovanni Agnelli of Fiat, Andre Citroen, Louis Renault, Herbert Austin and William Morris all visited the Ford plant in Highland Park and gained surprisingly quite transparent information.

European companies gained market shares over the next 20 years by having competitive product variation and introducing new product features. This automotive market competition between Europe and US would have continued if Japan had not developed a new type of production called lean production.

2.2 Toyota Production system (TPS)

In 1950 Eiji Toyoda a young engineer did a three months tour of the Ford Rouge plant in Detroit. This visit was going to revolutionise the global automotive industry.

Mr. Toyoda was born in 1913, near Nagoya in central Japan, the second son of Heikichi and Nao Toyoda. He spent much of his youth at his family's textile mill and took an early interest in machines, he said in his 1988 autobiography, "Toyota: Fifty Years in Motion" [5]. He graduated from the University of Tokyo in 1936 with a mechanical engineering degree and joined his family's loom business.

Toyoda then moved into manufacture of cars and trucks. Mr Toyoda Kiichiro president of the Toyota car company knew that if the automotive industry in Japan had to survive it needed to be competitive to US. He knew that large production batches as Ford would not suit the Japanese environment. The production volume of American worker against the Japanese one was 9:1.

The revolutionary new system of Toyota would focus on eliminating waste. A new system was born - Just in Time (JIT) [6].

The Toyota just in time production system could be justifiably accredited to Taiichi Ohno his very simple way of summarising the whole process in saying: "all we are doing is looking at the time line, from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value-added wastes".

This very simplistic quotation captures very well the pull concept, just in time and lean. In his book [6] what is very evident that yes it tackles the production process but it also highlights the respect of management had for the people. The fundamental difference between the Ford system and the Toyota is that the latter aims at making one product at the time rather than producing the same product in big amounts. Clearly in large production the stock is much bigger making the production not very economical.

As mentioned previously the respect for the people and their bigger role in the production line was a core part of Toyota JIT, in fact The Toyota production System (TPS) had two pillars:- [6]

- Just in time
- Automation, or automation with human touch

In a very complex manufacturing company which incorporates many process communications is key and fundamental. And even more so with the introduction of the innovative Just in time along the production line. In this lean and efficient manufacturing environment with parts entering along the line at the right time a new simple communication called “Kanban” [6] was introduced assuring that the correct parts are available at the right time of need and in the quantity required. This functioned as a “Work Order” within the manufacturing process. In this research this simplicity of communication in a complex development process will be kept in focus and also to how much of this lean manufacturing process can be applied to product development taking into account the handover between one stage and another in a process.

Automation simplistically had the inbuilt stop in the machine if a failure or error occurred. Rather than continuously producing errors the machine stoped and the operators intervened. This was a completely different approach than continuing to manufacture, rectify the problem and then flush out of the production the defect parts.

Toyoda also introduced the 5 why’s when confronted with a problem so as to get to the route cause. It is a really simple approach and can be applied to almost any problem-solving process. Toyota really concentrated on waste; waste of production, waste of time on hand or simply waiting, waste of transportation, waste of processing, waste of stock (i.e. inventory) and waste of making defective parts [6].

There is a lot to bring forward into product development utilising where possible the feasibility of a pull process. Not to lose sight that the TPS is a pull process which starts from the end goal and requests operation, parts from the previous machine and then move up the process to reach the end.

Another fundamental part of the JIT was the establishing of a balanced flow and production levelling the production so as to eliminate manufacturing of large inventories. The TPS manufactures what is needed and in fact Toyota Production system forecast demand is based only on needed numbers.

The success of this process was clearly shown in the later surprised announcement by Okuda of a new car with a hybrid system and a fuel economy that was a factor of two better than existing market ones. The biggest surprise internally was the delivery time which was promised in 12 months some 2 years quicker than the internal commitment. This public challenge was to gain strength in the Toyota company as pride and social responsibility to deliver commitment was at the core of Toyota culture [7] In order to bring a whole picture of the TPS bring forward the 14 principles;

1. Base your Management Decisions on Long Term Philosophy, even at the Expense of Short-term Financial Goal.
2. Create Continuous Process Flow to Bring Problem to the Surface
3. Use the Pull System to Avoid Overproduction
4. Level Out the Workload (Hejunka)
5. Build a Culture of Stopping to Fix Problems, to Get Quality Right First Time
6. Standardised Tasks are the Foundation for Continuous Improvements and Employee Empowerment
7. Use Visual Control So No Problems are Hidden
8. Use Only Reliable Thoroughly Tested Technology That Serves Your People and Processes
9. Grow Leaders Who Thoroughly Understand the Work, Live the Philosophy and Teach It to Others
10. Develop Exceptional People and Teams Who Follow Your Company’s Philosophy

11. Respect Your Extended Network of Partners and Suppliers by Challenging Them and Helping Them to Improve
12. Go and See for Yourself to Thoroughly Understand the Situation (Genchi Genbutsu)
13. Make Decisions Slowly by Consensus, Thoroughly Considering All Options; Implement Decision Rapidly
14. Become a Learning Organisation Through Relentless Reflection (Hansei) and continuous Improvement (Kaisen) living

Liker [8] in 2004 condensed these principles in the Toyota 4 P model Philosophy, Process, People /partners and Problem Solving which is shown in figure 2.1.

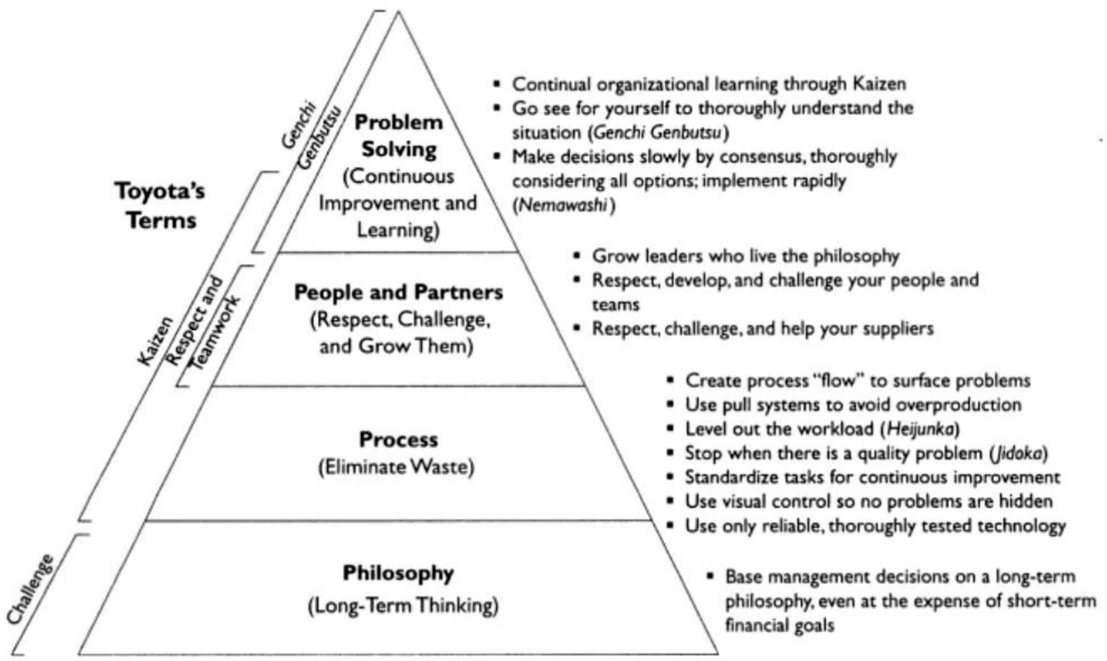


Fig 2.1 The Liker's 4P Model 14 Management Principles from the World's Greatest Manufacturer [8]

By looking at these principles it is quite clear of the importance of culture, leadership and team spirit.

"The Toyota Way can be briefly summarized through the two pillars that support it: "Continuous Improvement" and "Respect for People." Continuous improvement, often called *kaizen*, defines Toyota's basic approach to doing business. Challenge everything. More important than the actual improvements that individuals contribute, the true value of continuous improvement is in creating an atmosphere of continuous *learning* and an environment that not only accepts, but actually *embraces* change. Such an environment can only be created where there is respect for people—hence the second pillar of the Toyota Way. The Kanban system used to communicate took many years to mature its bases was simplicity and transparency of the wellbeing of the production process. There has been some application of this transparency outside the automotive industry applied to sustainable building projects [7]. This is an interesting piece of research demonstrating the solidity of the TPS approach on project delivery. The status of the project is key to ascertain progress. With a lean process transparency is a key requirement in fact Womack and Jones [7] in 2013 lean thinking, 'Banish Waste and Create Wealth In Your Corporation' defines it as the ability of all stakeholders in a system to see everything hence making easy to discover value or the opposite waste. The conclusion was that building projects will benefit from process mapping. The application of the TPS was and will be a force in combatting waste.

2.3 Value

The following sections will focus on lean and product development. One element which is common and important to grasp is value. The author would state that "if it adds no vale it has no value". According to Chase 2001 [9], there has been an evolution of the definition of value for product development. Table 2.1 describes the Value definitions.

These definitions will be useful as the history of lean manufacturing continues to unfold.

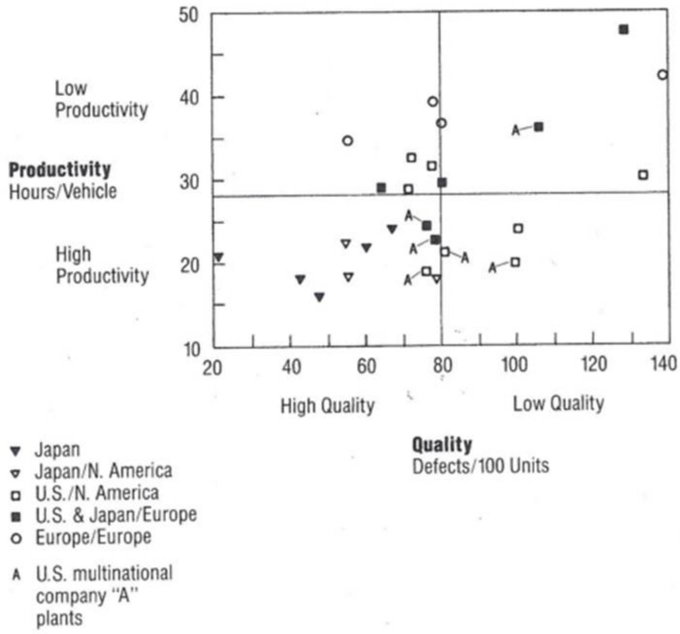
Table 2.1 Value definitions for product development (Chase, 2001)

Source	Value Definition
Miles, 1961	Value is the appropriate performance and cost.
Kaufman, 1985	Value is function divided by cost.
Shillito & DeMarle, 1992	Value is the potential energy function representing the desire between people and products.
Womack & Jones, 1996	Value is a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer.

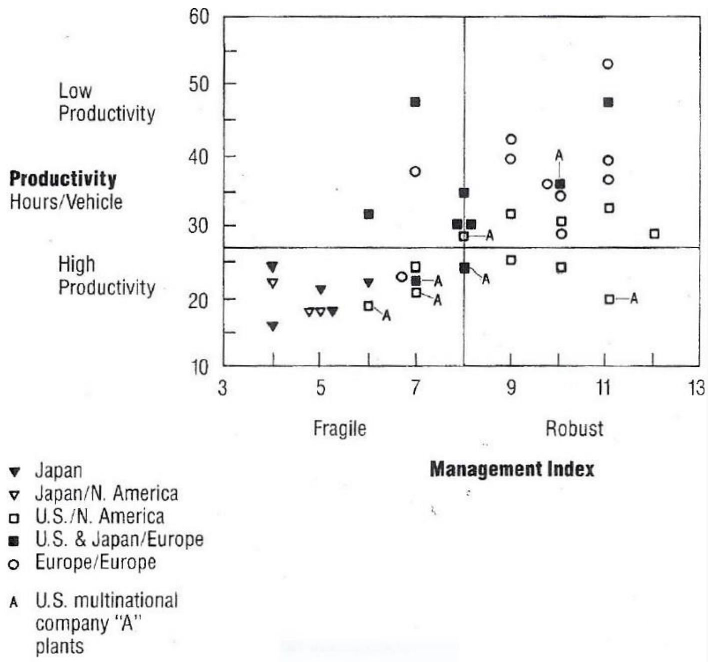
2.4 A History of Lean Manufacturing

The term 'lean production' first appeared in the public domain in Krafcik's 1988 article entitled '*Triumph of the Lean production System*' [10], however it did not come into widespread use until the publication in 1996 of 'Lean Thinking: Banish Waste and Create Wealth in Your Corporation' [7], by Womack and Jones which was a follow-up to their seminal book (with Roos), 'The Machine That Changed the World' [11]. While there is much debate and confusion, even two decades on, surrounding the difference between the Toyota Production System and Lean Production, it clear and widely acknowledged that Lean Production (and all of its variations, including Lean Principles, Lean Enterprise, etc) as a concept was derived directly from TPS. In 'Lean Thinking', Womack and Jones acknowledge the success of their previous book and the interest generated as the reason why they developed the concept as stand-alone from TPS.

In many ways Lean Production is an attempt to genericise TPS, but to say that LP is simply TPS with another name would be incorrect. The success of Toyota in the 1980's and 1990's and in some respect earlier was so profound that many organisations were keen to adopt their practises to share in that success. Even in Krafcik's [10] article in 1988, he not only clearly admires the paradigm shifting effect that TPS had on production methods from a manufacturing standing point, but he also shows evidence on the beneficial effect lean production methods has, from a business perspective, on quality and management criteria as a result of productivity increases (Figure 2.2 a and b). He even likens lean production to 'high risk/high reward' ventures in the world of finance, where mass production, with its emphasis on economies of scale and high inventory, provides low short-term risk but consequently low potential for long-term performance.



a) Productivity / quality Matrix: is the message lost in the west?



b) Lean=High Productivity? Usually …

Figure 2.2 a & b Quality and Management Criteria as a Result of Productivity Increases [10]

However, even with references to ‘The Machine That Changed the World’ and the many other publications detailing the various methods and tools used by TPS, such as JIT (Just In Time), Kanban, Kaizen, etc., the way in which an organisation could implement TPS was not clear. Womack and Jones [11] see the problem originating in the history of TPS itself, which grew organically from ‘the ground up’ as a reaction to the circumstances faced by Toyota in post-WWII Japan [12], as well as the tendency for the Japanese practitioners of TPS themselves to focus of the details of methods and practises used, but not the overriding philosophy that guided their choices and actions. Another, perhaps unacknowledged problem of organisations implementing TPS, particularly in the automotive industry, is that it is clearly Toyota’s system; adopting a competitor’s way of working can be seen as a weakness in the market, within the industry, even amongst staff within the organisation. Genericising TPS made it that much more accessible [12].

Therefore, Womack and Jones, through investigation of existing examples known to them, especially Toyota, and collaboration with various organisations world-wide that had successfully implemented aspects of TPS, they were able to derive a generic set of principles that would allow an organisation to change from mass production to lean production. The main result of this work is a philosophy of Lean, born out of but independent of TPS and free of specific tools, that is applied top-down in an organisation but lived bottom-up.

2.5 Lean – Fundamental Content

Liker, in his book ‘Becoming Lean: Inside Stories of U.S. Manufacturers’ quotes Shook’s definition of lean as “A manufacturing philosophy that shortens the time line between the customer order and the shipment by eliminating waste’ [12]. In manufacturing terms, lean can be characterised as a balance between two historic production systems; ‘craft’ production and ‘mass’ production, where ‘craft’ production example TPS utilises skilled workers with flexible “ intelligent” tools to produce small volumes of highly customised products, whilst ‘mass’ production focuses on very large production volumes of products with minimal variation and dominated by expensive task specific machinery operated by low skilled staff [13] Lean seeks to find a middle ground between these two systems that keeps the flexibility and productivity of the craft system and approaches the volumes of the mass production system without incurring the inherent wastefulness of large volumes or consequences of unexpected delays.

It is the eradication of exactly this waste, and how to do it, that is the central precept of Lean. Eliminating waste from production systems is one of the hallmarks of TPS, and even Womack and Jones credit Toyota's executive Taiichi Ohno as "the most ferocious foe of waste human history has ever produced' [7]. The seven *muda* definition of this in TPS are well known and well documented, even by the early-1990's, but this led to a haphazard approach by organisations of applying TPS to their own operations, tackling only the *muda's* or some of the *muda's* without applying TPS as an entire system, yet still expecting the same success as Toyota. This then, is where lean differentiates from TPS – by taking a wholistic, non-specific assessment of the entire system before applying appropriate tools to make improvements.

Implementing Lean requires that the five Principles of Lean are followed as a step-by-step process. To quote Womack and Jones; 'It provides a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively. In short, lean thinking is lean because it provides a way to do more and more with less and less [7].

<u>Principle 1: Identify Value</u>

Defining what value means to the customer is the critical first step of lean. Even though the producer/provider of the product/service creates the value, if that product or service does not meet the needs or fulfil the expectations of the customer, then there is waste in the product/service. With this explanation, it becomes clear how the definition of value is fundamental to the elimination of waste in the system – get this first step wrong and there is a great risk of misidentifying waste in the later steps, even creating new waste. Despite how critical this first step is to implementing Lean, much confusion surrounds what value means, and how it relates to a customer.

Kaufman provides an excellent example in his 2007 article 'The Practical Challenges in Defining Value in VM Practice' [14]. In it, the producer attempts to sell a used pair of shoes to a customer for $50.00, which the customer rejects. The producer then offers the customer a diamond, also for $50.00, which the customer accepts. Kaufman then explains that the producer *valued* both items at \$50.00, but to the customer only the diamond was *worth* \$50.00, the shoes were not.

He goes on to state that ‘People do not buy “things”. They buy the functions and outcomes that the things do.’ Thus, the aim of the producer is to provide the customer with the functions they need at minimal cost of production for the price

$$\text{Value} = \frac{\text{Function}}{\text{Cost}} \quad \Longleftrightarrow \quad \text{Worth} = \frac{\text{Benefit}}{\text{Price}}$$

and benefits the customer is willing to accept, i.e.; for value to equate with worth. Fittingly then, it is only the customer that can define value.

<u>Principle 2: Map the Value Stream</u>

Value Stream Mapping (VSM) is the method used to identify and eliminate waste in the production of a product for the entire process of making that product; from raw materials to delivery into the hands of the customer. As for the first action steps in implementing lean, there is a vast amount of literature in the public domain citing case studies of applying VSM to different manufacturers, analysing the before and after effects of VSM, and discussing ways to apply it to different aspects of production [15, 16, 17, 18].

The most significant text on Value Stream Mapping is a response to the attempts by readers of ‘Thinking Lean’ of applying Lean Principles but either ignoring or incorrectly working through the second principle of mapping the Value Stream [19]. Given the detail and effort required to map an entire production process for each product (Figure 2.3), it is no wonder that there was initial confusion and reluctance to take this step.

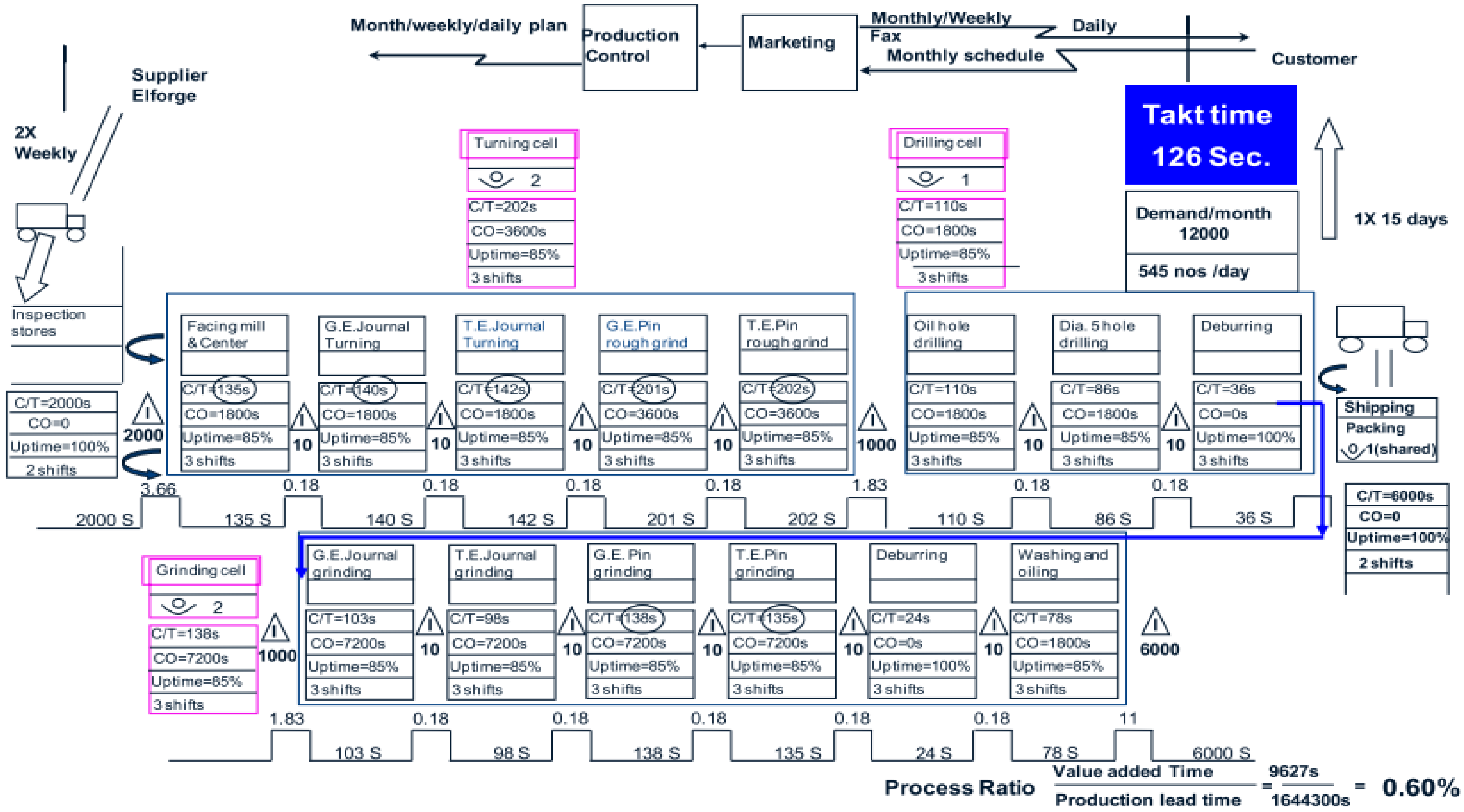


Figure 2.3 Example: Current state VSM for a domestic crankshaft production

Thus, only two years after ‘Thinking Lean’, ‘Learning To See: Value Stream Mapping to Add Value and Eliminate Muda’ was published in 1998 [19]. In it, Rother and Shook provide a detailed description of how go about creating a VSM based on three main steps per product family;

1. Create the VSM of the current state
2. Create the VSM of the future state (iterate if necessary) that eliminates waste
3. Devise a work plan and implement changes indicated in the future state map.

Rother and Shook assert the following reasons why VSM is an essential tool [19]:

- ‘It helps to visualise more than just a single process level in production. You can see the flow.’
- ‘It helps you to see more than waste. You see the source of the waste in your value stream.’
- ‘It provides a common language for talking about manufacturing processes.’
- ‘It makes decisions about the flow apparent so you can discuss them. Otherwise many details and decisions on your shop floor happen by default.’
- It shows the link between information flow and material flow. No other tool does this.’
- ‘it is much more useful than quantitative tools and layout diagrams that produce a tally of non-value-added steps, lead time, distance travelled, the amount of inventory, etc. VSM is a qualitative tool by which you describe in detail how your facility should operate in order to create flow. Numbers are good for creating a sense of urgency or as before/after measures. VSM is good for describing what you are actually going to do to affect those numbers.’

Principle 3: Create Flow

Creating flow encompasses the actions necessary to realise the productivity benefits that are revealed in the future state VSM. The term ‘flow’ in Lean Production describes a production process that produces a product not only as quickly as a possible, but as continuously as possible. This typically necessitates a major, if not complete overhaul of a traditional mass manufacturing system, not only in term of the tools, machinery and equipment used, but right down to the processes for each step, how those processes interact, even the roles and responsibilities of all involved in that specific production, from the shop floor through to management, sales, design, etc.

Lean seeks to eliminate the inherent stop-start nature of batch production, becomes easier to understand when contrasted against the traditional batch production used in mass manufacturing (Fig 2.4).

What the above example does not yet illustrate is the advantage Lean production has on overall flexibility, and therefore the reason why it is still a productive system even when producing a variety of products at small volumes. In the example above, the traditional batch method is producing in a continuous flow; one batch moves sequentially from one process to the next, usually involving large, complex, and specialist machinery. In a Lean Production environment, products comprising of the some of the same parts but that make up different eventual assemblies can move between or skip operators in a network or interrelated processes because only *one* product is affected, not an entire batch.

In addition, for a traditional mass production process to match the productivity of the Lean process, every machine and every operator must be 100% capable at all times – an unrealistic expectation. Since Lean Production focuses on building productivity and flexibility into the process not the resources, maintenance is built in and unexpected down-time is quickly compensated for, often only slowing the process rather than stopping it all together [7].

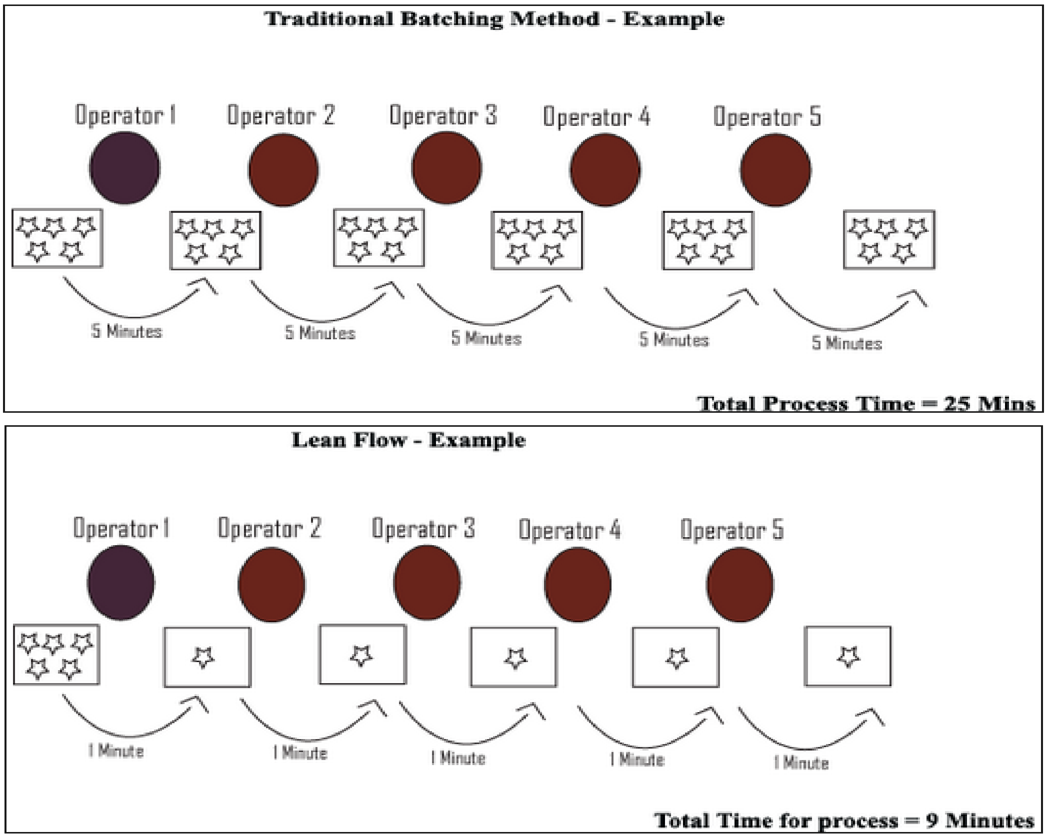


Figure 2.4 Traditional batch production compared to Lean flow production

As each product is treated individually throughout the process, Lean Production also promotes flow by dealing with quality issues at each stage of the process without interrupting the entire production line.

<u>Principle 4: Establish Pull</u>

Pull specifies that a product is only made once the customer requests it, no sooner. The main benefit of the pull system is that no product is manufactured without a specific demand for that product, thus eliminating the high inventories, storage costs and eventually scrapping of unwanted products associated with mass production.

The easiest way to understand the pull system is to take an example from the very mundane experience that inspired Taiichi Ohno to create the pull system (and Just In Time, the tool that supports it): the supermarket [7]. A customer 'pulls' products out the store when they make a purchase, this encourages the supermarket staff to replenish the shelves of those products to ensure they are available to other customers. When stock runs close to empty, the supermarket requests more stock from the supplier, and the supplier equally requests the product from the producers. The most salient aspect of this example is that customers determine what is waste by only purchasing the products they *value*: if they do not purchase the products, the supermarket no longer orders these products, the supplier allows their stock to diminish and eventually the product is no longer made. Thus, it is the value the customer places on the product, their need for that product, it what allows it to be created in the first place.

<u>Principle 5: Seek Perfection</u>

It is important to note that the five Lean Principle are steps in a cyclical process, and this is reflected in the final step: perfection. Once organisations live the Lean Principle, the natural result of a 'pull' system of production is that the harder the customer demand pulls on the process, the more impediments to flow that are exposed, consequently highlighting waste in the system that was not discovered during the first VSM exercise, perhaps even highlighting that the initial assessment of value does not quite match that of the customer. Thus, the cycle begins again, this time to perfect the Lean process that was established.

As per TPS, the application of Lean is a never-ending effort to perfect the process (not product!) upon which it is applied. Hence the constant repetition and reinforcement in the literature about 'continuous improvement' (*kaizen* in TPS); Lean is not a one-time corrective action but a 'way of life' [7].

2.6 Lean Implementation – An Organisational Challenge

As organisations world-wide began to adopt Lean Production throughout the late 1990's and early 2000's, many found that they were not able to achieve the expected success that adopting this approach seemed to promise. As mentioned above, the publication of 'Thinking Lean' was a direct response to early evidence of the difficulty experienced by organisation in real-life industry when they tried, and sometimes failed, to implement Lean. Liker's book, 'Becoming Lean: Inside Stories of U.S. Manufacturers' [12] was released as early as 1997, in part to convince the audience that this concept could be transferred from Japan to other manufacturing cultures, but also to stress that the tide had turned against mass production and was headed firmly in the direction of Lean, with automotive giants

General Motors and Ford supplying examples of their own Lean efforts [12]. However, the literature from the late 2000's begins to illustrate that these early difficulties were not teething issues associated with the acceptance of a new concept, since the amount of literature relating to implementation of Lean begins to steadily increase.

The initial thinking was that organisations were taking a piece-meal approach to implementing Lean, focusing only on tools like Just In Time (JIT), Kanban, and Value Stream Mapping to deliver their success [7,11,13,21]. The leading authorities had always stressed that Lean needed to be implemented as an entire system of production, and that the tools were not an end in themselves. What begins to emerge is that even when all principles of the Lean Production cycle are followed, it was still not a guarantee for success.

Increasingly, socio-technical factors emerged that were relevant for the successful implementation of Lean. Change management has become a critical factor. The necessity in Lean for constant communication and input from all individuals involved in the production process in order to make improvement and maintain quality, demands that the high stratified hierarchies of traditional mass production organisations be reorganised to permit effective communication. The literature by the early 2010's continually states that not only must the executive level of management be fully committed to Lean in order for it to succeed, but they must also be actively involved [13,21,22]. Contrary to the story of Toyota, which makes it appears that implementing the tools and strategies form the ground up leads to success, it becomes increasingly clear that Lean is a philosophy that must be applied from the top down thorough all levels of the organisation. Lean, then, becomes a socio-technical belief system that is constantly lived [22].

2.6.1 Problems Implementing Lean

From this point on, Lean faces increasing criticism, both for the difficulty in implementing it initially, sustaining it long-term, and for its relevancy in all manufacturing situations. Converting mass production organisations into Lean organisations has proved problematic for those organisations that do not neatly fit the template exemplified by Toyota, whose customer base was small relative to the number of variants they needed to produce, who were limited to space in which to manufacture, and had a closely-knit supply-chain around their manufacturing base. Organisations that do not have a neighbouring supply chain, produce large batches to customer demand, and/or have bases and suppliers across various national and global sites may be forced to keep stock as JIT is not applicable without considerable risk [21,22,23].

Often, changes that are made to implement Lean do not reflect well for the business as the traditional accounting structure are based around mass production, where value is place on processing time, labour hours, assets, capital investment, etc. What has emerged is that these traditional control systems of accounting management are incapable of accurately assessing the benefits for the innovations that come with Lean Production, thus, what may in fact be a success on the shop floor appears to be a costly error in the management budget meetings. As a result, a branch of Lean Accounting has emerged that puts more emphasis on non-financial controls to monitor success [24].

Another frequently stated challenge in implementing Lean is the demand on human resources. On top of the change management required to ensure that the entire workforce adopts a positive attitude to the change towards Lean, the emphasis on the high level of participation, low-level decision making, continuous improvement and continuous learning, has proved an issue not just as the initial stages of implementing Lean, but also the ability to maintain Lean practices over the long-term [22,23,24] .There is conflict in the literature between the affects Lean production in an organisation has on productions staff, particularly from middle-management down to the shop floor. Some studies state that, as claimed by TPS and Lean experts, the increased involvement and interaction required of Lean practises, as well as higher interaction amongst varying levels of the organisation, leads to increased employee satisfaction and productivity. Conversely, other studies claim that the pressure to be continuously productive, forcing low-level staff make significant decisions but being forced to do monotonous standardised task, the effort required my middle managers to ensure all systems are in flow, and the demand on all to constantly learn and improve has in fact increased stress on workers, there even being some evidence that Japanese works felt increased stress due to the implementation of Lean [23].

Finally, a major criticism of Lean is the time and effort required to establish and maintain it as a production system. Even the experts cannot agree with how to begin making the change in an established manufacturing organisation; start with a small, contained part of the operation, or make a wholesale change [7,12,13,22]. Others found that the effort to sustain a Lean change, with the continual improvement required of both processes and human resources was unsustainable in the long-term.

2.7 Summary

The literature reviewed in this chapter covered the origins and evolution of Lean principles in manufacturing and provides insight into different methods to eliminate waste and/or improve productivity. The next chapter describes the automotive product development process and a review of relevant literature.

Chapter 3 Automotive Product Development Process

Within the last decade, and particularly following the Global Financial Crisis, the Automotive Industry has been steadily refining the processes used to drive product development, so much so that at the time of writing a very uniform concept of the Product Development Process has emerged even at a global level. It is the author experience that this typical Product Development Process is commonly used with minor variation across a number of the world's OEM's.

3.1 Introduction

Figure 3.1 shows a conceptual view of the entire product development process, adapted from Ulrich and Eppinger [25].

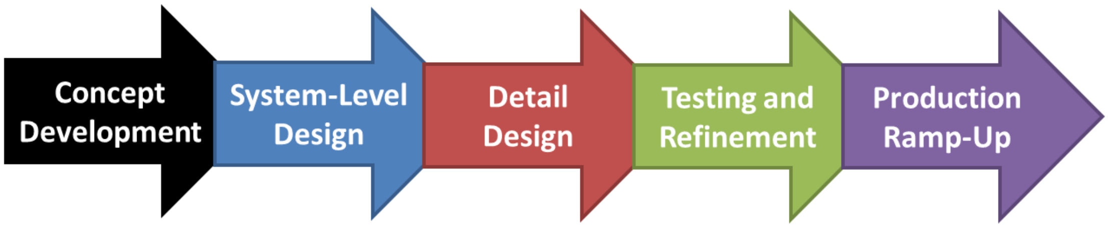


Fig. 3.1 Phases of Product Development

Given the close corporate ties of many of the leading manufacturers, common suppliers, and increasing mobility of the skilled talent pool, it is hardly surprising that such a widespread adoption of concepts would occur. One originating and fundamental process representing these widely similar approaches is the Ford Global Product Development System (GDPS) [26], launched by the Ford Motor Company at the beginning of 2008 as a concerted strategy to address the disparate product lines and development processes across the company's global operations. The key mantra supporting the One Ford concept; 'One Team. One Plan. One Goal', neatly illustrates not only the philosophy behind the ideal, but it's very structure.

The One Ford Global Product Development System necessitated a restructuring of the product development teams to standardise and align functional skill teams across its global business units [27]. In addition, external suppliers under the GPDS concept are integrated as part of the 'One Team' – a significant change to the prior Ford Product Development System (FPDS), as this obligates the supplier to comply with the One Ford concept [28]. This matrix structure enabled the standardisation of development processes globally, and more importantly, allowed a single product development team to guide the development of all its global products, right down to the use of a common reporting tool for providing standardised information to the global Executive level. The real-world implication of such a structure is two-fold: the execution of each product development task must be highly structured and coordinated, and there is a top-down approach to the distribution of responsibilities. As previously stated, this approach to structuring and delivering product development within the Automotive Industry is becoming an unofficial standard.

The scheduling for completing a development programme is typically also top-down; a timeline is set from the beginning to the end of development, and the timeline is further broken down through the management chain into the specific tasks required to meet the programme delivery. The project scheduling structure that Ford Motor Company uses as part of its GDPS is known as the ‘Perfect Drawing Process’ (PDP) which evolved out of Mazda’s ‘Final Drawing Plan’ with the aim to reduce process rework [28]. The PDP is related to familiar project scheduling tools in that along the timeline to completion, regular milestones or gateways are scheduled – these define the engineering need and deliverable required for successful programme delivery [29]. It appears that the PDP functions very similarly, and is likely to be based on, Stage-Gate® processes that emerged in the 1980’s [30]. In order to progress through to the completion of a product development cycle, each Stage must be successfully completed to allow progress past the next Milestone or Gate. In other words, progressing through the development programme depends entirely on successfully achieving all deliverables that lead up to that phase of development. In addition to defining a critical deliverable along the path of product development, Gates also serve as real-time markers along the development timeline during which point reviews are typically held with relevant stakeholders, so if a project is in trouble it is often during one of these reviews that remedial action or the extreme decision to terminate the project takes place [30]. In keeping with the GPDS, each stage in the PDP is highly planned, high prescriptive and links directly back to high-level process and goals.

Stage-Gate® and similar derived development processes make an implied demand: “sharp, early and fact-based product definition” [31, 32] before planning can begin. As these project scheduled processes originated historically in manufacturing-only operations and were applied typically after invention and innovation had taken place, dividing the product development process into discrete deliverables that can be realistically executed is easier to define. Recently, the traditional Stage-Gate process has been criticized for its lack of flexibility and inability to accommodate innovation within the process, often with respect to software development. In this area, it has been possible to modify Stage-Gate and/or combine it with concepts like Agile to incorporate innovation, for example, by accommodating iterative development loops or even allowing the product definition to remain somewhat undetermined at the beginning of the development process to give the product scope to grow with new information and input as the development process progresses [30].

Powertrain Development in the Automotive Industry exists between these two product development extremes; engine programmes involved both hardware development and validation, software development and validation, and calibration of vehicle attributes within the software to control the functional hardware to the customers' requirements. It is now almost universally the case for all OEMs that engine development meets not only internal company targets to bring a competitive and unique product to the markets but must also meet strict global criteria, e.g.; legislated emissions target for various global markets. This work is very resource intensive including test facility, equipment and skilled human resources. The challenge in industry has been; how to divide the powertrain product development programme into clearly defined, manageable stages that also respects the complexities and limitations imposed by the resources (facility and human) to successfully deliver the programme.

As already stated, the Stages are defined at the beginning of the product development process along with their corresponding Gates (deliverables) and once these are set the engine development attributes become fixed for the entire development process.

3.2 Application of Lean in Product Development

In 1996 Slack [33] referred to Womack and Jones [7] where it is put forward that application of five key principles to an entire enterprise (including product development) will lead to achieving a 'lean' state. These 5 principles are listed below and have the specific aim of waste elimination.

1) Precisely specify value by specific product.
2) Identify the value stream.
3) Make value flow.
4) Let the customer pull value.
5) Pursue perfection.

Slack continues to make the observation that at that point in time, the 'bulk of the discussion' and focus had been in the area of manufacturing, inferring that little 'lean' application was then present in product development. It was also stated that the processes used in manufacturing versus product development have 'striking differences'. The paper presents the problem of study as 'whether the value stream mapping and lean principles, which have been successful in facilitating the lean transition in manufacturing, are effective tools in identifying waste and identifying an improved product development process future state'. Figure 3.2 to 3.4 show the customer value relationship [33]. What follows is a critique of the first lean principle, 'value' and its applicability and adaption to product development.

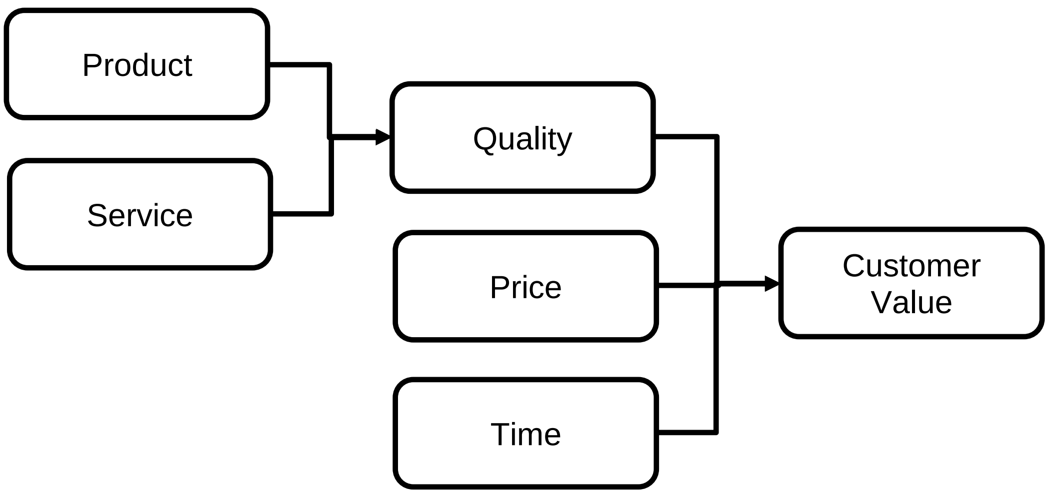


Figure 3.2. Customer Value Relationship with Time Attribute, Slack [33].

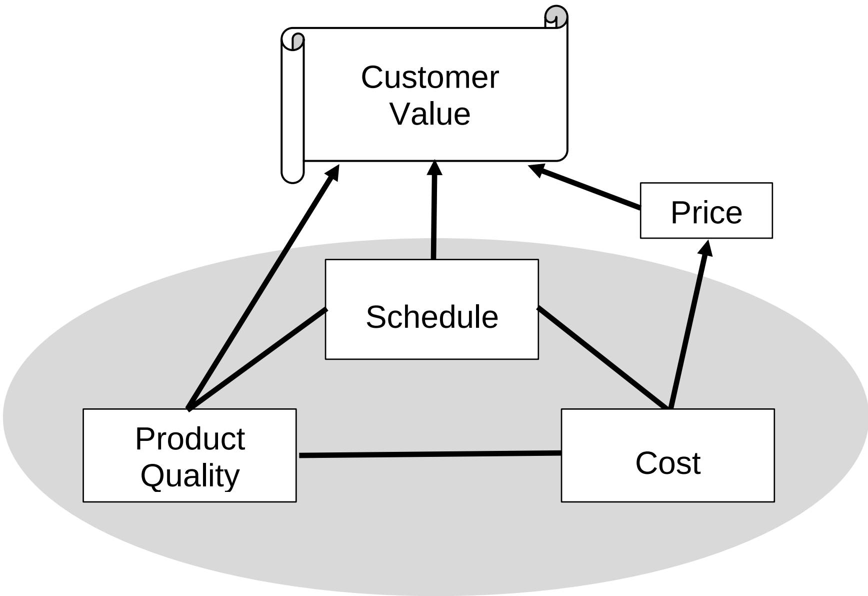


Figure 3.3 Primary Attributes of Customer Value in Product Development, Slack [33]

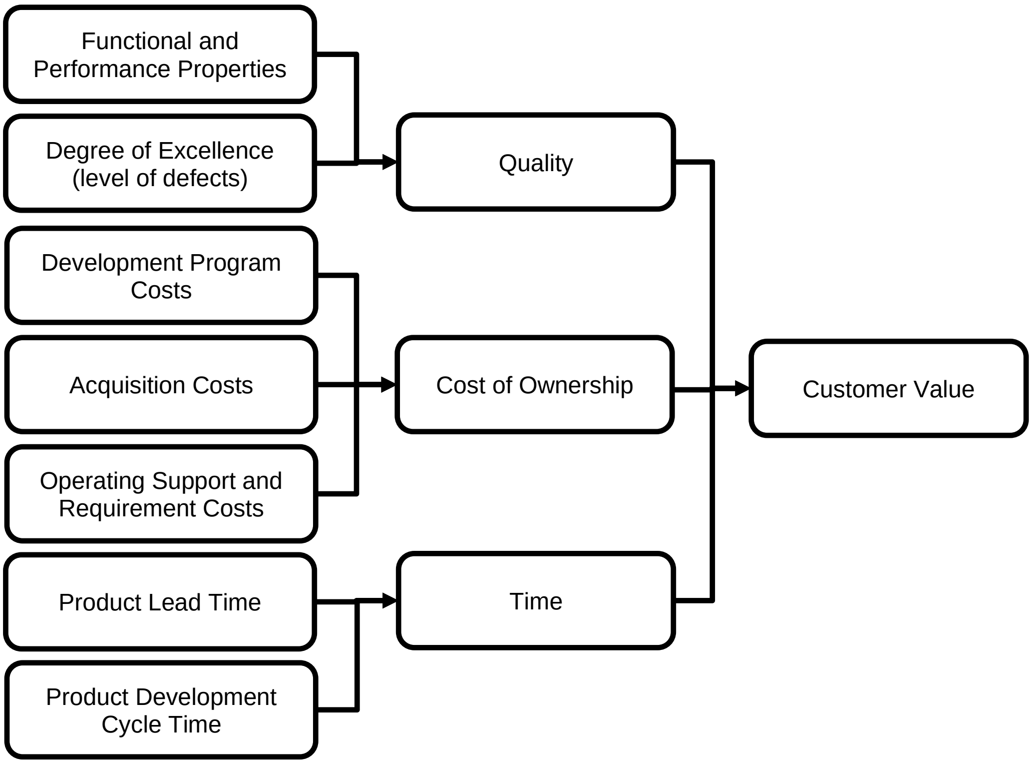


Figure 3.4 Expanded Product Development Customer Value Model, Slack [33]

Browning et al [34] also discussed the possibilities of lean product development and mentioned that some firms were attempting (in year 2000) to implement lean product development processes. They state that most of a product's life cycle cost is determined before production i.e. during development. The complex nature of product development activity versus typical manufacturing activity is highlighted including the need to be 'creative' and 'iterative'. Product designers are said to 'start with one design, find it deficient in several ways and then change it'.

3.3 Application of Value Stream Mapping in Product Development

An analysis of lean manufacturing applied to product development is presented in *Application of Value Stream Mapping in Product Development* [35]. It is based on the following:

Lean: is a production philosophy that focuses on the streamlining of value-added activities and eliminating waste within the process with the goal to better meet customer demand." The author would simply add that if it adds no value it has no value.

In this concept time is not specifically mentioned. Womack and Jones, [7] (1996) formulated five key lean principles that are expected to be addressed in order: Specify Value, Identify the Value Stream, Flow, Pull and Perfection. Definition of value: "A capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer" is the element 'the right time' implies it fits in their value stream? According to this definition, Value is described by three main attributes: Quality, Cost of Ownership and time. Slack [33] (1999) argued that in Womack's approach to value is measured against an ideal, a condition without waste, while the customers are sensitive to their need in the context of the entire market and they compare products to each other. The Value stream is all the activities required to provide a specific product, service or both through the "problem-solving" task (from concept to production launch); "information management" task (from order-taking to delivery); and "physical transportation" task (from raw material to a finished product) of any business [7].

According to Womack and Jones’s study [7], three types of activities could occur during the value stream: (1) Value Added (2) Non-Value Added (3) Necessary Non-Value Added. Slack [33] later added a fourth type of activities which not only do not create any value to the customer, but they reduce customer value.

Flow: The next principle in lean thinking, after specifying the value and identifying the value stream, is making value flow. Flow is defined “As the lining up of all necessary sequences of activities required to achieve a steady continuous job flow, without interruption, wasted steps, batches or queues” (Slack [33]). There are three techniques that make the flow more smoothly: (1) focusing on actual objects and values associated them, (2) ignoring the traditional boundaries of jobs, careers, functions and firms and (3) rethinking specific practices to eliminate backflows, scrap, and stoppages of any sort [7].

Pull: The fourth principle in lean concept is Pull. This principle applies in the whole value stream and thus means that upstream should not produce a good or service until the immediate customer downstream request it. This principle creates the ability to design, schedule and produce exactly what and when the customer wants while inventories are reduced [7]. Kanban and Just-In-Time are two related tools used to control resupply and to optimize inventories.

Perfection: The fifth and final principle of lean concept is perfection. Perfection plays an important role in getting value, so strive for perfection by continuously removing wastes because when the first four lean principles are fulfilled things will start to happen and these principles interact with each other in a vicious circle. The faster flow exposes hidden waste in the value stream, the harder you pull, and the more the disruptions and bottlenecks in the flow can be revealed and removed [7]. To pursue perfection, every organization needs to have both continuous radical and incremental improvements.

Waste: The Toyota Production System defined three types of waste, they are Muda ("non-value-adding work"), Muri ("overburden"), and Mura ("unevenness"). Usually all these wastes cannot be seen separately, they are interconnected. For instance, when a process is not balanced, this leads to an overburden on equipment, facilities and people which causes of all kinds of non-value adding activities.

Muda: (*English: Waste*) In management terms it refers to a wide range of non-value-adding activities. Eliminating waste is one of the main principles of the Just-In-Time system, the main pillar of the Toyota Production System. Considered as waste are unnecessary financing costs, storage costs, and worthless stock of old items

1 Overproduction;
2. Waiting;
3. Transport;
4. Inappropriate processing;
5. Unnecessary inventory;
6. Unnecessary motion;
7. Defects;
8. Unused human creativity

Muri (*English: Overburden*): Eliminating overburden of equipment and people is one of the main principles of the Just-In-Time system, the main pillar of the Toyota Production System. To avoid overburden, production is evenly distributed in the assembly processes

Mura (*English: Unevenness or irregularity*): Eliminating unevenness or irregularities in the production process is one of the main principles of the Just-In-Time system, the main pillar of the Toyota Production System.

Chapter 4 Test and Development Productivity

This chapter covers a measurement method for Test and Development Productivity that has been applied in real improvement programmes in the automotive powertrain development and testing sector.

4.1 A Metric for Test and Development Productivity

Test and development facility productivity is measurable. A concept based on four KPIs (Key Performance Indicators) or ‘levers’ has been used by the author and others [1] during many consultancy projects. The concept as well as an empirical summary of the data collected from many test and development organisations is shown in Fig. 4.1. Further detail is given in [52, 53] however a brief description of the ‘4 lever’ metric is given here.

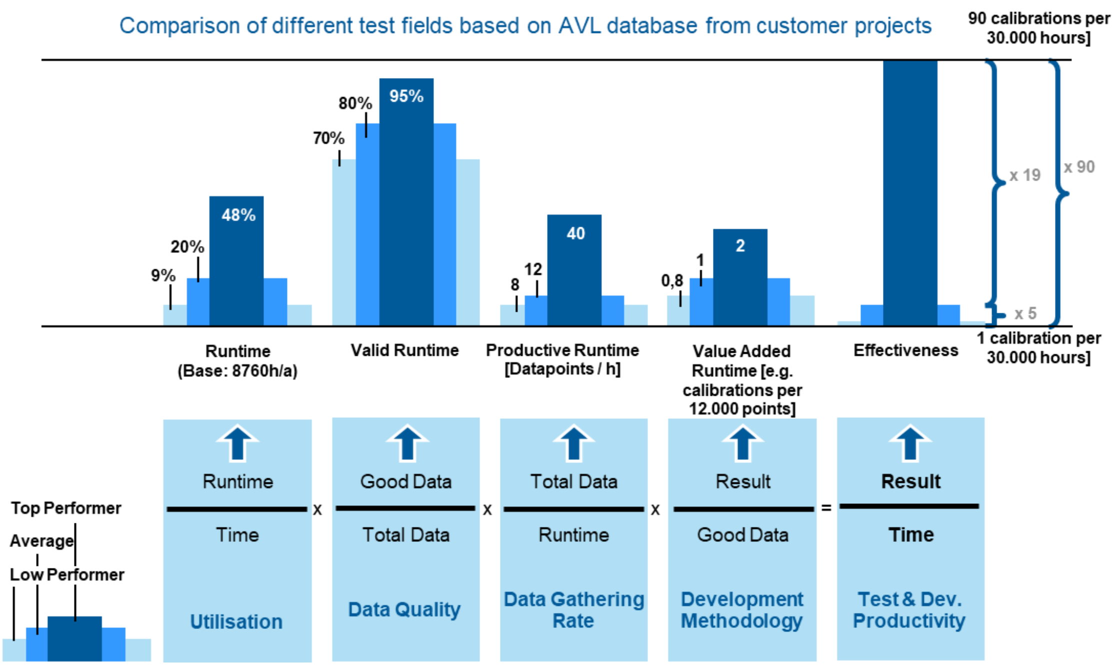


Figure 4.1 Metrics for Test Facility Productivity [1]

The four KPIs are arranged as series of factors resulting in an overall measure of productivity. This result has the units Result/Time and describes a task in the development process being delivered within a specific time. By example: an engine calibration is produced 3 months. The other 4 factors in the equation contribute to the result in a multiplicative way – i.e. any relative improvement in each of those 4 expressions can also be seen with the same percentage in the main result.

The expression Result / Good data describes the engineering approach or development methodology chosen – this is not influenced by test operations. By example this could be delivery of one engine calibration task requires 9000 steady state measurements. This means, test operations need to deliver 9000 good data points to enable engineering to calibrate an engine. If engineering finds a method to reduce this requirement by 900 data points, test efforts are reduced by 10% and the efficiency is increased by about 11%.

The expression of Good data / Total data addresses the quality of the data being produced, which is mainly influenced by testing methods. This can also be viewed as a measure of 'first time through', expressing the expectation that all data points are good data points. By example we assume 9000 required good data points vs. 11.000 data points actually taken due to the need of having to repeat 2000 data points.

The expression Total data / Runtime refers' to the data gathering rate. It describes all data gathered divided by the runtime required. By example 11.000 data points may be gathered in 1100 hours.

The Runtime / Time factor describes the facility utilization achieved in the test field – this is expressed as the ratio of runtime and available time. The latter can be any representative time interval (e.g. facility manned hours per year) but is typically set at 24hours/365days to allow meaningful benchmarking between test facilities.

Figure 4.1 also contains benchmarking data obtained from a number of consultancy exercises with various test and development organisations. The histogram for each KPI includes a 'low performer', 'middle performer' and 'high performer' bar. It is evident that there is a large range of performance as measured by the 4 KPIs. Taking the top and bottom performance values for each KPI and calculating a top and bottom Test and Development Productivity score reveals that a high performer is a factor of 90 more productive than a low performer. This of course is a hypothetical case because it includes the assumption that the high and low performers across the KPIs are the same organisations. However, it is still illustrative of the multiplicative power of the KPIs and large opportunity for improvement for many test and development organisations.

As stated before, the Development Methodology KPI is engineering controlled i.e. the type and amount of good data needed for a particular result. The other three KPIs are typically under the control of test operations. From another viewpoint the Development Methodology KPI can be interpreted as effectiveness or ‘doing the right thing’. The three testing KPIs (Utilisation, Data Quality and Data Gathering Rate) can be interpreted as efficiency i.e. ‘doing the thing right’. It follows that if an organisation is both effective and efficient then it is also ‘productive’ supporting the argument that the multiplicative result of the 4 KPIs is a measure of productivity.

4.2 Practical Application of Test and Development Productivity

Practical application of the metric to actual productivity improvement involves assessment of the subject organisation and selection of the improvement actions necessary to attack the individual KPIs. Table 4.1 contains a summary of the types of actions that can affect the four factors (KPIs) of Test and Development Productivity.

In some cases, it may be appropriate to focus wholly on one KPI. Table 4.2 lists common causes of poor data quality in test facilities, these manifest as a reduced value of the data quality KPI (Good Data / Total Data). Furthermore, process have been developed to provide a mechanism for data quality improvement. Figure 4.2 is one such example and is a process jointly developed at JLR [53]. The object is to improve data quality only when necessary to a known target and to uncover situations when the data quality demanded by the engineering development requirement is not practically achievable. This has proven a useful tool for determining the need for facility investment i.e. any expenditure on upgraded testing equipment is directly quantified.

4.3 Summary

This chapter has focused on a metric to measure productivity in Test and Development facilities. General examples have been given of practical application of the metric, supporting its validity to drive performance improvement programmes in the real world. The rest of this thesis now concentrates on a method of productivity improvement involving organisational consideration and change.

Key Performance Indicator (KPI)	Improvement Action Categories.				
	Standardization	Tools, Instrumentation	Development Methodology	Processes	Organization
Runtime/ Time	Reduce preparation time	Utilize unmanned hours	Adopt methods that enable automated testing	Appropriate and synchronized processes maximize availability	Operational model, resources, roles and responsibilities
Total Data/ Runtime	Standard for stabilization and measurement times	Select measurement devices for minimum cycle times	Rapid data collection techniques e.g. SDS	n.a	For manual operation working practices impact data collection rate
Good Data/ Total Data	Automation parameterization standards reduce chance of failure	Capability and online monitoring define achievable data quality	Methodology defines data quality targets and vice versa	Various processes, e.g.; maintenance, preparation, influence data quality.	Execution of maintenance on instrumentation and UUT influences data quality
Result/ Good Data	Reuse of methodology	Suitable tools enable and simplify the usage of development methodology	Defines what data is required	Development process defines methodology and best practices	Skills and experiences, motivation, costs

Table 4.1 Summary of Typical Actions for the Improvement of KPIs [1]

		Error Category					
		Human Errors	**Skills Lacking**	**Lack of Definition**	**Values out of Control**	**Control Limits not set right**	**Breakdown of Equipment / Facility**
Test Phase	**Test Planning & Preparation**	Wrong Hardware Spec	Does not understand Test	Channels Missing	Set right controllers up	wrong definition of limits	Paper, Filter OK for msmt. ?
	Text Execution	Typing Errors	Cannot run test	Where to mount sensor	Oil temperature too low	human error	Equipment not calibrated
	Test Postprocessing	Wrong Files Taken	Does not understand Software	No predefined reports	n.a.	model quality not achievable	n.a.
		All these lead to test repetition (= add on cost)					
	Corrective Measures	Standardization	Standardization	Standardization	Standardization	Standardization	Standardization
		Qualification	Qualification	Qualification	Qualification	Qualification	Qualification
		Automation	Automation	Automation	Automation	Automation	Automation
		Warning System	Warning System		Warning System		Warning System
					Design / monitor a robust system		Design a robust system
							Professional Maintenance

Table 4.2 Common Causes of Poor Data Quality in Test Facilities [1]

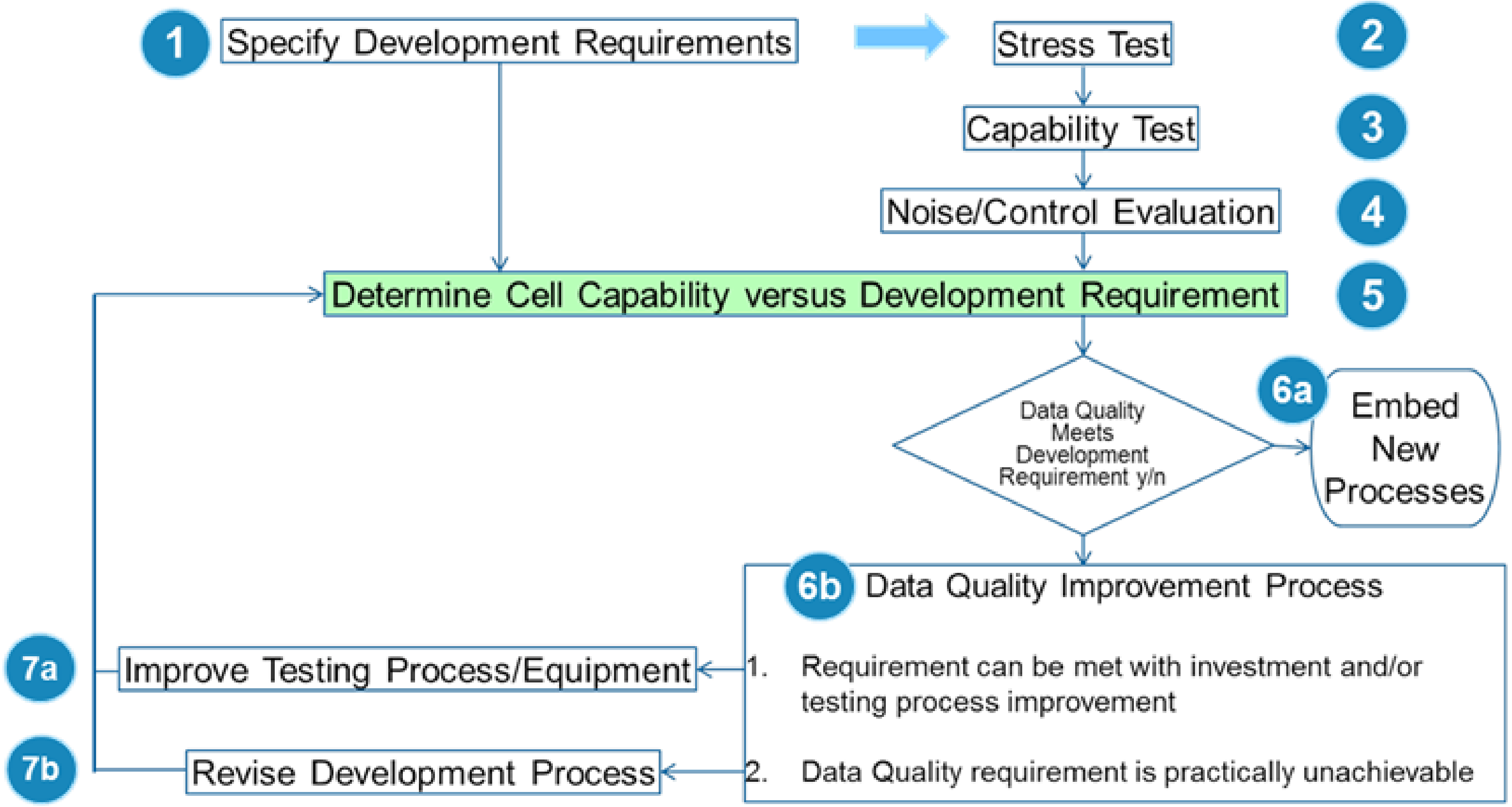


Figure 4.2 Synergistic Optimisation of Development and Test [1]

Chapter 5 Resource Model – Manpower & facility

Currently, there appears to be no literature available in the public domain that specifically addresses the actual state and decision-making processes used in industry to allocate resources for powertrain development programmes. The following, therefore, is a generic description of the way in which the author has experienced the allocation of manpower and facility resources at several automotive manufacturers.

5.1 Introduction

To begin with, an important distinction must be made; the powertrain development organisations that these resource models reference are departments within global corporations, and as such, are sizable organisations in and of themselves. For example, engine calibration departments could typically be made up of over one hundred staff, and that is per engine type (gasoline or diesel), and test facilities specifically dedicated to programme development can number between thirty and sixty individual dynamometers. Therefore, the allocation of resources is highly complex.

5.2 Process for allocating resources

The allocation of manpower and resources for a powertrain programme begins much higher up the organisation structure than would initially seem intuitive. Detailed characteristics such as performance targets, handling quality and emissions targets are determined for a vehicle programme even before a concept has been decided. Some of these characteristic, such as emissions targets, can be driven by legislative requirements, others are a result of extensive marketing research and analysis. And despite the precise engineering nature of some of these characteristics (e.g. a quantifiable numerical value), the ultimate decisions for what becomes a requirement for future vehicle programme attributes are made by very senior management. This process alone is a consequence of the type of global, top-down, cross-functional organisational structure put into practise by so many automotive manufacturers.

Once the requirements have been decided, these will be broken down into attributes for the engine programme which are then distributed to the existing functional teams. The functional teams will deal with specific powertrain development tasks such as thermal management, fuel efficiency and emissions. Specific manpower resource is determined for each task, typically based on experience from similar programmes in the past and how many people (of appropriate skill sets) were required to deliver that attribute. These teams could then allocate dedicated test facility resources, such as an engine test cell, for the duration required for the delivery of the attribute (figure 5.1).

This process of attribute distribution is typically referred to as an 'attribute cascade', with the hierarchy of task allocation as follows;

Attribute –> engineering target(s) –> system target(s) –> component target(s).

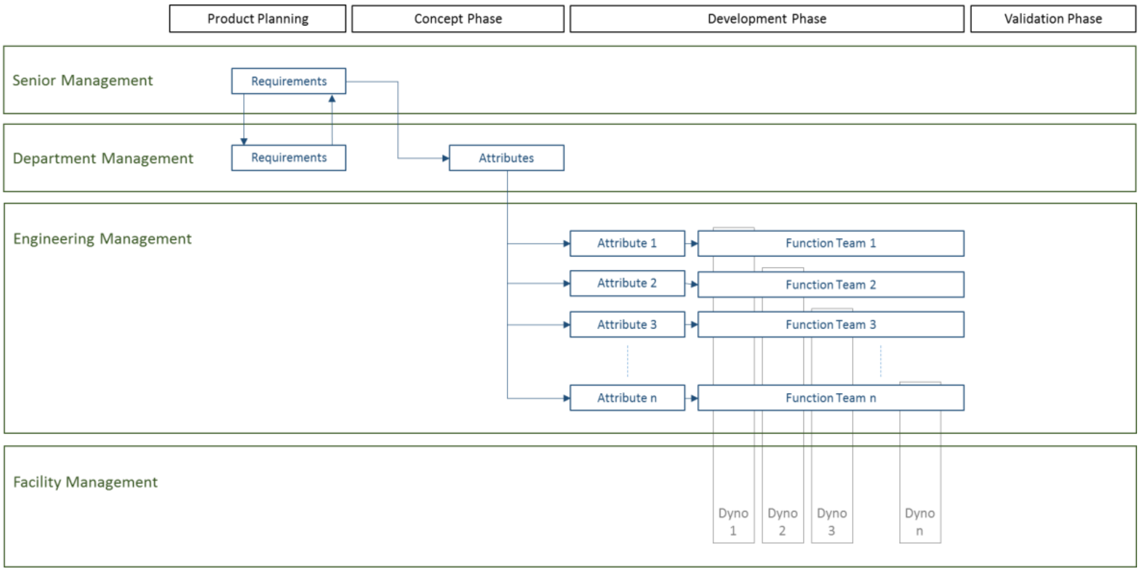


Figure 5.1. Example of Process for Allocating Resource in Powertrain Development

5.3 Manpower

As mentioned above, calibration teams for powertrain development tend to be very large, and this does not include the various component development teams and other cross functional staff and skills required to meet the delivery for the development phase, but for the sake of simplicity, engine calibration will be taken as the example.

Each new powertrain development programme will be allocated a dedicated team from within the calibration team. The programme team typically consists of ten to fifteen people depending on the importance, complexity and innovation of the programme, and this team many handle the development of one or more interrelated attributes. For example, a team for a diesel engine programme may be further split into smaller teams dealing with the attributes of combustion, after-treatment and vehicle validation. How attributes are distributed amongst and within teams is rarely a static formula, due to the rate of technological change in powertrain development, and also the internal culture and history of powertrain departments. As the increasing complexity of powertrains appears set to continue in the near future, so too does the increasing size of development teams.

Each individual attribute team of three to five people typically has one senior engineer or calibrator as a leader, supported by more junior members, such a recent graduate. The leaders are often highly experienced, with many years of delivering the same attribute for development programmes, and whilst these individuals may work on other attributes throughout their careers, typically the attributes they work on will be related and thus the individual will have a focused expertise and a working practise unique to themselves. Consequently, product development departments tend to have well established teams across the entire department that will focus on the same attribute from programme to programme. This is a benefit in terms of consistency, but a hindrance with regards to flexibility.

5.4 Facility

The most striking aspect of this process of resource allocation is the fact that the facility resources are not only allocated last, but that it these resources are allocated to the development teams for their exclusive use for the duration of a development programme. Given the extremely high capital investment of these facilities (engine test cells, including dynamometer, measurement equipment and test cell conditioning currently cost well into the millions in any currency), plus the overheads of maintenance and compliance, it seems unusual that the facility resource is not a high priority in the allocation process. The author is aware of two possible supporting reasons for this case.

The first reason links back to the ‘pull’ principle of lean production; the facility resource is only used when the customer demands. Therefore, rather than viewing an idle facility as an unused resource, the other perspective is taken where a facility is only providing value if it is to meet a customer demand. Any use of facility resources not directly linked to customer demand is considered a form of waste.

The second and most common argument is that the facility is almost always intended to be operated at full capacity. This is a broad statement of a concept that comes in two parts. Once an attribute or project development team is allocated a facility resource, then that resource is considered to be run at full capacity from a planning perspective. Once all of the resources are allocated to a development programme, the facility is considered to be incapable of accepting additional work. Whilst many OEM’s do monitor utilisation metrics of their test facilities in terms of run-time, data output, scheduled down-time, etc., this is very often a monitoring practise within the facility department itself and does not factor into the resource allocation process for a development programme. Regardless of the actual utilisation performance of development test facilities, it is typical for these facilities to be planned to run at full capacity as it is a common policy amongst OEM’s to have fewer resources than would be needed to meet peak testing capacity. By factoring a need to outsource testing work during peak periods, it ensures that the facility resources are fully allocated during normal workloads.

5.5 Critical Observations

Though common throughout the industry, the process for resource allocation has a number of weaknesses that cause persistent and repeated problems from development programme to development programme.

Dedicating one facility resource to one team for the duration of an attribute delivery invariably leads to under-utilisation of that testing resource. Even when the automation technology is in place to test unattended, the effort required to plan, prepare, and verify the testing schedule each day is often higher than is manageable for a team also required to perform calibration tasks. Thus an allocated test cell can regularly remain idle whilst the attribute team catches up on the analysis of previous work and makes decisions on how to continue. The author has long observed this discrepancy between high manpower utilisation and low facility utilisation, and the effects this has on programme delivery.

Even under the best circumstances it is difficult for development teams to analyse and post-process the vast amounts of data generated in modern powertrain development programmes. One possible reason for this is that it has been difficult to estimate and track the work of powertrain development programmes because, unlike in manufacturing, powertrain development programmes produce information not discrete physical products. And because information is often intangible, interrelated and generated in parallel, it has been traditionally very difficult to accurately assess the work produced in development [36]. There is also a practise to allocate manpower so that individuals are always working to full capacity. The net result of these practises is that there is no slack within the development teams to allow for unforeseen problems, let alone innovate and develop improved process.

As problems in powertrain development programmes invariably arise due to the innovative nature of the work, the author has frequently observed individuals from other teams pulled in to alleviate the workload on another teams at a critical stage in their programme. The knock-on effect of this type of fire-fighting strategy is that another team is depleted of a necessary resource and they in turn also run into trouble at a critical stage of their own programme and need assistance. It is not unusual for this cycle to continue from programme to programme.

Another factor in this comes from the scheduling of the programmes themselves. There is no time allocated for problem solving or innovation, as there is an expectation that the teams can deliver the work 'first-time-through' based on previous experience. This pressure to 'get it right first time' encourages individuals to always take the safe option, so that when problems do arise, they have neither the time nor the experience to innovate their way to a solution [36].

Thus, if the facility resources were geared and allocated in such a way as to operate at high utilisation, the manpower resource under this current structure would not be able to support the potential output.

5.6 Summary

- Resource is allocated based on prior experience with similar programme tasks

- Resources are allocated according to an attribute cascade, starting with manpower and finally facility

  Test facilities are allocated to the development teams for their exclusive use
- Once a test facility is allocated it is assumed to be fully utilised
- One advantage of this way of working is that the cell is a flexible resource
- A typical operational state is high manpower utilisation and low facility utilisation
- The impact of low facility utilisation is that product development costs begin to spiral; the under-utilised facility remains a cost burden, and drives outsourcing. You pay for the test twice.
- With this resource model, with the facility being allocated last and valued least, it is very difficult to take actions to increase facility utilisation

Chapter 6: Methodology, hypothesis and Questionnaire Design

Programme resource planning and associated challenges were discussed in chapter 5. This chapter focuses on how product development tasks are performed and by whom and how to design questionnaire to achieve objective results of the research cases. to bring out the two modes of handover and validate the hypothesis which are highlighted later A detailed look at the real actions currently delivering the programmes versus what is truly necessary can reveal multiple sources of waste.

This chapter proposes a solution involving fundamental changes in test facility and engineering resource allocation. Identify the two distinct types of development task delivery: firstly, Professional Handover, and secondly, Factory Handover. These represent extremes of organisational practices, personal behaviours and skills furthermore look for potential to become more efficient by introducing a mix of these handover in existing work practises.

It is further proposed that for any development and test organisation there is an optimum split between the two operational types that maximises productivity.

This chapter concludes with the description of a proposed case studies to determine if the hypothesis presented is valid and is applicable to organisational performance improvement.

6.1 Development Program Execution

Programme timeline and gateways trigger development actions and reporting. Product functional and quality requirements (attributes) are cascaded to the individual teams that are responsible for the actual delivery (see figure 6.1). Product attribute status reviews are triggered at program gateways or quality gates. As each gateway is reached in the program timeline, information is presented as to which product requirements are satisfied. Appropriate action is then determined to tackle any product deficit. Executive reporting often takes the form of a ‘red, amber, green’ status or another simple identification and is as follows:

> Green – Product attribute is in specification with no known risk to program continuation.

Amber – Product attribute is out of specification but there is a feasible plan in place to recover in time for projected start of production.

Red – Product attribute is out of specification but there is no feasible plan in place to recover in time for projected start of production.

The knock-on effects of necessary containment action may drive product launch delay. In extreme cases, if there is no feasible recovery plan, then the decision may be made to cancel the product launch. At this level the author considers the product development process described as essentially common across global automotive manufacturers. A key hypothesis presented here is that the major differentiator between development and test organisations lies in the practical delivery of product development tasks.

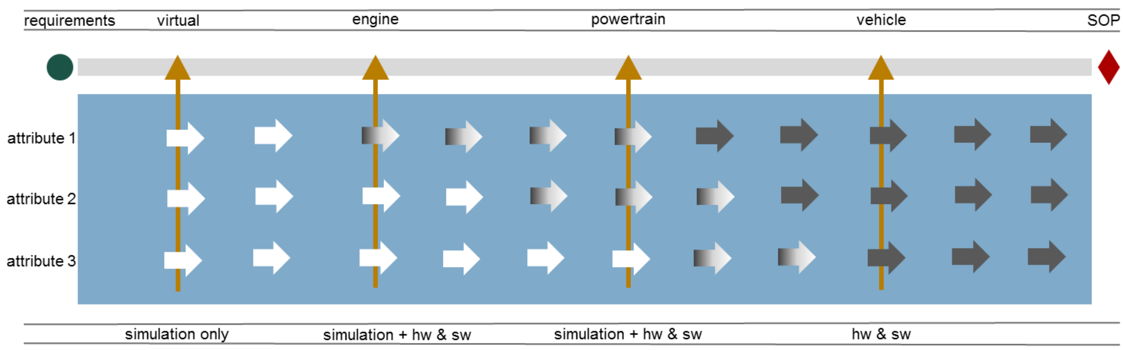


Figure 6.1 Programme delivery timeline

6.2 The Two Modes of Delivery

How a product development task is practically delivered is highly linked to the resources available and preferred operational practices of an organisation. This preference is not arbitrary nor a state that changes from one product development cycle to the next. A preference for how powertrain product development is practically executed can be viewed almost as a fixed characteristic of an organisation that usually can be traced back over decades, if not generations. The reasons why, are linked back to an organisation’s own history and operational habits. In addition, the cultural, socio-economic and local historical background of an organisation are also significant. In the case of some organisations, their own effect on their regions history influences them in the present day.

The author has observed that the operation modes in an automotive powertrain product development organisation can be classified into two new definitions i.e. how a functional team delivers the attribute for which they are responsible. In this work the two modes will be referred to as 'Professional Handover' and 'Factory Handover'. Whilst these modes represent two extremes, real organisations usually operate under a mix of the two. It is common to find an organisation biased to one or other mode, perhaps more so than any moderate combination in between.

6.2.1 Professional Handover Mode – Definition

The key feature of this mode of operation is that the development task delivery is handed over to the individual.

The individual delivers an attribute subject to their working style and previous experience of similar programmes. In fact, experience shows that how they go about meeting the delivery is not necessary tracked or well documented. The individual is trusted to manage any design and consequently testing as they see fit. In other words, they provide a professional service.

This mode of delivery is commonly found in traditional organisations following the resource model discussed in chapter 5.

This mode of operation relies on expert skills. In fact, without an expert available, this mode of working is not possible.

6.2.2 Factory Handover Mode – Definition

The key feature of this mode of operation is that the development task is handed over to the functional team.

In a specific example of the powertrain development, the attribute delivery is subject to process and formalised structures. How the attribute is delivered is very clearly defined, documented and there is very little to no innovation required to complete it. Thus, much like a factory process in manufacturing, the development task is highly specified, standardised, and therefore 'trackable'.

This mode of operation relies on teams comprised of people with an appropriately broad range of experience and skills.

Organisational conditions which are favourable or unfavourable to Professional Handover and Factory Handover are shown in table 6.1.

Table 6.1 Successful/Unsuccessful Conditions for Professional Handover and Factory Handover

	Professional Handover	**Factory Handover**
Successful Conditions	▪ Highly skilled staff ▪ Autonomy of team (respected and left to self-manage) ▪ Strong team leader ▪ Testing facility dedicated to individuals ('R&D lab' style) ▪ Flexible planning	▪ Task is well defined and standardised ▪ Team is highly organised ▪ Facility is capable of high utilisation
Unsuccessful Conditions	▪ High 'interference' from management ▪ Varied or inconsistent facility available to team ▪ Understaffed and/or low expertise in team ▪ Collaboration/input required with other functional skill teams/team-members	▪ The task is new/unknown ▪ Moderate to high level of innovation is required ▪ Roles within team not clearly defined ▪ Programme deliverables not clearly defined

6.3 Professional Handover Characteristics

There are several clear advantages to delivering a powertrain development programme using a professional handover mode despite it going against the current trend of increasing the amount of process applied to the business of product development.

Without question, the greatest advantage of the professional handover mode is the opportunity for product innovation. A team of experts that is unencumbered by strict processes or deliverables, free to operate at its own discretion, capability and trusted by management to meet requirements has the ability to rapidly develop technologies that are new and/or under uncertain conditions. Much like a true Research and Development team, such a highly autonomous team typically thrives under freedom from process. There is an absence of daily process, reporting, meetings, deadlines and other such requirements, the very lack of these demands that monitor behaviour and work styles means this type of team has the freedom to create their work practises and thus feel ownership over the development task. This kind of personal investment reinforces the sense in the individual and in the whole team that they are experts, special, and therefore vital to the products creation and the organisation.

The disadvantages of this mode of operation begins with the highly personalised attitude of these teams in some sense an elitism with its drawbacks. Team dynamics, organisational disputes and personality conflicts can have a very disruptive impact on the practical work of product development, and as such, it is not unusual to find that the successful teams in industry tend to be long established, with a strong leader and with close personal relationships between individuals, in much the same way as is evidenced in successful competitive teams. On the other hand, unstable teams with a high turnover of personnel or weak leadership typically struggle to meet deadlines or achieve satisfactory delivery.

Even successful teams, however, are unable to fully and continually contribute to the improvement of the organisation as they leave very little documented evidence of work completed (and what does exist is normally intended for internal team use, so an outside audience will find this information difficult to apply). Teams do not develop internally in a way that incorporates wider organisational aims and ultimately view themselves and their knowhow as a contained subset of the organisation. In this way, the organisation is at the mercy of a product development team that operates under a professional handover mode, which if in the unfortunate event of an organisation needing to outsource or there is absentee of key member, work becomes painfully apparent, as little or no processes or methodology can be provided to the supplier or colleagues to conduct the work and there is no data or process driven way to verify the quality of the work supplied. Of course it cannot be excluded that there are some exceptions to this situation. Table 6.2 summarises some of the advantages and disadvantages of Professional Handover.

Provided a specific or particular development programme is on-time, on-budget and to-specification Professional Handover is virtually invisible to senior management. It is only when programs start to deviate from plan that frustration is caused as there is little recourse but to depend on the expert. There is often no way to extract in understandable detail, the steps taken towards delivery at any stage.

Table 6.2: Advantages and Disadvantages of Professional Handover

Category	**Advantage**	**Disadvantage**
Standardisation	Standardisation of actual tasks not necessary providing product attributes are successfully tracked.	Difficult if not Impossible to standardise methods of delivery.
Process	No process overhead.	Process difficult/impossible to determine.
Innovation	Intellect and experience in place to tackle unplanned setbacks as the development process progresses.	
Agile Reaction	Intellect and experience in place to react fast and in some cases to avoid unplanned setbacks.	
Implementation of new technologies	Almost a necessity for delivery.	
Team	Recognised expert one-stop for specialist across all levels.	Dependant on one expert for consistent delivery. Knowledge not communicated and shared with other team members.
Tools	Individuals develop their own tools as necessary.	Tools cannot be standardised and universally deployed.

6.4 Factory Handover Characteristics

Product development teams that operate a factory handover mode distinguish themselves with being highly integrated with the wider aim of their organisation. The processes adopted within that team reflect the process steps at a higher organisational level, refined down from the broader business targets and philosophies into the more detailed technical product development tasks, and by virtue of building its operating mode upon overall organisational strategy, it will also be integrated with other teams working on parallel or adjacent programmes. For example, a powertrain development team operating in a factory handover mode will consider the testing facility as a valuable resource provider in its own right that also must operate within the same organisational targets.

By operating under standardised processes with transparent methods and targets, the factory handover mode enables planning of personnel, skill level and resources based on the task at hand, rather than flatly budgeting for a team and a facility for the duration of the programme. As the development tasks themselves are standardised, they can be deployed across personnel and the facility thus allowing the development team to be flexible in how it uses is resources rather than being dependant on a particular set of expert individuals, maximising the utilisation of manpower and facility. While an experienced engineer would still be required to oversee that the deliverables are successfully met, the execution of the tasks can be handed over to less skilled staff as they are supported by a standardised process.

The disadvantage of the factory handover mode is that little to no innovation is allowed for during a development programme. The very standards and processes that enable the application of lean principles in a development programme, especially with regards to personnel and skill sets, also can lead to a rigidity in the development team to established ways of working. When faced with unexpected challenges or innovation demands, the freedom and the skills to problem solve may not be available, placing carefully budgeted development under threat. To avoid complacency and always have very lean approach the standards and processes must be under constant scrutiny, particularly at the planning stage of a development programme to ensure they are appropriate.

Another disadvantage of Factory Handover mode, is that despite the high level of organisation and resource streamlining, the demand on personnel remains just as high as with the professional handover mode. The difference being that effort shifts from within the development team to the leadership level in place in the factory handover mode. As the individual task and resource allocation is more flexible and likely shared across many more individuals and parts of the facility, the task of monitoring the appropriateness of the processes used typically falls to team leaders. This is because the overall complexity of the development task remains the same, regardless of the operational mode used to deliver the programme. Table 6.3 summarises some of the advantages and disadvantages of Factory Handover.

Table 6.3 Advantages and Disadvantages of Factory Handover

Category	**Advantage**	**Disadvantage**
Standardisation	Clear and repeatable task definition, deployable across global sites	Inflexible, requires continual reassessment against current requirements
Process	Transparent methods and targets in line with organisational goals. Documentation	High effort in documenting process. Limits ability to innovate
Innovation		Little to no innovation supported
Nimble Reaction	Highly efficient reaction only if situation can be handled with established processes and standards	Unable to efficiently react to situations that are unusual and cannot be solved with current standards and process
Implementation of new technologies		Not supported unless integrated in new designed process
Team	Skilled staff required, but need not be experts. High level of cross functional skills allow staff to rotate according to task, not programme	Expert may not be available if unexpected issues arise. Low experience level available for high level problem solving.
Tools	Standard tools encourage standardised processes and vice versa	

6.5 Modern Development Organisations

6.5.1 The Trend Away from Professional Handover Mode.

As already emphasised in previous sections, the profession handover mode relies heavily on high skilled and experienced employees. This operational mode may be attractive or even more “natural” to a product development department that has flexibility and innovation as key targets in the product development road map. Two key points are exerting pressure on this thinking

1. Efficiency with increasing pressure on time delivery
2. The available talent pool.

The author has witnessed examples of several global manufacturers and suppliers who have struggled to maintain or create teams that can operate in professional handover mode and maintain an elevated level of efficiency. This phenomenon of resource pool appears to have a cultural component, local jobs available, adaptation of studies institutes can be evident and widely noted in Western economies, but increasingly noted in Eastern economies. The encouragement of aspiring to and pursuing professional careers through higher education with less practical experience on several generations has slowly eroded the availability of technically skilled labour in the work force. This has occurred to such a degree that now, as economic conditions are changing in certain sectors, organisations are finding that they are unable to fill positions due to a lack of skilled technical labour, especially in the United States and United Kingdom [37], [38].

One country which is bucking this trend; Germany, Europe’s third most competitive economy at the time of writing according to the World Economic Forum [39], arguably the European economic train motor and recognised for the innovative technologies driving to market strength in manufacturing, Germany also has an enviable training and education structure that ensures the supply of highly skilled technical workers. Their on-the-job apprenticeship schemes are so admired that businesses and governments in other countries, such as the United States, are considering adopting the structure actively visiting Germany in order to meet directly with companies that benefit from this scheme [37], [38].

However, the reaction of these American visitors and the response from their German hosts provides a telling clue to the operational, and social, culture that permits the success of this scheme in supplying a technical talent pool. When discussing the costs of implementing an apprenticeship scheme within an organisation, the Americans wished to know how long they would have to wait to see a return on their investment. In response, their German counterparts almost dismissed the immediate cost of investment, imploring the Americans to take a long-term view, both for their businesses and the wider social implications of the investment [37].

It is possible that it is Germany's long standing and deeply rooted respect for technical skills that allows them to build a sustainable talent pool, and therefore establish product development teams made up entirely of experienced experts. It has been witnessed on many occasions how this deep respect for technical skills translates to executing and delivering powertrain programmes in the form of a professional handover mode. These teams are assigned tasks and subsequently left to their own devices to deliver their programmes, and even if they are subjected to periodic progress reviews (as per a Stage Gate style process), their methods of executing their task are seldom questioned. Individuals, regardless of rank, are automatically and implicitly trusted to get the job done, micro-management and oversight appears to only occur once a major set-back has taken place. Moreover, the technical qualification, skill and experience of these individuals is highly respected, not just in academic terms, but truly valued through professional advancement in responsibility, hierarchy and salary.

By contrast other Western manufacturers, most notably the Anglo-American organisations, have an inherent disrespect of technical skills that prohibits them from building the talent pool that they need. In addition to the increased aspirational value of professional roles, these organisations have often been instrumental in dissolving the influence of trade unions, increasing the use of manufacturing style automation and processes, and phasing out the need for artisan skills, and all of this is still within the living memory of mature staff. Now this historical context which created the perceived disrespect of technical skills is reinforced through practical ways within these organisations. Technically skilled staff, even those with professional qualifications (now almost a standard prerequisite for these roles), are not offered a direct path for career progression and therefore are often limited to the hierarchy and salary they can achieve within their careers. There is even evidence to suggest that savvier young professionals see this limitation almost as soon as they enter the workforce and position themselves early for management or sales roles (where high advancement is possible), deliberately avoiding technical roles.

Hence if an organisation is having difficultly building a highly skilled, highly experienced team of technical experts in one locality, the task of doing so across an organisation that operates globally becomes almost impossible. The largest manufacturers now spread their operations beyond their own national borders (where they already may have multiple established sites throughout their own country), and out to locations right around the globe. And the work conducted at these sites is no longer just manufacturing and assembly but increasingly development and verification work, such as emissions testing, for the local and global markets. To enable such global operations, different sites must conduct and deliver programme tasks in a complimentary way, if not the exact same way. The only viable way of ensuring this is through the adoption of standards and processes, therefore the introduction and rolling out of a suitable percentage of factory handover mode of operation may become a requirement for globalised operation.

Therefore, the ability for organisations to build teams that operate in the professional handover mode for product development is not only increasingly unlikely but also a product of their own internal culture and history. As such, organisations can no longer afford to blindly demand the same skills, or even configuration of teams and skills, as they have habitually done to deliver their product development tasks. They must acknowledge the resources they have already available to them and are able to attract in order to create operational modes of working that are balanced and achievable for their specific circumstances. A suggested method for determining this balance is proposed in the following sections.

6.6 Identifying the Current Operational Mode

A logical first step in determining which operational mode is best suited to a particular organisation is to identify the current operational mode prior to making any improvements. Most organisations will find that they do not operate fully in one extreme or the other; the questions in table 6.4 are posed to assist in identification of predominant modes of operation.

Table 6.4. Key indicators of Professional and Factory Delivery

Category	Professional Handover	Factory Handover
People	When employees leave the post, delivery is adversely affected	When employees leave the post others take over with minimal disruption
Process	Progress between gateways is difficult to determine	Progress between gateways is clearly measurable and easily obtainable
Process	Product consistency difficult to achieve (in the case of parallel professional handovers)	Product delivery consistent and repeatable.
Process	Late surprises are commonplace	Delivery usually to plan
Process	Knowledge-base, documentation minimal or non-existent	Knowledge-base/ documentation in abundance and readily available
Tools & Software	Inconsistent/fragmented tools and usage	Tools & usage of tools are standardised
People	Hands-On delivery by highly skilled professionals/artisans with emphasis on the individual	Team delivery involving diverse skill levels
People	Leadership attributes success to individuals	Leadership attribute success to the team
Process	Firefighting occupies a high proportion of available resources	Resource allocated as original cycle plan
People	Leadership assigns individuals to tasks, then allocates resources	Leadership views task in terms of resources required, then allocates skills
innovation	When innovation is often introduced in the process	No innovation is introduced in the process

6.7 Factory Delivery – An Enabler for Application of Lean Principles

The concept of Lean is now known in almost every manufacturing and production industry worldwide, none more so than in the automotive industry where it originated out of the Toyota Production System [40]. Lean has been viewed as a tool, a management approach, a manufacturing system, and possibly many other things. The experts in Lean steadfastly maintain that it is foremost a philosophy that has at its heart the goal of increasing customer value whilst eliminating waste [41]. Despite the wide array of literature and expert consultation available, especially over the last two decades, confusion and misunderstanding of what Lean really is continues to persist. Thus, the implementation of Lean into organisations has been notoriously difficult, so much so that accounts of real experiences in successfully (and unsuccessfully) implementing Lean are enthusiastically attended at conferences and are the basis of entire books [12].

If it continues to be difficult to implement Lean into traditional manufacturing operations than it is little wonder that attempting to establish Lean in an organisation that deals with more research and development business can appear not automatic thinking. What is more Lean principles, like any philosophy, is a high-level concept which must be adopted at a high level of an organisation – it is widely reported that without the full commitment of the executive level of management, the implementation of Lean fails [13]. So how does an organisation go about introducing Lean principles into its powertrain product development programmes, which are a meeting of software development, software programming, hardware design and component development.

The Factory Handover concept proposed earlier fits neatly into Lean principles as it is integrated with the high-level objectives of the organisation and is highly process and standards orientated. This is hardly surprising as Lean concepts were designed to improve manufacturing or ‘Factory’ processes. To illustrate this, the 5 lean principles [7] are directly related to Factory Handover implementation suggestions in table 6.5. In addition, tables 6.6 and 6.7 link lean waste categories [42] to characteristics of Factory Handover.

Table 6.5. Lean Principles Related to Factory Handover Implementation Suggestions

Principle	Concept	Factory Handover implementation suggestions
1st	Precisely define what 'value' means for the customer	▪ What does the customer need to deliver? ▪ What is their upstream process ▪ Exactly how much data is required to permit them to complete *their* tasks (data quantity) ▪ What statistical tolerances ensure (data quality)
2nd	Value Stream	▪ Match customer requirements to standardised tests ▪ Standardise parts of the deliverables ▪ Identify what test equipment is necessary to deliver the required data
3rd	Flow	▪ Plan and allocate correct skill resources to complete necessary testing or design without interruption or repetition (first-time-through) ▪ Use automated tests where possible to increase cycle time without overburdening resources ▪ Group tests where possible to make best use of resources at different times (e.g. exploratory tests during attended day-time hours, unmanned automated tests overnight)
4th	Pull	▪ Sequence testing to match customers schedule (the data they need when they need it) ▪ Establish a tracking system as part of the test schedule to notify customer when a test is complete and which tests will be performed next.
5th	Perfect	▪ Any deviations from standard tests or test set-up are evaluated; should these changes be embedded in the standard process? ▪ Use the actual sequence testing performed to inform the next programme test schedule

Table 6.6. The Three Types of Waste related to Factory Handover Characteristics [42]

Waste	Concept	Factory Handover Characteristics
Muri	Overburden	▪ Understanding of the customer requirement allows the identification of necessary testing to deliver the programme ▪ Standardisation allows the identification of which resources will be required prior to commencement
Mura	Unevenness or irregularity	▪ Standardising tests reduces circular workflows and allows scheduling ▪ Standardisation of tests and test equipment improves data quality and utilisation
Muda	Waste, futility, superfluity	▪ Superfluous tests are eliminated at the scheduling phase ▪ Any deviation from the plan is clearly identifiable for further investigation and improvement

It is plausible that the difficulty reported in applying lean principles in product development is, in part, due to a high proportion of Professional Handover. Consideration of the 5 lean principles listed in Table 6.5 versus the characteristics of Professional Handover shows the result that Professional Handover is an effective roadblock to their adoption. Figure 6.2 pictorially reinforces the points raised so far.

Table 6.7. The Seven Types of Muda Related to Factory Handover Characteristics [42]

Waste	Explanation	Factory Handover Characteristics
Transport	Moving what is not required	▪ Standardised test facility equipment ensures only the Unit Under Test needs to be moved. ▪ Unit Under Test transportation can be further optimized through palletisation
Inventory	Not using all planned components/data in finished product	▪ Clear definition of customer requirements for downstream process and test standardisation help to eliminate superfluous data production
Motion	Using more movement than is required to finish the process	▪ Standardisation of test facility ensures that once the UUT is in place for testing, no additional movement from equipment or staff is required ▪ Mobile measurement devices mean entire test cells need not be interrupted if that device is required by another programme
Waiting	Waiting for next step in process. Interruptions	▪ Test scheduling and reporting systems ensure that there is not wait time due to poor process ▪ Test interruptions can be managed through automation software, especially during unmanned testing
Overproduction	Production ahead of demand	▪ The customer requests a test or series of tests to be completed by a certain deadline as they need new data.
Over Processing	Adding more value to the product than the customer requires	▪ Clear definition of customer requirements means standard tests can be adjusted to provide exactly the data that is required ▪ Smart automation can ensure each test meets requirements during an actual test, rather than discovering gaps during post processing
Defects	Effort in inspecting and/or correcting defects	▪ Automated pre-test and in-test error checks help to catch issues as they arise ▪ Scheduled maintenance and standard pre- and post-test routines help to identify issues before they affect data quality, e.g. daily checks

It is plausible that the difficulty reported in applying lean principles in product development is, in part, due to a high proportion of Professional Handover. Consideration of the 5 lean principles listed in Table 6.5 versus the characteristics of Professional Handover shows the result that Professional Handover is an effective roadblock to their adoption. Figure 6.2 pictorially reinforces the points raised so far.

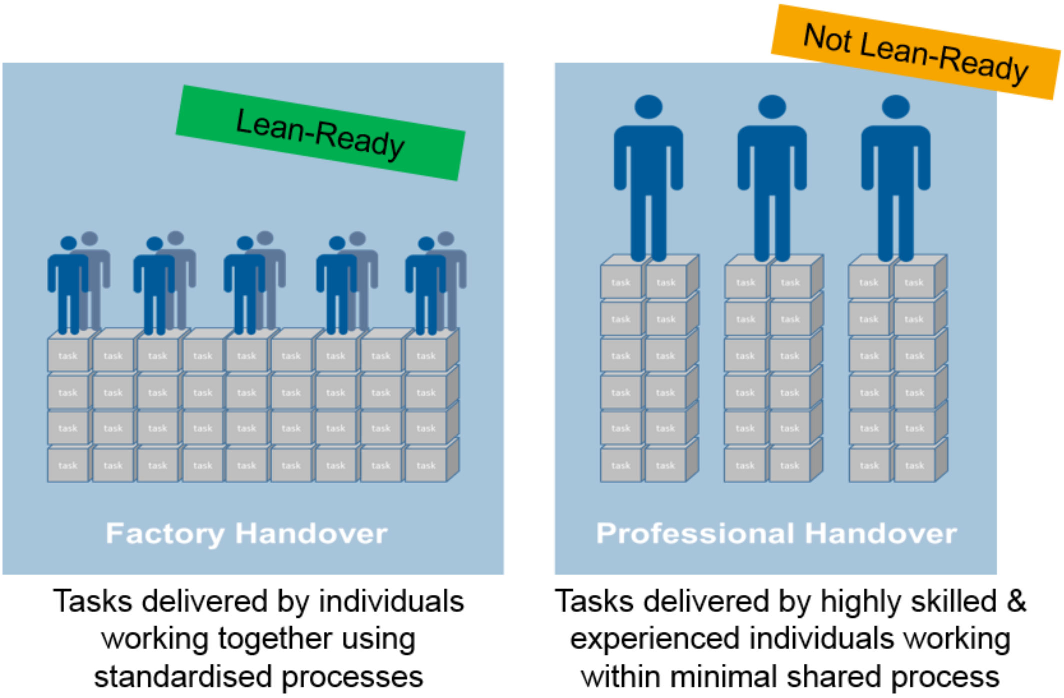


Figure 6.2. Pictorial Representation of Professional Handover and Factory Handover

6.8 Determining the Optimum Balance

It follows that there is an optimum proportion between the two operational modes for minimum waste in product development organisations. A key observation is that this optimum split is highly likely to be different from organisation to organisation and is dependent on local conditions such as product type, market position (e.g. leader versus fast follower), skills, facility and manpower availability, organisational maturity and structure. A proposed differentiator for best competitive position is to recognise and correctly define this optimum split for a particular organisation.

Determining an optimum work-split of operational delivery modes should not be an arbitrary task based entirely on quantifiable factors such as available facility or manpower. An understanding of how different splits affect the ultimate task execution and deliverables is also required. Figure 6.3 is provided to support this discussion.

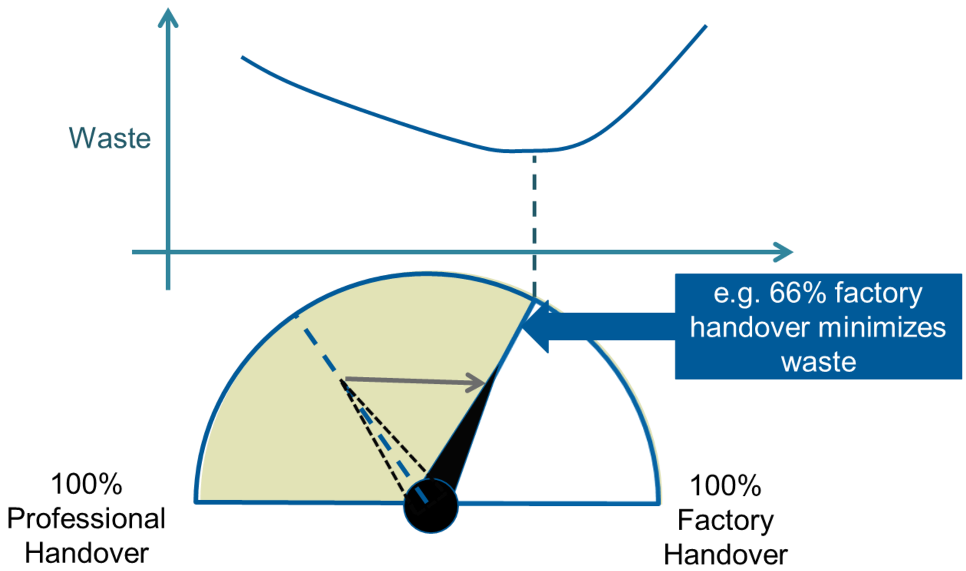


Figure 6.3. Theoretical Optimum Balance of Professional Handover versus Factory Handover Yields Minimum Waste

At the left most extreme, a product development programme is operating under a full (100%) professional handover mode, i.e. the work is executed by experts in any way they see fit to deliver that task and there is no formalised structure for executing or delivering the task. The actual work split is not 100% ‘professional’, as some level of technical or maintenance support is always required in a test facility. In this scenario, by way of example, we often see the test cell operator ensuring the test cell is operating and prepared for the task but with the (very experienced) calibration engineer directing all of the testing work, short of actually starting the Unit Under Test. It is also usual to see a test cell dedicated to one engineer or team for the duration of their programme. Day-to-day tasks are loosely planned at best and complete at the discretion of the calibration engineer. The resulting task delivery is typically of a high quality but not always trackable or reproducible. In this state waste generated by under use of the facility is maximised although manpower utilisation is typically high. In other words, people are working intensively but the facility is under used. It is practically possible to operate at close to 100% Professional Handover and experience suggests that some organisations are extremely successful in doing this.

At the other extreme of the continuum is full factory handover mode of operation. In this scenario, if we apply the example of the test facility here it has the power to allocate tasks from many product development programmes amongst its resources. Typically, a calibration engineer will request a predefined type of test (parameterised or modified to suit their requirements) and the test facility will allocate this programme to a test cell based on the test requirements, priority and test cell availability (engineers may request certain cells or operators and could not be guaranteed to receive them). The test is then performed by the test facility and the resulting data and any additional information provided to the development engineers – the engineers are not required to be present for testing. The task delivery of this type of operational mode is also of a high quality, with the advantage that the test facility can operated very efficiently as they are able to manage their operations for best output. It is not practically possible to deliver development programs with 100% factory handover, as it is not possible for all testing tasks to be predefined prior to the first test – even new tests require some innovation and refinement by experts prior to being approved as a standard. Any unforeseen setbacks during product development that require innovation will typically require reverting to Professional Handover.

Between these extremes, various combinations can be assembled along the continuum. The author has been a member of a team tasked with implementing one such combination at a European manufacturer. In this example, a concerted attempt was made to standardise and automate as much of a certain engine development task as possible, work that had previously been considered too variable. In standardising these tests, highly competent technical staff from the facility were also educated as to the nature and purpose of the tests. The ultimate aim was build a close working relationship between the development team and test facility, so that the development team could request engine tests to the detail and complexity that they required but without need of performing that test themselves (thereby allowing them more time for data analysis and calibration work), whilst the test facility could parameterise, schedule and execute the test themselves as best suited to their resources but always with the knowledge that an expert was available should they come to difficulty in applying a standard test. In this example, staff and facility resource was very efficiently distributed and the working relationship between departments was very complimentary, benefiting the product development programme overall.

A combination that does not function, in the author's experience, is when a factory handover mode of operation is not supported with structured and standardised tasks, the extreme in this case being if a test cell operator was required to deliver a data set for a calibration task without recourse to standard test procedure and little support for the development team. The operator would, unfairly, be required to use their experience and best judgement to complete the task, but without the level of experience of a development expert or understanding of the wider development programme, it is unlikely that the task would be delivered satisfactorily or on time.

Thus, an organisation that wishes to adopt more of a factory handover mode of operation must commit to an effort of standardising tasks that were previously determined ad-hoc, raising the level of involvement of test facility technical staff, and encouraging sharing and cooperation of product development teams.

It is apparent that waste would be generated in the theoretical state of 100% factory handover by failure to innovate at appropriate times resulting in non-delivery of product attributes that ultimately results in flawed or failed product launches.

The curve in figure 6.3 illustrates a key hypothesis in this study. It is postulated that overall waste is high at the two operational extremes with a minimum somewhere in between. The curve is drawn arbitrarily to show the case where waste is minimised at 66% Factory Handover. The needle in figure 6.3 shows a hypothetical case when a subject organisation's waste is minimised by increasing the proportion of Factory Handover to Professional Handover.

6.9 Core Hypothesis

1. There are two distinct types of delivery in any automotive test and development organisation.
2. There is an optimum proportion of Professional Handover and Factory Handover in any subject automotive test and development organisation where waste is minimised.

6.10 Case Study

To establish the validity of the observations made in this thesis, the resulting hypotheses stated above was tested by a suitable case study performed on actual automotive test and development organisations. The case study had following objectives:

- Determine the product development process structure and triggers (time line, milestones, gateways etc.). Classify according to recent literature on project management. Identify any differences from standards.

- Understand how resource (people and facility) is planned to meet product development programme requirements.

- Understand and quantify the flow (cascade) from high level business requirements, to product requirements (attributes) and finally engineering targets. Identify supporting information handovers and processes.

- Establish how the product attributes and engineering targets are communicated to the engineering teams responsible for delivery.

- Understand the processes supporting management review of product attributes and engineering targets. Determine how corrective action is triggered if a programme falls behind schedule.

- Determine how individual engineering tasks are actually delivered and by who; classify using the concepts of professional and factory handover.

- Determine the existing proportion of Professional Handover to Factory Handover.
- Assess the suitability of the subject organisation for adoption of lean principles.
- Determine the potential for minimising waste by optimising the proportion of Professional Handover to Factory Handover.

The first element of the Case Study was to design and deliver a questionnaire to gather raw data about the organisational behaviour of automotive test and development teams.

While a questionnaire can appear to be a simple, rudimentary tool to gather information about a subject population, a survey questionnaire design can be fraught with a large number of subtle but significant pitfalls that can dramatically affect the accurate and efficient collection of result data. However, a thoughtfully designed questionnaire is a powerful and effective tool for gathering qualitative information.

This chapter will review the existing literature on questionnaire and survey design, discuss how the questionnaire for this Case Study was constructed, and compare the resulting questionnaire to current best practise as described in the literature.

6.11 Research Intent

Possibly the most common recommendations regarding questionnaire design is for the researcher/s to be clear about their research aims and to design a questionnaire with the direct intent of obtaining results to reach those aims [43], [44], [45]. An unclear research aim can result in a poor questionnaire design that, if delivered, can have the following consequences; inaccurate data, insufficient data, inaccurate or inconclusive interpretation of results, and inaccurate, misleading or inclusive research outcomes. Furthermore, once a poorly designed questionnaire has been delivered it is often not possible or not fruitful (with regards to data integrity) to interview the respondents again, thereby reducing the subject population available for research.

Broadly, the recommendations in the literature fall into two categories;

- Turn research aims into information requirements, then turn information requirements into questions [45].

  This methodical process ensures that not only will the survey questions link directly to research aims, but also protects against including questions that are at the forefront of the researchers minds but should not be asked of respondents, for example, questions that include company jargon, complex questions, or questions that may give away the intent of the research, thus introducing bias [45].

- Give thought to how collected data can/will be analysed, and the implications of this on result analysis [44].

  Practical considerations, such as how much access the researchers have to the subject populations, the time and resource available to process the result data, and in what format the researchers would like to view the results (e.g. qualitative or quantitative data), has implications on the appropriate way to structure the questionnaire.

For this work, the research aim was to confirm the validity of the two core hypothesis statements, so the information required to understand if automotive organisations operate in Factory of Professional Handover, and if so, in what proportions, is;

- What is the organisational structure? Is it as intended as per the organisational chart or is it 'lived' differently?
- Discover the potential to apply factory handover mode
- Are projects delivered in Professional, or Factory Handover mode of operation, or a combination of the two modes?

Each of the questions used for the surveys intend to gather detailed responses from the interviewee that address one or the other of the information requirements above.

6.12 Data Collection

Data collection implies delivering the questionnaire to an intended subject population and gathering their responses to take away and analyse. There are many ways to go about collecting data, with advantages and disadvantages for each.

Identifying Subject Population

Identifying the subject population is simple but critical for the collection of accurate results to address the research aims, however, having the time, resource and access to the subject population can have equally critical implications on the results. Frequently, only a subset sample of the entire population is available for questioning, and of that population it is expected that a certain proportion of individuals will not respond and of those that do, some responses may be invalidated. For example, indirect survey responses are commonly around 20% of the targeted sample population, therefore over 150 surveys would have to be distributed in order to gain 30 complete responses [44]. This suggests that access to a large enough sample population is critical to accurate result data. If most of the population is interviewed then there will be good quality of results

In addition, the sample population needs to be either knowledge or experienced enough with regards to the field of research but have no prior knowledge of the research itself to ensure responses are as unbiased as possible.

For this thesis work, two distinct sample groups were identified and questioned. Both groups work within testing and product development in the automotive industry, but from different ends of the supply chain. The first sample population is located within the Powertrain Test department of a large premium Automotive vehicle OEM. Fourteen individuals of a wide mix of responsibilities and skills responded to the questionnaire. The second sample population is located within the Mechanical Design team of a SME in UK, which is the UK affiliate of a leading EU based automotive test equipment and engineering company. Ten individuals responded to the questionnaire. As this organisation is smaller than that of the OEM test team, the SME individuals have a narrower and more focused experience and skill base.

Delivery method

As hinted in the section above, the method for collecting the responses from the survey selected group has an effect on the quantity and quality of data collected. There are various methods of data collection; self-completed surveys that can be completed online, on a database or on a paper hard copy, or interviewer administered surveys, which can be completed face-to-face, over a video call, or telephone call [45].

For this thesis work, the only viable option for collecting data was with a face-to-face interview where the interviewer met the selected person at their place of work. This was especially necessary for interviewing the group at the large OEM; as this busy testing organisation operates multiple shifts throughout the day to meet very demanding programme delivery targets, thus the research team needed to be on-hand and flexible to take advantage of the limited time and access to these individuals. Therefore, the second round of interviews with SME followed the process of the first with face-to-face interviews. In both cases, interviews ensured that a very large, if not the entire, proportion of the identified sample population could participate in and provide complete responses to the questionnaire, thus making the most of a very small and specific target population hence delivering quality result.

Though practice considerations were the driving force for choosing this data collection method, the research team was still cognisant of the advantages and disadvantages of face-to-face interviews. One key advantage is the opportunity for the interviewer to explain the questionnaire and clarify any confusion on the part of the respondent in real time, ensuring a high number of fully completed questionnaires .In all cases the thesis two modes of operation were not introduced as explanation However, the interviewer was responsible for recording accurately the data, mindful that errors can be introduced if the interviewer incorrectly records a response or misinterprets a response, or if they are vague in an explanation of a question, or even if they paraphrase a questions rather than pose it as written. Also, the mere presence of the interviewer can introduce a bias, for example, if the respondent has a positive or negative perception of the interviewer, or if they simply give an answer that they think the interviewer wants to hear [45], [46].

Regional /cultural considerations

Finally, regardless of the delivery method for a questionnaire, a research team can put themselves into a stronger position by having an appreciation of regional and cultural influences that affect their sample population. The literature suggests that there is variation in response rates between countries, refusal rates between countries, and response rates declining over time [47]. Therefore, it would be reasonable to assume that responses between organisations and industries could vary.

For this case study, the questionnaire was conducted on two sample populations based in the same region of the same country, and in the same industry, who have regular contact at the working level, so it would be reasonable to assume that cultural and regional influences would be the same for both populations, and therefore not create variation in the result data. However, if the questionnaire were to be delivered in another country, for example, Germany, at the very least the existing questions need to be reviewed to ensure the questionnaire is neutral in terms of language and cultural references.

6.13 Questionnaire Design

The design of the questionnaire itself, as mentioned in the introduction of this chapter, has the power to uncover a wealth of qualitative and quantitative information about a subject population, but done poorly can lead researchers to discover, after time used to data gather, post processing and analysis, that inconclusive outcomes are the result of a poorly designed questionnaire.

The literature consistently mentions the cognitive load demanded of respondents when answering questionnaires and surveys, siting the sophisticated process of listening to and interpreting the question, retrieving the information to answer the question from memory and in the time allotted for the questionnaire, and then either deciding which option of the possible answers best fits their experience, or providing a succinct written or verbal response as accurately as possible. And this process is repeated numerous times over a prolonged period of time [45], [46], [48].

It's little wonder then, that designing a questionnaire that demands as little of the respondent as possible yet still delivers sufficient data to address the research aims is a challenging task. Luckily, the literature consistently suggests a set of recommendations and guidelines to make the task of designing a successful questionnaire easier;

Question Content from [43], [44], [45], [46], [48]:

- Ask about behaviours, not thoughts or motives
- Ask about discreet events that can be independently verified (can help reach conclusions about research validity)
- Break down complex questions
- Group questions about similar topic sections
- Ask demographic questions at the end of questionnaire about organisations, make it optional and minimise number
- Ask about current or recent history events. Memory is not reliable – respondents often estimate events to be more recent than the reality
- If attitudes towards a topic is desired, ask these questions after the behaviour/factual questions. Respondents may find themselves adjusting their questions to defend a stated attitude if such questions come first.

Question Type Content from [43], [44], [45], [46], [48]:

- Regardless of response scale (i.e. 5 or 7 response option) avoid vague quantifiers.
- Vague quantifier (e.g. sometimes, fairly, very good, etc) options depend too much on individual interpretation and experience
- Open vs closed, single vs multiple response, ranked response (options in priority order), rated response (rating per response option).

Question Length & duration Content from [43], [44], [45], [46], [48], [49], [50]:

- Keep questions as short as possible (30 words)
- Keep all questions to similar length
- Keep the questionnaire duration as short as possible (max 20min or 30min recommended)

- Avoid too many questions of the same type in a row, e.g.; rating scales. Bored respondents trying to finish the questionnaire faster may repeat their pattern of answers without considering the question.

Question Wording Content [43], [44], [45], [46], [48]:

- Keep questions neutral to avoid ‘socially desirable’ responses
- Keep wording as simple as possible. This helps to eliminate undesirable influences resulting from language and cultural differences.
- Avoid leading questions – do not introduce bias

Questionnaire Measurement Content [43], [44], [45], [46], [48], [49], [50].

- Use the same response scale (number of responses) if possible, or limit the amount of variation
- Use a response scale the asks for frequency in numbers
- A middle response option (no preference, don’t know, etc) does not significantly impact results

Table 6.8 The list of designed questions.

n	**Question**	**possible responses**	**response interpretations**	**coding**
1	Q1.1 How many layers of managers are above you?	a)1-2 b) 2-5 c) >5	a) b) c)	org chart
2	Q1.2 How many people are under your direction?	a) 1-2 b) 2-5 c) >5	a) b) c)	org chart
3	Q1.3 What is the size of your team?	a) 1-2 b) 2-5 c) >5	a) b) c)	org chart
4	Q1.4 How would you describe your tasks?	a) It is a black-art b) it is a scientific/engineering process c) Mix of the two	a) professional b) factory c) no bias	detection
5	Q1.5 Do you think it is possible to change or improve the tasks?	a) Yes b) No	a) potential for change b) no change	change potential
6	Q1.6 Do you think there is a need to change the way that you deliver the tasks?	a) No b) Yes c) I don't know	a) no change b) potential for change c) no bias	change potential
7	Q1.7 Do you know who your internal customers are?			
8	Q1.8 Do you know who your supplies are? IS THIS SECTION 2?			
9	Q2.1 Do you plan your typical working day?	a) I don't, somebody plans it for me b) I don't, I face the problems as they arise c) I keep a formal work plan d) Periodic team and manager reviews	a) factory b) professional c) no bias d) no bias	detection
10	Q2.2 How far do you plan ahead?	a) Daily b) Weekly c) Monthly d) Yearly	a) professional b) professional c) factory d) factory	detection
11	Q2.3 How are your tasks communicated to you?	a) Direct instruction from S.V b) Meetings c) Programme documentation (charts & milestones) d) Verbal or other	a) no bias b) no bias c) factory d) professional	detection
12	Q2.4 How do you know you are delivering your programme/product on time?	a) Periodic review meetings b) Programme documentation (charts & milestones) c) I don't know d) Other	a) professional b) factory c) professional d) no bias	detection
13	Q2.5 How do you know you are delivering your programme/product to required	a) Periodic review meetings b) Direct from planning documentation	a) professional b) factory c) professional d) no bias	detection

n	**Question**	**possible responses**	**response interpretations**	**coding**
	targets? E.g. attribute/engineering targets	c) I don't know d) Other		
14	Q2.6 How do you quantify your product development goals? (how do you measure success/output?)	a) Periodic review meetings b) Direct from planning documentation c) I don't know d) Other	a) professional b) factory c) professional d) no bias	detection
15	Q2.7 How is facility/equipment allocated for your use?	a) I get facility/equipment allocated to me b) I don't get personal allocation, shared equipment c) Other	a) professional b) factory c) no bias	detection
16	Q2.8 Are you aware of any limitations of the testing facility resource? (e.g. resource limits to do the job)	a) Yes b) No c) Other	a) factory b) professional c) no bias	detection
17	Q2.9 Do you have freedom to determine the technical steps/actions necessary to deliver your task?	a) Yes b) No c) Other	a) professional b) factory c) no bias	detection
18	Q2.10 Are the development tasks you perform assigned to you as an individual?	a) Yes b) No (as part of a team) c) Other (as part of a team)	a) professional b) factory c) no bias	detection
19	Q2.11 Can you decide upon how to define and/or manage any necessary testing as you see fit?	a) Yes b) No c) Other (as part of a team)	a) professional b) factory c) no bias	detection
20	Q2.12 Do you see any need to standardise product development tasks or should the focus be on a successful outcome/result only	a) Yes b) No c) Other	a) b) c)	change potential
21	Q2.13 Do the development tasks you perform rely on a high degree of expertise to ensure a successful outcome? (Do you need to be a super specialist?)	a) Yes b) No c) Other	a) professional b) factory c) no bias	detection
22	Q2.14 Could some/all of your product development tasks be assigned to a less experienced/junior member of staff with minimal mentoring necessary for a successful outcome? (is there a process in place?	a) Yes b) No c) Other	a) professional b) factory c) no bias	detection
23	Q2.15 Do you share your working methods and knowledge for this task with your fellow team members?	a) Yes b) No c) Partly d) Other	a) factory b) professional c) no bias d) no bias	detection
24	Q2.16 Are your engineering targets clearly defined?	a) Yes b) No	a) factory b) professional	detection

n	**Question**	**possible responses**	**response interpretations**	**coding**
		c) Partly d) Other	c) no bias d) no bias	
25	Q2.17 Are you responsible for defining your engineering targets, and if so, are these related to vehicle/powertrain attribute targets?	a) Yes b) No c) Partly d) Other	a) professional b) factory c) no bias d) no bias	detection
26	Q2.18 Who do you feel that engineering delivery in your department relies on?	a) A few highly experienced individual experts b) A team with a range of skills and experience c) A mix of the two d) Other	a) professional b) factory c) no bias d) no bias	detection
27	Q2.19 Is the task you perform clearly defined and planned upfront with supporting documentation? If so, Who does it?	a) Yes b) No c) Partly d) Other	a) factory b) professional c) no bias d) no bias	detection
28	Q2.20 Are your development tasks assigned to you personally or as a team?	a) Personally b) As a team c) Mix of the two d) Other	a) professional b) factory c) no bias d) no bias	detection
29	Q2.21 Is the process of the development tasks you perform easily quantifiable or trackable? E.g. "My task is 50% compete at this time"	a) Yes b) No c) Partly d) Other	a) factory b) professional c) no bias d) no bias	detection
30	Q2.22 Are development tasks allocated to engineers recognising their level of experience? i.e. are the more demanding tasks assigned to the more experienced members of the team?	a) Yes b) No c) Partly d) Other	a) professional b) factory c) no bias d) no bias	detection
31	Q2.23 What do you see as the major factor/roadblock to you completing your development tasks on time and quality? E.g lack of facility, testing support, engineering staff etc)	a) Lack of manpower/expertise b) Lack of facility c) Both (what is the split?) d) Other	a) professional b) factory c) no bias d) no bias	detection
32	Q3.1 Do you use standard documented processes procedures to guide your work?	a) Yes b) No c) Partly d) Other	a) factory b) professional c) no bias d) no bias	detection
33	Q3.2 Do you feel you need to report every detail to your manager and they like to see every detail frequently?	a) Yes b) No c) Partly d) Other	a) b) c) d)	detection

n	Question	possible responses	response interpretations	coding
34	Q3.3 Do you feel you are given the necessary freedom to innovated when required?	a) Yes b) No c) Partly d) Other	a) professional b) factory c) no bias d) no bias	detection
35	Q3.4 How much of your time do you spend on documenting your work?	a) 5% b) 10-20% c) >20% d) Other	a) professional b) no bias c) no bias d) no bias	detection
36	Q3.5 Do you feel that resource spent documenting the process is a waste of time?	a) Yes b) No c) Partly d) Other	a) professional b) factory c) no bias d) no bias	detection
37	Q4.1 Do you feel that the working environment is a learning organisation? Documenting 'lessons learned'	a) Yes b) No c) Partly d) Other	a) factory b) professional c) no bias d) no bias	detection
38	Q4.2 Do you feel that engineering solutions are often re-invented when they are repeated on a known level of technology? If so, what are the reasons for this?	a) Yes b) No c) Partly d) Other	a) professional b) factory c) no bias d) no bias	detection
39	Q4.3 Does your organisation reward 'team' or 'individual' effort?	a) Team b) Individual c) Both d) No rewards	a) factory b) professional c) no bias d) no bias	detection
40	Q4.4 How often are you involved in the first time execution of the new task?	a) 0-25% of your time b) 25-50% of your time c) 50-75% of your time d) 75-100% of your time	a) factory b) no bias c) professional d) professional	detection
41	Q4.5 Are the existing methods/processes for your task flexible enough to accept new technologies?	a) Yes b) No c) Partly	a) professional b) factory c) no bias	detection
42	Q4.6 In dealing with new technology, do you:	a) Get the new knowledge from your team b) Use outside consultants c) Find it yourself d) Not get new information	a) no bias b) no bias c) professional d) professional	detection
43	Q4.7 What are the steps in dealing with the new technology?	a) Apply new technology, then update process b) Update process, then apply new technology c) Apply new technology, do not update process	a) factory b) factory c) professional	detection
44	Q4.8 With new technology, how much of the process is kept the same?	a) 0-25% b) 25-50% c) 50-75% d) 75-100%	a) b) c) d)	change potential

n	**Question**	**possible responses**	**response interpretations**	**coding**
45	Q4.9 If the process for routine tasks is inadequate, do you:	a) Deal with the task, then update the process b) Update the process, the deal with the task c) Deal with the task but do not update the process	a) factory b) factory c) professional	detection
46	Q4.10 In dealing with routine tasks, how much is repeatable?	a) 0-25% b) 25%-50% c) 50-75% d) 75-100%	a) no change b) no bias c) potential for change d) potential for change	change potential
47	Q4.11 How often is your task 'routine'?	a) 0-25% b) 25%-50% c) 50-75% d) 75-100%	a) no change b) no bias c) potential for change d) potential for change	change potential
48	Q4.12 Are the existing methods adequate for the routine work?	a) Yes b) No c) I don't know	a) no change b) potential for change c) no bias	change potential
49	Q4.13 What do you do when you encounter difficulties with your task?	a) Use past knowledge/existing experts b) Employ consultants to support in-house c) Delegate/outsource the task d) Solve it yourself	a) professional b) no bias c) no bias d) professional	detection
50	QA.1 What is your age?	a) 20-30 b) 30-40 c) 40-50 d) Above 50	a) b) c) d)	demographic
51	QA.2 How long have you worked in testing for?	a) 0-2 Years b) 2-5 years c) Over 5 years	a) b) c)	demographic
52	QA.3 What is your level of qualification?	a) Professional qualification (HNC,HND) b) Bachelor degree (BSc/BEng) c) Masters degree d) PhD	a) b) c) d)	demographic
53	QA.4 How long have you worked at JLR?	a) 0-2 years b) 2 to 5 years c) Over 5 years	a) b) c)	demographic
54	QA.5 What engine testing facilities have you used in the past or are using currently?	a) Engine dyno (steady state) b) Engine dyno (transient) c) Chassis dyno (rolling road) d) Powertrain dyno (transient) e) Vehicle testing (on the road) f) Emission measurement g) Other	a) b) c) d) e) f) g)	demographic

6.14 Conclusions and Continuation

The initial premise of the questionnaire was to identify, primarily, to detect Factory and/or Professional Handover behaviours in an organisation, as outlined in the hypothesis. The success of this detection exercise will be discussed in Chapter 7 with a review of the results. In addition, the questionnaire sought to identify certain specific behaviours and characteristics, such as understating how an organisation communicates requirements, how those requirements are delivered, if there is potential to reduce waste, etc, as outlined in the beginning of this chapter. Specific questions regarding the planning, execution and delivery of requirements are spread throughout this questionnaire because the original intent was to understand the subject organisations, so the questionnaire sections were grouped into individual questions with an organisational perspective in mind.

As the research progressed, it became evident that some of these questions could be rearranged (and supplemented) into different groupings that could roughly correlate with the sequential tasks needed to deliver a requirement. This kind of grouping has the potential to use the results data in a way that is more powerful than simply detecting Professional or factory Handover behaviour.

6.15 Tool for productivity improvement

Figure 6.4 illustrates two potential structures for grouping questions for a subject organisation based on their core business; Customer A's core business is to build and deliver a functioning powertrain test cell, Customer B's core business is to deliver powertrain calibrations that meet predefined functional goals.

By grouping questions into the **'steps required to deliver a product/service'**, it is then possible to discreetly calculate the proportion of factory or Professional Handover for each step of the delivery. The summation of all of the groups gives an overall proportion of the Factory/Professional split, as with the original questionnaire, however knowing the proportion of Factory/Professional split for each step of the delivery permits a deeper analysis of the business case.

Each step can be scrutinised against an ideal Factory or Professional proportion. These steps in the delivery of the product or service where the factory/Professional proportion deviates the most from the ideal have the most potential for productivity gains. Taking the example of Customer B above, the resulting of the ‘Test’ step indicate that the organisation is Factory dominant for this step at 80% factory, and perhaps the ideal proportion would be 85%, so while there is potential for more productivity, it would not be a significant gain. However, if the ideal proportion for the ‘Calibration’ step is 75% factory, compared to the reality of 50% factory, this would indicate an area of high improvement potential. Thus, structing the questionnaire in this way, which reflects the steps taken to achieve a delivery, can be used by organisations as a tool to quickly identify where the biggest potential for improvement is in their delivery processes. Therefore, this concept of Factory and Professional Handover can be used as a tool to reduce cost and time to market.

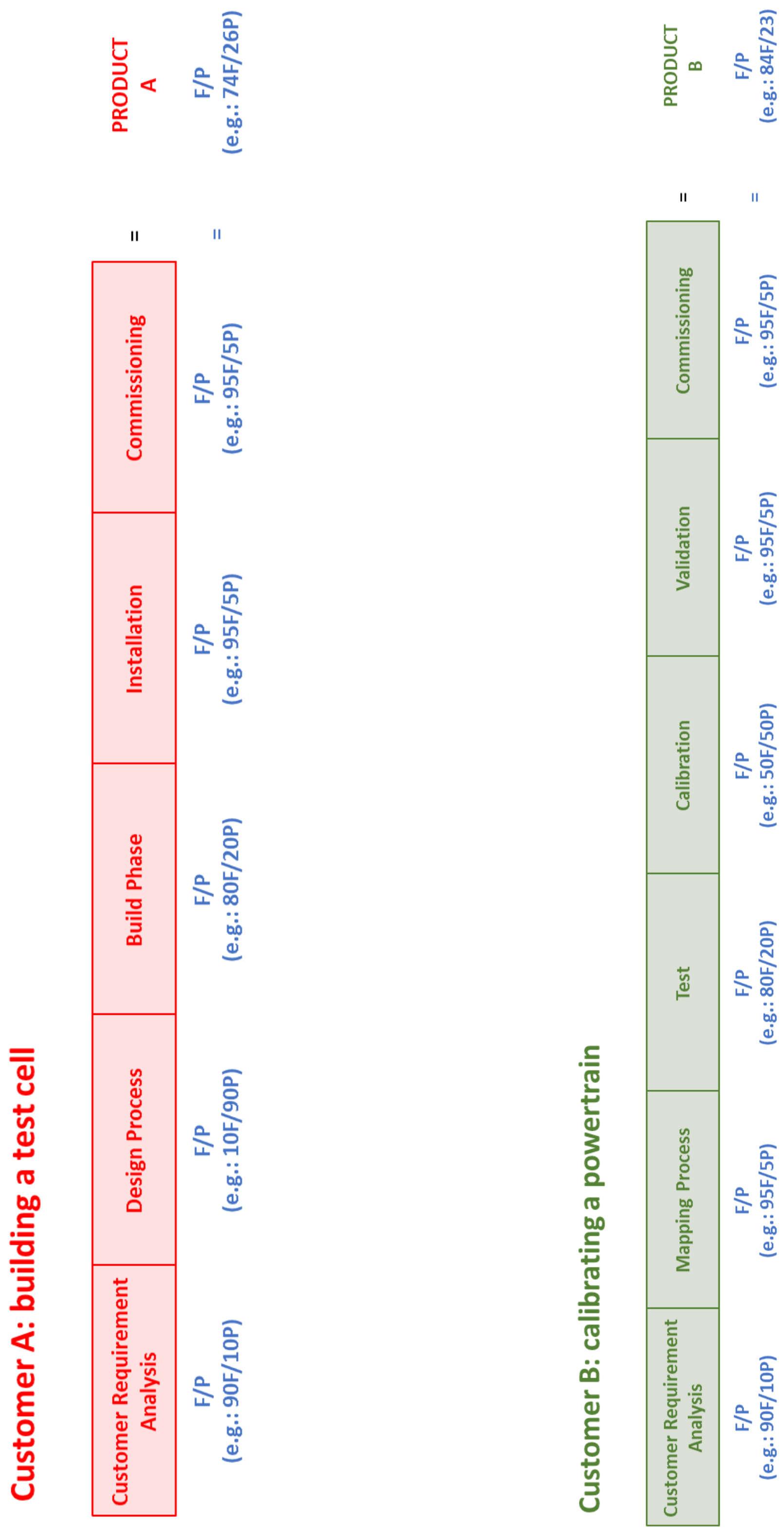


Figure 6.4. Steps Required to Deliver a Product/Service for two Organisations

6.16 Summary

One initial cautionary element to consider in using the Factory and Professional Handover concept as a tool in this way is that it may involve considerably more effort than was required with the questionnaire as delivered in this research. For example, before a questionnaire can be designed where the groupings reflect real delivery steps, those steps need to be established with the target organisation upfront. Not only would that involve two rounds of questioning with the same organisation (which is additional time and effort they may not agree to), the identification of the steps may involve a thorough investigation, such as a Value Stream Map, if that information does not already exist.

And finally, there is the issue of determining an ideal proportion of Factory versus Professional Handover for each step of the delivery process. This determination is highly likely to be subjective, unless metrics are available to drive a realistic target proportion. This subjectivity is acceptable provided the subject organisations are able to understand and accept that the tool is to be used to identify 'large' potential productivity gains. If not, the subject organisation could run the risk of chasing small, incremental gains suggested by a subjective target that may not be feasible. Therefore, the idea of deploying this concept as a tool would need further research and refinement to ensure robustness.

Chapter 7 Empirical Study

7.1 Introduction

The methodology and hypotheses core to this work were presented in chapter 6. Also included were the design and definition of a questionnaire-based research strategy to determine if the two distinct categories of professional and factory handover can be detected in an actual product development organisation with a high degree of certainty. Two subject organisations were selected to trial the questionnaire and provide a set of results for analysis. The actual organisations were selected based on the following criteria:

1) It must have a clear delivery in terms of product development and/or design.
2) It is given/communicated clear design/product requirements from another part of the organisation.
3) It must contain a clear organisational hierarchy in which design/product requirements are cascaded to a team of individuals.
4) The organisation was accessible to the author and willing to invest the time taken to participate in the study.
5) The individuals chosen for the study must have had no exposure to any material or discussion related to the key concepts presented in this work.

7.2 Organisations Under Review (OUR)

Two distinct organisations were selected for study. In attempt to cover a wide spectrum an automotive Original Equipment Manufacturer (OEM) and a subsidiary affiliate of a global company that provides Instrumentation and Test Systems i.e. Test System Engineering (TSE) were considered.

The lessons learnt from the first questionnaire trial were applied to the second and consequently the second data set presented is the more comprehensive and cohesive.

The first subject group was selected from a large automotive OEM. The participants were randomly selected from a large department (of 200+ employees) responsible for testing powertrains destined for passenger car usage. The department provides a diverse testing service to the product development teams. Typical testing includes engine testing on dynamometer, emission testing, vehicle on chassis dynamometer and complete powertrain rigs. The individuals selected did not necessarily communicate on a regular basis as they were selected from sub-teams with different deliveries. Individuals from sub-teams were broadly split into two job functions i.e. execution of tests or maintenance of the facilities and equipment necessary to perform testing.

The second subject group was the Engineering department in a UK branch of a global leading company in engineering and instrumentation and test. The department's primary function is to provide mechanical and electrical engineering solutions/designs related to powertrain test facility projects. The department has ten employees with an operational manager (who also has responsibility for other sub-divisions).

For the key characteristics of the two OURs highlighting diversity see table 7.1 below.

Table 7.1 Summary Characteristics of Organisations Under Review

	Manufacturing DNA	Delivery	Organisational Interdependence	Development/Engineering	Test
OEM	Large Volume	Test Results	Yes	No	Yes
TSE	Bespoke & Small Batch	Manufacturing-Ready Design	Yes	Yes	No

7.2.1 OUR1: OEM

The first interview group was from a large OEM Emission Testing Organisation and included:

- Emission Test Delivery
- Electrification, Transmission and Driveline (ETAD) Operations Manager
- Four by Four (4x4) – Four wheel drive

7.2.1.1 Emission Test Delivery Organisation

All organisation charts detailed below fall under the responsibility of Powertrain Operations and Product Development as shown in figure 7.1.

The Emission Test Delivery team is a sub-part of Powertrain Test Operations and Product Development. The team maintains productive workflow from the emission test facility and delivers test capability to the Powertrain Engineering and Certification teams. The delivery of testing using complex emission measurement instruments is required to drive the design and optimization of control technology in order to meet required vehicle targets. They support delivering of results from facilities across multiple sites.

The group interfaces with complex cross functional teams, this includes: test facility support team, the customer/stakeholder groups, external agencies and organisations. Several other IT related tasks and functions are also supported.

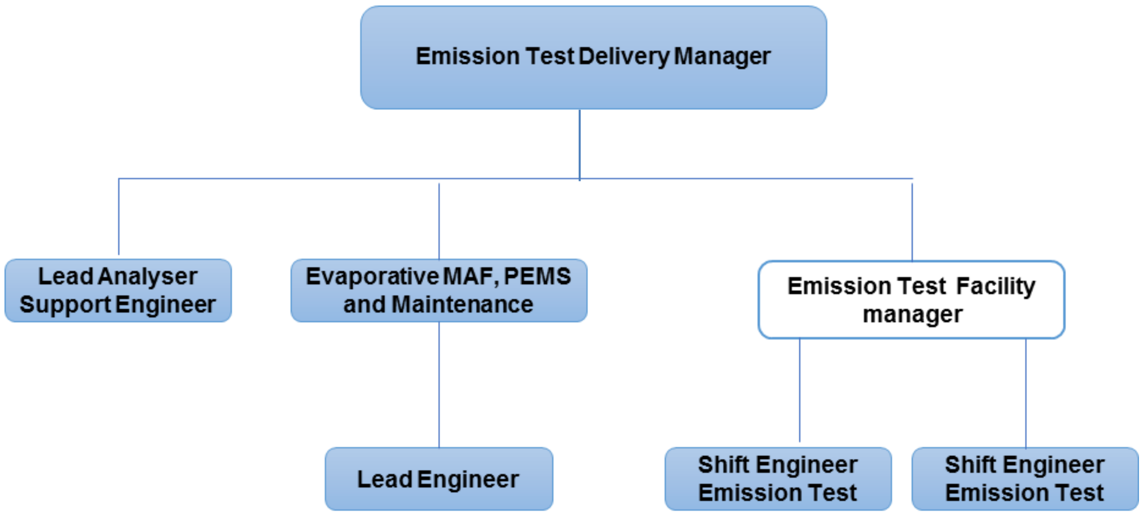


Fig 7.1 Organisational Chart - Emission Test Delivery Organisation

The **Emission Test Delivery manager** is in charge of the team skill, effective delivery and leads the specialist test facility requirement both in hardware and software needs to achieve the department goals.

Key Interactions

- Manager and Lead Engineers
- Internal Customer groups

- Technical Specialists
- Test Operations Team, i.e. Vehicle Workshop and Fabrication

The shift engineer - Is responsible for leading the emission operation test team in delivering high quality output in support of Development and Certification activities, as well as day-to-day issue resolution, new techniques and methods development. He works as part of a team who assure the workflow and quality from different cross site capability.

Evaporative, MAF (Mass Air Flow), PEMS (Portable Emission Measurement System) and Maintenance Lead Engineer - Responsible for a number of key areas within the emission test area including: Evaporative Emissions, Mileage Accumulation, PEMS and leading the maintenance team.

- Evaporative Emissions Measurement: Maintenance, calibration, scheduling and evaluation of future requirements.
- Mileage Accumulation Facility: Maintenance, calibration and scheduling along with evaluation of future requirements.
- The Portable Emission Measurement System activity includes: Leadership of a support team responsible for the delivery of PEMS tests to meet legislative and internal requirements.

Key Interactions

- Emission Test Supervisors, Technicians, Testers and Manager
- RDE (Real Driving Emissions) and PEMS Customer groups
- Suppliers, i.e. Sealed Housings for Evaporative Determination, Running Loss (point source sampling system), PEMS, Chassis Dyno and Automation System
- Technical Specialists
- Test Operations Team, i.e. Vehicle Workshop and Fabrication

Lead Analysis Engineer To analyse the results and make sense of them according to test planning, legislation and customer request.

7.2.1.2 Electrification, Transmission and Driveline (ETAD) Operations Manager

The ETAD Operations Manager is in charge of support across internal and external sites this role is within the Powertrain test operations area; it will focus on operational leadership to ensure delivery of test and development industry leading technology to a world class standard as shown in figure 7.2.

The ETAD's key Interactions:

- Internal Product Engineering teams
- Internal Business support teams
- PTTO Team
- Strategic Suppliers
- Internal Subject Matter Experts
- Safety and Quality performance
- Facility availability and uptime measured by Schedule Performance.
- Management of the outsource budget and delivery of value for money.

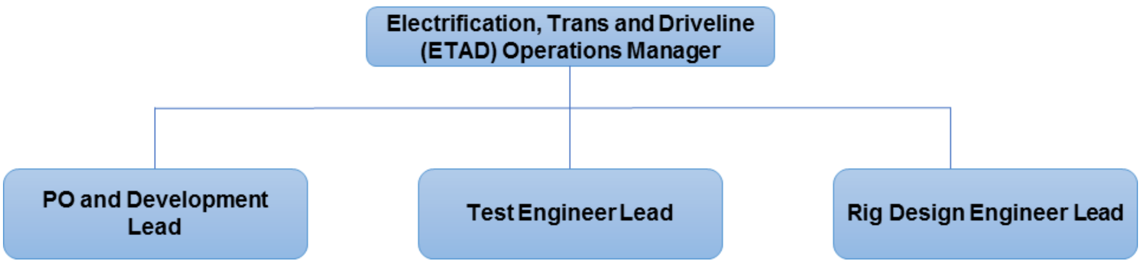


Figure 7.2 Organisational Chart - Electrification Transmission, Driveline

Productive Output and Development Lead Electrification, Transmission and Driveline Engineer is key to increasing efficiency of testing and development within the Powertrain in Loop (PiL) test field.

Ensuring that they utilise the potential of modern test automation to reduce development times through new approach and application of a combination of new technology and methodology.

Manage the skilled hourly team, and develop a technician capability, to ensure that Test Engineer specialists are able to realise the full potential from the facility and methodology.

Key Interactions

- Skilled Hourly team and Technicians
- ETAD Manager and Lead Engineers
- Suppliers i.e. test equipment (drive units and battery emulators)
- Internal Customer groups
- Technical Specialists
- Test Operations Team, i.e. LCC, Engine Test, Build and Fabrication

Test Engineer Lead Responsible for 'Test Property' acceptance, running and reporting of tests to the agreed schedule. Supports best practice test development. Selects and develops appropriate methodologies. Maintains forecasts from customer inputs, generates facility capacity plans, evaluates and reports any resource concerns and constraints.

Key Interactions

- ETAD Lead Engineers, Technicians and Manager
- Internal Customer groups
- Suppliers, i.e. transmission, ECU and test equipment (drive units and battery emulators)
- Technical Specialists
- Test Operations Team, i.e. SWAT, Engine Test

Rig Design Engineer Lead Responsible for planning, co-ordinating and allocating the work activity of the System Rig Design team, including upward looking customer relationship management and future strategy. Also responsible for the day to day task management of all System Rig Design Engineers and for conducting system rig design activity.

Key Interactions

- Internal Customer Teams
- External suppliers

- PTTO Managers
- Operations and Delivery Team
- Test and Methodology Engineers

7.2.1.3 Four by Four (4x4) operations

The Four by Four (four wheel drive) operations manager is responsible for leadership and management of the team to ensure continuity and efficiency of Operations and Delivery to agreed schedule. Team shaping, training and development to achieve operational efficiencies as shown in figure 7.3.

Development of customer and supplier relationships to ensure all objectives and commitments are met.

Key Interactions

- Internal Product Engineering teams
- Internal Business support teams
- PTTO Team
- Strategic Suppliers
- Internal Subject Matter Experts

Supervisor (Shift Leader)

Member of the 4x4 Operations & Delivery Team, part of a small organisation tasked with understanding and adapting hybrid and electric vehicle propulsion systems to fulfil a suite of tests as defined by the vehicle programme, this will include Powertrains in component form and full vehicle testing.

Key Interactions

- 4x4 Manager and Lead Engineers
- Internal Customer groups
- Technical Specialists
- 4x4 Team

4x4 Rig Technician

Technical activities, analysis and technical leadership to enable successful commissioning and test delivery.

Including: manual running, loading/starting and monitoring of approved test sequences

Key Interactions

• TCC Operations Team,

• Supplier service and support teams

• Internal Product Engineering teams

• Test Operations team

• Internal Subject Matter Experts

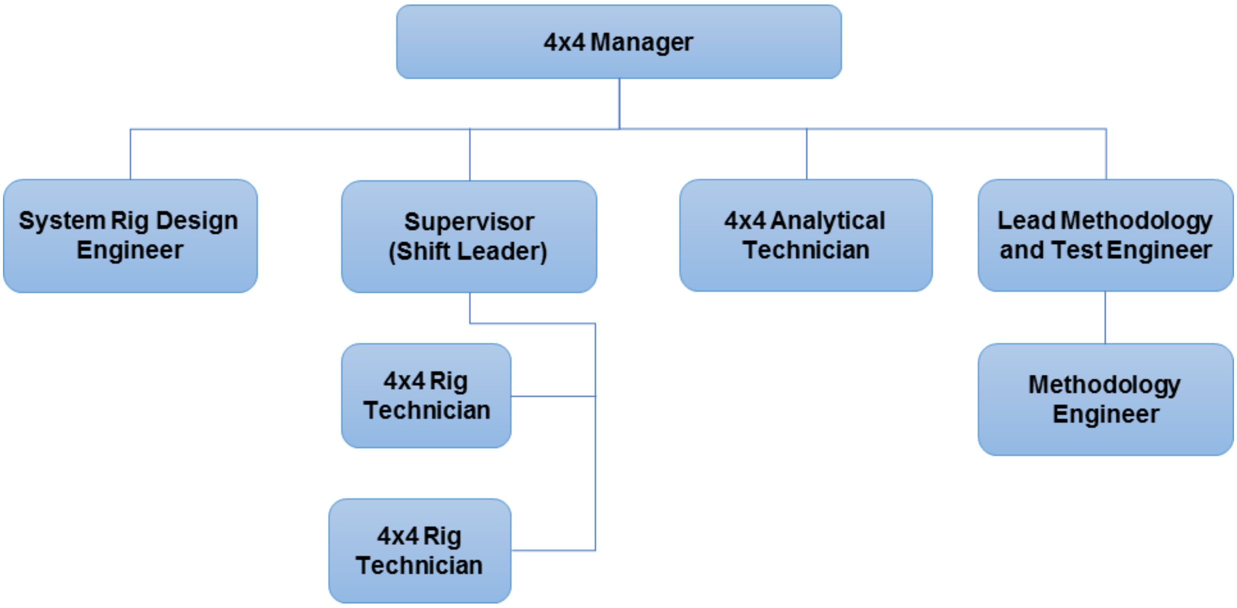


Figure 7.3 Organisational Chart – 4x4

Lead Methodology and Test Engineer Responsible for 'Test Property' acceptance, running and reporting of tests to the agreed schedule. Supports best practice test development. Select and develop appropriate methodologies

Key Interactions

- 4x4 Manager and Lead Engineers
- Customer groups
- Technical Specialists
- 4x4 Team

Methodology Engineer

Develops and delivers test methodology and automation solutions to enable the delivery of high-quality automotive systems. Writes and develops software to combine prototype vehicles and Powertrain systems into the test environment.

The service offered will be an end to end service, taking requests and transferring them to a working and commissioned integrated solution that generates timely, high quality accessible data.

The Test Methodology is key to increasing efficiency of design and development by maximising use of the 4x4 Powertrain test bed capability that can be dramatically reduced and high levels of data quality delivered at reduced cost.

Key Interactions

- Lead Engineer
- Data Quality, Planning and Process
- Internal Customer groups
- Technical Specialists
- 4x4 Team, Manager and lead Engineers

System Rig Design Engineer Responsible for taking customer requirements and delivering a full System under Test (SuT) design, including all soft and hard interfaces across the system and test facility. Deliver other work as directed by their line manager.

Key Interactions

- Internal Customer Teams
- External suppliers
- Operations and Delivery Team
- Test and Methodology Engineers

4x4 Analytical Technician. The emissions analytical technician will ensure that we provide the capability to make quality measurements and deliver tests to fulfil customer requests.

Will be responsible for providing and maintaining common processes, and for ensuring that equipment is available to maintain productive capability.
Will seek to improve operations by appropriate involvement in challenging redundant practices and using a flexible approach.
Apply strong technical capability, critical and analytical reasoning, robust planning, co-ordination and control of own workload.
Will provide continuity of testing and assurance that our facility and output meet the requirements of established international standards for laboratory accreditation.

The primary focus is on providing point of use support to maintain the productive capability through strong personal leadership and high-level analytical skills.

Ensures that analytical equipment is available to support test programme.

Development of quality measures and enhanced understanding of equipment capability.

Key Interactions

- Engineering customers
- Skilled test facility operators
- Suppliers, external agencies and organisations

Lead Analyser Support Engineer. Operates across the facility managing workflow, leading and guiding the team, retaining responsibility for conducting some of the practical/technical activities. The goal is to ensure provision of the capability to satisfy customer requests. Responsible for ensuring that productive capability is maintained whilst providing and maintaining common processes. Seeks to improve operations by appropriately challenging redundant practices and using a flexible approach.

The main focus is on maintaining productive capability, assurance of data quality and maintenance of our process documents.

Key Interactions

- Manager and Lead Engineers
- Suppliers, i.e. analytic equipment and consumables (inc. span and service gas)
- Internal Customer groups
- Technical Specialists
- Test Operations Team, i.e. Vehicle Workshop and Fabrication
- Team members reporting in to successful candidate
- Service, Maintenance and Calibration plan

7.2.2 OUR2: Test System Engineering (TSE)

The second subject organisation is the Engineering department in a UK branch of a global leading company in engineering and instrumentation and test. The department's primary function is to provide mechanical and electrical engineering solutions/designs related to powertrain test facility projects. These solutions, designs are then provided to other downstream departments for manufacture, installation and commissioning at customer sites. It was also known beforehand that the department had a mix of work of varying complexity and repetitiveness. This was considered a critical characteristic as the mix of engineering tasks would not have restricted the natural evolution of either factory or professional handover. The department has ten employees with an operational manager (who also has responsibility for other sub-divisions). Fig 7.4 shows the organization chart of this engineering department with a department head, Chief Engineers and engineers of varying levels of skills and experience.

Head of Facility Engineer

To manage the design and execution of facility engineering solution for projects. Needs clear understanding of all mechanical, fluid, electric, Noise Vibration and Harshness (NVH) and thermodynamics in context of the project.

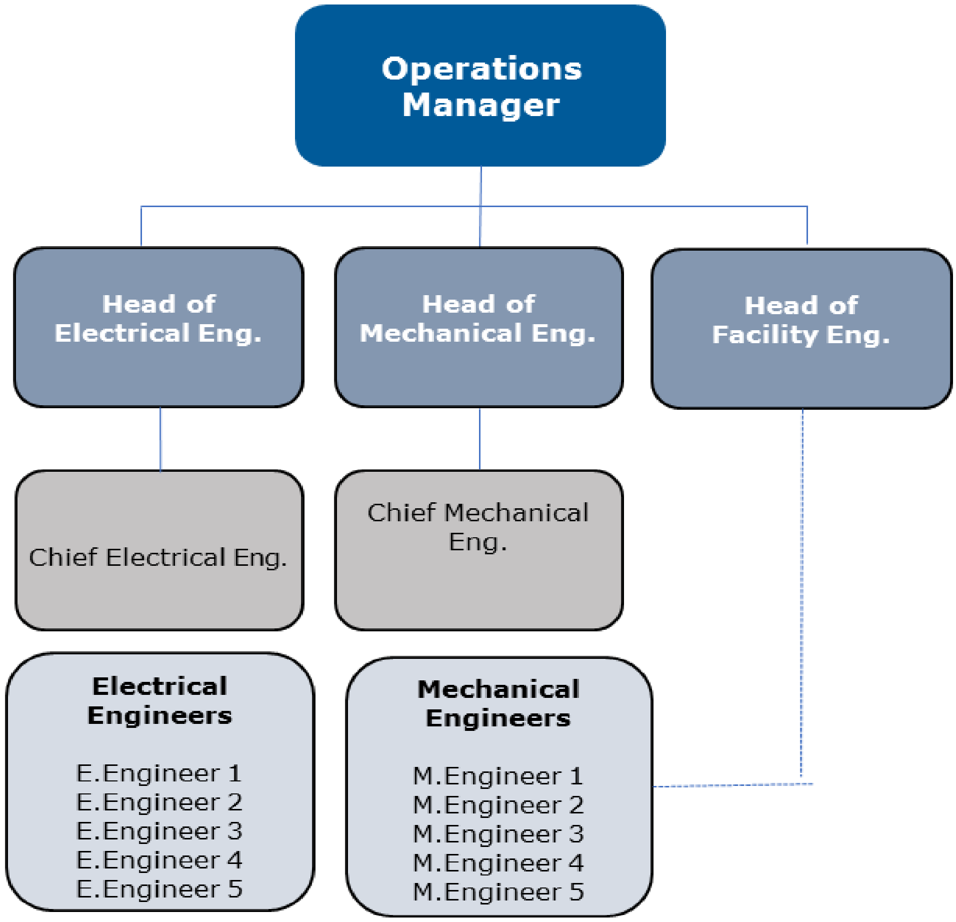


Fig 7.4 Organisation structure of Engineering department

Key Interactions

- Sales Department
- End Customer
- Third party supply chain
- Business Units delivering specific solutions
- Project management
- Site management

Head of Mech Engineer

To manage and lead the Mechanical Engineering department. Lead the design engineers, assign priorities and integrate Chief Engineer responsibilities. A high level of technical capability is required in this discipline. Maintains continuous improvement of the Mechanical Engineering Process.

Key Interfaces

- Mechanical Design Engineers
- Head of Operations
- Sales Department
- Third Party Supply Chain
- Manufacturing
- Project management
- Site management

Head of Electrical Engineering

Lead the design engineers, assign priorities and integrate Chief Engineer responsibilities. Continuous development of Electrical Engineering process. Collaborate with manufacturing for optimum solutions. High level of technical capability is required in this discipline.

Key Interface

- Electrical Design Engineers
- Head of Operations
- Sales Department
- Third Party Supply Chain
- Manufacturing
- Final Customer
- Project management
- Site management

Chief Mechanical Engineer

To provide and guide best in class analysis and mechanical design. Interact with sub-contractors technically and financially (both departmentally and within projects).

To be the senior representative of the mechanical engineering function within the organization

Key Interface

- Chief Engineer Electrical
- Head of Electrical Engineering
- Head of Mechanical Engineering
- Final Customer
- Head of Project managers
- Head of Sales
- Legal Contractual Lead

Chief Electrical Engineer

To provide and guide best in class analysis and electrical design. Interact with sub-contractors technically and financially (both departmentally and within projects).

To be the senior representative of the mechanical engineering function within the organization.

Key Interfaces

- Chief Mechanical
- Head of Electrical Engineering
- Head of Mechanical Engineering
- Final Customer
- Head of Project managers
- Head of Sales
- Legal Contractual Lead

Electrical Design Engineer

To undertake all electrical design functions allocated by departmental management in support of product, system integration and test facility design. Includes calculations, schematic circuit diagrams, graphical representations of build and installations. To liaise with build and installation when required and to visit customer sites.

Key Interfaces

- Chief Mechanical Electrical
- Head of Electrical Engineering
- Head of Mechanical Engineering
- Final Customer
- Head of Project managers
- Head of Sales
- Legal Contractual Lead
- Third Party Supply Chain
- Manufacturing
- Commissioning Engineering

Mechanical Design Engineer

To undertake all functions allocated by departmental management in support of product design, system integration and test facility design. Includes calculations, production drawings, documentation and graphical representations of installations. The principal area of work will be the production of drawings using AutoCAD and Solid-works software. To visit customer's and sub-contractor's sites as required by the role.

Key Interface

- Chief Mechanical Electrical
- Head of Electrical Engineering
- Head of Mechanical Engineering
- Final Customer
- Head of Project managers
- Head of Sales
- Legal Contractual Lead
- Third Party Supply Chain
- Manufacturing
- Commissioning Engineering

7.2 Interview selection group

Tables 7.2 and 7.3 list the job titles and interview dates of the subjects for both OURs.

Table 7.2 OEM Interview Group

Date	Job Title
June 2017	Manager of Powertrain Test Operation
June 2017	Manager of Powertrain Test Operation (Chassis Dynos)
June 2017	Lead Methodology & Test Engineer
June 2017	4x4 Technician
June 2017	System Rig Design Engineer
June 2017	4x4 Technician
June 2017	4x4 Supervisor
June 2017	Emissions Technician
June 2017	Methodology Engineer
June 2017	Powertrain Test Operations Manager (4x4 Rigs VIL & PIL)
June 2017	Dyno Shift Engineer S.V
June 2017	C.M
June 2017	Test Engineer
June 2017	Test Engineer

Table 7.3 TSE Interview Group

Date	Job Title
December 2017	Ops manager
December 2017	Mechanical Engineer
December 2017	Electrical Engineer
December 2017	Electrical Engineer
December 2017	Electrical Engineer
December 2017	Electrical Engineer
December 2017	Electrical Engineer
December 2017	Mechanical Engineer
December 2017	Mechanical Engineer
December 2017	Mechanical Engineer

7.3 Summary

To perform a stringent test to verify the hypotheses the OURs were strategically selected to represent a wide spectrum of operational characteristics. The managers of the respective OURs were approached to nominate the participants. It was ensured that no participant had been involved in any discussion related to this work. Data was gathered on the organisation, roles, responsibilities and interfaces relevant for each individual.

The next chapter includes the questions posed with the appropriate implications and the actual responses given during the interviews. This is then followed by a qualitive analysis of the questionnaire data to validate the hypothesis.

Chapter 8 Assessment and Evaluation

This chapter contains a brief description of the interview process followed by presentation of the questions and responses given for both OURs. As well as the raw results, comment is provided for each question and any implications discussed. The chapter closes with an overall scoring of the two OURs related to detection of Professional and Factory Handover and potential for productivity improvement and/or waste reduction.

8.1 Interview Process

The answers to the questions were obtained by one to one interviews conducted by the research team. In this way the interviewer could not only provide clarification of the questions if necessary but could also obtain any additional information if the subject chose to add background or reason behind their responses. Also, immediate feedback would be obtained on the individual questions related to their ability to provoke a meaningful response. The questionnaire responses were recorded in note form by the interviewer, assessed by the author and subsequently processed and presented in a tabular and graphical format. This format was chosen as it gives not only very strong visual representation but also is a structured way to view results and then asses them.

Each interview lasted one hour. This length of the interview was chosen to keep the necessary attention and focus of the interviewee.

8.2 Assessment

The following sections describe and discuss the questions posed in the survey, their grouping and how the responses to each question were categorised (see Table 6.8). The findings for each OUR group are represented graphically and numerically for each question as the discussion progresses. Table 6.4 ‘Key Indicators of Professional and Factory Delivery’ was used as a guideline to the analysis.

8.2.1 Questionnaire Section A: About You

This series of questions was the last set delivered to both sample groups, as according to the literature reviewed, it is recommended to ask demographic questions at the end of a survey. This is because it has been demonstrated that respondents are more likely to provide more accurate information, and also because these are the easiest responses for individuals to give at the end of survey when they may be experiencing cognitive fatigue that may affect responses to more challenging questions.

Question QA.1: What is your age?	
TSE	80% of this sample group is aged 40 or older. There are no individuals in the team under the age of 30.
OEM	Nearly half of this sample group is aged between 20 and 30, whilst nearly two thirds are aged between 30 and 40. There are no individuals in this team over 50 years of age.
Question QA.2: How long have you worked in testing?	
TSE	More than two thirds of this team have been working in testing for over 5 years, suggesting a very experienced team.
OEM	Approximately a third of this team has worked in testing for less than 2 years, another third has worked in testing for 5 years, and a final third has worked in testing between 2 and 5 years. This suggests a team with a wide spectrum of experience level, from almost no experience to highly experienced.
Question QA.3: What is your level of qualification?	
TSE	Most of the respondents in this team have either a Professional or Bachelor level of qualification, only a couple have a Masters level of qualification and there are no PhD's. This is a moderately educated team.
OEM	The breakdown of qualification levels for this team is about a third each for Professional, Bachelor and Master's qualifications. There is one PhD. This is a highly educated team.
Question QA.4: How long have you worked at your organisation?	
TSE	This team is split almost evenly between individuals who have worked for the organisation for either a very long time (over 5 years) or a very short time (less than two years). This indicates an organisation that has experienced sudden growth.
OEM	This sample group is split almost evenly between individuals with less than 2 years' experience, more than 5 years' experience and between 2 and 5 years' experience. This suggest an organisation that is growing but more steadily.
Question QA.5: What engine testing facilities have you used in the past or are using currently?	
TSE	This team has a broad range of experience on all type of testing facilities in approximately equal amounts.
OEM	This team has experience in a wide range of testing, with a slight emphasis on emissions testing.

Table 8.1a – TSE data: questions QA.1 to QA5

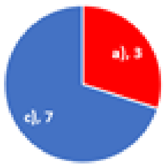
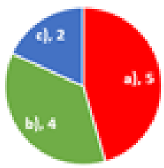
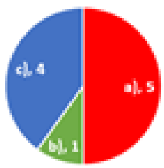
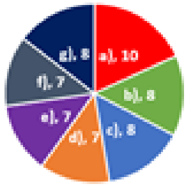
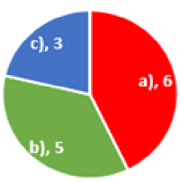
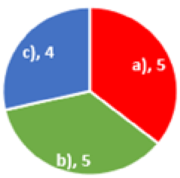
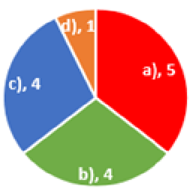
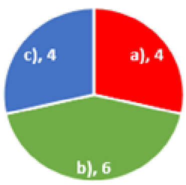
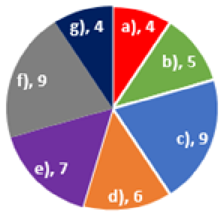
QA.1 What is your age? a) 20-30 b) 30-40 c) 40-50 d) Above 50		QA.2 How long have you worked in testing for? a) 0-2 Years b) 2-5 years c) Over 5 years		QA.3 What is your level of qualification? a) Professional qualification (HNC,HND) b) Bachelor degree (BSc/BEng) c) Masters degree d) PhD		QA.4 How long have you worked at this company ? a) 0-2 years b) 2 to 5 years c) Over 5 years		QA.5 What engine testing facilities have you used in the past or are using currently? a) Engine dyno (steady state) b) Engine dyno (transient) c) Chassis dyno (rolling road) d) Powertrain dyno (transient) e) Vehicle testing (on the road) f) Emission measurement g) Other	
									
a)	0	a)	3	a)	5	a)	5	a)	10
b)	2	b)	0	b)	4	b)	1	b)	8
c)	3	c)	7	c)	2	c)	4	c)	8
d)	5			d)	0			d)	7
								e)	7
								f)	7
								g)	8

Table 8.1b – OEM data: questions QA.1 to QA.5

QA.1 What is your age? a) 20-30 b) 30-40 c) 40-50 d) Above 50		QA.2 How long have you worked in testing for? a) 0-2 Years b) 2-5 years c) Over 5 years		QA.3 What is your level of qualification? a) Professional qualification (HNC,HND) b) Bachelor degree (BSc/BEng) c) Masters degree d) PhD		QA.4 How long have you worked at this company? a) 0-2 years b) 2 to 5 years c) Over 5 years		QA.5 What engine testing facilities have you used in the past or are using currently? a) Engine dyno (steady state) b) Engine dyno (transient) c) Chassis dyno (rolling road) d) Powertrain dyno (transient) e) Vehicle testing (on the road) f) Emission measurement g) Other	
									
a)	6	a)	5	a)	5	a)	4	a)	4
b)	5	b)	5	b)	4	b)	6	b)	5
c)	3	c)	4	c)	4	c)	4	c)	9
d)	0			d)	1			d)	6
								e)	7
								f)	9
								g)	4

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Questionnaire Section 1: Organisation Reporting and Structure

This first section of questions looks primarily at the organisation of the sample group as it is today, focusing particularly at the management structure. These first three questions are aimed specifically at understanding the organisations management structure and is used to verify the understanding of the hierarchy and interfaces of the organisation. The last set three questions are a mix of 'change potential' and detection questions'.

Question Q1.1: How many layers of management are above you? (org Chart)	
TSE	Approximately two thirds of this team have no more than two managers above them, the remained have between 2 and 5 managers above them. This suggest either a lean organisational structure or that this sample group has several senior individuals amongst the respondents.
OEM	Half of the respondents have between 2 and 5 managers above them, and more than a third have between 2 and 5 levels of management above them. This suggests either a large organisation or a sample group dominated by junior individuals.
Question Q1.2: How many people are under your direction? (org chart)	
TSE	Nearly two thirds of the respondents have 1 or 2 people under their direction, whilst about a quarter have between 2 and 5 people under their direction. Only one individual has more than five people to manage. This suggests either a medium sized organisation or a sample group with a significant amount of mid-level managers and one high level manager.
OEM	Nearly two thirds of the respondents have more than 5 people under their direction, with a quarter having between 2 and 5 people to manage. This suggests either a large organisation or a sample group with a substantial proportion of senior managers.
Question Q1.3: What is the size of your team? (org chart)	
TSE	Half of the respondents are in a team of between 2 and 5 individuals, and more than a third is in a team with more than 5 individuals. This suggest a medium sized organisation.
OEM	About 85% of the respondents work in a team of more than 5 individuals. This suggest a large organisation

Table 8.2a TSE data: questions Q1.1 to Q1.6

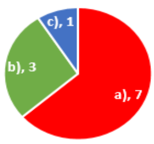
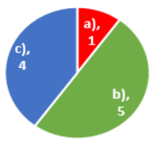
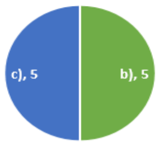
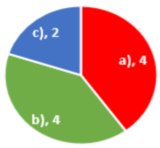
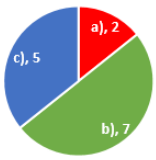
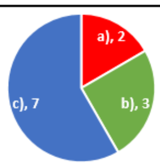
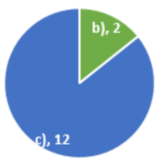
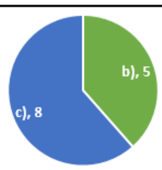
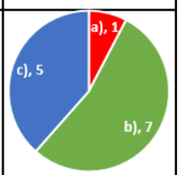
Q1.1 How many layers of managers are above you? a) 1-2 b) 2-5 c) >5		**Q1.2** How many people are under your direction? a) 1-2 b) 2-5 c) >5		**Q1.3** What is the size of your team? a) 1-2 b) 2-5 c) >5		**Q1.4** How would you describe your tasks? a) It is a black-art b) it is a scientific/engineering process c) Mix of the two		**Q1.5** Do you think it is possible to change or improve the tasks? a) Yes b) No		**Q1.6** Do you think there is a need to change the way that you deliver the tasks? a) No b) Yes c) I don't know	
											
a)	6	a)	7	a)	1	a)	0	a)	9	a)	4
b)	4	b)	3	b)	5	b)	5	b)	1	b)	4
c)	0	c)	1	c)	4	c)	5			c)	2

Table 8.2b OEM data: questions 1.1 to 1.6

Q1.1 How many layers of managers are above you? a) 1-2 b) 2-5 c) >5		**Q1.2** How many people are under your direction? a) 1-2 b) 2-5 c) >5		**Q1.3** What is the size of your team? a) 1-2 b) 2-5 c) >5		**Q1.4** How would you describe your tasks? a) It is a black-art b) it is a scientific/engineering process c) Mix of the two		**Q1.5** Do you think it is possible to change or improve the tasks? a) Yes b) No		**Q1.6** Do you think there is a need to change the way that you deliver the tasks? a) No b) Yes c) I don't know	
											
a)	2	a)	2	a)	0	a)	0	a)	11	a)	1
b)	7	b)	3	b)	2	b)	5	b)	1	b)	7
c)	5	c)	7	c)	12	c)	8			c)	5

Question Q1.4: **How would you describe your tasks? (detection)**	
TSE	All responses for this question were either answer b) or c), split evenly between the two. Not a single respondent chose answer a), this indicates that these subjects' perception of their tasks as mostly Factory Handover oriented work. As half the subjects answered c) 'Mix of the two', there is the implication that some proportion of the work is perceived by the respondents as a 'black art'. However, the term 'black art' is very emotive, particularly for a technical work force that tends to value process/data/experience over instinct/iteration, so there is a possibility that respondents chose answer c) in lieu of response that suggested the task needed creative problem solving. Result: No bias
OEM	This team responses indicate that there is little bias between Professional and Factory Handover in their tasks. The next most popular response is for answer b), suggesting that if there is a bias, it would be towards a Factory mode of operation, however the dominance of answer c) suggest a larger proportion of the sample group perceive their tasks as a 'black art' than within the Engineering Org. sample group. This is interesting as there may have been an expectation that an OEM would be more process/standardisation oriented compared to an engineering supplier/consultancy. Result: No bias
Question Q1.5: Do you think it is possible to change or improve the tasks? (Change Potential)	
TSE	This question is designed to indicate if there is a potential to change the organisation from Professional Handover to Factory, or vice versa. A strong majority of the respondents answered a) to this question, indicating that they feel their tasks can be changed or improved. This implies that there is some commonality and repetition of their tasks, which further suggests that this team can move to a more Factory Handover oriented approach to its business. Result: potential for change
OEM	The respondents also responded strongly with answer a), suggesting this team can also change to a more Factory oriented approach to its business. Whilst it may appear surprising that an OEM testing operation has not yet maximised its potential for Factory Handover operation, many of the comments indicate that there a significant changes and new situations for this team, and as such, the organisation may not have stabilised enough to implement Factory methods. Result: potential for change
Question Q1.6: Do you think there is a need to change the way that you deliver the tasks? (change potential)	
TSE	This question is designed to indicate if there is a potential to change the organisation from Professional Handover to Factory, or vice versa. A strong majority of the respondents answered a) to this question, indicating that they feel their tasks can be changed or improved. This implies that there is some commonality and repetition of their tasks, which further suggests that this team can move to a more Factory Handover oriented approach to its business. Result: potential for change
OEM	The respondents also responded strongly with answer a), suggesting this team can also change to a more Factory oriented approach to its business. Whilst it may appear surprising that an OEM testing operation has not yet maximised its potential for Factory Handover operation, many of the comments indicate that there a significant changes and new situations for this team, and as such, the organisation may not have stabilised enough to implement Factory methods. Result: potential for change

Questionnaire Section 2: Working practice: How do you see your job?

Questions in Section 2 focuses primarily on the type of work that is done by the respondents themselves and the work done within their own team. The majority of the questions are detection questions to uncover Professional or factory Handover practices within the sample groups' organization. They are written in a way that should encourage a subjective response from the respondents to uncover true perceptions and behaviours rather than factual data that can be verified with metrics. Some of the questions were designed to determine the actual communication and information flow and hierarchy throughout the organisation. The aim is to describe the organisation 'as lived' rather than organisation 'as published' i.e. as shown in the formal organisation chart.

Question Q2.1: Do you plan your typical working day? (detection)	
TSE	The majority of responses answered d) suggests that the respondents perceive the structuring of their own work as their own responsibility, and as only occasional reviews are required with management or a team, this suggests that the organisation also encourages self-structured work. This behaviour indicates Professional Handover. The next most popular response is answer c) 'I keep a formal work plan', however this could be equally self-directed or dictated by superior. The keeping of a formal workplan again indicates a plan for that particular action and not a repeated plan as in factory handover. Result: professional
OEM	The respondents are almost equally split between having planned daily work, either by themselves or others, and self-directed daily work. Whilst this may indicate an even split between factory and Professional Handover modes of operation, some of the comments indicate that some respondents are responsible for unforeseen maintenance and repair task and general 'firefighting'. This type of work cannot be scheduled in advance, indicating Professional Handover, however there is a possibility that there are standardised processes for executing the individual task, which would indicate Factory Handover. Result: no bias

Table 8.3a – TSE data: questions 2.1 to 2.6

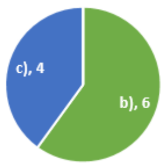
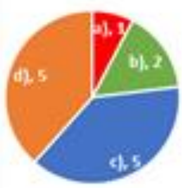
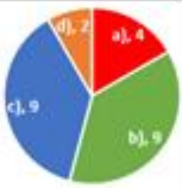
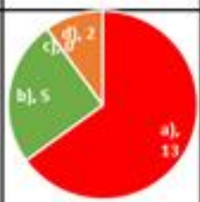
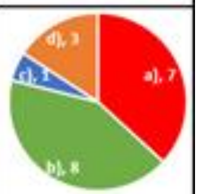
Q2.1 Do you plan your typical working day? a) I don't, somebody plans it for me b) I don't, I face the problems as they arise c) I keep a formal work plan d) Periodic team and manager reviews		**Q2.2** How far do you plan ahead? a) Daily b) Weekly c) Monthly d) Yearly		**Q2.3** How are your tasks communicated to you? a) Direct instruction from S.V b) Meetings c) Programme documentation (charts & milestones) d) Verbal or other		**Q2.4** How do you know you are delivering your programme/product on time? a) Periodic review meetings b) Programme documentation (charts & milestones) c) I don't know d) Other		**Q2.5** How do you know you are delivering your programme/product to required targets? E.g. attribute/engineering targets a) Periodic review meetings b) Direct from planning documentation c) I don't know d) Other		**Q2.6** How do you quantify your product development goals? (how do you measure success/output?) a) Periodic review meetings b) Direct from planning documentation c) I don't know d) Other	
											
a)	0	a)	0	a)	2	a)	8	a)	7	a)	5
b)	1	b)	6	b)	6	b)	4	b)	5	b)	3
c)	4	c)	4	c)	4	c)	0	c)	0	c)	1
d)	6	d)	0	d)	2	d)	1	d)	0	d)	2

Table 8.3b – OEM data: questions 2.1 to 2.6

Q2.1 Do you plan your typical working day? a) I don't, somebody plans it for me b) I don't, I face the problems as they arise c) I keep a formal work plan d) Periodic team and manager reviews		**Q2.2** How far do you plan ahead? a) Daily b) Weekly c) Monthly d) Yearly		**Q2.3** How are your tasks communicated to you? a) Direct instruction from S.V b) Meetings c) Programme documentation (charts & milestones) d) Verbal or other		**Q2.4** How do you know you are delivering your programme/product on time? a) Periodic review meetings b) Programme documentation (charts & milestones) c) I don't know d) Other		**Q2.5** How do you know you are delivering your programme/product to required targets? E.g. attribute/engineering targets a) Periodic review meetings b) Direct from planning documentation c) I don't know d) Other		**Q2.6** How do you quantify your product development goals? (how do you measure success/output?) a) Periodic review meetings b) Direct from planning documentation c) I don't know d) Other	
											
a)	1	a)	4	a)	5	a)	13	a)	9	a)	7
b)	2	b)	9	b)	12	b)	5	b)	3	b)	8
c)	5	c)	9	c)	7	c)	0	c)	2	c)	1
d)	5	d)	2	d)	6	d)	2	d)	5	d)	3

Question Q2.2: How far do you plan ahead? (detection)	
TSE	The majority of responses were for answer b), with the remaining for answer c), indicating that future planning for the respondents is typically projected between one week and up to one month. Whilst this could suggest that the majority of complete jobs/projects are short and last a week or two, in an automotive environment this would be unlikely. Planning of a week or two in advance for medium to long term projects suggests very changeable circumstances that require short term reactions, indicating Professional Handover. The long-term plan shows a task set and an engineer planning the delivery of this task. Each engineer regardless of discipline has developed a plan to deliver. Based on above answers it can be assumed that even if the plan is long term it is made up of short-term sections which would indicate a tendency towards professional. Result: professional
OEM	There is an indication of an even split between Factory and Professional Handover in the planning projections of this sample group. This may be related to the fact that this group contains a wider range of responsibilities and hierarchical position than the Engineering Org. sample group. As mentioned in the results for Question 2.1, some comments suggested that some of the respondents were responsible for unforeseen issues, which may need to be resolved in days, if not weeks. Meanwhile other respondents in supervisory or scheduled maintenance roles may be able to plan task months or a year in advance. Result: no bias
Question Q2.3: How are your tasks communicated to you? (detection)	
TSE	The majority of respondents answered b), 'Meetings' to describe how tasks are communicated to them. 'Verbal or other' and 'Direct instruction from Supervisor' were also answers provided, however, with the exception of answer c), 'Programme documentations', all of the other possible responses can be interpreted as a kind of verbal instruction. Therefore, the results of this question may lead to indicate Professional Handover. This answer shows a wide scatter with many lines of communication with also verbal. The lack of formality, and structure in a verbal instruction can be interpreted as a professional handover environment. This question has led to unclear detection and it should not be considered in overall evaluation. For future work this type of detection question could be split in smaller steps hence bringing out a clearer result. Result: no bias
OEM	This group responses are likely to inaccurately indicate Professional Handover for the same reasons as the TSE responses, hence this question is not to be considered in the analysis.
Question Q2.4: How do you know you are delivering your programme/product on time? (detection)	
TSE	A clear majority of respondents answered a) 'period review meetings' as the primary source of consultation to ensure their work is delivered on time. This strongly suggests Professional Handover, due to the reliance of a verbal response from other individuals at discrete times. For Factory Handover, one would expect all individuals would be able to access clear and transparent schedules and deadlines for a task at any time and of their own accord. A process driven structure is very evident here with no evidence of factory handover. Result: professional
OEM	As with the response from the TSE group, the OEM sample group are also heavily reliant on review meetings to understand their timing and progress. In fact, more so. This may however, be a consequence of the unplanned nature of the work, as

	discussed earlier, thus making meetings a necessary and practical means of communicating deadlines for tasks that are unforeseen and/or urgent. Result: professional
Question Q2.5: How do you know you are delivering your programme/product to required targets? E.g.; attribute/engineering targets? (detection)	
TSE	The respondents answered mostly a) “Periodic review meetings”, suggesting a strongly Professional Handover approach to monitoring delivery to target/s. A strongly Factory Approach would rely mostly on documentation, particularly in the case of this team which does not have a centralised location for manufacturing or the projects themselves. Reliance on meetings suggests there is no transparent mechanism for the team members to independently orient themselves with targets and must instead depend on managers who hold this information. Result: professional
OEM	These respondents also answer mostly a) to this question, showing a reliance on instruction from managers for programme/project target information. However, this may not suggest a Professional Handover mode of operation as strongly as for the TSE. This team operates from fixed locations, with set shift patterns, and fairly consistent types of testing work, therefore it’s possible that the review meetings are similar to the types of meetings that are recommended by Lean practises. These meetings are regular, short, and convey predetermined information that is quickly communicated to instruct the team for a defined period of time and may involve a notice board or other visual document. In other words, while this a meeting, it is a very structured form of meeting making it a Factory approach to communication. Therefore, the results of this question for this OEM have to be evaluated in context of the types of review meetings the respondents participate in. Result: no bias
Question Q2.6: How do you quantify your product development goals? How do you measure success/output? (detection)	
TSE	This group responded mostly with answer a) “Periodic review meetings”, indicating that the team relies on verbal communication to measure success or output for projects. This is strongly Professional behaviour, indicating that quantifiable measures of success are not a strong feature of program delivery. It may also suggest that the projects may vary in nature sufficiently to make it difficult to establish a common set of metrics, however simple metrics against the promised deliverable per project should be achievable. In these answers it shows that the goals are individual and not evidence of factory handover. Result: professional
OEM	The respondents answered mostly b), indicating that documentation is the most used method to quantify success against goals. Coupled with comments that state the specific metrics that are used by/for the respondent to measure success. This indicates a strongly Factory approach to measuring output versus deliverables over time. Result: factory

Table 8.4a – TSE data: questions 2.7 to 2.13

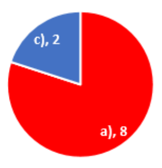
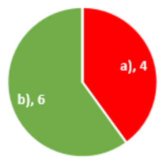
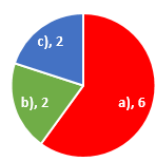
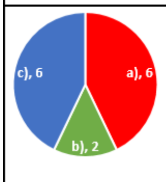
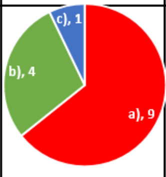
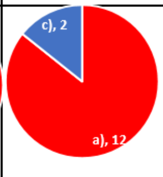
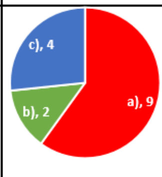
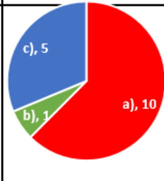
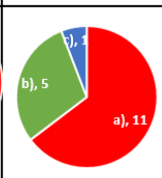
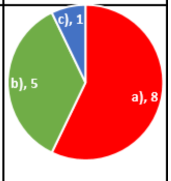
Q2.7 How is facility/equipment allocated for your use? a) I get facility/equipment allocated to me b) I don't get personal allocation, shared equipment c) Other		**Q2.8** Are you aware of any limitations of the testing facility resource? (e.g. resource limits to do the job) a) Yes b) No c) Other		**Q2.9** Do you have freedom to determine the technical steps/actions necessary to deliver your task? a) Yes b) No c) Other		**Q2.10** Are the development tasks you perform assigned to you as an individual? a) Yes b) No (as part of a team) c) Other (as part of a team)		**Q2.11** Can you decide upon how to define and/or manage any necessary testing as you see fit? a) Yes b) No c) Other (as part of a team)		**Q2.12** Do you see any need to standardise product development tasks or should the focus be on a successful outcome/result only? a) Yes b) No c) Other		**Q2.13** Do the development tasks you perform rely on a high degree of expertise to ensure a successful outcome? (Do you need to be a super specialist?) a) Yes b) No c) Other	
													
a)	8	a)	4	a)	8	a)	5	a)	4	a)	6	a)	6
b)	0	b)	6	b)	1	b)	3	b)	0	b)	0	b)	2
c)	2	c)	0	c)	1	c)	2	c)	6	c)	4	c)	2

Table 8.4.b – OEM data: questions 2.7 to 2.13

Q2.7 How is facility/equipment allocated for your use? a) I get facility/equipment allocated to me b) I don't get personal allocation, shared equipment c) Other		**Q2.8** Are you aware of any limitations of the testing facility resource? (e.g. resource limits to do the job) a) Yes b) No c) Other		**Q2.9** Do you have freedom to determine the technical steps/actions necessary to deliver your task? a) Yes b) No c) Other		**Q2.10** Are the development tasks you perform assigned to you as an individual? a) Yes b) No (as part of a team) c) Other (as part of a team)		**Q2.11** Can you decide upon how to define and/or manage any necessary testing as you see fit? a) Yes b) No c) Other (as part of a team)		**Q2.12** Do you see any need to standardise product development tasks or should the focus be on a successful outcome/result only? a) Yes b) No c) Other		**Q2.13** Do the development tasks you perform rely on a high degree of expertise to ensure a successful outcome? (Do you need to be a super specialist?) a) Yes b) No c) Other	
													
a)	6	a)	9	a)	12	a)	9	a)	10	a)	11	a)	8
b)	2	b)	4	b)	0	b)	2	b)	1	b)	5	b)	5
c)	6	c)	1	c)	2	c)	4	c)	5	c)	1	c)	1

Question Q2.7: How is facility/equipment allocated for your use? (detection)	
TSE	The majority of respondents answered that facility/equipment is allocated to themselves to execute their tasks. This question is one of the strongest indicators for identifying an organisation as either Factory or Professional, as the link between equipment and individuals is highly illustrative of how the organisation executes its tasks or projects. However, this question if it's just on facility it may not be applicable to the specific team that participated in this survey. As much of the work is bespoke to customer requirements and often on-site at the customer, meaning that allocation of equipment and facility is difficult to share. So, the very nature of the business promotes a Professional approach for utilizing facility for this team. Because the allocation of test facility is not directly linked to their daily task this result is excluded as not relevant to the subject organisation. Result: professional
OEM	The responses from the sample group indicates no bias between a Factory or Professional approach to equipment allocation, however this may have much to do with the fact that this team runs the facility and is largely responsible for planning and allocation of the facility, i.e.; they are not the users of the test facility. Result: no bias
Question Q2.8: Are you aware of any limitations to the test facility resource, e.g.; resource limits on tasks? (detection)	
TSE	An answer of b) "No" to this question would suggest a mostly Professional Handover oriented operation, as Factory oriented organisations are highly aware of their resources and the availability and limitations to those resources. However, again the work for this group is Professional by nature due to the relatively bespoke customer projects, thus making facility and resource limitations difficult to exclude from general project challenges especially when incorporating lean in the design. As per previous question comments the result is excluded as not directly relevant to the subject organisation. Result: professional
OEM	The majority of the respondents were aware of limitations to the facility and resource availability, as would be expected of a powertrain testing organisation, and this awareness indicates that this team is very Factory orientated in its perception of their operations. Result: factory
Question Q2.9: Do you have freedom to determine the technical steps/actions necessary to delivery your task? (detection)	
TSE	A clear majority of responses to this question were a) for the respondents, indicating that they have the freedom to take technical initiative to deliver a task. This suggests highly Professional behaviour, provided that the implication/understanding of this question is that the individual need not consult with peers or superiors. For an individual to be able to act independently to achieve a delivery suggests either a process for that task is not in place, or that process can be ignored. The answer to this question is by far the biggest evidence of a professional handover environment. Result: professional
OEM	As with the TSE respondents, the OEM sample group also answered a), though with a slightly smaller majority. Some of the comments suggest that the autonomy to make technical decisions stems from a breakdown in planned activity or process, e.g. issues with capacity or lack of engineering support, nonetheless, this still indicates a highly Professional mode of operation. Result: professional

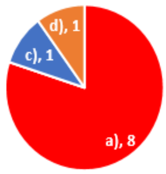
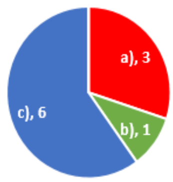
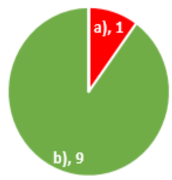
Question Q2.10: Are the development tasks you perform assigned to you as an individual? (detection)	
TSE	Half of the respondents answered a), indicating that tasks are assigned to individuals which would suggest classic Professional Handover organisational behaviour. Approximately a third responded c) “Other”, with one comment suggesting that even though a task might be assigned to a team, there is the potential to adapt that team with specific individuals, further indicating Professional behaviour. In the answers the biggest portion is assignment as individual. The process is clearly to give a task from beginning to the end to one individual who will then use his best judgment to proceed. A classis professional handover. Even as a team is the same conclusion. So far still no evidence of factory handover. The “I don’t know” is new starter whom are unclear all the rules of engagement. That is in itself is a professional handover status as there are no standard parts which they can perform regularly but they await training and immersion in the department. Result: professional
OEM	A large majority of respondents also answered a), indicating that task are assigned to individuals, however this response may be misleading as it is possible that the respondents misinterpreted the question, as it is highly unlikely in a testing environment of an OEM that people are selected for their individual skills in an operation that runs several shifts a day, including many weekends. More likely, the respondents are assigned individually to tasks, but they share that same task with other individuals, as per shift work, which is supported by one of the comments made by a respondent. That then would indicate a more Factory approach to task allocation. Result: professional
Question Q2.11: Can you decide upon how to define and/or manage any necessary testing as you see fit? (detection)	
TSE	As the sample group used of this study is not directly involved in testing, this question is not relevant to their organisation and therefore not applicable to the results. Result: no bias
OEM	The respondents answered in the majority a), that they can decide on how to define or manage any necessary testing. Again, like the previous question, this may have been misinterpreted by the respondents. This team is responsible for the test facility, and therefore the planning of all tests, and whilst managers and team leaders responsible for this planning were part of the sample group, this activity is more likely to be part of a Factory operation, as this team is responsible for planning and executing the tests request of their customers. However, if the scheduled planning fails on a consistent basis, this may force the team (including individuals) to improvise to rectify the situation, which would indicate Professional organisational behaviour. Therefore, the results of this question for the JLR sample group should be read as inconclusive. It can be concluded that this question as detection question not relevant to this particular research case but would be valid for test engineers running the test beds. To be more specific if the engine test beds are operated by the development engineers then an answer would show a strong professional handover. If on the other hand the test beds are operated by test bed operators the expected answer could be b as they would test according to planned testing, indicating a strong factory handover. Result: Professional

Question Q2.12: **Do you see any need to standardise product development tasks or should the focus be on a successful outcome/result only? (change potential)**	
TSE	The answers here are clearly yes as intuitively standardisation is seen as direction toward efficiency. This wish is an openness in factory handover even if this definition is not known to them. The following questions will go deeper in this understanding. The results of this question are excluded from analysis as this question is ambiguous and there is no certainty that all respondents interpreted the question in the same way. In future research, this question would be better separated into two.
OEM	Question not included in questionnaire.
Question Q2.13: **Do the development tasks you perform rely on a high degree of expertise to ensure a successful outcome? (Do you need to be a super specialist?) (detection)**	
TSE	This question, which focuses on whether an organisation relies on highly skilled individuals or a combination of process and a team of moderately experienced individuals, is one of the key questions to determine Factory of Professional Handover behaviours of an organisation. This sample group responded strongly to a), that tasks rely on highly on experienced individuals, and even those who responded with an answer other than a) placed caveats on their response by commenting that is depends on the task or that it is possible to succeed in the task with less experienced individuals but that this incurs a cost. These responses indicate that this team is highly oriented towards Professional Handover behaviour where individual competencies and experience are concerned. The dominant answers fall entirely in professional handover definition. Where personal expertise is the driver to performed task. There is no evidence in segmentation to lower skill set and execute standard work. Result: professional
OEM	The sample group also answered mostly a), that a high degree of experience and skill are required for their tasks, yet a higher proportion respond that this is not necessary and all of the comments suggest that training could overcome a lack of skill and experience to successfully execute the tasks. Nonetheless, this still demonstrates Professional Handover behaviour as there is a reliance on focusing on individual skills rather than supporting existing skills with process and documentation. Result: professional

Question Q2.14: **Could some/all of your product development tasks be assigned to a less experienced/junior member of staff with minimal mentoring necessary for a successful outcome? (Is there a process in place?) (detection)**	
TSE	Half of the SME respondents answered a), that tasks could be assigned to less experienced individuals with minimal mentoring, which would indicate a desire for a more Factory based approach to resource allocation, as assigning task to less experience members with minimal intervention would provide the organisation with more flexibility. However, one respondent who answered a) commented that there would be a limitation to approach, this, coupled with the other half of the responses being b) or c), indicates that this team is currently reluctant to change its practices to a more Factory based approach even if it can appreciate the benefits. The question is probing to find out if a process is in place for factory handover and the willingness to pass on work to less skill. The management do wish to introduce standardisation based on Q2.12, this is a first sign of a potential for factory handover. The lack of process and potentially precise documentation for this, obviously hinders this move and of course also the feeling that all engineers should be skilled at the highest level which of course is Professional handover behaviour. Result: no bias
OEM	This sample group answered inconclusively to the question of allocating tasks to inexperienced individuals with minimal support and training, indicating that there are limitations to moving to a more Factory based approach to skill allocation. This is to be expected if the two handovers are detailed in advance of questions. Result: no bias
Question Q2.15: **Do you share your working methods and knowledge for this task with your fellow team members? (detection)**	
TSE	The sample group answered a) "Yes" with a strong majority, stating that knowledge is shared amongst their team members. This willingness to share information is a key indicator of Factory Handover openness and practices. The dominant answer that confirms the willingness to share best practice is laudable and a very good base to create the two environments of factory and professional handover. Result: factory
OEM	This sample group also answered a) "Yes" with a strong majority, stating that knowledge is shared amongst their team members. This willingness to share information is a key indicator of Factory Handover practices and openness to operate in the two handover environments. Result: factory
Question Q2.16: Are your engineering targets clearly defined? (detection)	
TSE	Half of the respondent answered a) 'Yes', their engineering targets are clearly defined, however the other half answered either b) 'No' or c) 'Partly', with comments suggesting engineering targets may vary even after definition. Therefore, there appears to be no clear bias between a professional of factory approach to engineering target definition. Result: No bias
OEM	The respondents answered mostly a), indicating that engineering targets are clearly defined, with the comments evidencing processes like score cards to support those target deliveries. This demonstrates a clear example of Factory Handover practices. Result: Factory

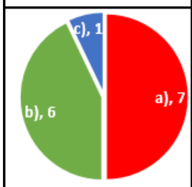
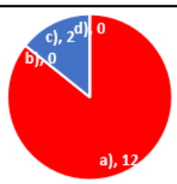
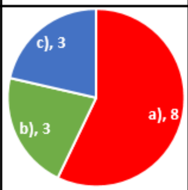
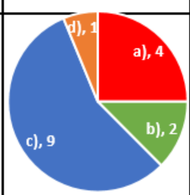
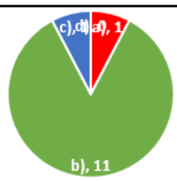
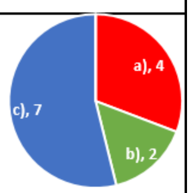
Question Q2.17: Are you responsible for defining your engineering targets, and if so, are these related to vehicle/powertrain attribute targets? (detection)	
TSE	The respondents answered mostly c) “Partly”, indicating that the engineering target definition is not consistently the responsibility of the same individuals/team. One comment suggests there may be several targets and this team is responsible for a faction. Therefore, the results of this question do not indicate a preference for Professional or Factory behaviour. Result: no bias
OEM	Respondents also answered mostly c) “Partly”. However, several comments suggest that there a collaborative effort to define engineering targets with testing customer. Therefore, the results show no bias towards Professional or Factory behaviour, but this result may be skewed by the influence of the customer on the testing teams’ practices. Result: no bias
Question Q2.18: Who do you feel the engineering delivery in your department relies on? (detection)	
TSE	The respondents almost unanimously responded b) “A team with a range of skills and experience”, which would indicate a team set up for Factory operation. This appears to contradict the previous responses with regards to team skills and deployment, which suggested a very Professional organisation of skills. Result: factory
OEM	The respondents also answered almost unanimously with answer b), indicating a team set up for a Factory Handover style of operation. Given that this team has a much more focused range of tasks than the TSE team, coupled with previous responses, this suggests that the team structure is intended for Factory operation. Result: factory
Question Q2.19: Is the task you perform clearly defined and planned upfront with supporting documentation? If so, who does it? (detection)	
TSE	Half of answers to this question were c) “Partly”, followed by b) “no”, which indicates that there is little upfront process, planning or documentation to the task performed by the team, suggesting strongly Professional Handover behaviour i.e. reliant on individual skills to deliver the task. Result: professional
OEM	Over half of the respondents answered c) “Partly” when asked if their tasks are clearly defined, documented and planned, however the next highest response was for a) “Yes”. One comment gives a clue to this contradictory response, suggesting that whilst plans and definitions are in place, there are many changes to these during the execution of the task. Therefore, it is possible that the team attempts to work in Factory manner, but if this is disrupted, they revert to Professional behaviour. Result: no bias

Table 8.5a TSE data questions 2.14 to 2.19

Q2.14 Could some/all of your product development tasks be assigned to a less experienced/junior member of staff with minimal mentoring necessary for a successful outcome? (is there a process in place? a) Yes b) No c) Other	**Q2.15** Do you share your working methods and knowledge for this task with your fellow team members? a) Yes b) No c) Partly d) Other	**Q2.16** Are your engineering targets clearly defined? a) Yes b) No c) Partly d) Other	**Q2.17** Are you responsible for defining your engineering targets, and if so, are these related to vehicle/powertrain attribute targets? a) Yes b) No c) Partly d) Other	**Q2.18** Who do you feel that engineering delivery in your department relies on? a) A few highly experienced indiviual experts b) A team with a range of skills and experience c) A mix of the two d) Other	**Q2.19** Is the task you perform clearly defined and planned upfront with supporting documentation? If so, Who does it? a) Yes b) No c) Partly d) Other
					

a)	5	a)	8	a)	5	a)	3	a)	1	a)	2
b)	4	b)	0	b)	2	b)	1	b)	9	b)	3
c)	1	c)	1	c)	3	c)	6	c)	0	c)	5
		d)	1	d)	0	d)	0	d)	0	d)	0

Table 8.5b OEM data questions 2.14 to 2.19

Q2.14 Could some/all of your product development tasks be assigned to a less experienced/junior member of staff with minimal mentoring necessary for a successful outcome? (is there a process in place? a) Yes b) No c) Other	**Q2.15** Do you share your working methods and knowledge for this task with your fellow team members? a) Yes b) No c) Partly d) Other	**Q2.16** Are your engineering targets clearly defined? a) Yes b) No c) Partly d) Other	**Q2.17** Are you responsible for defining your engineering targets, and if so, are these related to vehicle/powertrain attribute targets? a) Yes b) No c) Partly d) Other	**Q2.18** Who do you feel that engineering delivery in your department relies on? a) A few highly experienced indiviual experts b) A team with a range of skills and experience c) A mix of the two d) Other	**Q2.19** Is the task you perform clearly defined and planned upfront with supporting documentation? If so, Who does it? a) Yes b) No c) Partly d) Other
					

a)	7	a)	12	a)	8	a)	4	a)	1	a)	4
b)	6	b)	0	b)	3	b)	2	b)	11	b)	2
c)	1	c)	2	c)	3	c)	9	c)	1	c)	7
		d)	0	d)	0	d)	1	d)	0	d)	0

Question Q2.20: Are your development tasks assigned to you personally or as a team? (detection)	
TSE	Similar to Q.2.10, this question attempts to uncover if an organisation is Factory or Professional Handover oriented, if an organisation places emphasis on individual experience and skills over teams and processes, this would be a key indicator of Professional behaviour. This is the case for this team, where a clear majority of the respondents are directly responsible for development tasks. Result: professional
OEM	A smaller majority of the respondents are directly responsible for development tasks, however one that answered c) “Partly” commented that the assignment of development tasks is related to team objectives. Nonetheless, there is an indication that even within the teams, individuals are assigned responsibilities for development tasks, which is a clear example of Professional behaviour. Result: professional
Question Q2.21: Is the process of the development tasks you perform easily quantifiable or trackable, e.g.; my task is 50% complete at this time? (detection)	
TSE	A clear majority of respondents answered a) “Yes”, that their process for completing tasks is quantified and trackable, which would indicate Factory oriented tasks. This appears to contradict previous responses where the sample group results clearly show Professional behaviour where task allocation and planning are concerned, and this is supported in this question by a comment from a manager that states the process is not clearly defined. It’s possible that the respondents did not distinguish between the task and a process for the task, however in the absence of any other information, this result will remain Factory for this question. Result: factory
OEM	A large majority of the respondents answered a) “Yes”, processes for their tasks are clearly defined, and several comments state the use of metrics, KPI’s and targets for tracking those tasks. Whilst there is no specific mention of processes, and some respondents suggest that those processes and metrics are only partly defined, this is still a clear attempt to operate the test facility with Factory practices. Result: factory
Question Q2.22: Are development tasks allocated to engineers recognising their level of experience, i.e.; are the more demanding tasks assigned to the more experienced members of the team? (detection)	
TSE	The response from the sample group overwhelming shows that experience is the driving feature of allocating tasks to team members. In fact, for one of the two c) “Partly” responses, the individual commented that resources levels are a determining factor, which further suggests availability of experienced individuals is more of a priority in allocating tasks that skill base across a team or processes. This result indicates a highly Professional oriented team – there is no evidence of Factory practices where task allocation is concerned. Result: professional
OEM	The respondents answered in equal thirds to a), b) and c). From the comments there is an indication of an attempt to allocate tasks to a team and follow a process, which would indicate a desire for a Factory based approach to task allocation. However, there were several comments that suggested training and individual skill bases are a factor in determining allocation, which indicates processes alone cannot be relied on to complete the task, which indicates Professional behaviour. The overall result for this question is indeterminate. Result: no bias

Question Q2.23: What do you see as the major factor/roadblock to you completing your development tasks on time and to quality, e.g.; lack of facility, testing support, engineering staff, etc? (detection)	
TSE	Half of the respondents answered a) “Lack of manpower/expertise” was the major roadblock to delivering their tasks, and over a third answered c) “Both” facility and manpower/expertise where roadblocks. This is another key question for determining if an organisation operates in Factory or Professional mode; a reliance (real or perceived) on equipment and facility would suggest Factory, whilst reliance on expertise would indicate Professional. In this case, the response of this SME team suggests a Professional Handover operation. Result: professional
OEM	The responses from the sample group were almost evenly split between all of the available answers. Many of the comments suggest that there are challenges to have enough facility and enough manpower for the operation, which indicates a high demand for testing out of this organisation. As such, it would not be appropriate to draw a conclusion for this question as neither the circumstance or the results suggest either Factory or Professional behaviours. Result: no bias

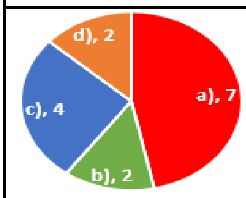
Table 8.6a – TSE data: questions 2.20 to 2.23

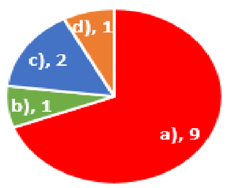
Q2.20 Are your development tasks assigned to you personally or as a team?	**Q2.21** Is the process of the development tasks you perform easily quantifiable or trackable? E.g. "My task is 50% compete at this time"	**Q2.22** Are development tasks allocated to engineers recognising their level of experience? i.e. are the more demanding tasks assigned to the more experienced members of the team?	**Q2.23** What do you see as the major factor/roadblock to you completing your development tasks on time and quality? E.g lack of facility, testing support, engineering staff etc)
a) Personally **b)** As a team **c)** Mix of the two **d)** Other	**a)** Yes **b)** No **c)** Partly **d)** Other	**a)** Yes **b)** No **c)** Partly **d)** Other	**a)** Lack of manpower/expertise **b)** Lack of facility **c)** Both (what is the split?) **d)** Other

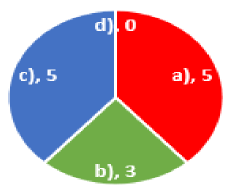
a)	5	**a)**	6	**a)**	8	**a)**	5
b)	2	**b)**	2	**b)**	0	**b)**	0
c)	2	**c)**	2	**c)**	2	**c)**	4
d)	1	**d)**	0	**d)**	0	**d)**	1

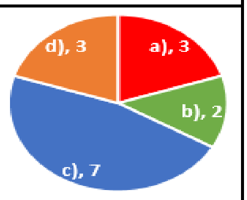
Table 8.6b – OEM data for Q2.20-Q2.23

Q2.20 Are your development tasks assigned to you personally or as a team?	**Q2.21** Is the process of the development tasks you perform easily quantifiable or trackable? E.g. "My task is 50% compete at this time"	**Q2.22** Are development tasks allocated to engineers recognising their level of experience? i.e. are the more demanding tasks assigned to the more experienced members of the team?	**Q2.23** What do you see as the major factor/roadblock to you completing your development tasks on time and quality? E.g lack of facility, testing support, engineering staff etc)
a) Personally **b)** As a team **c)** Mix of the two **d)** Other	**a)** Yes **b)** No **c)** Partly **d)** Other	**a)** Yes **b)** No **c)** Partly **d)** Other	**a)** Lack of manpower/expertise **b)** Lack of facility **c)** Both (what is the split?) **d)** Other









a)	7	**a)**	9	**a)**	5	**a)**	3
b)	2	**b)**	1	**b)**	3	**b)**	2
c)	4	**c)**	2	**c)**	5	**c)**	7
d)	2	**d)**	1	**d)**	0	**d)**	3

Questionnaire section 3: Task Definition

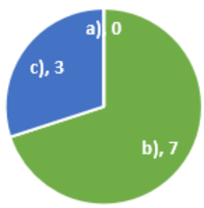
Section Three focuses on understanding how tasks are defined, and specifically to uncover the existence and use of processes to detect a bias towards Factory or Professional Handover behaviours in the subject organisations which is shown in Tables 8.7.a and 8.7.b.

Question Q3.1: Do you use standard documented processes/ procedures to guide your work? (detection)	
TSE	Approximately two-thirds of the respondents answered a) "Yes", and approximately a third answered c) "Partly" to the question of if they use standard processes and documentation to guide their work, which indicates that this team aims for Factory practices for task delivery. Result: factory
OEM	Half of the respondents answered 'yes' and approximately one third answered 'partly' with the remainder 'no'. Result: factory
Question Q3.2: Do you feel you need to report every detail to your manager and they like to see every detail frequently? (detection)	
TSE	This question and its results are excluded from the survey analysis as the question cannot provide a clear indication if the organisational practices are Professional or Factory Handover in nature. Micromanagement is predominantly an outcome of management style/personality and can occur equally in Professional or Factory environments.
OEM	Same as TSE
Question Q3.3: **Do you feel you are given the necessary freedom to innovate when required? (detection)**	
TSE	The respondents answered overwhelmingly with answer a), the only other answer was c) "Partly". This indicates that there is a strong perception amongst the team of freedom to execute tasks as they see fit, which suggests highly Professional organisation. Result: professional
OEM	Approximately a third of the OEM respondents answered 'a', they have the freedom to innovate when required. This indicates a highly Professional behaviour particularly for an OEM testing organisation. Result: professional
Question Q3.4: **How much of your time do you spend on documenting your work? (detection)**	
TSE	Half of the respondents spend more than 20% of their time documenting their work, approximately a third spend 5% of their time documenting their work, and the rest spend between 10%-20% of their time. This distribution indicates a slight bias towards Professional Handover practices but not enough to be significant for the results. There is a risk here that documented cold be understood as output drawings and not process or detailed task steps, if that is the case it would strengthen the professional handover behaviour. Result: no bias
OEM	Note applied to TSE and OEM: This question is unable to uncover Factory practices, as depending on the position of individual in a Factory they may either create a vast amount of documentation (e.g.; a manager creating process documents, reports, etc) or almost no time on documentation (e.g.; result output is

	automated, or a process is so established there is very little to document). Therefore, all this question can uncover is if there are strong Professional practices, indicated by very little documentation across an organisation.
Question Q3.5: Do you feel that resource spent documenting the process is a waste of time? (detection)	
TSE	80% of the Engineering Organisation respondents answered b), that time spent on documenting process is not a waste of time. As processes and standards are some of the foundation elements of Factory Handover practices, this result indicates a strongly Factory Handover oriented organisation. Result: factory
OEM	Approximately two thirds of the respondents answered b), that time spent on documenting process is not a waste of time. As processes and standards are some of the foundation elements of Factory Handover practices, this result indicates a strongly Factory Handover oriented organisation. Result: factory

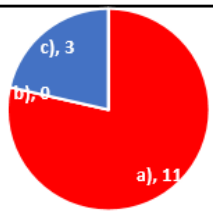
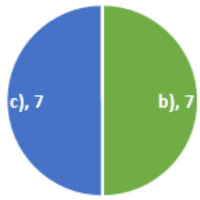
Table 8.7a – TSE data: questions 3.1 to 3.5

Q3.1 Do you use standard documented procosses/procedures to guide your work? a) Yes b) No c) Partly d) Other	**Q3.2** Do you feel you need to report every detail to your manager and they like to see every detail frequently? a) Yes b) No c) Partly d) Other	**Q3.3** Do you feel you are given the necessary freedom to innovated when required? a) Yes b) No c) Partly d) Other	**Q3.4** How much of your time do you spend on documenting your work? a) 5% b) 10-20% c) >20% d) Other	**Q3.5** Do you feel that resource spent documenting the process is a waste of time? a) Yes b) No c) Partly d) Other



a)	6	a)	0	a)	9	a)	3	a)	8
b)	1	b)	7	b)	0	b)	2	b)	0
c)	3	c)	3	c)	1	c)	5	c)	2
d)	0	d)	0	d)	0	d)	0	d)	0

Table 8.7b – OEM. data: questions 3.1 to 3.5

Q3.1 Do you use standard documented procosses/procedures to guide your work? a) Yes b) No c) Partly d) Other	**Q3.2** Do you feel you need to report every detail to your manager and they like to see every detail frequently? a) Yes b) No c) Partly d) Other	**Q3.3** Do you feel you are given the necessary freedom to innovated when required? a) Yes b) No c) Partly d) Other	**Q3.4** How much of your time do you spend on documenting your work? a) 5% b) 10-20% c) >20% d) Other	**Q3.5** Do you feel that resource spent documenting the process is a waste of time? a) Yes b) No c) Partly d) Other
				

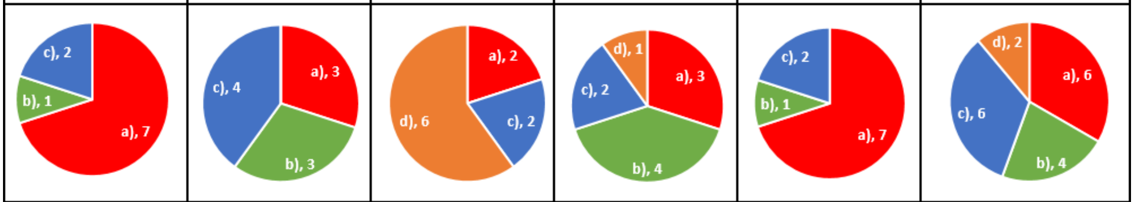
a)	7	a)	1	a)	11	a)	0	a)	0
b)	2	b)	5	b)	0	b)	7	b)	10
c)	5	c)	8	c)	3	c)	7	c)	4
d)	0	d)	0	d)	0	d)	0	d)	0

Questionnaire section 4: Culture and Environment

Section 4 focuses on the culture and environment of the subject organisations to determine the true practices of delivering tasks in that organisation. Unlike Section 2, this section asks the respondents for percentage estimates in certain questions to being to build some quantitative, especially around repeatability of work, to determine a bias towards Factory or Professional practices. Some of the questions in this section also aim to uncover a potential for change from one mode of operation to another, particularly the potential to change to mode Factory Handover practices, which is shown in Tables 8.7.a and 8.7.b.

8.8a – TSE data: questions 4.1 to 4.6

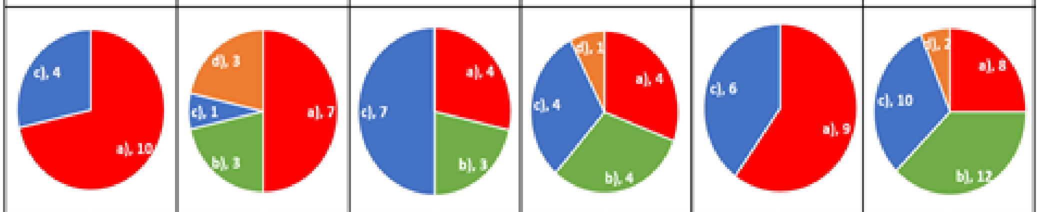
Q4.1	Q4.2	Q4.3	Q4.4	Q4.5	Q4.6
Q4.1 Do you feel that the working environment is a learning organisation? Documenting 'lessons learned' **a)** Yes **b)** No **c)** Partly **d)** Other	**Q4.2** Do you feel that engineering solutions are often re-invented when they are repeated on a known level of technology? If so, what are the reasons for this? **a)** Yes **b)** No **c)** Partly **d)** Other	**Q4.3** Does your organisation reward 'team' or 'individual' effort? **a)** Team **b)** Individual **c)** Both **d)** No rewards	**Q4.4** How often are you involved in the first time execution of the new task? **a)** 0-25% of your time **b)** 25-50% of your time **c)** 50-75% of your time **d)** 75-100% of your time	**Q4.5** Are the existing methods/processes for your task flexible enough to accept new technologies? **a)** Yes **b)** No **c)** Partly	**Q4.6** In dealing with new technology, do you: **a)** Get the new knowledge from your team **b)** Use outside consultants **c)** Find it yourself **d)** Not get new information



a)	7	a)	3	a)	2	a)	3	a)	7	a)	6
b)	1	b)	3	b)	0	b)	4	b)	1	b)	4
c)	2	c)	4	c)	2	c)	2	c)	2	c)	6
d)	0	d)	0	d)	6	d)	1			d)	2

8.8b – OEM data: questions 4.1 to 4.2, 5.1 to 5.4

Q4.1	Q4.2	Q5.1	Q5.2	Q5.3	Q5.4
Q4.1 Do you feel that the working environment is a learning organisation? Documenting 'lessons learned' **a)** Yes **b)** No **c)** Partly **d)** Other	**Q4.2** Do you feel that engineering solutions are often re-invented when they are repeated on a known level of technology? If so, what are the reasons for this? **a)** Yes **b)** No **c)** Partly **d)** Other	**Q5.1** Does your organisation reward 'team' or 'individual' effort? **a)** Team **b)** Individual **c)** Both **d)** No rewards	**Q5.2** How often are you involved in the first time execution of the new task? **a)** 0-25% of your time **b)** 25-50% of your time **c)** 50-75% of your time **d)** 75-100% of your time	**Q5.3** Are the existing methods/processes for your task flexible enough to accept new technologies? **a)** Yes **b)** No **c)** Partly	**Q5.4** In dealing with new technology, do you: **a)** Get the new knowledge from your team **b)** Use outside consultants **c)** Find it yourself **d)** Not get new information



a)	10	a)	7	a)	4	a)	4	a)	9	a)	8
b)	0	b)	3	b)	3	b)	4	b)	0	b)	12
c)	4	c)	1	c)	7	c)	4	c)	6	c)	10
d)	0	d)	3	d)	0	d)	1			d)	2

Question Q4.1: Do you feel that the working environment is a learning organisation, documenting 'lessons learned? (detection)	
TSE	Over two thirds of the respondents agreed that their working environment is a learning organisation, which would suggest a Factory Handover oriented organisation. Result: Factory
OEM	Over two thirds of the respondents agreed that their working environment is a learning organisation, which would suggest a Factory Handover oriented organisation. Result: Factory
Question Q4.2: Do you feel that engineering solutions are often re-invented when they are repeated on a known level of technology? If so, what are the reasons for this? (detection)	
TSE	This question seeks to uncover Factory or Professional practices by examining how known technology is handled by the organisation. An organisation with a Factory approach would seek to establish a process with new technology as soon as possible, so that known technology is approached via a standard process. A Professional organisation is more likely to repeat the solution/invention work with known technology because of less value being placed on processes and standards. The respondents answered in equal thirds with responses a) "Yes", b) "No" and c) "Partly", suggesting that a lack of clear processes for known technology would lean the organisation towards Professional Handover practices. Result: Professional
OEM	Half of the respondents felt that engineering solutions were often re-invented on known technology, this is a strong professional behaviour. The remainder of responses indicates that there is uncertainty regarding how known technology is handled within the organisation. This indicates sparingly Professional behaviour in an OEM testing organisation. Result: Professional
Question Q4.3: Does your organisation reward 'team' or 'individual' effort? (detection)	
TSE	Approximately one-third of the Engineering Organisation respondents stated that the organisation does not reward efforts. Of the respondents that did feel that efforts are rewarded by the organisation, half stated that the team is rewarded, the other half suggest that both individuals and teams are rewarded. While this appears to lean the organisation toward Factory practices, there are too few positive responses to draw a conclusion from these results. Result: no bias
OEM	(Q5.1) Half of the OEM respondents stated that both the team and individuals are rewarded for effort, and approximately a third of respondents stated that the team is rewarded. Less than a quarter feel that individuals are predominantly rewarded. The perception that team efforts (in total) are valued more indicates that the organisation is more Factory orientated. Result: factory
Question Q4.4: How often are you involved in the first-time execution of the new task? (detection)	
TSE	This question seeks to uncover a bias toward Factory or Professional practices by uncovering how much work is perceived to be totally new and how much is perceived to be standard process. If the majority of individuals believe almost all of their time is spent on first-time execution, this would indicate Professional practices. If the majority of individuals believed that almost none of their time is spent on first-time processes, this would indicate Factory practices. As these respondents answered almost equally to all possible responses, no bias is indicated either way with this question. Result: no bias

OEM	(Q5.2) The respondents also answered almost equally to all possible responses, though with noticeably fewer respondents stating that they spend more than 75% of their time on first-time tasks. While this suggests a slight lean towards Factory practices, there is not enough bias to definitively detect Factory or Professional practices. Result: no bias
Question Q4.5: Are the existing methods/processes for your task flexible enough to accept new technologies? (detection)	
TSE	Approximately three quarters of the Engineering Organisation respondents felt that their methods and processes are flexible enough to adapt to new technologies. This suggests that this team is not restricted by strict processes and instead is able to innovate when met with new technical challenges, which indicates strong Professional practices. Result: professional
OEM	(Q 5.3) One third of the team answered that their processes are flexible enough to accept new technologies, the remaining third feel they are only partly able to accept tasks with new technologies. Though it appears this team are more constrained by processes than the Engineering Org team, the results still suggest a Professional practice based on their freedom to innovate through challenged. Result: professional
Question Q4.6: In dealing with new technology, do you: (detection)	
TSE	The team responded approximately equally to all four available answers in fact many of the respondents provided multiple answers. This suggests that the question was not worded accurately enough to detect behaviours in the organisation that are either Factory or Professional Handover oriented. Result: no bias
OEM	(Q 5.4) Similarly, to the Engineering Org. team, these respondents gave multiple answers to this question per respondents, however the overall result suggests a slightly higher reliance on outside consultants, which may indicate a preference for Factory behaviour. However, given that most respondents provided more than one answer suggests again that this question needs to be refocused in future research to obtain a more definitive response. Result: no bias

Table 8.9a – TSE data: questions 4.7 to 4.13

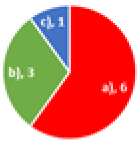
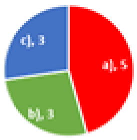
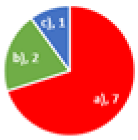
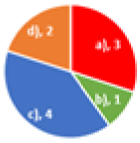
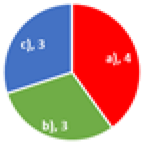
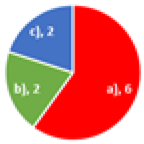
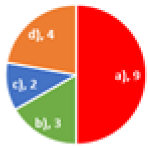
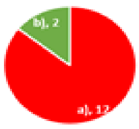
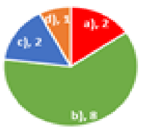
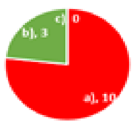
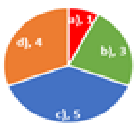
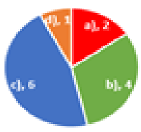
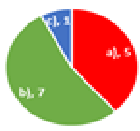
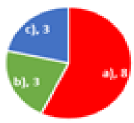
Q4.7 What are the steps in dealing with the new technology? a) Apply new technology, then update process b) Update process, then apply new technology c) Apply new technology, do not update process		**Q4.8** With new technology, how much of the process is kept the same? a) 0-25% b) 25-50% c) 50-75% d) 75-100%		**Q4.9** If the process for routine tasks is inadequate, do you: a) Deal with the task, then update the process b) Update the process, the deal with the task c) Deal with the task but do not update the process		**Q4.10** In dealing with routine tasks, how much is repeatable? a) 0-25% b) 25%-50% c) 50-75% d) 75-100%		**Q4.11** How often is your task 'routine'? a) 0-25% b) 25%-50% c) 50-75% d) 75-100%		**Q4.12** Are the existing methods adequate for the routine work? a) Yes b) No c) I don't know		**Q4.13** What do you do when you encounter difficulties with your task? a) Use past knowledge/existing experts b) Employ consultants to support in-house c) Delegate/outsource the task d) Solve it yourself	
													
a)	6	a)	5	a)	7	a)	3	a)	4	a)	6	a)	9
b)	3	b)	3	b)	2	b)	1	b)	3	b)	2	b)	3
c)	1	c)	3	c)	1	c)	4	c)	3	c)	2	c)	2
		d)	0			d)	2	d)	0			d)	4

Table 8.9b – OEM data: questions 5.5 to 5.6, 7.1 to 7.2, 6.1 to 6.3

Q5.5 What are the steps in dealing with the new technology? a) Apply new technology, then update process b) Update process, then apply new technology		**Q5.6** With new technology, how much of the process is kept the same? a) 0-25% b) 25-50% c) 50-75% d) 75-100%		**Q7.1** If the process for routine tasks is inadequate, do you: a) Deal with the task, then update the process b) Update the process, the deal with the task c) Deal with the task but do not update the process		**Q7.2** In dealing with routine tasks, how much is repeatable? a) 0-25% b) 25%-50% c) 50-75% d) 75-100%		**Q6.1** How often is your task 'routine'? a) 0-25% b) 25%-50% c) 50-75% d) 75-100%		**Q6.2** Are the existing methods adequate for the routine work? a) Yes b) No c) I don't know		**Q6.3** What do you do when you encounter difficulties with your task? a) Use past knowledge/existing experts b) Employ consultants to support in-house c) Delegate/outsource the task d) Solve it yourself	
													
a)	12	a)	2	a)	10	a)	1	a)	2	a)	5	a)	8
b)	2	b)	8	b)	3	b)	3	b)	4	b)	7	b)	3
		c)	2	c)	0	c)	5	c)	6	c)	1	c)	3
		d)	1			d)	4	d)	1			d)	0

Question Q4.7: What are the steps in dealing with the new technology? (detection)	
TSE	This question seeks to uncover strongly Professional behaviour, as strongly Professional organisation would perceive the majority of its task as being unique from each other and therefore unfit for applying processes and standards. 90% of the SME respondents would update a process (approximately two-thirds after the fact, and one third beforehand), which would indicate a Factory oriented organisation. Result: factory
OEM	(Q 5.5) All of the respondents answered that a process would be updated when dealing with new technology, indicating a Factory oriented operation. Result: factory
Question Q4.8: With new technology, how much of the process is kept the same? (change potential)	
TSE	*Note: This question and its results are excluded from the analysis. Firstly, this assumes there is existing process, however that option is not available as an answer, and then it seeks to uncover Factory or Professional modes of operating by scrutinising the stability of the existing process. However, this is very much dependent on the new technology that is being introduced, for example, if an organisation is testing a vehicle on a dynamometer with a hybrid powertrain, there may be significant changes to a successful process that was developed on internal combustion powertrains, even though the test itself might be exactly the same. Therefore, this question is not a good indicator of Factory or Professional Handover orientation in an organisation and will be excluded from this research.*
OEM	Same as TSE
Question Q4.9: If the process for routine tasks is inadequate, do you?; (detection)	
TSE	Similarly, to Question 4.7, this question seeks to uncover how Factory oriented an organisation is by how it updates processes, this time when faced with process that are inadequate for routine tasks. As before, if the organisation updates the process, this would indicate a Factory oriented organisation, however if the process left as before this would indicate that processes are not values or adhered to for known routine tasks, which would indicate a Professionally oriented organisation. Only one of the respondents answered that processes were not updates, the remaining 90% stated that processes are updated for routine tasks, either beforehand or after the fact, indicating Factory orientated operation. Result: factory
OEM	(Q 7.1) All of the respondents answered that processes for routine tasks are updated if inadequate, indicating a strongly Factory oriented operation. Result: factory
Question Q4.10: In dealing with routine tasks, how much is repeatable? (change potential)	
TSE	Repeatability of tasks is a key indicator of Factory or Professional Handover oriented practices. By definition, a factory repeatedly manufactures the same object or performs the same task and does so very effectively using fixed processes. Professional organisations often deal with first-time tasks that have little or no process for guidance and therefore rely on expertise to innovate through the challenge. This question seeks to determine if there is potential for Factory operation by uncovering how much of the routine workload is repeatable. Approximately one third of the respondents answered that between 50% and 100% of their tasks are repeatable, indicating a high potential for Factory operation. Result: potential for change
OEM	(Q 7.2)

	Almost three quarters of the respondents answered that between 50% and 100% of their tasks are repeatable, showing potential for Factory operation. Result: potential for change

Question Q4.11: How often is your task routine? (change potential)	
TSE	This question seeks to uncover if there is potential for the organisation to adopt Factory Handover practices by determining how often the tasks are routine and repeatable. If there is a high proportion of repeatable tasks it would be possible to create processes and standards for the organisation so that is less reliant on experience and skills, i.e., less Professionally oriented. Approximately two thirds of the respondents answered that 50% or less of their tasks are repeatable, in fact more than a third suggest that less than 25% of their tasks are repeatable. This suggests that there would be opportunity for this team to adopt Factory practices if the details of their engineering output can be standardised. Result: no bias
OEM	(Q6.1) More than half of the respondents answered that their tasks are routine between 50% and 100% of the time. This suggests a high potential for adopting or maintaining Factory practices. Result: potential for change
Question Q4.12: Are the existing methods adequate for the routine work? (change potential)	
TSE	This question seeks to understand if there is enough interest within an organisation to adopt Factory practices if the potential to do so is indicated in previous questions. Approximately two thirds of the respondents answered that their current methods for routine work are adequate. The comments suggest there is room for improvement, however there does not appear to be sufficient interest to adopt a more Factory approach even if potential is there. Result: no change
OEM	(Q6.2) Approximately half of the respondents answered that current methods for routines task are not adequate and that improvements are needed. This suggest a high level of interest and high potential to adopt Factory practices, which is in line with results from previous questions for this team. Result: potential for change
Question Q4.13: **Question 4.13: What do you do when you encounter difficulties with your task?** (detection)	
TSE	This question is similar to previous questions in that is seeks to uncover Factory or Professional practices by discovering what the reactionary behaviour is when faced with challenges to delivering a task. While it is not optimal to determine Factory behaviour from this question, Professional behaviour will show itself in a reliance on expertise and/or individual effort. Half of the respondents answered a) that they would use past know or existing experts to handle a difficulty, a further quarter answered d) that they would solve the problem themselves. This suggest that this team is highly Professionally oriented. Result: professional
OEM	(Q6.3) More than half of the respondents answered a) that they rely on past experience or experts to solve a difficulty with a task, while slightly less than half of the respondents would redistribute the task, either to internal consultants or by outsourcing. This suggests that the practices of this team are Professional, but there appears to be a desire to adopt a more Factory approach to handling challenges. Result: professional

8.3 Analysis and Evaluation

From the survey that contained 52 questions in total, 39 of those were 'detection' questions designed to determine the organisations bias towards Professional Handover or Factory Handover practices and behaviours. Five questions of the 52 were 'change potential' questions to help determine if an organisation can see the possibility and be willing to adopt more Factory practices. Even if the results show a strong professional way of working One self-criticism of this set of 'change potential' questions is that all focus on a shift towards more Factory practices, but do not offer the respondents an opportunity to express a need or desire to adopt more Professional practices. In chapter 8 from the Engineering Organisation the design of the Electronic Control Cabinet will be detailed. This is often an element of the engine test bed and has a step process to achieve the engineering drawing to be sent to production for manufacturing such a cabinet. Three questions focused on the 'organisational chart' of the respondents to understand and uncover the management structure of the subject organisations. A final five 'About You' questions were used to understand the individual respondents' professional profile, i.e.; experience, qualifications, etc.

8.4 Detection of Professional and Factory Handover

From the set of 39 detection questions, three were eliminated from the results as they were deemed to be too ambiguous, therefore the overall results were calculated based on 36 responses from 24 respondents (10 Engineering Org., 14 OEM). Figure 8.1 shows the overall unweighted scores for percentage factory handover, professional handover and no bias.

The results for the TSE sample group indicate a noticeable bias towards Professional Handover, which is clearly indicated in the qualitative comments as well as the raw data. As per the demographic answers the group is a very experienced one and had over a number of years developed and designed many test facilities. The content of which can go from simple to very complex ones. As we have seen from the data this group has strong tendency to operate in Professional Handover mode. In Chapter 9 the analysis modelling will consider one of the elements designed in the test bed, namely the Electronic Control Cabinet. The author has seen that this is normally tackled in almost complete

Professional Handover, because of this it will be very useful research to see the result after the introduction of some Factory Handover.

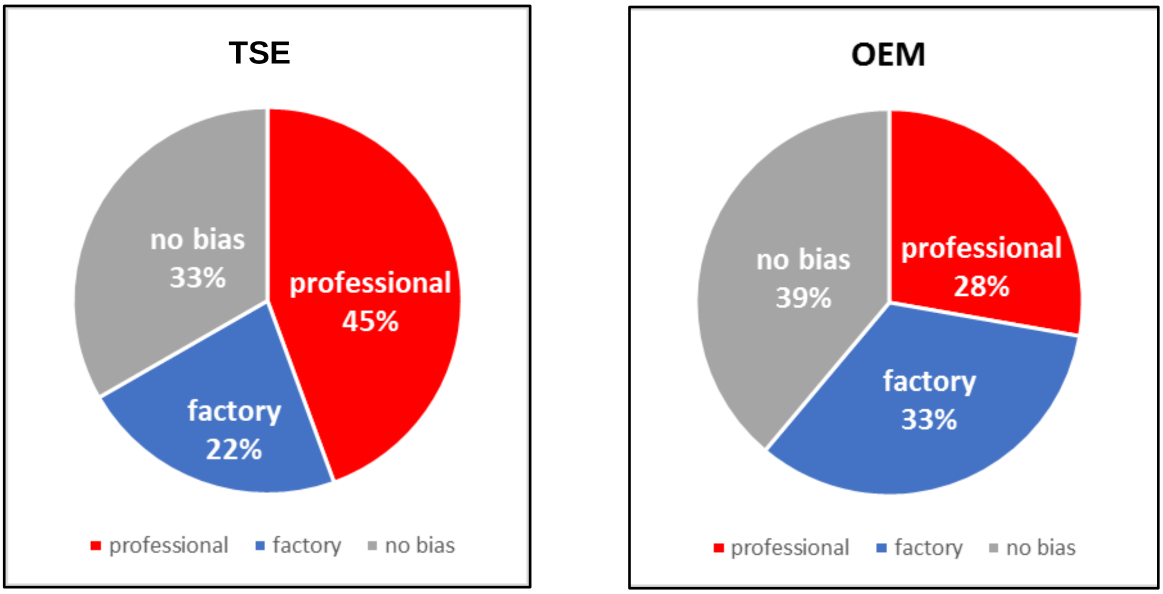


Figure 8.1 – Results: Detection of Professional and Factory Handover

The results for the OEM sample group are split almost equally between Professional, Factory and No Bias responses, indicating that this group has no overall biases towards any particular type of behaviour. However, the qualitative comments suggest that there is an effort to follow more Factory practices, but these efforts are frequently frustrated by other influences.

The results show a significant proportion of ‘no bias’ this could be a genuine reflection of the actual situation but could also indicate ambiguity in the individual questions. It follows that in any future work on this topic question design should be such as to clarify better the status and aim to reduce the no bias answers

8.5 Potential for Change

Referring to figure 8.2 of the five ‘Change Potential’ questions, the TSE sample group answered 40% positively towards seeing the need or potential to change towards more Factory Handover practices. This supports the hypothesis that there is potential to reach an optimum state with a larger proportion of factory handover with commensurate opportunity for higher productivity.

The result for the OEM sample group indicates very strong potential for change towards a more Factory Handover focused operation; each of the five questions was a positive result for change to Factory practices.

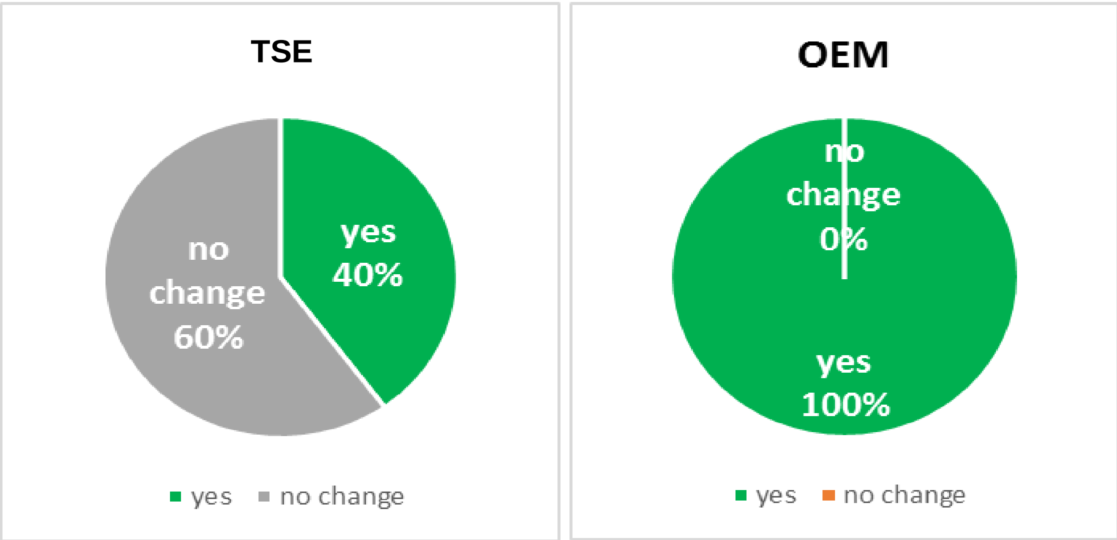


Figure 8.2 Results: Potential for Change

8.6 Summary

This chapter has clearly demonstrated that the states of factory and professional handover are identifiable subject to the criteria defined in the thesis in the two OURs. Furthermore, the diversity of the two OURs further supports the validity of the concepts. Although it is accepted that the use of a qualitative questionnaire-based study may not provide absolute confidence due to low sample size the results so far are very encouraging.

The following chapter presents an analytical approach to determine if a particular task(s) is best performed in professional or factory modes for a subject organisation.

Chapter 9 Decision Method and Supporting Algorithm

The emphasis now changes to how the methodology presented in chapter 6 (Methodology, Hypothesis and Questionnaire Design) can be used to drive actual tangible improvements in real organisations. This chapter begins with a general discussion of key lessons learnt from the questionnaire results. This is followed by an explanation of how development processes can be examined to determine the suitability of each process step for Professional or Factory Handover. A method and algorithm are then presented to aid this decision-making process by providing a definitive result. This is then followed by a worked example considering a typical design task performed by the Test System Engineering (TSE) group previously described in Chapter 8.

9.1 Lessons learnt

From the questionnaire results it is obvious that the results in chapter 8 indicate a strong overall bias towards professional handover for the TSE organisation under study. The working practices are essentially the same irrespective of the task complexity and familiarity. Although there is in general a strong desire for improvement there is little insight into how or what to do to achieve. There is also a strong disconnect between the operational manager's view and the engineers who deliver the tasks. The manager clearly understands that many tasks are composed of a high degree of repetition. Conversely the engineers responsible for the actual task see the need to treat each as a custom delivery. There is a tendency to view each task as a whole rather than a series of subtasks many of which are repeated frequently from job to job. The engineers tend to view improvement as a vehicle to make their current working practices in their current environment easier to execute rather than to change how and what they do.

Although questionnaire participants were able to see that the execution of their tasks could be improved they could not see how this could be achieved. Procedural boundaries were often cited as constraints for the development tasks but little reference was given to process describing actual task delivery. This supports the conclusion that participants were unable to distinguish between task and process.

From the verbal responses to the questionnaires it was almost universal to see management wanting to improve how the task is delivered but also felt cornered by perceived constraints set by their local organisation processes and working practices. Also, participants were able to identify with the characteristics or ‘symptoms’ of both professional and factory handover but did not recognise the categorisation. What became clear was that change must start with an analysis of the individual process steps (whether documented or not) that lead to successful delivery of a development task. These process steps should then be assessed on their individual merit as to their suitability for Factory or Professional handover. As previously discussed Professional and Factory Handover have their advantages and disadvantages and many factors affect the suitability of either for a development task. A general observation is that where there are tasks currently performed under Professional Handover that are suitable for Factory Handover then these tasks should be carried out under Factory Handover with commensurate savings in time and cost. Evidently, there will always be exceptions to this e.g. Professional Handover is mandatory for tasks that are being performed for the first time i.e. no process exists, or innovation is critical for success.

Even though the categorisation and characteristics that identify, and organisational conditions that favour Professional and Factory Handover may appear clear-cut it soon became apparent that there is scope for ambiguity when individuals or groups try to assess tasks versus their suitability for Professional or Factory Handover. Consequently, it became it became evident that a prescriptive method was needed to guide organisations to make these decisions. To this end, a method supported by a decision-making algorithm called “Analytical Hierarchy Process” (AHP) was selected to show how recommendations for Professional of Factory Handover can be made with no ambiguity. The following is a description of the algorithm, followed by a worked example.

Figure 9.1 shows the flow describing the proposed decision-making process for selecting Professional of Factory Handover for a specific operation. Either the implementation is clear cut as shown in phase one of the figure 9.1, or it has to be decided by management team.

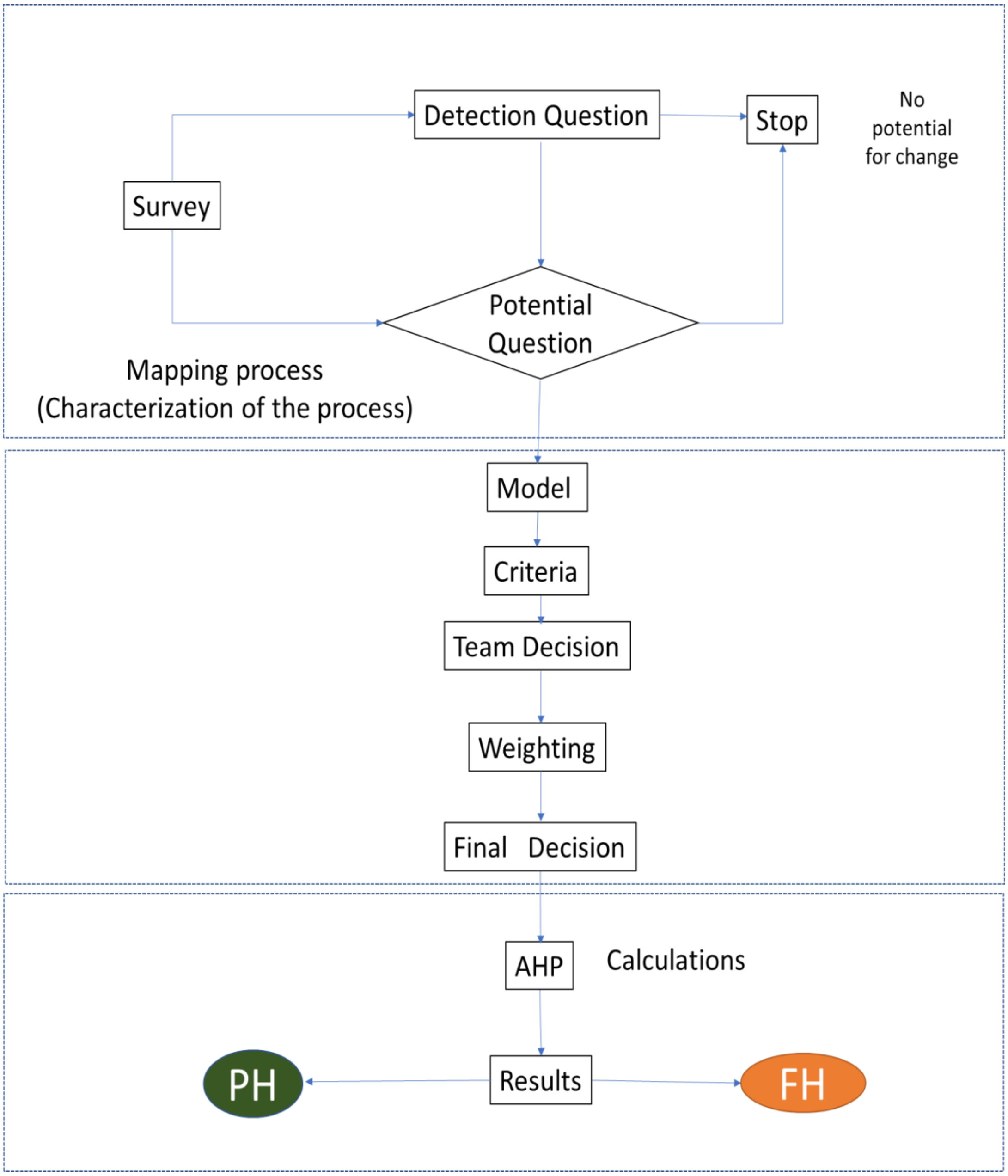


Fig 9.1 Flow diagram of the Multi-Criteria Decision-Making Process

The decision making is outlined for the team using the process shown in phase two, where the management team embarks on developing the model and criteria for evaluating the process. The following section shows a very simplified example of implementing the decision-making tool.

The decision-making is enabled by using criteria for judging suitability for Professional or Factory Handover. Examples of these are:

Criteria:

1. Overall Cost e.g. PH requires a highly skilled employee (higher hourly rate) versus lower skilled (lower hourly rate) for FH.

2. Production Time e.g. FH may be faster due to process directly applied with no ‘thinking’ time.

3. Quality (tolerances) e.g. FH may deliver higher quality due to process checks being applied.

4. Repeatability e.g. Result may be more repeatable in cost, time and quality in FH versus PH.

This list is clearly not exhaustive, and many other criteria may be selected depending on suitability to the organisation under study such as, level of expertise or skill level required and the level of innovation that is critical to delivery.

9.2 Engine Test Bed Design

In figures 9.2a and 9.2b there are two examples of an overall concept of the Engine Test Bed. A drawing is presented in easy to read blocks of all the elements. This has been prepared by the TSE organisation and normally by one expert and then each individual block is designed.

In this analysis case the focus will be on one of the individual blocks, namely the Electronic Control Cabinet (identified as a shaded block).

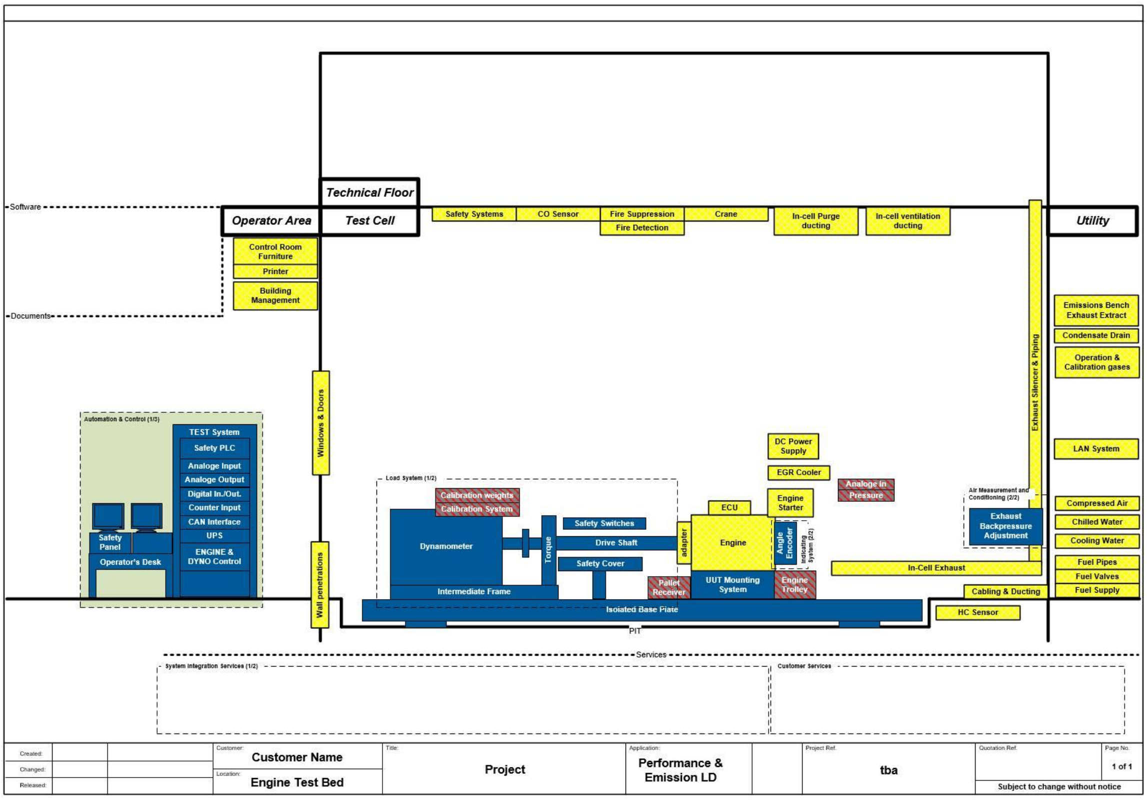


Figure 9.2.a. Engine Test Bed with Control Cabinet Schematic

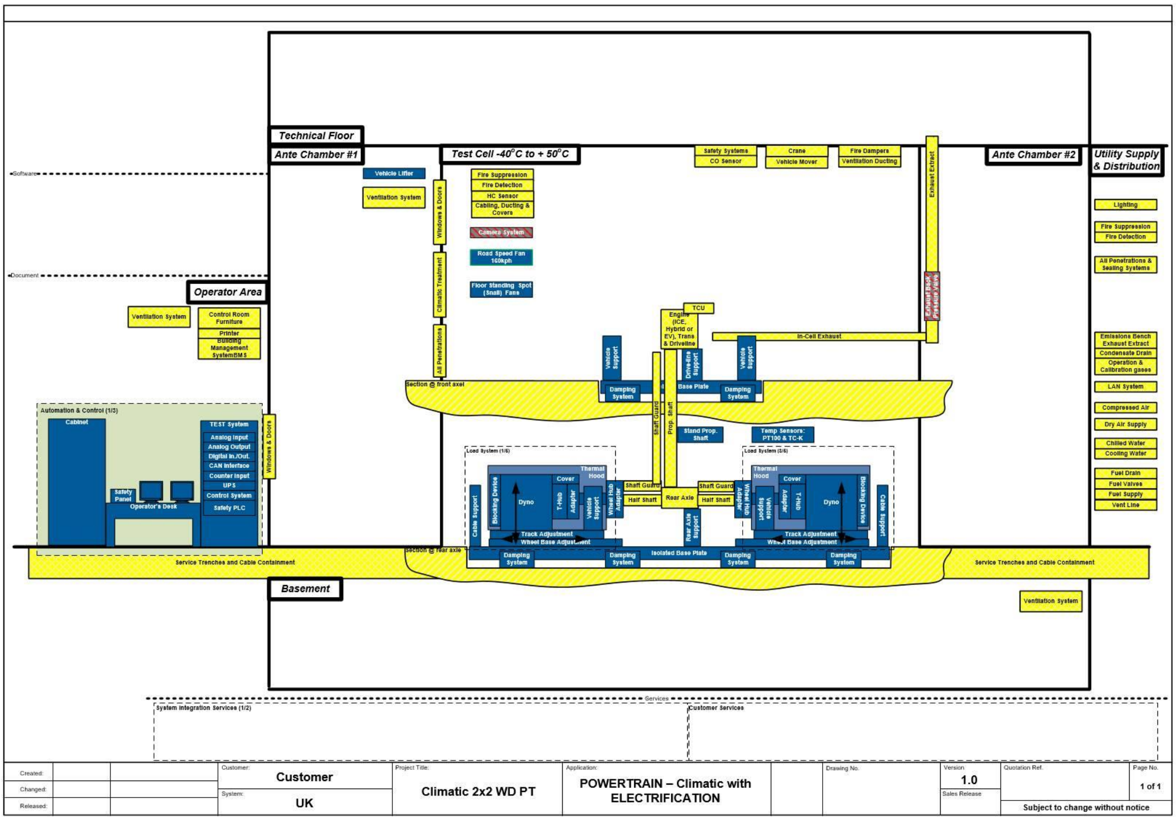


Figure 9.2.b Two Wheel Powertrain test Bed with Control Panel Schematic

9.2.1 Control Cabinet

More details of the design of the front panel and the inside panel of the Cabinet are shown in figure 9.3. The process to achieve this design with the final aim to provide manufacturing drawings is shown in fig 9.4. For this example, task 4 (Core Automation Design) is considered.

This process is normally executed by one engineer in complete professional handover. The skill of the engineer is high, and he is an expert and will design it very much according to personal experience and past designs.

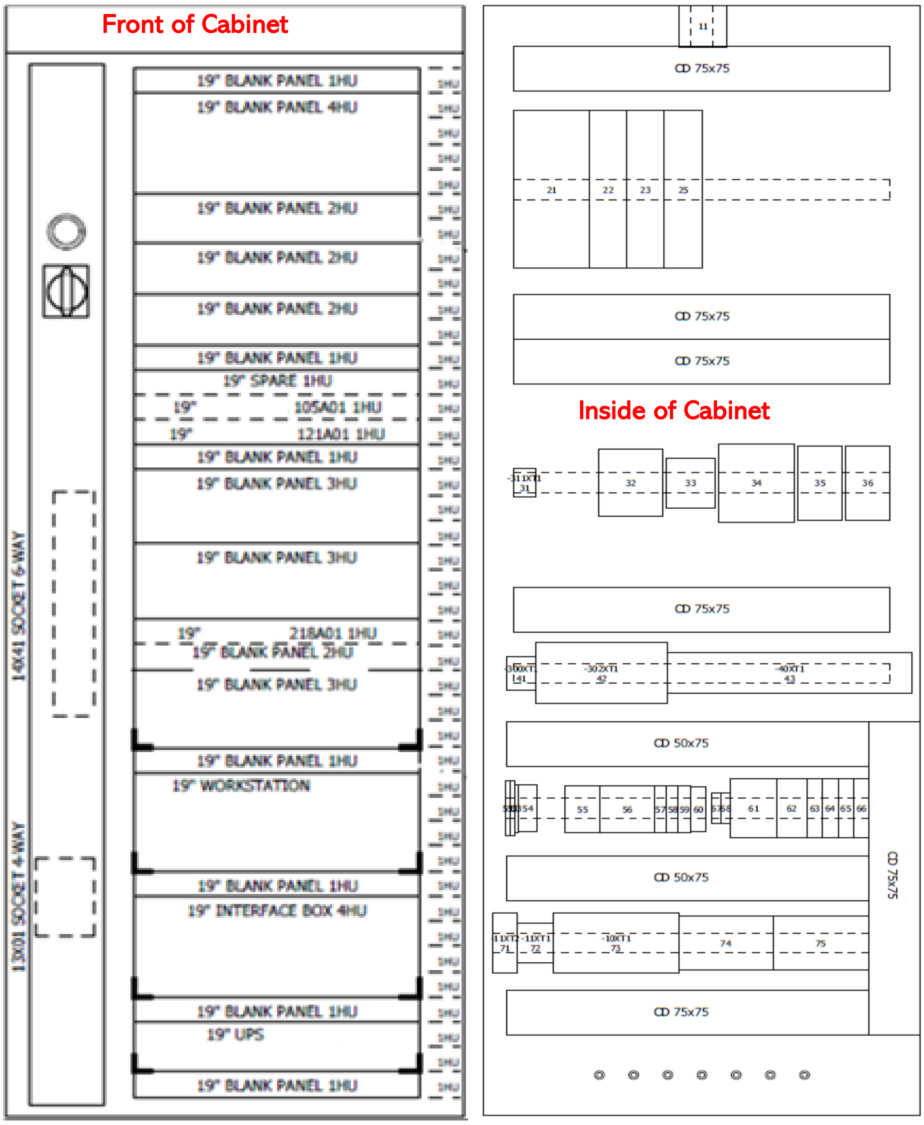


Figure 9.3 Manufacturing Drawing of Control Cabinet

Task No	Task	Duration (Days)	Current status
1	GENERATE DRAWINGS TEMPLATE BORDER	2	PH
2	DOOR LAYOUT FOR PRODUCTS	3	PH
3	BACKPLATE LAYOUT FOR CONTROL CABINET	3	PH
4	**CORE AUTOMATION DESIGN**	3	PH
5	INTEGRATION DESIGN TO CORE PRODUCTS	2	PH
6	STANDARD PARTS LIST	1	PH
7	PARTS LISTS FOR INTERFACES	2	PH
8	BUILDING AND FACILITY INTEGRATION	2	PH
9	COLLATE DRAWINGS	2	PH
10	4 EYE CHECK	2	PH

START PRODUCTION

Time

Figure 9.4. Manufacturing Process for Electronic Control Cabinet

9.3 Decision Making Process

The AHP (Analytical Hierarchy Process) is a multi-criteria decision making method which was originally presented by Saaty [55] in 1970s. It is capable of solving the decision making for identifying suitability for Professional Handover (PH) or Factory Handover (FH).

This section presents how the key factors that may facilitate or inhibit the decision making for implementing PH or FH. The Analytical Hierarchy Process method is applied to the Test System Engineering (TSE) organisation and the results are presented in this chapter.

Starting with multiple and uncertain decision criteria, the method is based on three key principles: priority setting, constructing the hierarchy and logical consistency. By development and construction of hierarchy, a complex decision that centres around weighing contributions to a focus or an objective is decomposed and structured into sub-problems. The priority setting is usually established by comparing the contribution of all the elements in terms of the criteria where a causal relation exists.

In this method, multiple paired comparisons are normally based on nine levels of a standard scale used in AHP, as shown on table 9.1.

Table 9.1. The Ranking Scale for Criteria and Alternatives.

Paired Comparisons	Levels
Equally preferred	*1*
Equally to moderately preferred	*2*
Moderately preferred	*3*
Moderately to strongly preferred	*4*
Strongly preferred	*5*
Strongly to very strongly preferred	*6*
Very strongly preferred	*7*
Very strongly to extremely preferred	*8*
Extremely preferred.	*9*

9.4 AHP structure

AHP is applied to develop a mathematical framework to decide between the PH or FH in an organization by deriving priorities. This framework gives an effective means to decision making.

In addition, AHP assists with analysing the data and expediting the decision-making process and comes up with a numeric scale required for prioritizing decision alternatives. The process involves applying a matrix of pair-wise comparisons usually between factors (criteria) and it is useful for evaluating the

AHP application has three key steps: establishing the weights, structuring the hierarchy and the decision phase (selecting the important choice/alternative from others). Saaty (2001) [55] defines AHP as a methodology that ranks alternative courses of action depending on the decision maker's view or judgment related to the usefulness of the criteria. In order to comprehensively solve problems involving decisions using AHP, there are four critical steps:

1. The process steps to be categorised as FH and PH are identified.
2. Criteria or factors affecting the decision are determined and a comparison matrix between factors is developed
3. Percentage distributions of the criteria/factor are determined.
4. Finally, the calculation for factor comparison is completed.

In this context, a hierarchy of decision criteria is defined, and the alternative course of actions developed. AHP algorithm is composed of two key steps:

1. Establish the **priorities** of relative rankings of alternatives and **weights** of the decision criteria. Both quantitative and qualitive information are compared by applying informed judgments to derive priorities and weights.
2. Establish and check the consistency of the results.

The AHP theory has four key axioms, and the results should be validated using a consistency check which are explained in Appendix.

9.5 Worked Example of Application of AHP in PH or FH Decisions

Pairwise comparisons are usually made using the grades ranging from 1 and 9 given in table 9.1. The objectives, alternatives and criteria used in this example are shown in Table 9.2.

If element A is absolutely more important or essential than attribute/element B and is rated at 9, then automatically, B must be absolutely less essential/important than A and is presented as 1/9. These pairwise comparisons should involve all factors considered but normally not more than 7 to complete the matrix.

In this case, there are two alternatives and four criteria. Extent of our choices or alternatives (PH or FH) is expressed using the Saaty scale [55]. The derived results provide the optimal choice based on the team preferences. Figure 9.5 gives the structure of the working of the AHP framework.

Table 9.2 Ranking Scale for Criteria and Alternatives.

<table>
<tr><td colspan="3">Process:
-1st level: goal (selecting the best Manufacturing process MP)
-2nd level: how each of the five criteria contributes to realizing the objective
-3rd level: How each of the MPs contributes to each of the four criteria (handover, Innovation level, repeatability)</td></tr>
<tr><td colspan="3">Objective: delivering the “Core Automation Design”
Manufacturing process (MP)</td></tr>
<tr><td colspan="3">Alternatives: PH or FH</td></tr>
<tr><td colspan="2">Criteria:</td><td></td></tr>
<tr><td>1</td><td>Overall Cost e.g. PH requires a highly skilled employee (higher hourly rate) versus lower skilled (lower hourly rate) for FH.</td><td>Cost (C)</td></tr>
<tr><td>2</td><td>Production Time e.g. FH may be faster due to process directly applied with no ‘thinking’ time.</td><td>Time (T)</td></tr>
<tr><td>3</td><td>Quality (tolerances) e.g. FH may deliver higher quality due to process checks being applied.</td><td>Quality (Q)</td></tr>
<tr><td>4</td><td>Repeatability e.g. Result may be more repeatable in cost, time and quality in FH versus PH.</td><td>Repeatability (R)</td></tr>
</table>

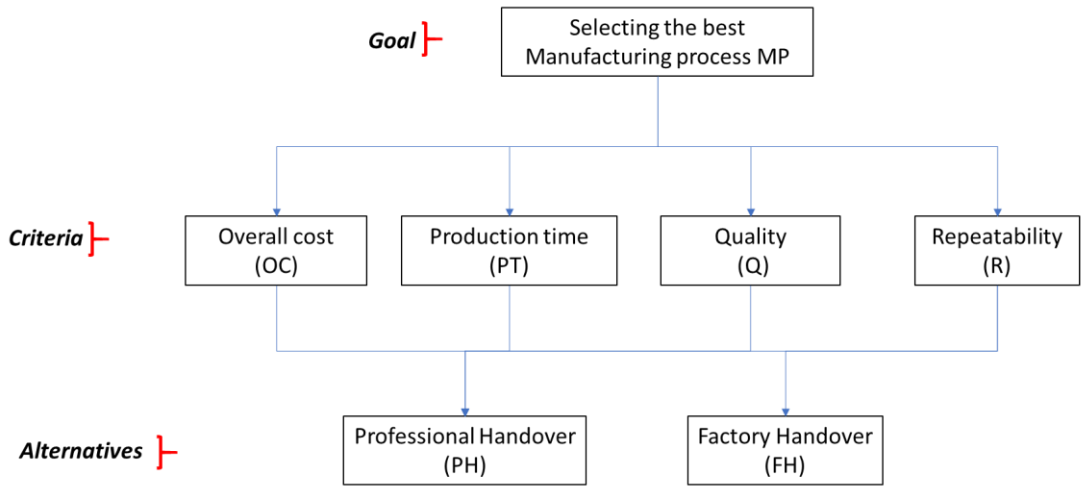


Figure 9.5. AHP structure for cabinet control manufacturing

9.5.1 Application to Task 4 - CORE AUTOMATION DESIGN

Pairwise comparisons are used to score each alternative of a criterion. This is indicated using a standard preference scale unique to AHP. A criteria table is constructed including a ranking scale for criteria and alternatives. In all the tables below the entries follow these requirements.

When PH is compared with FH with respect to the criteria and the preference for PH is 3, then according to Saaty's rule then the preference value of comparing FH with PH would be 1/3. Saaty rule of pairwise comparison applied in all the following tables. The first example of pairwise comparison shown in table 9.4.

Table 9.4. Pair-wise comparisons between FH and PH for Core Automation Design

Criteria	Overall cost (C)	Production time (T)	Quality (Q)	Reusable (R)
Overall cost (C)	1	2	3	7
Production time (T)	0.5	1	2	2
Quality (Q)	0.33	0.5	1	2
Reusable (R)	0.14	0.5	0.5	1
Colum sum	1.97	4.0	6.5	12

Once the comparison is complete, each column total sum is calculated.

Developing preferences within criteria

The first step involves:

- ✓ -prioritizing the decision preferences/choices within each criterion
- ✓ -To achieve this objective, sum the values in each column of the pairwise comparison matrices.
- ✓ -Divide each value in a column by its corresponding column sum to corresponding column sum to normalize preference
- ✓ -values (numbers) in each column to 1

Next- Average all the values in each row. Lastly the most preferred alternative or choice is provided. Last column is usually referred to as preference vector. The values below are imported directly from the excel sheet bearing the final results.

Process: Divide each value in a column by its corresponding column sum to corresponding column sum to normalize preference values.

The values below are imported directly from the excel file bearing the final results by Saaty rules have been applied while filling in the rest of the tables.

Divide each value in a column by its corresponding column sum to corresponding column sum to normalize preference values

Table 9.5 Developing preferences within criteria

Criteria	Overall cost (C)	Production time (T)	Quality (Q)	Reusable (R)
Overall cost (C)	1 / 1.97	2 / 4	3 / 6.5	7 / 12
Production time (T)	0.5 / 1.97	1 / 4	2 / 6.5	2 / 12
Quality (Q)	0.33 / 1.97	0.5 / 4	1 / 6.5	2 / 12
Reusable (R)	0.14 / 1.97	0.5 / 4	0.5 / 6.5	1 / 12

Average all the values in each row is shown in table 9.6

Table 9.6. Preference vectors for all the criteria are presented in this table

Criteria	Overall cost (C)	Production time (T)	Quality (Q)	Reusable (R)	Criteria weight
Overall cost (C)	0.51	0.50	0.46	0.58	0.51*
Production time (T)	0.25	0.25	0.31	0.17	0.24
Quality (Q)	0.17	0.13	0.15	0.17	0.15
Reusable (R)	0.07	0.13	0.08	0.08	0.09

* (0.51+0.50+0.46+0.58) / 4 =0.51

Ranking the criteria and normalizing for Core Automation Design

- ✓ Determine or establish the relative weight or importance of the criteria i.e. the criteria that the most important and the criteria least important.
- ✓ This step is accomplished in a similar way used for ranking.

Table 9.7, shows the determination or establishment of the relative weight or importance of the criteria i.e. the criteria that the most important and the criteria least important. Table 9.8 presents the Normalize of the results of table 9.7. This step is accomplished in a similar way used for ranking the methods within each criteria by employing pair-wise comparison.

Table 9.7 Developing overall ranking

Criteria	Overall cost (£)	Production time	Quality	Reusability
Criteria weight	**0.51**	**0.24**	**0.45**	**0.09**
PH	£1000	8	2	2
FH	£2000	3	7	9

The table represents average values of all the methods in term of the four criteria.

Table 9.8 Normalize results

Criteria	Overall cost	Production time	Quality	Reusability
Criteria weight	**0.51**	**0.24**	**0.45**	**0.09**
PH	1000/2000	8/8	2/7	2/9
FH	2000/2000	3/8	7/7	9/9

Finally the results and the preference vector is shown in table 9.9, which shows average score of each criteria using preference vector.

Table 9.9 Preference vector,

Criteria	Overall cost	Production time	Quality	Reusability
Criteria weight	**0.51**	**0.24**	**0.45**	**0.09**
PH	0.5	1	0.285	0.222
FH	1	0.375	1	1

Preference vector,

Criteria	Average
Overall cost	0.51
Production time	0.24
Quality	0.45
Repeatability	0.09

Overall score for Core Automation Design:

PH = (0.51)(0.5)+(0.24)(1)+(0.45)(0.285)+(0.09)(0.222) = 0.713

FH = (0.51)(1)+(0.24)(0.375)+(0.45)(1)+(0.09)(1) = 1.069

9.6 Results and Summary

Based on the final results FH scores highest 1.069 and that is the best alternative in this scenario. The overall results are shown in table 9.10

The AHP tool developed by Saaty [57, 58] in 1980 entails creating a pair-wise comparison matrix for each decision alternative/ choice for each criterion. The next step is the synthetization process that involves:

- ✓ Summing all values in all columns
- ✓ -Dividing each value (number) in each column by the corresponding column sum
    - An average of the values or numbers in each row generates preference vector useful for decision alternatives

- ✓ -Next the preference vectors are combined.

It is worth noting that developing the preference vector for criteria i.e. Overall cost, Production time, Quality and Repeatability is done in the same way. Computation of overall score for individual decision alternative is completed. It is useful and easy methodology that allows for pair wise comparison in areas of expertise. AHP integrates the concept of hierarchical structure analysis and fuzzy set theory for the selection the best alternatives when presented with feasible alternatives. This paper employed AHP method to explain the process and steps involved in deciding the best method.

Table 9.10 Overall results for the control cabinet study.

Task No	Task	PH Score	FH Score
1	Generate Drawings Template Border	**0.34**	**0.92**
2	Door Layout for Products	**0.45**	**1.87**
3	Backplate Layout for Control Cabinet	**0.56**	**0.96**
4	Core Automation Design	**0.71**	**1.07**
5	Integration Design to Core Products	**0.67**	**1.56**
6	Standard Parts List	**0.35**	**0.89**
7	Parts Lists for Interfaces	**0.85**	**1.34**
8	Building and Facility Integration	**0.87**	**0.74**
9	Collate Drawings	**0.91**	**0.82**
10	4 Eye Check	**0.65**	**1.2**

Colour code:			
Change to FH		Change to PH	

Chapter 10 Discussion and Conclusion

The origins of this thesis link to empirical observations in several automotive business environments observed by the author which seemed contradicting, tough to understand and perhaps special or unique to the respective domain. However, a hypothesis put forward based on two statements was able to explain in a qualitative way what was observed.

1. There are two distinct types of delivery in any automotive test and development organisation.
2. There is an optimum proportion of Professional Handover and Factory Handover in any subject automotive test and development organisation where waste is minimised.

Typically, the symptoms would manifest as an underlying pattern which when noticed, identified and questioned delivered negative outcomes for a particular stage of the development. It can be summarised that as long as the symptoms did not appear nothing seemed wrong. In other cases, the symptoms were obvious but employees when questioned were unable to identify and progress a solution.

The symptoms can be typified by one or more of the following cases:

- Total breakdown of output without any visible or intended change of the system
- Lack of result on a task and yet process is followed
- Peak performance once the right person was brought in, the “diva” phenomenon
- Qualified teams coming up with different solutions and output level on the same technical problem.

Further cases can be listed.

The first statement from the core hypothesis suggests that organisations typically work - by design' by chance or for historic reasons - in a mix of two extreme modes of operation:

Factory Handover: The attribute delivery or handover is subject to detailed process and formalised structures. It is highly regulated, and individuals deliver according to strict rules and documented instructions. Due to this a person can be replaced by another of similar skill without loss of output. How the attribute is delivered is very clearly defined, documented and there is very little to no innovation required to complete it. Thus, much like a factory process in manufacturing, the development task is highly specified, standardised, and therefore ‘trackable’ and well documented.

Professional Handover: The key feature of this mode of operation is that the development task is fully dependent on a highly skilled staff to deliver it. It supports innovation and the ability to tackle new challenges and introduce new development aspects.

The highly skilled individual delivers a product development element subject to their working style, skill and previous experience of similar programmes. In fact, experience shows that how they go about meeting the delivery is not necessary tracked or well documented. The individual based on past performance and ability is trusted to manage any design and consequently testing as they see fit. In other words, they provide a professional service.

This mode of operation relies very much on expert skills with innovative ability. In fact, without an expert available, this mode of working is not possible.

On observation most organisations exhibit a mix of the two modes above and whilst most people when presented with the concept intuitively agree, they cannot see the application to organizational design, change management or performance optimization.

For any product development organisation, it is proposed in this work that there is an ideal mix of the two modes to achieve best output. This mix will depend on many boundary conditions - a few are listed here:

- Locally established process know-how in the organisation (e.g. very high in most production environments).
- Availability of knowledge-based tools, partly replacing humans and already including process knows how and product
- Highly repetitive and defined work as in production or in testing vs. creative work such as encountered in design or product development

- Availability of an appropriate mix of skills in the workforce

Of course, this list of boundaries is not exhaustive, but the examples already indicate that boundaries and hence the ideal mix of modes for best output may change over time. In particular to adapt to changes of technology and competitive landscape.

Clearly for new emerging technologies needing innovation it is a necessity to start in professional mode. Over time once knowledge is accumulated and capable tools developed it is possible to shift gradually towards more of a factory mode.

Managers should be aware of these two types of handover and then find ways to review the organisation and target the appropriate mix for optimised output. If a gap is known, it is possible to bridge it and further optimize the mix and hence the output.

10.1 Conclusion

This thesis has delivered the following 6 elements:

- Review of the author's empirical observations in industry
- Review of the past and current literature tracing manufacturing process improvement and later application to product development
- A presentation of the new hypothesis, the underlying descriptive characteristics and its consequences for organizational development and productivity improvement and/or waste reduction
- Two case studies to verify the hypothesis
- A decision tool to aid the selection of Professional or Factory Handover for particular product development tasks in a subject organisation
- The tool is applied to a real case of the design and development of an electronic control cabinet for engine test bed application

The case studies presented in this thesis were conducted in two environments:

1. An automotive OEM test organization
2. An engineering organisation.

A great deal of time, effort and experience went into the design of questionnaires to target the verification of the hypothesis. In addition, this was supported with in-depth structured analyses of the working environments

The key conclusions from this research are listed as follows:

- Evidence of both working modes was found and both organizations used a mix of the two extremes. The TSE was strongly biased towards Professional Handover in contrast the OEM had a small overall bias towards Factory Handover. Because a meaningful evidential difference was shown between the OURs this encouraging result makes a good case to proving the existence of Professional and Factory Handover as defined in this thesis i.e. the first statement of the hypothesis is supported.
- The TSE sample group answered 40% positively towards seeing the need or potential to change towards more Factory Handover practices. The result for the OEM sample group was even stronger (100% potential for change). This shows there is potential to reach an optimum state with a larger proportion of factory handover resulting in real productivity gains and/or reduction of waste.
- Application of the decision algorithm tool which applied to each step of the process, subject to boundary conditions on a real design and development example, yielded an improvement potential circa 50%-time savings. This strongly supports the second statement of the hypothesis as presented in this thesis.

10.2. Further work

With the encouraging positive results of the case studies in this thesis, further work will concentrate on testing and validation on more cases in Powertrain Development. It would be beneficial if the diversity of the cases is as wide and varied as possible so as to further substantiate the concepts and methods presented in this thesis.

It would be extremely interesting to further test in different countries and discover the cultural impact on the results.

Future work could be expanded to test the validity of application outside the Automotive Powertrain Development industry and prove/disprove the existence of the two handover modes a in a wider context.

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Appendices

AHP theory has four key axioms. It is imperative to satisfy all the four axioms so as to successfully apply the AHP tool to a decision-making situation. The four axioms as described are:

Reciprocal Comparison: the intensity of the alternatives or preferences must at all times satisfy the reciprocal condition. For instance, if A is n times more preferred compared to B, then B is 1/n times more preferred compared to A.

Homogeneity: The preferences are usually represented using a bounded scale.

Independence: while expressing preferences, all criteria are assumed as being independent of the alternatives.

Expectations: For decision making purpose, the hierarchic structure presented is assumed to be complete.

The primary objective of the AHP tool is to choose between the FH or PH. AHP works out by scaling the weights of elements or attributes at all level of the hierarchy using decision maker's knowledge and experience in a matrix of pair-wise comparison of elements

Calculating the consistency

Check the consistency of the results

Criteria weight	0.51	0.24	0.15	0.09
Criteria	**Overall cost**	**Production time**	**Quality**	**Repeatability**
Overall cost	1	2	3	7
Production time	0.5	1	2	2
Quality	0.33	0.5	1	2
Repeatability	0.14	0.5	0.5	1

Criteria weight	0.51	0.24	0.15	0.09
Criteria	Overall cost	Production time	Quality	Repeatability
Overall cost	1 *0.51	2 *0.24	3 *0.15	7 *0.09
Production time	0.5*0.51	1 *0.24	2 *0.15	2 *0.09
Quality	0.33 *0.51	0.5 *0.24	1 *0.15	2 *0.09
Repeatability	0.14*0.51	0.5 *0.24	0.5 *0.15	1 *0.09

Criteria weight	0.51	0.24	0.15	0.09
Criteria	Overall cost	Production time	Quality	Repeatability
Overall cost	1 *0.51	2 *0.24	3 *0.15	7 *0.09
Production time	0.5*0.51	1 *0.24	2 *0.15	2 *0.09
Quality	0.33 *0.51	0.5 *0.24	1 *0.15	2 *0.09
Repeatability	0.14*0.51	0.5 *0.24	0.5 *0.15	1 *0.09

Criteria	Overall cost	Production time	Quality	Repeatability	Weighted sum value	Criteria weight
Overall cost	0.51	0.48	0.45	0.63	2.07	0.51
Production time	0.255	0.24	0.3	0.18	0.98	0.24
Quality	0.1683	0.12	0.15	0.18	0.62	0.15
Repeatability	0.0714	0.12	0.075	0.09	0.36	0.09

Criteria weight	0.51	0.24	0.15	0.09
Criteria	**Overall cost**	**Production time**	**Quality**	**Repeatability**
Overall cost	0.51	0.48	0.45	0.63
Production time	0.255	0.24	0.3	0.18
Quality	0.1683	0.12	0.15	0.18
Repeatability	0.0714	0.12	0.075	0.09

Criteria	Overall cost	Production time	Quality	Repeatability	Weighted sum value	Criteria weight		λ
Overall cost	0.51	0.48	0.45	0.63	2.07	0.51	=2.07/0.51	4.0588
Production time	0.255	0.24	0.3	0.18	0.98	0.24	=0.98/0.24	4.0833
Quality	0.1683	0.12	0.15	0.18	0.62	0.15	=0.62/0.15	4.1333
Repeatability	0.0714	0.12	0.075	0.09	0.36	0.09	=0.36/0.09	4.0000

Average of $\lambda_{max} = 4.0689$ n is the number of criteria

$$\text{Consistency Index (C.I)} = \frac{\lambda_{max} - n}{n - 1} = \frac{4.0689 - 4}{4 - 1} = \frac{0.0689}{3} = 0.0229$$