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Measurement of Waste in Concrete Construction using Lean Construction Methodologies

A dissertation submitted by

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Abstract

This dissertation develops and analyses the quantification of all wastes present in particular construction process. This has been conducted from a lean construction perspective where waste has been defined as any non-value adding process or activity. The specific processes chosen were concrete paving, hand-pouring concrete and the installation of formwork. The types of wastes present in the construction industry have been researched and a comprehensive list collated. A number of waste classifications have been evaluated to organise these wastes into manageable groups. These classifications were also selected on their usability and the potential techniques of measurement. A suitable format for waste reporting has been established and trialled in a construction environment. This has been evaluated by Professional Engineers in management positions within the construction industry.

Due to the individual nature of construction projects there are significant inefficiencies in comparison to similar industries such as manufacturing. Of these wastes concrete construction has been deemed the largest contributor to wastage. This leads us to the question of how do we measure not only the materials wasted but the other types of waste in processes. This needs to be answered as efficiencies cannot be improved without the knowledge of where and how they are occurring.

This project has been conducted utilising; theoretical research, practical on-site observations and by seeking industry feedback on the conclusions drawn from these investigations. The theoretical research took the form of a literature review on lean construction methodologies and types of 'waste'. This focused on waste management and classification and how this has been applied to construction projects around the world. Practical on site observations were used to develop activity mapping and waste sampling which were used in the case studies for waste classification and quantification. From this a suitable format for waste reporting has been established and trialled in a construction environment. Industry feedback was sought in the form of structured interviews and an accompanying questionnaire. These interviews were conducted with four Engineering Managers working on a variety of large construction projects. From this evaluation improvements can be made to this structure and a future direction for this research has been determined.

This research can be used as a base for lean construction waste reporting within the Australian construction industry. It has shown this it is both practical and useful to implement this reporting process on site. The dissertation has also identified the need for a cost/benefit analysis into waste reporting on construction sites to determine the efficiency of the process itself.

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List of Abbreviations

BIM	Building Information Model
CPA	Construction Process Analysis
CSMS	Construction Site Management System
EWL	European Waste List
FPC	Flow Process Chart
ISPS	Integrated Site Planning System
JIS	Japanese Industrial Standards
JIT	Just in Time
KPI	Key Performance Indicator
LCI	Lean Construction Institute
LPS	Last Planner System
MAC	Multiple Activity Chart
NVA	Non-value Adding
NVAN	Non-value Adding but Necessary
PESTLE	Political, Economic, Social, Technological, Legal, Environment
RAS	Random Activity Sampling
RFI	Request for Information
TFV	Transformation Flow Value
TPS	Toyota Production System
VA	Value Adding
VSM	Value Stream Mapping

Chapter 1

Introduction

“There has never been a systematic attempt to observe all wastes in a construction process.” (Koskela 1997, p. 6)

1.1 Outline

The above statement suggests the need for a study into the quantification of all the wastes present in a particular construction process. This report endeavours to both classify and measure the wastes present in particular concreting processes.

1.2 Introduction

The temporary nature of construction projects is but one reason for the vast inefficiencies within the Australian construction Industry. The resulting product of these inefficiencies is waste whether it be wasted time, materials or monetary losses. This report will begin with a background of the presence and effects of waste in construction. This is followed by a literature review focusing on appropriate topics such as waste and lean construction methods for waste reduction. A study of classification and measurement of these examined types of waste present in construction will be used to determine the methods best used to map the sources. A suitable format for waste reporting will be established and trialled in a construction environment.

1.4 Aim

This research will study the application of lean construction methodologies to the Australian construction industry. To achieve this the report will examine production processes involved in construction and identify and measure waste with the aim of improving performance. In order to do this it is necessary to focus on a specific group of processes. The scope of this project will include the process of concreting with associated processes such as formwork and reinforcement assembly.

1.3 The Problem

The construction industry is one of the largest producers of waste in Australia. This is an industry characterised by low efficiencies and lagging environmental credentials. It has been proven that this can be improved by the implementation of Lean Construction principles. (Koskela 1997, p. 6) Given that concreting operations account for a large proportion of the cost of construction it is useful to examine these issues in relation to concrete construction.

1.4 Research Objectives

The following research objectives will be used as a guide for conducting research and experimentation. Additionally they will be used to monitor progress and measure the overall success of the research project:

1. Investigate current methodologies for construction of concrete structures and the types of waste present. This will focus on the construction phase of traditional design, tender and construct projects.
2. Identify lean construction techniques for reducing waste
3. Establish techniques for measuring waste and a framework to implement these.
4. Select specific processes to study (foundations, culvert, bridge pier etc) and measure waste.
5. Synthesise a suitable format for waste reporting based on the literature review
6. Seek feedback from construction industry professionals on Key Performance Indicators for waste
7. Use waste classifications and corresponding remedial actions for report recommendations
8. Conduct a case study for concreting including; classification of wastes, process mapping and application of reporting formats.

1.5 Methodology

This report will begin with a review of current literature relevant to lean production in the construction industry. This will be broken up into a number of interconnected sections consisting of; lean construction, types and classification of waste and different concrete construction methodologies. The objectives will be used to create a template for reporting waste in traditional design, tender and construct projects. To achieve this the report has been broken up into the following chapters:

- Literature review
- Methodology

- Waste reporting structure
- Case studies
- Industry Feedback
- Conclusions and Recommendations

1.6 Conclusions

This research has outlined the current methods for waste measurement and methods for implementation of lean production methods in construction. This research will provide a framework for the classification and measurement of waste in concrete construction. The outcomes of this study could be used in the planning and execution of concreting processes in construction projects. The framework developed through this research can also be modified for use in other areas of construction processes.

Chapter 2

Literature

2.1 Background

The construction industry has been slow to implement environmentally friendly practices with many Australian companies yet to implement waste minimisation strategies (Faniran & Caban 1998). Landfill is generally the most cost-effective and convenient solution to construction waste with 20-30% of all landfill originating from construction projects. (Teo & Loosemore 2001) Australia generates 32.4 million tons of waste annually. 42% of this is generated from the construction and demolition sectors where concrete constitutes 81.8% of this. Unfortunately only 57% of this is recycled. (Tam 2009)

From my previous comments I have chosen to focus on concrete construction. I have chosen concrete as this is the largest contributor of waste in the building and construction industry. A study into waste generated in the Dutch residential building industry by Bossink found that 80% of waste from the residential building industry consisted of materials such as concrete, bricks, piles and roof tiles. (Bossink & Brouwers 1996)This is partly due to the prevalence of concrete structures as well as the issues related to batching and timing of pours.

Construction of concrete structures can be broken down to the major processes of; design, planning, formwork, reinforcement assembly, pouring, removing formwork and any resulting defects or required re-work. This research will primarily focus on the processes of formwork, reinforcement and pouring.

There are many different contracts and types of organisations utilised in construction. Contracts can be tendered as design and build but this is regularly divided between a design firm and a construction company. Within the construction process there is often a complex relationship between the main contractor, sub-contractors and suppliers. A large amount of waste is generated both within and at the interface between each of these organisations. For the purpose of this research the scope will be restricted to waste generated by the main contractor.

This leads us to measurement of this waste. Waste in construction activities need to be measured to determine productivities, costs and environmental impact. To do this first the waste needs to be identified to determine both the reason and source. Once this is established it can be categorised into a particular group to determine the method of measurement. Measurement of some wastes can be easy, however, others are both difficult. This research will attempt to determine methods to measure all types of waste according to different classifications.

2.2 Lean construction

According to the Lean Construction Institute Australia, lean construction is; "a production management-based approach to project delivery"(LCI 2014). This concept of "lean" is focused on: elimination of waste; maximisation of customer value and increasing workflow. (LCI 2014)

The concept of lean production originated from the Toyota Production System (TPS), developed by the vice president of the Toyota Motor Company (Sugimori et al. 1977). The system was developed to reduce costs through the elimination of waste using just in time production (JIT). JIT requires that everything is produced as needed in only the necessary quantities and only when needed (Sugimori et al. 1977).

Koskela states; "Manufacturing has been a reference point and a source of innovations in construction for many decades." (Koskela 1997, p. 1) The article also states that lean production is the major manufacturing practice used in western countries. By combining this information it is obvious that it is only natural that lean production be applied in the construction sector.

Lean production has been very useful in mass production. This is because manufacturing cheaply produces large volumes of standard materials using a low skilled workforce and specialised machinery. However, construction is considered a craft industry. This is where products are built one at a time using a highly skilled workforce and an assortment of flexible tools at a high cost. The development of lean construction endeavours to integrate the benefits of both these industries. (Choo 2003)

The principal outcome of all lean construction elements is increasing value generation and the elimination of waste. The methodologies to achieve this can be classified into the phases of; increased flexibility, flow smoothing and continuous improvement. Examples of these methods include; the pull system, Just-in-time delivery, supply chain management and value stream mapping. (Koskela 1997)

2.3 Types of waste

This section will demonstrate the types of waste identified by a number of literary articles. From these lists a comprehensive list can be made for use in classification. Formoso identifies waste as any inefficiency where larger than necessary amounts of; capital, resources, equipment or labour are expended in construction (Formoso, Isatto & Hirota 1999). The following lists outline the types of waste identified by a selection of literary sources:

Abeysekera (2009) provides the following extensive list of waste:

- Processing waste
- Waiting/idle time
- Transporting
- Making-do
- Inventory
- Unnecessary motion
- Requests for information (RFI's)
- Design errors
- Lack of communication
- Constructability concerns

  (Abeysekera 2009a)

A survey by (Faniran & Caban 1998) indicates the five largest sources of waste:

- Material
- Design changes
- Design and detailing errors
- Poor weather
- Packaging and non-reclaimable consumables

However, this research focuses on the construction portion of the traditional design-tender-construct project. For this reason types of waste such as design changes and detailing errors have little relevance to this analysis.

(Hines & Rich 1997, p. 47)) lists the seven commonly accepted wastes derived from the Toyota Production system:

1. Overproduction
2. Waiting

3. Transport
4. Inappropriate transport
5. Unnecessary inventory
6. Unnecessary motion
7. Defects

Bossink 1996 provides a list of causes of waste and in which stage in the construction project they originated. These 'causes' could be loosely defined as descriptive definitions of types of waste.

Source	Cause
Design	Error in contract documents
Design	Contract documents incomplete at commencement of construction
Design	Changes to design
Design	Choices of specifications of products
Design	Choosing low quality products
Design	Incorrect sizing of products
Design	Designer unfamilliar with possibilities of differnet products
Design	Lack of influence of contractors and lack of knowledge about construction
Procurement	Ordering error, overordering and underordering
Procurement	Lack of possiilities to order small quantities
Procurement	Use of products that do not fit
Materials handling	Damaged during transport
Materials handling	Damage due to inappropriate storage
Materials handling	Unpacked supply
Materials handling	Throwaway packaging
Operation	Error by tradesperson or labourer
Operation	Equipment malfunction
Operation	Inclement weather
Operation	Accidents
Operation	Damage caused by subsequent trades
Operation	Replacement of incorrect material
Operation	Method to lay foundation
Operation	Required quantity of products unknown due to imperfect planning
Operation	Information about types and sizing of products arrives too late to contractor
Residual	Conversion waste from cutting uneconomical shapes
Residual	Offcuts from cutting materials to length
Residual	Overmixing of materials for wet trades due to lack of knowledge of requirements
Residual	Waste from application process
Residual	Packaging
Other	Criminal waste due to damage or theft
Other	Lack of on site materials control and waste management plans

Figure 1 - Sources and cause of construction waste. (Bossink 1996 p 59)

This list once again introduces the design wastes, however, only the construction stage wastes of procurement, materials handling, operation and residual will be considered for this analysis. This table groups the traditionally considered types of waste such as offcuts and packaging in a new group labelled residual. (Bossink 1996 p 59) The following is a comprehensive list of the wastes identified through the research process:

Types of waste

- Error in contract documents
- Detailing errors
- Contract documents incomplete at commencement of construction
- Design changes
- Choices of specifications of products
- Choosing low quality products
- Incorrect sizing of products
- Designer unfamilliar with possibilities of differnet products
- Lack of influence of contractors and lack of knowledge about construction
- Ordering error, overordering and underordering
- Lack of possiilities to order small quantities
- Transport time
- Waiting/idle time
- Damaged during transport
- Inappropriate transport
- Unnecessary motion
- Unnecessary inventory
- Damage due to inappropriate storage
- Lack of communication
- Request for information (RFI's)
- Constructability concerns
- Error by tradesperson or labourer
- Damage caused by subsequent trades
- Equipment malfunction
- Making do
- Poor weather
- Accidents
- Replacement of incorrect material
- Method to lay foundation
- Required quantity of products unknown due to imperfect planning
- Information about types and sizing of products arrives too late to
- Overproduction
- Defects and Re-work
- Processing waste (conversion from cutting uneconomical shapes)
- Offcuts from cutting materials to length
- Overproduction
- Waste from application process
- Packaging
- Criminal waste due to damage or theft
- Lack of on site materials control and waste management plans

Figure 2 - Comprehensive list of wastes developed through research.

2.4 Identification of waste – Transformation flow value

Before waste can be measured it needs to be identified and traced back to its source in the construction process or supply chain. The Transformation Flow Value (TFV) approach represents construction as transformations, value generation and flow of materials or resources. Each of these representations allow us to analyse construction activities different ways.

Koskela states that there are two aspects in production; conversions and flows. Both of these activities require time and materials, however, only conversions create value by converting one material into another. Conversion activities are linked together by flow activities which include processes such as; transporting, waiting or inspecting. The aim of this classification is to identify flow activities which can be eliminated and increase efficiency of conversion activities. (Koskela 1997)

Transformation simplifies construction into the conversion of inputs to outputs. The inputs can be materials, labour or capital and the outputs represent the final product. The transformation or conversion is representative of the particular construction activity needed to create the desired output. The transformation activities are seen as value-adding and anything that is non-transformation is non-value adding or waste. Planning in construction is the identification of what processes are needed to convert the required inputs into outputs and generate value. (Abeysekera 2009a, p. 204)

Figure 3 - Transformation model (Abeysekera 2009, p. 204.)

Construction can also be represented by the flow of materials and other resources - and the efficiency of any project is directly linked to the continuation of this flow or continuity of work. Below is the flow model applied to the generic transformation of materials. This shows the actual value of processing surrounded by necessary 'waste' procedures. This also shows that this can be broken down into cycles simplifying the identification process. (Abeysekera 2009a, p. 214)

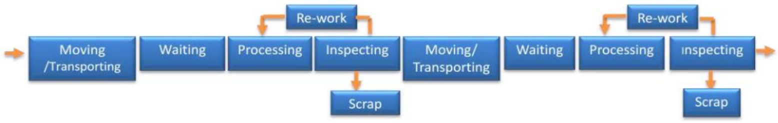


Figure 4 - Flow model applied to the transformation of materials repeated over two cycles. (Abeysekera 2009, p. 205)

This method can be applied to discrete construction processes. These are processes which can be narrowed down to a relatively small repetitive cycle mostly unaffected by other outside processes. One such example is the generic concreting process which is shown in the following diagram:

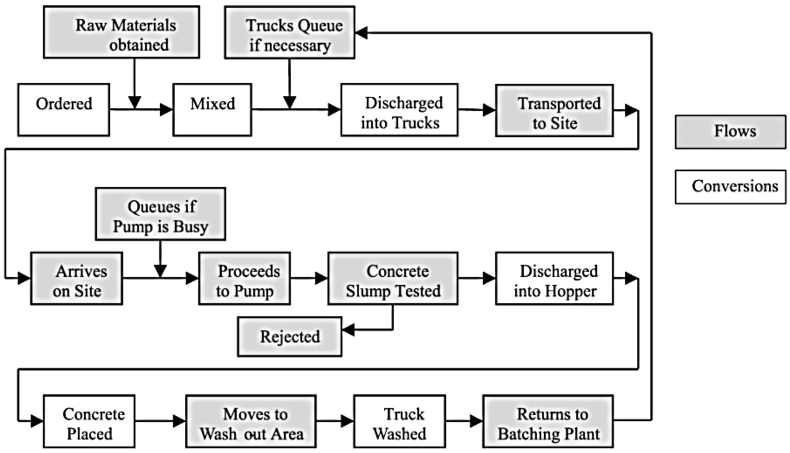


Figure 5 - Flow process of concrete batching and on-site production (Dunlop & Smith 2004, p. 57).

Lastly construction processes can also be represented by the value provided to customers. Value is created when the products and services created by the suppliers meet the expected requirements of the customer. This relationship can also be applied to a consultant and client relationship or any other customer-supplier relationship as shown in the following figure.

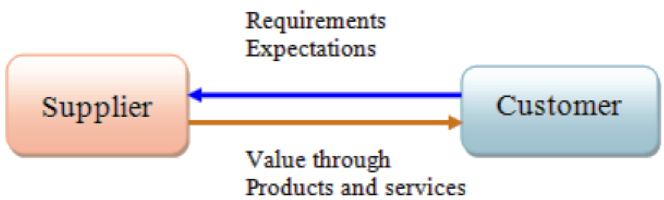


Figure 6 - Relationship and expectations of the supplier and customer (Abeysekera 2009a, p. 217).

One of the biggest challenges in a supplier-customer relationship is understanding what is of value to the client. In other words what are their requirements and expectations of the products and services the supplier is going to provide? The supplier is often made up of a number of organisations consisting of consultants, contractors, subcontractors and material and equipment suppliers. In construction it can often be quite difficult to coordinate all these parties to achieve these expectations and requirements. (Abeysekera 2009a, pp. 217-9)

Bertelsen and Koskela discuss methods to operationalise the TFV model of construction for Managing the Three Aspects of Production in Construction. The successful integration of the three concepts of transformation, flow and value is the foundation of implementing the TFV model. These three concepts can be used in different situations to improve our production system. (Bertelsen & Koskela 2002, pp. 1-6)

Bertelson and Koskela portray the three TFV tools in a managerial environment demonstrating the way in which management is responsible for handling the production system. The overall production flow is broken up into three management functions of contracts management, process management and value management. The role of contracts management is setting up the production system which is different for each construction project. Process management aims to maintain high efficiencies and predictable flow of work by maintaining cooperation between all parties involved in the construction process. Value management ensures the outputs from the process meet the client's needs. This involves ensuring the timeliness; quality and cost are all satisfactory for the client. Basically these three roles work together to determine the inputs required, oversee the transformation and validate the outputs. (Bertelsen & Koskela 2002, pp. 6-7)

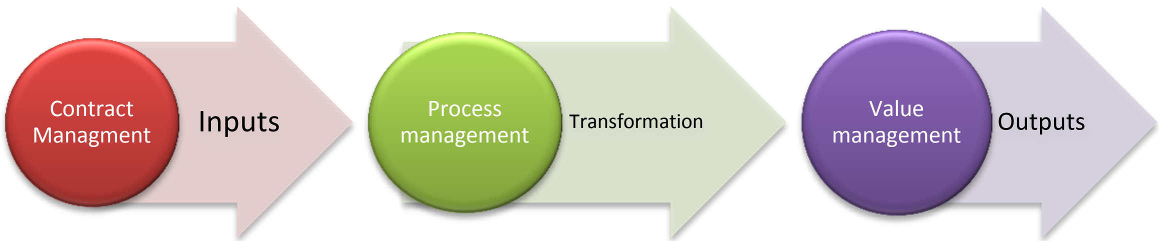


Figure 7 - Flow diagram of Transformation Flow Value applied to management

Bertelson and Koskela promote the implementation of these three roles of management separately for two reasons. Firstly, of the three aspects discussed only contract management is currently implemented. This means that it would be easier to simply add process and value management as two separate positions leaving the current contract management role intact. Secondly, considering the differences in the roles it would seem more convenient to recruit people with different skillsets specific for the requirements of each role. (Bertelsen & Koskela 2002, p. 8)

In conclusion the article provides a guide for the implementation of TFV by splitting the managerial structure into the three separate roles.

2.6 Measurement of waste – Value Stream Mapping (VSM)

Another useful example of waste identification is value stream mapping. This approach categorises all processes into three groups: value adding (VA), necessary but non-value adding (NVAN) and non-value adding. (Hines & Rich 1997) Value stream mapping categorises the critical path into these groups and identifies the non-value adding processes. Once these are eliminated the new critical path is then mapped and wastes identified continuing the iterative process. By continually iterating the critical path value stream mapping can not only be applied linearly but also to complex systems.(Braglia, Carmignani & Zammori 2006)

VSM can be used to map production processes or entire construction projects. (Hines & Rich 1997, p. 50) Hines and Rich describe the uses and origins of the following seven value stream mapping tools:

1. Process activity mapping
2. Supply chain response matrix
3. Production variety funnel
4. Quality filter mapping
5. Demand amplification mapping
6. Decision point analysis
7. Physical structure mapping

2.6.1 Process activity mapping for Construction Process Analysis (CPA)

Process activity mapping originates from industrial engineering and is conducted by studying the flow of the processes and subsequently identifying waste. Improvement by rearranging the process layout and elimination of unnecessary tasks – very similar to Construction Process Analysis. (Hines & Rich 1997, p. 50)

Construction process analysis is a tool used for the identification and quantification of waste in construction activities. Research indicates that this method is particularly effective for highly repetitive processes. (Lee et al. 1999, p. 63) Unlike traditional process analysis tools CPA can distinguish between value and non-value adding processes to identify waste. CPA uses process analysis tools such as top-view flow diagrams and process charts to find problems in construction processes. To map processes the method utilises symbols from the Japanese Industrial Standards (JIS Z 8206) summarised in the following table taken from (Lee et al. 1999, p. 65).

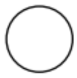
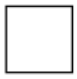
No.	Basic Step	Specific Step	Symbol	Meaning	Comment
1	Operation	Operation		Alters the shape or other characteristics of a material, semi-finished product, or product	
2	Transpor-tation	Transpor-tation		Changes the location of a material, semi-finished product, or product	The transportation symbol is a circle measuring half the diameter of the circle used as the operation symbol. An arrow can be used in place of this small circle. The direction of the arrow does not imply the direction of transportation.
3	Retention	Storage		A scheduled accumulation of materials, parts, or products	
4		Delay		An unscheduled accumulation of materials, parts, or products	
5	Inspection	Volume Inspection		Measurement of amounts of materials, parts, or products for comparison with the specified amounts to judge whether a discrepancy exists	
6		Quality Inspection		Testing and visual inspection of materials, parts, or products for comparison with quality standards to judge whether defective (substandard) products are being produced.	

Figure 8 - Symbols JIS Z 8206 (Lee et al. 1999, p. 65)

Lee uses an example of a steel erection process to demonstrate the steps involved in CPA:

	Title: Erection (3 Girders)										Date		
	Step	Process Number	answer y/n	Flow	Machine/ Tool	Distance (feet)	Crew Number	Crew Cost($/min)	Time (min)	Bare Cost($)	Chart Symbol ○	□	⇨
1	Finding a member for erection	1		□			E-2	5.42	0.15	0.81		●	
2	Hook- on hoist and tagline	2		○	Crane		E-2	5.42	0.48	2.60	●		
3	Is there another member for lifting/maneuvering?	3	y	□			E-2	5.42	0.13	0.70		●	
4	Is the number of members less than the limit of policy?	4	y	□			E-2	5.42		0.00		●	
5	Lifting to hook another member	5		⇨	Crane	4.7	E-2	5.42	0.38	2.06			●
6	Finding a member for erection	1		□			E-2	5.42	0.22	1.19		●	
7	Hook- on hoist and tagline	2		○	Crane		E-2	5.42	0.22	1.19	●		
8	Is there another member for lifting/maneuvering?	3	y	□			E-2	5.42	0.08	0.43		●	
9	Is the number of members less than the limit of policy?	4	y	□			E-2	5.42		0.00		●	
10	Lifting to hook another member	5		⇨	Crane	26	E-2	5.42	0.95	5.15			●
11	Finding a member for erection	1		□			E-2	5.42	0.15	0.81		●	
12	Hook- on hoist and tagline	2		○	Crane		E-2	5.42	0.23	1.25	●		
13	Is there another member for lifting/maneuvering?	3	n	□			E-2	5.42	0.05	0.27		●	
14	Lift/maneuver pieces	6		⇨	Crane	120	E-2	5.42	2.95	15.99			●
15	Does member fit properly?	7	y	□			E-2	5.42	0.4	2.17		●	
16	Connect by minimum requirements	8		○	Crane		E-2	5.42	1.5	8.13	●		
17	Unhook hoist	9		○	Crane		E-2	5.42	0.33	1.79	●		
18	Is there another member for connecting?	10	y	□			E-2	5.42		0.00		●	
19	Lift member for another connecting	11		⇨	Crane	11	E-2	5.42	1.75	9.49			●
20	Does member fit properly?	7	y	□			E-2	5.42	0.62	3.36		●	
21	Connect by minimum requirements	8		○	Crane		E-2	5.42	3.9	21.14	●		
22	Unhook hoist	9		○	Crane		E-2	5.42	1.92	10.41	●		
23	Is there another member for connecting?	10	y	□			E-2	5.42		0.00		●	
24	Lift member for another connecting	11		⇨	Crane	30	E-2	5.42	1.55	8.40			●
25	Does member fit properly?	7	y	□			E-2	5.42	0.52	2.82		●	
26	Connect by minimum requirements	8		○	Crane		E-2	5.42	1.87	10.14	●		
27	Unhook hoist	9		○	Crane		E-2	5.42	2.98	16.15	●		
28													
29													
	Total			27 steps		191.7			23.33	126.45	9times 13.43min	13times 2.32min	5times 7.58min
Notes	Before Improvement										Group:		
											By:		

Value added

Non-value added but necessary

Non-value added and unnecessary

Figure 9 - Flow process chart of steel erection process (Lee et al. 1999, p. 66)

The flow process chart is a list of all processes undertaken to complete the steel erection process. This defines the processes according the symbols from JIS Z 8206 such as operation, transportation, inspection etc. and whether they are value-adding, non-value adding but necessary or non-value adding and unnecessary. This chart can be used to measure waste by a simple calculation:

$$\frac{7.58}{13.43 + 2.32 + 7.58} * 100 = \mathbf{32.33\%\ waste}$$

This chart is accompanied by a flow diagram providing a plan view of the site illustrating the steps spatially. 23.33

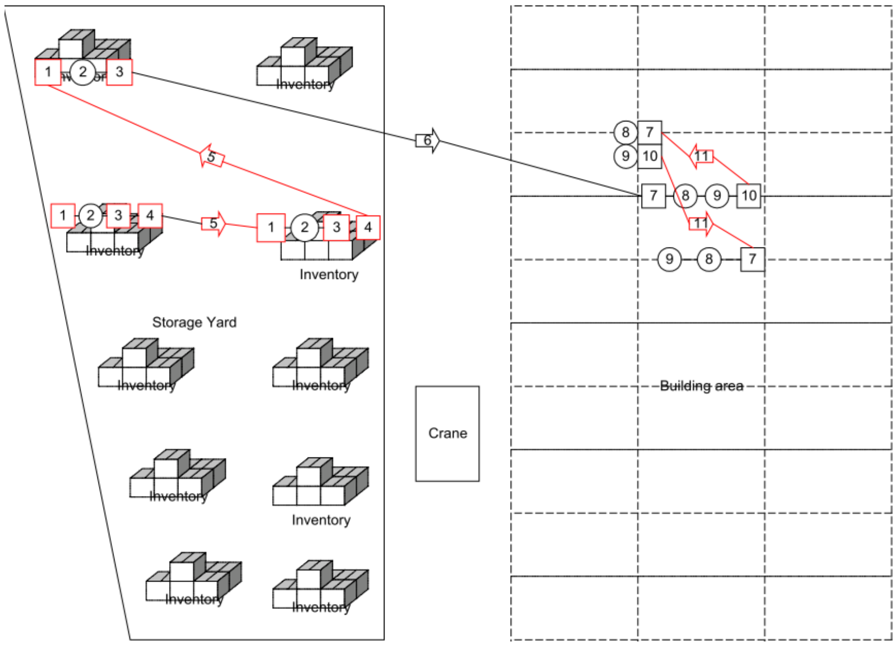


Figure 10 - Plan view flow diagram of steel erection process (Lee et al. 1999, p. 67)

These charts can then be summarised into the following table. The time and cost spent on operation, transportation and inspection is divided into categories of value-adding, non-value adding but necessary or non-value adding and unnecessary. Now that these non-value adding and unnecessary processes have been identified the aim is to reduce the number and overall share of these activities.

Table 1 - Tabulated process analysis with non-value adding and unnecessary processes outlined in red. (Lee et al. 1999, p. 69)

Chart		Value added				Non-value added but Necessary				Non-value added and Unnecessary			
Symbol	Number	Number	Time (min)	Cost ($)	Dist. (feet)	Number	Time (min)	Cost ($)	Dist. (feet)	Number	Time (min)	Cost ($)	Dist. (feet)
○	9	9	13.43	72.79	0.00	0	0	0.00	0.00	0	0	0.00	0.00
□	13	0	0	0.00	0.00	6	2.06	11.17	0.00	7	0.26	1.41	0.00
⇨	5	0	0	0.00	0.00	1	2.95	15.99	120.00	4	4.63	25.09	71.70
Total	27	9	13.43	72.79	0.00	7	5.01	27.15	120.00	11	4.89	26.50	71.70

In this particular example improvements were made from this identification process which reduced the number of these unnecessary activities. One of these improvements was dividing the building area into bays each with a corresponding inventory. Originally the materials were stored according to the steel manufacturer's inventory spread across multiple locations. This was changed to store the materials according to the construction sequence with each inventory incorporating all the materials needed for a particular construction bay. This eliminated a number of transportation processes therefore resulting in less unnecessary activities.

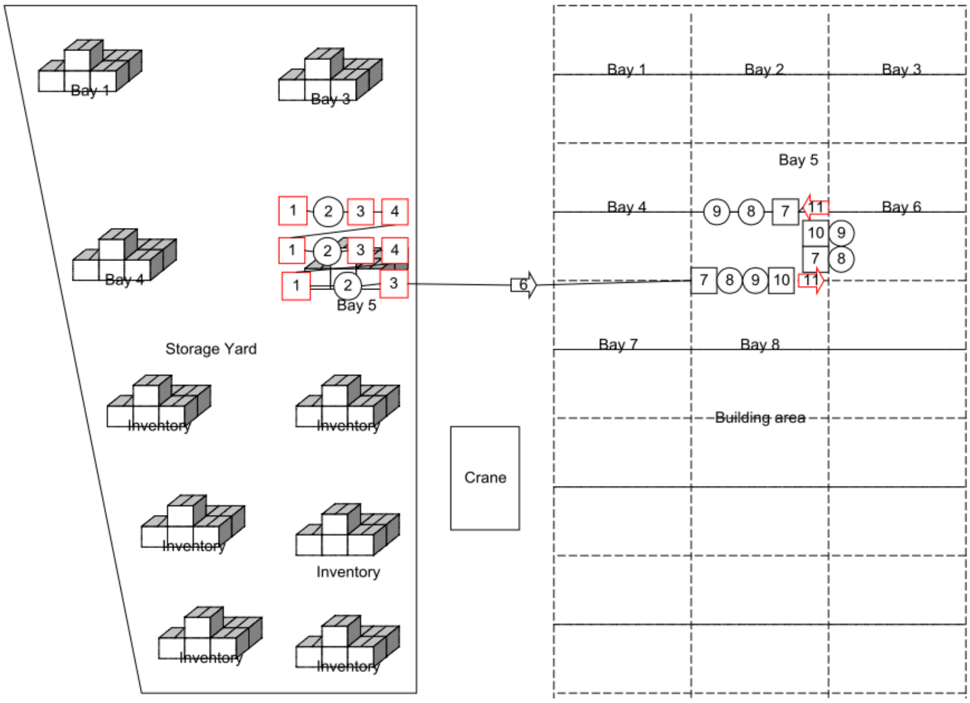


Figure 11 - Plan view of construction with implemented improvements

Table 2 – Comparison of process before and after implementation of improvements with change in number of transportation steps outlined in red. (Lee et al. 1999, p. 69)

Step	No. of Steps			Time (min)			Cost ($)			Distance (feet)		
	Before Improvement	After Improvement	Effect	Before Improvement	After Improvement	Effect	Before Improvement	After Improvement	Effect	Before Improvement	After Improvement	Effect
Operation	9	9	0	13.43	8.33	5.1	72.79	45.15	27.64	0	0	0
Vol. Inspection	13	13	0	2.32	1.54	0.78	12.57	8.35	4.23	0	0	0
Transportation	5	3	2	7.58	4.4	3.18	41.08	23.85	17.24	191.7	128	63.7
Total	27	25	2	23.33	14.27	9.06	126.45	77.34	49.11	191.7	128	63.7

As well as identification of waste and comparing improvements to construction processes CPA can be used to compare similar construction activities. This allows a direct comparison of efficiencies on different projects. This is a graphical method which can easily be integrated into existing project management tools. One limitation is that a CPA conducted at this level can only identify waste processes and not waste within individual process.(Lee et al. 1999, pp. 69-72)

2.6.2 Supply Chain response matrix

Supply chain response determines the lead-time constraints on the supply chain for a particular process. This produces a diagram of lead times for products at specific points in the supply chain allowing the identification of individual problematic lead times on the critical path. Identification of these lead times allows better planning of procurement and reducing waste time waiting for materials. This can also reduce 'making do' waste by having the right products there at the right time. (Hines & Rich 1997, pp. 51,2)

2.6.3 Product variety funnel

Product variety funnel is used to describe the addition of complexity to a process as it proceeds along the process path. The funnel represents the often exponential growth in variety of a product due to the addition of variety at each production phase. Figure 12 shows this model applied to a brewing example. This model shows how the variety of products increases with factors such as brew type and can size creating a complex array of products form the same set of materials. This can be seen in construction with the use of raw materials used to build with. There is now such are variety of types and sizes of all products from excavators to bolts and nuts. This complexity requires suppliers to have huge inventories to please the daily needs of construction projects which is the origin of inventory waste. The product variety funnel can be further applied to products such as precast concrete items which are often custom made due to the infinite combinations of size, shape, amount and placement of reinforcing and the strength and composition of concrete required.

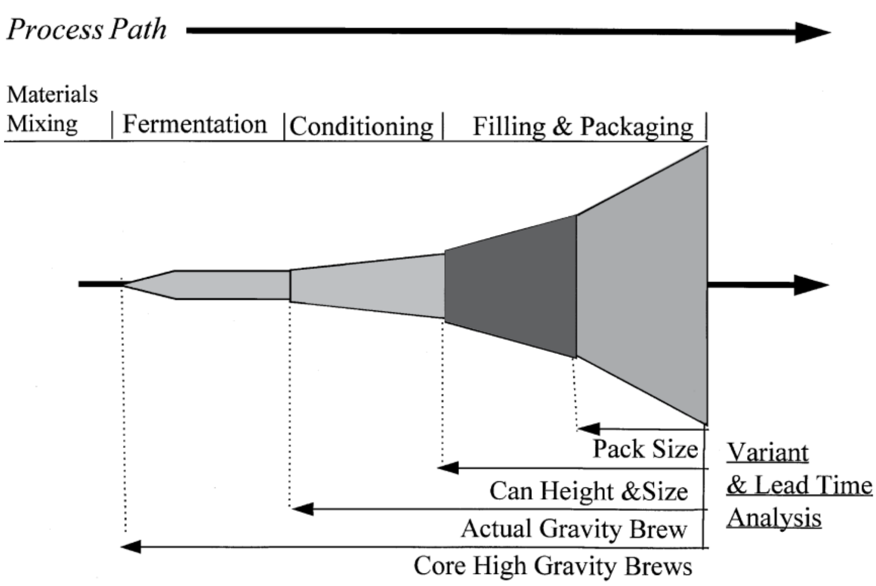


Figure 12 - Product variety model applied to a brewing example (Hines & Rich 1997, p. 54).

2.6.4 Quality filter mapping

Quality filter mapping plots the rates for particular types of defects along the supply chain. This tool allows the identification of quality problems and where they occurred along the supply chain. Defects are a large source of waste at the end of any project and the prevention of these earlier in the project can save a lot of time and money (waste) in the end. Three types of defects have been plotted in the following figure. (Hines & Rich 1997, pp. 54,5)

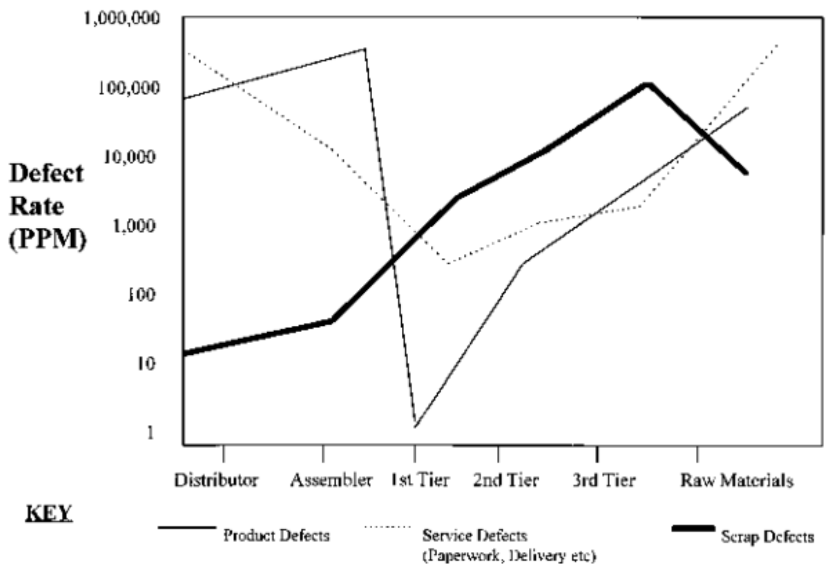


Figure 13 - Quality filter mapping applied to automotive supply chain (Hines & Rich 1997, p. 55).

2.6.5 Demand amplification mapping

Demand amplification is mapping the supplies and demands of particular products. Supply is a relatively constant flow while demand can fluctuate wildly. This means that while supply may meet demand on average there will still be a number of occurrences where demand will be much greater. This tool can be used to determine the impact of consumers on suppliers at different levels further up the supply chain.

2.6.6 Decision point analysis

Decision point analysis is a tool used to analyse supply chains exhibiting both push and pull philosophies. The method relies on determining the decision point of a supply chain. This point is where the supply chain changes from a demand driven pull system to a forecast-driven push system. In construction this point often occurs between the suppliers and contractor where the suppliers only replenish stocks when depleted and contractors purchase based on future works. This is one of the reasons suppliers often need to keep large inventories to meet the wild fluctuations of the construction industry. Determining the decision point is critical to understanding how supply chains react to changes. This understanding can be used for suppliers to better plan inventories and for contractors to form better relationships with suppliers.

2.6.7 Physical structure mapping

This method allows us to see an overview of supply chains from at an industry level. To do this we need to map the relationships between the interconnected suppliers, producers and consumers at an industry level. This method can be used to map either the costs incurred or volumes produced at each point within the supply chain. Figure 14 - Physical structure map of an automotive industry example (Hines & Rich 1997, p. 58) demonstrates these two maps with the number of firms involved in each production tier on the left and the map of costs involved on the right. The cost adding map areas are determined by the value adding processes. This is yet another way to represent the value adding process. In a manufacturing environment the assembler is situated in the middle of the diagram being fed by various tiers of suppliers. In a construction model the site production will be set in the middle of the map. This Is potentially a very useful tool for analysing waste within the supply chain as we are able to see a physical representation of where excessive costs are being incurred. These costs at this point can then further be investigated to reveal the wastes causing this.

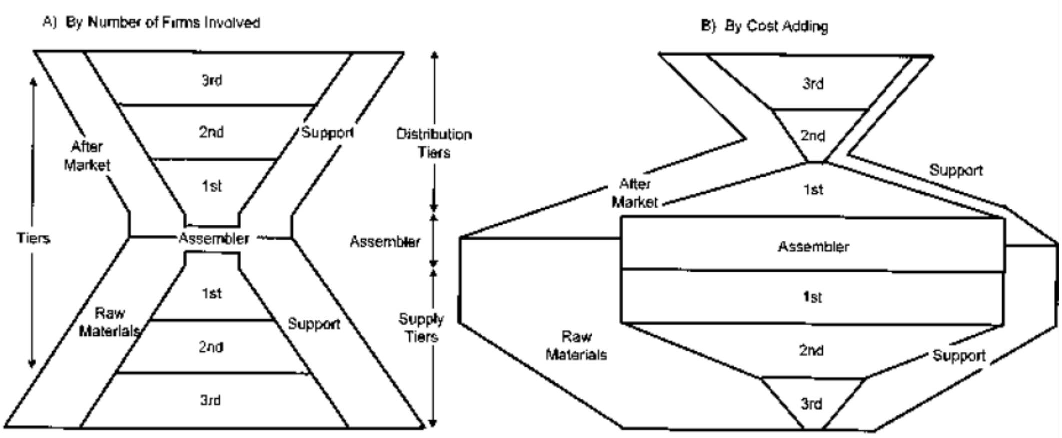


Figure 14 - Physical structure map of an automotive industry example (Hines & Rich 1997, p. 58)

Figure 14 provides a decision support tool which measures the correlation and between each of the chosen wastes and the proposed method of mapping. To determine the best mapping tool for a specific waste the waste is first selected in the table and following the row across the column or mapping tool with a 'H' denoting high correlation is selected. For example if we need to map the unnecessary motion waste in a system using the table the tool with highest correlation is process activity mapping. This array of tools can be used to map waste throughout the production process. The most difficult task is to decide which tools are applicable to measure which types of waste.

	Mapping tool						
Wastes/structure	Process activity mapping	Supply chain response matrix	Production variety funnel	Quality filter mapping	Demand amplification mapping	Decision point analysis	Physical structure (a) volume (b) value
Overproduction	L	M		L	M	M	
Waiting	H	H	L		M	M	
Transport	H						L
Inappropriate processing	H		M	L		L	
Unnecessary inventory	M	H	M		H	M	L
Unnecessary motion	H	L					
Defects	L			H			
Overall structure	L	L	M	L	H	M	H

Notes: H =High correlation and usefulness
M = Medium correlation and usefulness
L = Low correlation and usefulness

Figure 15 - Decision support tool used based of correlations between tools and wastes. (Hines & Rich 1997, p. 50)

The article provides a framework for the implementation of a value stream analysis tool (VALSAT). This framework uses the following procedure:

1. Identify value stream
2. Identify wastes present in particular value stream
3. List wastes in A and tools in B with correlation matrix in C
4. Identify a benchmark company for each waste
5. Weightings applied to wastes and overall structure
6. Add up total weightings for each tool

This process is undertaken by filling out the table in Figure 16. The process is best completed by the managers involved in the particular value stream as these are the people most effective at producing change in that area. The total weightings for each tool are then used to determine which tool is deemed most effective in identify waste most important to the particular value stream. The reason a benchmark company is listed is to determine what competitors are best at reducing that particular waste and what the company undertaking the process can learn from this. This is also a point to measure the company's performance off, thus creating a benchmark. (Hines & Rich 1997, pp. 59-61)

WASTES/ STRUCTURE	WEIGHT	TOOLS: Process activity mapping	Supply chain response matrix	Production variety funnel	Quality filter mapping	Demand amplification mapping	Decision point analysis	Physical structure (a) volume (b) value	COMPETITOR ANALYSIS
Overproduction	1	L	M		L	M	M		
Waiting		H	H	L		M	M		
Transport	0.5	H						L	
Inappropriate processing	0.4	H		M	L		L		[D]
Unnecessary inventory	0.5	M	H	M		H	M	L	
Unnecessary motion	0.8	H	L						
Defects	1	L			H				
Overall structure	1	L	L	M	L	H	M	H	
	TOTAL WEIGHT	[F]							

Figure 16 - Layout for application of VALSAT to determine effectiveness of waste identification tools. (Hines & Rich 1997, p. 60)

2.6.8 Commitment Reliability as a measure of waste

Commitment reliability is the level of dependability that a contractor executes the works specified in the contract according to construction program. Commitment reliability can also be understood as the commitment of the contractor to undertake these works in a way that meets all the requirements of quality assurance according to the project specifications. (Sharma 2013, p. 1)

Sharma provides the following example for the measurement of the Commitment reliability of specific tasks within a project plan:

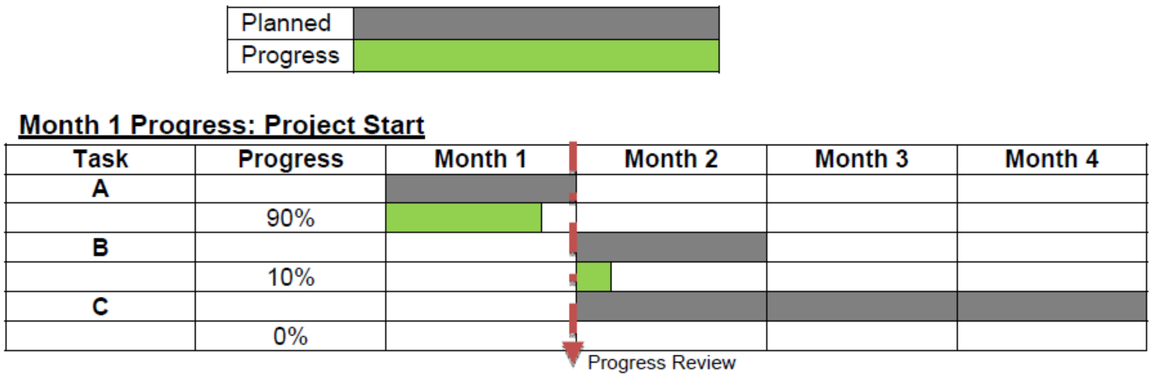


Figure 17 - Expected vs actual progress of tasks within a project plan.(Sharma 2013, p. 25)

The above figure illustrates the actual progress (green) as a percentage of the planned progress (grey) during a progress report. The commitment reliability can be measured as a percentage by Actual progress/Planned progress:

Task A

Commitment Reliability = Actual/Planned
= 90/100 x 100
= **90%**

Only 90% of work has been achieved out of 100% as planned this shows that there is some deviation that has occurred during the project task which has created delay in completion of the task as planned.

Task B

Commitment Reliability = Actual/Planned
= 10/0 x 100
= **-**

10% of work has been achieved out of 0% as planned. The project task is ahead of the planned schedule.

Task C

Commitment Reliability = Actual/Planned
= 0/0 x 100
= **-**

The task has not commenced yet however as per the actual plan this task should in next month.

Figure 18 - Commitment Reliability calculation for tasks represented in the above schedule. (Sharma 2013, p. 25)

Commitment reliability is a useful measurement in any project and could potentially be used as a Key Performance Indicator (KPI) when reporting on waste. This possibility will be explored further in the report structure section of this report.

Once the commitment reliability has been established the next step is to increase this reliability. One method proven to achieve this is the Last Planner system.

2.6.9 Activity Sampling as an estimate of waste

The most convenient measure of waste is to estimate the efficiencies of individual work processes on site. This simple method to detect productivity problems is known as Activity Sampling. This method involves recording the total number of workers or machines working in a particular area. Then the number of the workforce working is recorded at timed intervals over a period of time such as a day. (Abeysekera 2009a, p. 2)

Time Interval	No. working
6:00 AM	8
7:00 AM	6
8:00 AM	8
9:00 AM	9
10:00 AM	5
11:00 AM	3
12:00 PM	11
1:00 PM	12
2:00 PM	8
3:00 PM	7
Average	**7.7**

Total workers		12
Average/total		
	7.7 / 12 =	0.641667
Percentage Efficiency		
	64.17%	

Figure 19 - Activity sample example demonstrating collected data and calculations.

In this example we can see that 36% are not working on average. This means there is room for improvement and that this activity should be further analysed to determine causes and potential solutions. (Abeysekera 2009, p. 2)

To better understand the accuracy of this data we need to determine the % confidence of this data and potentially the amount of samples we need to achieve our desired level of confidence. This data can also be represented graphically in the form of a distribution. If enough data is collected the graph should resemble a normal distribution as shown in the following figure. The following process is used to calculate the confidence level of a particular set of data collected:

Sample size = 10

Average result = 7.7

Range = 0-12

Proportion (p) = 7.7/12 = 64%

The following method is used to calculate the number of samples required to achieve the required level of confidence:

$$p^{\wedge} \pm z^{*}\, SE(p^{\wedge})$$

The standard error (SE) can be calculated from the following equation:

$$SE(p^{\wedge}) = \sqrt{\frac{p^{\wedge}(1-p^{\wedge})}{n}} = \sqrt{\frac{0.64 * 0.36}{100}} = 0.048$$

Using a confidence level of 95% the critical value (z*) = 1.960

0.5 ± 1.960 x 0.048

0.5 ± 0.09408

The 95% confidence limit is from 0.40592 to 0.59408. Therefore, we are 95% confident that between 40% and 60% of the labour was utilised over the time period.

Similarly this equation can be rearranged to determine the number of samples required to satisfy a pre-determined confidence level:

$$n = \frac{z^{*} * p^{\wedge}(1-p^{\wedge})}{SE^{2}}$$

$$n = \frac{1.960 * 0.64 * 0.36}{0.048^{2}}$$

$$n = 196$$

Therefore by taking 196 samples the proportion of unproductive work can be determined within 5% accuracy. Similarly completing the same calculation for 90% confidence only 49 sample would need to be taken.

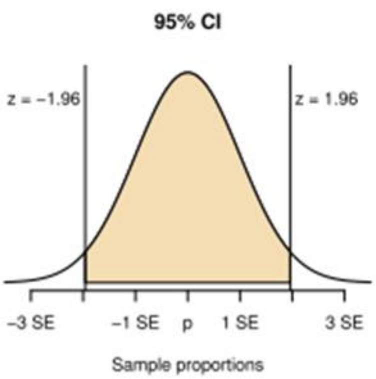


Figure 20 - Normal distribution demonstrating the range of data within a confidence level of 95%.

2.6.10 Multiple Activity Chart (MAC)

Once an Activity Sampling study has been conducted the data can be further analysed with a Multiple activity chart to provide an optimum solution. The chart shows the interconnected movements of people and plant against a common timeframe. This allows us to better understand the process and potentially rearrange it in such a way as to increase the output or decrease the cycle time without any additional inputs. (Abeysekera 2009b, p. 262)

To build this chart an array of data must first be collected. The construction process must be broken up into repetitive cycles which can be analysed as discrete process. Within these processes the activities are then listed in order and depending on any overlaps or interdependencies. Once this cycle is defined the times required for each activity are used to plot them on the common time scale. An example of this process applied to a concreting operation is demonstrated in the following figure.

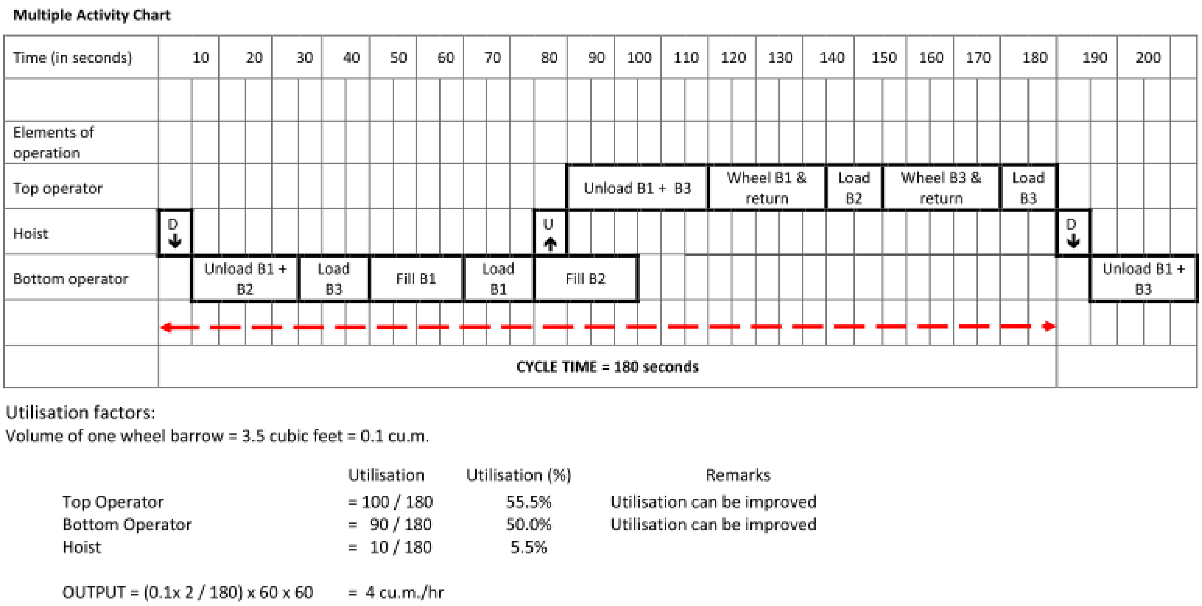
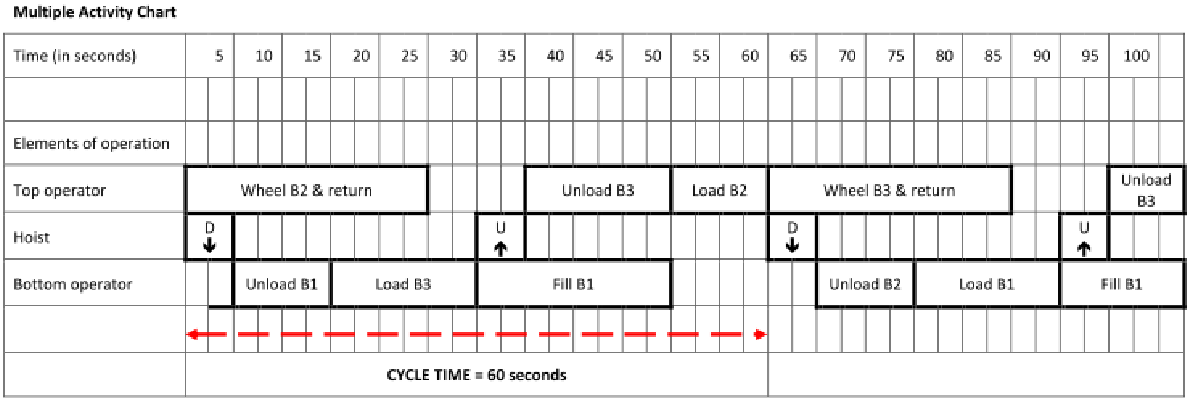


Figure 21 - Multiple activity chart of a concreting operation transporting concrete using 3 wheelbarrows and a hoist. (Abeysekera 2009b, p. 263)

B1, B2 and B3 denote the actions of the three wheelbarrows while the U and D arrows indicate the movement of the hoist lifting the barrows up and down. The movements of the hoists and the emptying and filling of the wheelbarrows is rearranged to produce the following chart. (Abeysekera 2009b, p. 262)



Utilisation factors:

	Utilisation	Method 2	Method 1	Existing Method	Remarks
Top Operator	= 50 / 60	= 83.2%	58.8%	55.5%	
Bottom Operator	= 45 / 60	= 75.0%	52.9%	50.0%	Method 2 utilisation levels significantly higher
Hoist	= 10 / 60	= 11.8%	11.8%	5.5%	
OUTPUT = (3.5 / 60) x 60 x 60		= 6 cu.m./hr	4.24 cu.m./hr	4 cu.m./hr	Output 150% higher than Method 1

Figure 22 - Optimised version of the original Multiple Activity chart where all three wheelbarrows are used and empty barrows are sent down straight after filled barrow is unloaded. (Abeysekera 2009b, p. 265)

The rearranged chart has increased the output of the concreting by 150% by reducing the cycle time and therefore increasing the amount of concrete moved in the same amount of time. (Abeysekera 2009b, p. 265) This example shows how a MAC can optimise a process by enabling the used to visually rearrange activities to achieve an optimum outcome without the need for trials.

2.7 Classification of Construction Waste

2.7.1 European Waste List (EWL)

The European Waste List (EWL) has proposed a waste classification based around a structure of three construction processes. These broadly classify construction and demolition waste into; packaging, remains and soil. Packaging of the materials and products supplied to the works includes materials such as cardboard, plastic and metal containers and wooden pallets. Remains includes any left-over building materials such as concrete, ceramics or wood. Soil includes any material left over from excavations and not used as fill. (Llatas 2011, p. 1266)

The early stages of work include clearing and setting up the site and excavations. This involves enclosing the worksite and providing basic infrastructure, access and facilities. Most of the waste generated from this stage consists of unsuitable soil from clearing and initial excavations. (Llatas 2011, p. 1266)

The second stage is the reception and storage of materials. Much of the waste from procuring materials consists of; packaging, incorrect purchases, substandard quality, damage during transport and the transport time itself. Lack of space and poor storage conditions are often reasons for damage occurring on site. (Llatas 2011, p. 1266)

The third and largest stage is the execution of construction activities. This stage can produce a large variety of wastes depending on the activities being undertaken. Common wastes are:

- Soil from excavation
- Excess components and building materials
- Remains of temporary elements
- Breakages and losses
- Defects

(Llatas 2011, p. 1266)

Llatas proposes a model to quantify the waste produced on construction and demolition sites. This uses the basic principle of measuring materials inputs and applying relevant equations and factors producing a theoretical output of waste. These basic tools used in this model has been shown graphically in Figure 15 with the supplied materials as the input on the left and waste generated as the output on the right. To achieve this theoretical output the input is multiplied by the corresponding factors listed in between.

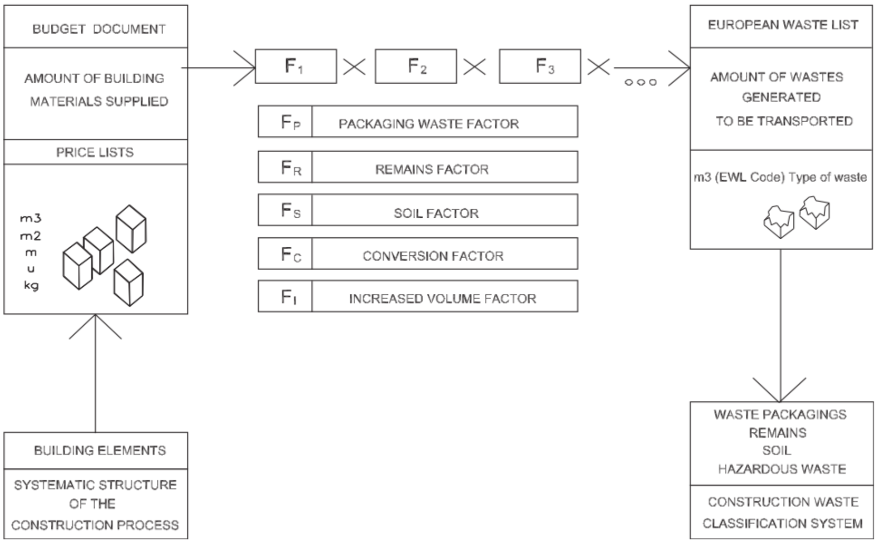


Figure 15 - Tools used to implement the model. (Llatas 2011, p. 1266)p1266

The model consists of three steps:

1. Identification of elements of the construction process
2. Categorise waste according to EWL list
3. Application of analytical equations to estimate waste

   (Llatas 2011, p. 1265)

The identification of elements involves systematically defining the structure of the project to determine all the components and materials that are needed to produce each element. The analytical expressions combine the waste type, amount and a number of factors to estimate the waste into three equations depending on the three categorisations of waste. The general expression for packaging is given in Equation 1. (Llatas 2011, p. 1267)

Equation 1 - Analytical estimation of waste. (Llatas 2011, p. 1267)

$$CW_{Pi} = \sum_{k} (EWL)_{Pk} \cdot Q_i \cdot F_P \cdot F_C \cdot F_I$$

- CW_{Pi} - expected construction waste amount for waste EWL.
- P - represents packaging waste
- $_k$ - type of packaging waste
- Q_i amount of the building element I inputted into the system
- F_p - packaging waste factor
- F_c – conversion factor
- F_i – increase in volume factor

The packaging waste factor transforms the amount of building material into the amount of waste based on how the material is packaged. This information can be obtained from the supplier and consists of a volume or weight ratio of the material to packaging. Fc is the conversion factor for the units of measurement for materials and their waste. Fi accounts for the increase in volume for some types of waste known as the ‘sponge effect’. This can be due to the increase in volume of some materials due to how it is stored or collected, however, this is not needed if the mass of materials is used. The following diagram shows the input material types typically required by construction projects on the left. On the right is a selection of the common types of materials wastes generated from these input materials. These materials will either end up in landfill of incinerated or taken to a secondary market for re-use and recycling.

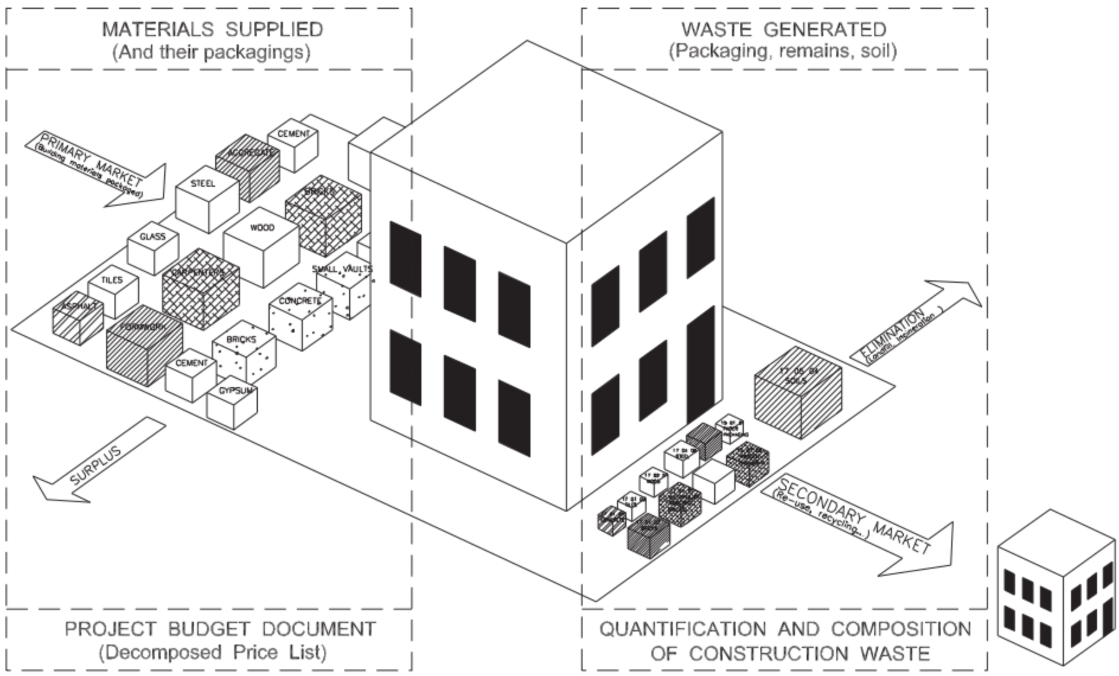


Figure 23 - Representation of material inputs and waste outputs for a construction site. (Llatas 2011, p. 1274)

There are a number of limitations of this classification. This method only considers types of material waste neglecting other types such as time. However, it would be difficult to implement this method for waste time. This classification relies on the European Waste List database and this would need to be adjusted for the Australian construction industry. (Llatas 2011, p. 1275)

The model is very usefull for the intended purpose of classifying material wastes which is but one facet of waste that is considered in lean construction. This method is relevant for the current view of waste management but if a comprehensive view of waste is adopted a more comprehensive view of classification will need to be adopted.

2.7.2 Lean Construction

One of the original lean construction methodologies is the concept of JIT delivery. This means the materials needed are brought to site and installed immediately; negating the need for storage or double-handling. This is an example of a 'pull' method where materials are ordered and manufactured as needed. The opposite of this is the more commonly used 'push' system which involves ordering anticipated materials based on forecasting. The problem with this method is often exact amounts are not known in advance and more is ordered than needed to compensate for uncertainties. The pull system eliminated this overproduction by only replenishing material. However, for the pull system to work efficiently leads times need to be reduced and an effective mechanism to notify the upstream producer needs to be implemented. Concrete supplied from batch plants is an example of a pull system. As ready-mix concrete cannot be stockpiled on site it must be delivered to site as needed and is placed immediately. This is a process which requires a high level of cooperation and interdependence between the supplier and contractor. (Tommelein & Li 1999)

Often attempts at JIT delivery by reducing inventories have just pushed these inventories back to suppliers which need to hold an even greater inventory to supply construction needs – increasing 'total' supply chain costs. According to Russell (2009) this is a very narrow-minded approach which does not consider the entire supply chain as a system. (Russell 2009, p713)

Abeysekera suggests the following steps should be considered when increasing **flow** in activities:

- Improving constructability by simplifying the number of steps
- Reduction of variability in number of parts in sizes
- Flexibility to substitute materials and source subcontractors at short notice
- Process transparency and planning

  (Abeysekera et al, 2009)

Koskela presents the following principles for improvement of flow:

- Reduction in variability
- Compression of cycle times
- Simplification

The article then continues on suggest flexibility, transparency and the need for constant improvement not unlike that of (Abeysekera et al, 2009)(Koskela 1997).

Abeysekera provides an overview of the traditionally implemented improvements for increasing productivities:

- Technology such as pre-stressed and pre-cast concrete
- Plant and equipment (excavators, cranes)
- Automation and factory production
- Innovation of products and processes
- Scale economies (mass production and learning curve effects)
- Modularisation and type-plans for residential housing developments
- Specialisation using subcontractors and outsourcing.

  (Abeysekera et al, 2009; Hennayake and Ponnampalam,1982)

All these methods for increasing flow and efficiency has been proven to work in today's construction industry. However,

2.7.3 4D construction site management

For large structural concrete operations cranes are often used to move formwork and other materials into location. With the increased size and capacity if modern cranes this is now far more efficient and greater access to locations is available. Lin writes about planning construction activities using these large semi-stationary equipment. Due to the size of this equipment it is desired to minimise movements which requires planning on behalf of the engineer. (Lin & Haas 1996)

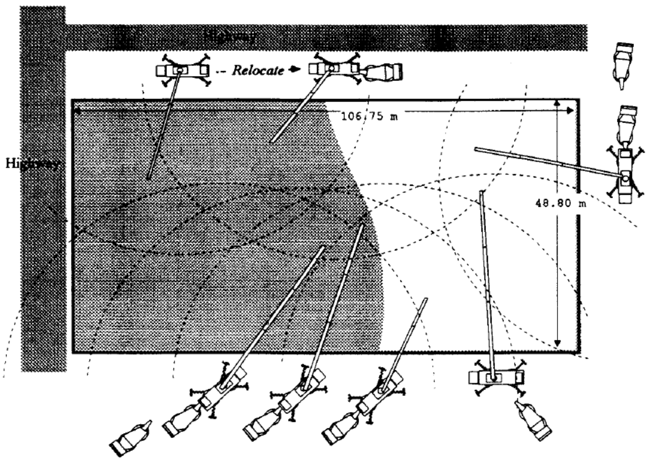


FIG. 12. Concrete Pour at the Atlanta Federal Center

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Figure 24 - Optimisation of movements of concrete pumps.(Lin & Haas 1996, p. 220)

Planning concrete pours such as the one pictured above requires rigorous planning of positioning of equipment in conjunction with how much equipment needed to achieve your desired productivity. The pump movements must be timed with productivities and what area of the slab can be reached from each position. The productivities of the concreting crews must be equivalent to the planned rate of concrete delivery and how many concrete trucks are available to service the pour. If this is not the case waste will be generated. If the productivity of the crew is greater than the supply they will be waiting and inactive therefore increasing the total time required for the same amount of production. On the other hand if delivery times are too close and trucks will be waiting also increasing the likelihood of sending trucks away.

Lin describes the benefits of using an interactive computerised planning process to better illustrate and evaluate these complex activities. This method allows the planned to visualise the process before it is implemented and to test alternative plans before commencement. This technology is not only very useful for the planners but can potentially save large amounts of time and resources on-site. Lin states, “Planning is typically the responsibility of a small pool of experts whose knowledge is largely undocumented.” (Lin & Haas 1996) An added benefit of this system is a detailed record of the planning process can then be kept for future record. This can help planners to both better understand any problems that occur and provide learnings for further similar operations.

One area currently being researched is 4D visualisation of construction site management. There are a number of systems being developed for this purpose such as Integrated Site Planning System (4D-ISPS) and Construction Site Management System (CSMS). 4D modelling involves the combination of the planning schedule into a 3D model of the worksite. Adding time allows the planner to visually analyse the workflow of the project using a graphical simulation to better locate and understand potential problems therefore avoiding waste This can be created by programs such as AutoCAD which is generally already completed in the design stage of the project. This allows the construction and movement of 3D elements to be directly linked to the time schedule of the project. (Ma, Shen & Zhang 2005; Zhang, Ma & Pu 2001)

This 4D model can be further expanded into a 5D model with the added dimension of cost. Incorporating this into the model allows the instant generation of costs at any point in time over the project. The core concept of this modelling is Building Information Model or BIM which manages both the information and the graphical model. BIM can be used to model the entire life cycle of a structure as well as the construction phase and can incorporate other dimensions such as sustainability and energy-savings. (Popov et al. 2010, pp. 359,60) (Kamardeen 2010, p. 285)

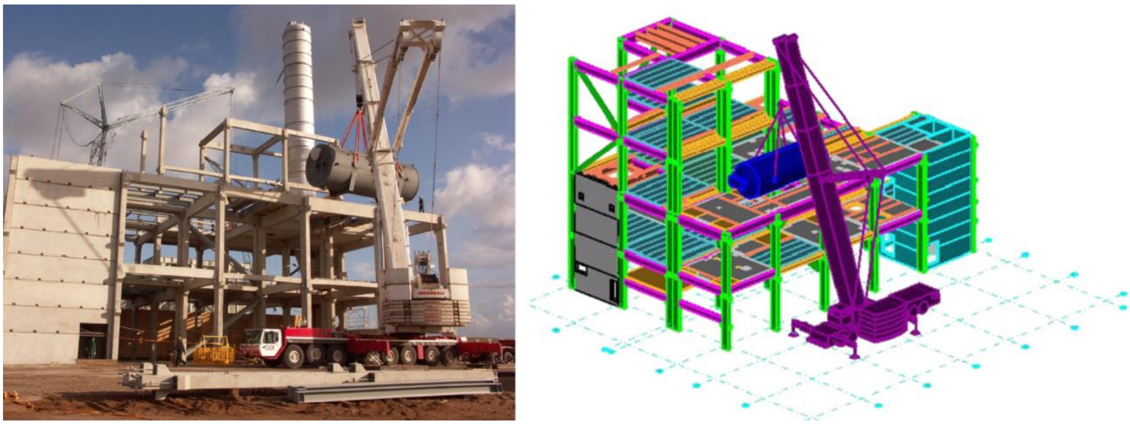


Figure 25 - Building Information Model representing a real construction operation. (Popov et al. 2010, pp. 364,5)

This BIM model allows planners to more easily optimise and predict the performance of construction projects before starting. This concept is very applicable for construction of buildings and other complicated structures where accurate 3D drafting and modelling would have already taken place. This would be somewhat more difficult for some civil projects where 2D plans are used as some volumes and materials cannot be calculated from the model. (Kamardeen 2010, p. 285) Another issue in some circumstances is that these plans would need to more accurately portray the actual activities taking place. For many of these projects a 2D staging approach may still be more efficient.

Theoretically an infinite number of dimensions can be added to this model and some literature describes models with up to 8 dimensions. These dimensions can be aspects such as; facilities management, sustainability, safety and potentially waste. (Kamardeen 2010, p. 285)

This model can be used to better plan and track waste generation leading to more accurate problem diagnosis when reducing waste. This would also help in creating more realistic plans to increase commitment reliability, a concept which will be introduced in the next section. The possibility of incorporating waste into this model is outside the current scope for this research but is potential direction for further research.

2.7.5 Last Planner System for concreting operations (LPS)

Due to the ever increasing size and complexity of construction projects the need to plan effectively is continually growing in importance. Due to this resulting increase in complexity of planning a hierarchical system has been developed to delegate various levels of planning to different groups. The top level of planning deals with the global constraints of the project and the overall inputs and outputs. This provides an outline for the subsequent layers of planning from project staging right down to weekly plans of site activities. (Ballard 2000, pp. 3-1)

The aim of the LPS is increasing reliability of planning and the stabilisation of production-level workflow. The LPS uses concepts of "front-end planning"," lookahead planning" and "commitment planning" are utilised for various levels of planning required by different levels of the hierarchy. From this master schedule, lookahead and a weekly work schedule are created. According to Choo the purpose of a master schedule is to show what can feasibly be completed in the allotted time and what lead times are required. A lookahead provides an overview of all the activities in the best sequence with all the required resources. The weekly schedule is work that is currently available and what work needs to be done to satisfy the lookahead plan. (Choo 2003, pp. 37-41)

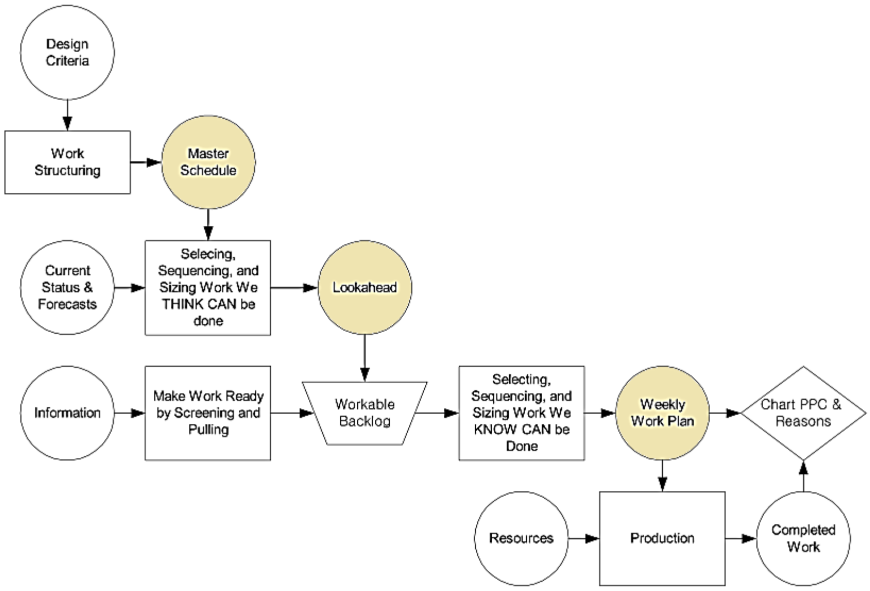


Figure 26- Last Planner System flowchart. (Choo 2003, p. 40)

The LPS implements production control into the traditional systems of project management. The last planning process looks at what should be done and rationalises this into what can be done. This then creates an inventory of work from which what will be done can be planned. (Ballard 2000, pp. 3-14)

The LPS has two components; production unit control and work flow control. Production controls work within the production units and work flow controls work flow between production units. Production unit control is measured directly by the output quality of the work being performed for each given assignment. To achieve high outputs the provided assignments must be well defined. The right sequence and amount of work for the assignment must also be selected. The final criteria for planning assignments is that the work selected can be done, meaning the appropriate resources are available and prerequisite work has been completed. Work flow control ensures that this work flows through these production units in the appropriate sequence and rate. (Ballard 2000, pp. 3-2 - 3-5)

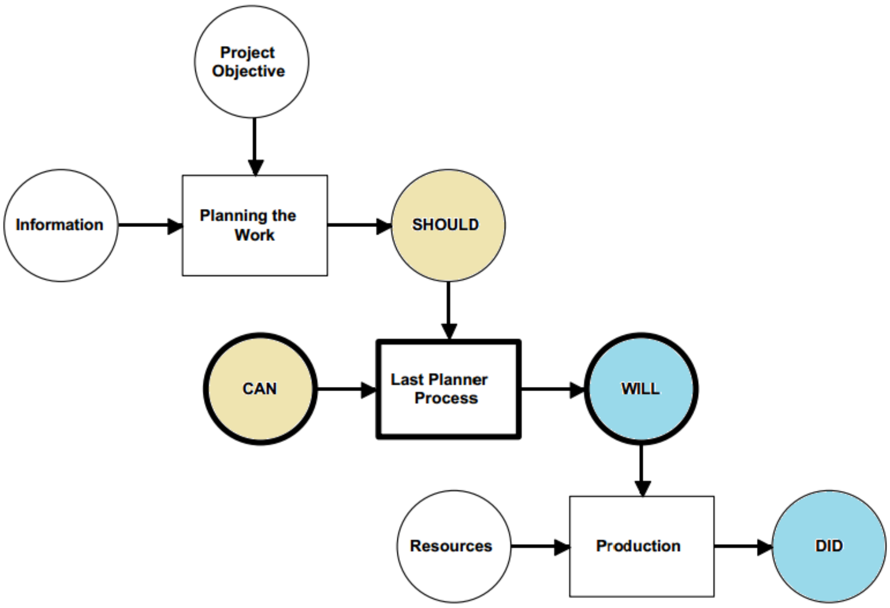


Figure 27 - The Last Planer System in terms of should, can, will and do. (Ballard 2000, pp. 3-15)

The research conducted by Ballard shows that the LPS can be used to achieve 90% reliability of planning on site. This reliability and increased ability to plan has profound effects for the productivities of construction sites. This in turn can reduce waste generation across all categories. (Ballard 2000, pp. 10-, -1)

2.7.6 Classification of waste by source

Two methods of source-based classification will be defined:

- Types of waste (time, materials, information)
- Materials, plant, people

The first source-based method involves grouping types of waste into the three categories of time, material and information. This results in the following example lists:

Table 3 - Classifications of example wastes into materials, time and information.

	Type of waste
Materials	Processing waste Overproduction (offcuts, excess etc.) Lack of materials control and waste management plan Unnecessary inventory
Time	Accidents Weather Defects Waiting/idle time Ineffective work Transporting Unnecessary motion
Information	Making-do Lack of communication Request for information (RFI's) Design errors/changes Constructability concerns

Another potential classification of waste is by attributing them to their sources being; people, plant and materials. This approach simplifies classification by using easily identifiable sources increasing usability on site.

2.7.7 Classification of waste by processes

Classification by process is determining the total waste attributed to each of the defined activities in either the construction project or a defined process within the project.

The first method is process based where waste can be classified according to the different processes involved in completing the task. For the example of concreting these processes include; planning, formwork, reinforcement assembly, pouring, removing formwork and any resulting defects or required re-work. Wastes can then be classified according to the process in which they occur. For example waste time may occur across all processes whereas waste material such as reinforcement will only occur in reinforcement assembly.

The second is taken from Serpell's "Characterisation of waste in building construction projects" and categorises waste into different stages of the construction process. These categories are broadly classified as:

- Design
- Procurement,
- Materials handling
- Operational
- Residual and
- Other

Where residual is material waste such as offcuts and excess and other includes theft, damage and lack of material control plans. Waste time is further broken down to categories of work inactivity and ineffective work. Work inactivity includes waiting, travelling, resting and any other time when work has ceased. Whereas ineffective work focuses on efficiency of working time as well as re-work and having to invent new ways to complete work. (Serpell, Venturi & Contreras 1995)

2.7.8 Management classification of waste

This approach classifies waste according to the management structure responsible for that process. The three management structures are production management, project management and business management. These classifications represent the major facets of any construction company. This approach is very useful as it directly implies the responsibility and that responsible for the occurrence of each type of waste detected.

Production management	Project management	Business management
Processing waste	Requests for information (RFI's)	Inventory
Waiting/idle time	Design errors	Unnecessary motion
Transporting	Constructability concerns	
Making-do	Error in contract documents	
Lack of communication		

Figure 28 - Classification of wastes according to management structures.

2.7.9 PESTLE classification of waste

The PESTLE framework is an acronym for political, economic, social, technological, legal and environment. This classification system originates as a strategic management plan for companies when analysing the impacts of decisions and policies. Typical wastes can be attributed to the different areas as follows:

Political	Economic	Social	Technological	Legal	Environment
Requests for information (RFI's)	Processing waste	Lack of communication	Transporting	Error in contract documents	Contaminated materials
Design changes	Transporting				Poor weather
Design and detailing errors	Waiting/idle time				
	Making-do				
	Inventory				

Figure 29 - PESTLE framework for classification of wastes according to their specific impacts. (Abeysekera, 2014)

2.7.10 Project management classification of waste

The following classification originates from typical Key Performance Indicators (KPI's) used in reporting construction projects. The University of Oxford defines a number of KPI's based on the specific areas of a project being; client satisfaction, environmental, finance, personnel and process. (Oxford 2013, p. 2) Ngoc gives a number of example KPI's including; time, issues, quality, resources and costs. (Ngoc 2014, pp. 5-6) From these examples a number of KPI's can be developed to measure the performance of a project in relation to waste generation:

Time	Cost	Quality	Safety	Environment	Etc
Waiting/idle time	Constructability concerns	Processing waste	Unnecessary motion	Contaminated materials	Criminal waste
Transporting	Inventory	Making-do	Poor weather		
Lack of communication	Design and detailing errors	Design errors	Accidents		
	Requests for information (RFI's)	Design changes	Equipment malfunction		

Figure 30 - Classification of wastes according to common project management KPI's. (Abeysekera, 2014)

2.7.11 Value adding classification of waste

This classification groups all processes into the categories of; value adding, non-value adding and non-value adding but necessary. Both subgroups of non-value adding and necessary but non-value adding are considered wasteful. Non-value adding or 'pure waste' includes processes such as unnecessary movement, storage between processes and waiting times. Necessary but non-value adding process, such as transportation and unpacking materials, are those which add no value but are required in the current operational environment. These can only be eliminated with major changes to the operating system.

Hines goes on to state that there are seven categories of waste; overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion and defects. All of these can be categorised into these to subgroups depending on the operation. (Hines & Rich 1997) Russell lists the same categories with the addition of talent, which is underutilising potential skills and knowledge of employees. (Russell 2009)

This concept presents us with a method of classifying processes depending on their value and necessity. It further provides 7 categories of waste which fall under the classifications of non-vale adding and non-value adding but necessary.

2.8 Concrete construction

2.8.1 Technology

Over the past few decades the use of new technologies has led to vast improvements in speed and productivity of concrete construction. In recent years there has been an explosion in the variety of concrete mixes and applications. These mixes cater to everything from freezing temperatures to reducing carbon emissions. New technologies for placement using machines have meant that concrete can be placed in more locations and in larger quantities without human error. The use of concrete pumps is now commonplace for pours ranging from small hard to get to locations to pours for monolithic structures involving hundreds of cubic meters. Another common technology is slip form pavers which utilise a mobile formwork to move along the concrete pour continually placing, compacting and finishing the concrete. This technology has an array of applications ranging from construction of high-rise cores to pavements and traffic barriers. However, these are expensive machines and are only cost effective for large volume concrete pours. (Zayed, 2008 p1).

2.8.2 Current methodologies

Concrete has many applications for construction, including: buildings, roads, bridges and drainage structures. These are all constructed in different ways, but for most the actual process of concreting stays the same. Concrete pumps are now used for most operations with the exception of small easily accessible locations or tall buildings where a crane and bucket may be employed. Although pumps are costly they are still much more efficient than traditional methods of carting concrete by hand. This allows the pour to be completed more quickly and with less labour needed. This is quite important in Australia where labour costs are quite high compared to material costs. Pumps also allow us to pour in locations previously inaccessible meaning less time and material needs to be spent on creating an access to the pour location. (Dunlop & Smith 2003, p. 274)

2.8.3 Current Reporting Structures

This section will analyze a number of reporting structures used by construction companies. The first report to be analyzed is a Construction Waste and Spoil Management Plan from Aurizon.

Aurizon – Construction Waste and Spoil Management Plan.

This document is developed at the beginning of the project to outline the expectations and monitoring required to fulfill the waste management obligations. The report structure is as follows:

1. Purpose
2. Construction Waste Generation
3. Classification of waste streams
4. Construction Demobilization
5. Environmental Impacts and Controls
6. Environmental monitoring and reporting

   (Aurizon 2014)

The purpose provides a summary of the contents of the report, including; waste identification, waste handling, storage and disposal, spoil management and sewerage and wastewater treatment. This section also includes a schedule of the construction activities and a risk assessment for sewerage and wastewater. (Aurizon 2014, p. 7)

Construction waste generation includes both the strategy for waste reduction and the potential sources of waste. These sources are categorized by construction activity such as earthworks or road construction. These activities are then further broken down into the specific waste types such as asphalt, concrete, steel or timber. Materials were the only type of waste considered in this report which focused on waste from an environmental perspective. (Aurizon 2014, p. 7)

Construction demobilization and environmental impacts and controls are planning sections outlining responsibilities and procedures at different stages in the project. Waste monitoring and reporting is a very useful section outlining all the expectations of the company. Waste monitoring outlines how waste will be tracked including:

- Date and time of Departure
- Classification
- Amount
- Waste use (recycled/stored/treated/disposed)
- Reference to track waste

  (Aurizon 2014, p. 7)

Reporting covers what reviews will need to be undertaken over the life of the project. The reviews will consider all changes in the project and any incidents or audit finding on the project taking the form of a compliance report.

SKM – Construction waste management plan

This waste management report is produced as a sub plan for the Construction Environment Management Plan. This defines waste management as a subset of environmental controls and as a means of complying with legislation. Another way of defining waste management is as a subset of production management and as a means of improving efficiencies. The report structure is as follows:

1. Introduction
2. Legislative and regulatory compliance
3. Environmental aspects, impacts and risks
4. Environmental control measures and procedures
5. Training
6. Inspections, monitoring, auditing and reporting
7. Review and improvement of the CWMP
8. Waste management register

Section 3 includes plans for waste minimization and classification of waste. In this case the classifications of waste are defined by the type of risk posed to the environment. Following this there is a methodology for classifying wastes on site which is summarized by Figure 31- Waste classification flowchart (Xstrata coal 2014)..

Xstrata coal – Project Waste Management

As with the other plans this focused on physical wastes purely from an environmental management perspective. A similar structure is used as follows:

1. Regulatory framework
2. Methodology
3. Environmental values
4. Potential impacts and mitigation
5. Cumulative impacts

This plan focuses on defining and tracking the impacts of each specific waste and applying specific management methods.(Xstrata coal 2014)

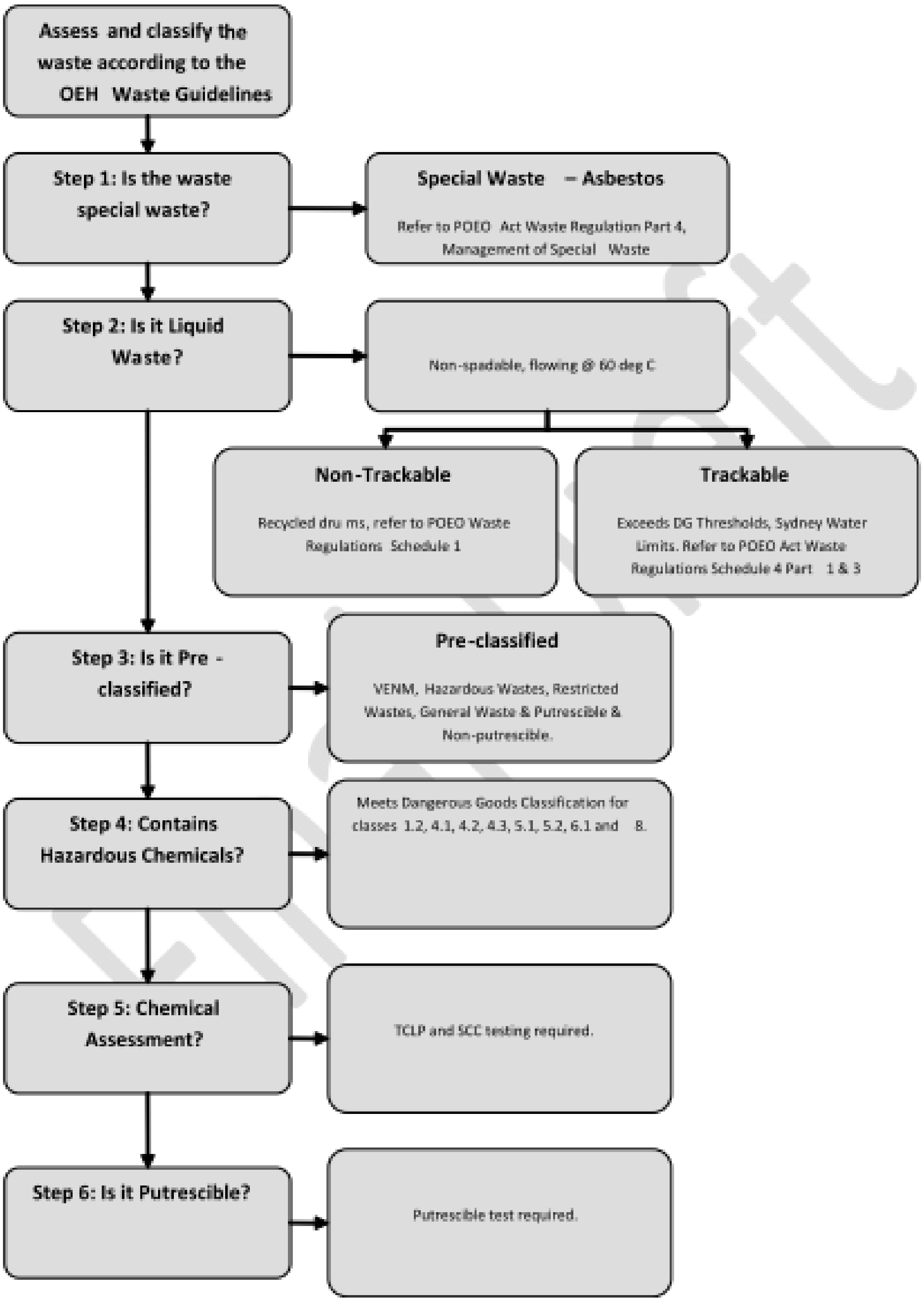


Figure 31- Waste classification flowchart (Xstrata coal 2014).

An interesting addition to this plan is the Review and Improvement of the plan. This is an essential tool for ensuring the continued effectiveness of any plan. This included monthly, quarterly and annual reviews on the adequacy of the plan on varying levels of detail. The waste management register is included as a template for recording all the wastes and their properties. (Xstrata coal 2014)

A number of useful ideas have been presented in this plan and can be integrated into a productivities based waste management report. The waste reporting will need to be part of an overall waste management plan which will outline how this report will be used. Including a waste classification method into the plan will increase the usability of the reporting ensuring the waste is classified correctly and increasing the reliably of the report. (Xstrata coal 2014)

Project Status Report Template

This is a template for summarizing an entire project by determining the status of a number of key performance indicators. These being; scope, schedule, cost, risks and quality. The status of each indicator is determined by the percentage variance from the plan with those with a large variance highlighted red and the inclusion of an explanation why. The body of the report follows the standard format of:

- Work completed
- Planned work
- Open issues
- Open risks
- Deliverables and milestones
- Key performance indicators

(Piscopo 2013)

These reports can be broken up into two categories of waste planning and waste reporting, of which the latter we will be focused on. Most of the waste plans define waste management as a subset of environmental controls and as a means of complying with legislation. For the purpose of this research we want to define waste management as a subset of production management. This directly relates waste to productivities and as means of increasing efficiencies. The Reporting templates introduces the concept of Key Performance Indicators (KPI's). For projects these are important indicators such as cost and timeframe. However, it would be useful to determine representative KPI's for waste.

2.9 Summary of literature

Manufacturing has been a reference point and a source of innovations in construction for many decades. Lean construction is now the major manufacturing practice used in western countries.

Lean construction has been effectively implemented on construction projects in some European countries such as Finland and England. There is a reasonable amount of literature available regarding methodologies, outcomes and effects of this application. However, there is still very little literature on this application within the Australian construction sector.

A number of types of waste have been identified through this review which can be summarised into the three broad categories of transformation, flow and value. The TFV approach represents construction as transformation, value generation and flow of materials or resources. Each of these representations allows us to analyse construction activities in different ways. The most important step is understanding what is of value to the customer and their requirements and expectations. (Abeysekera 2009a, pp. 217-9)

Once this waste is identified it can be mapped by techniques derived from Value Stream Mapping (VSM). This approach categorises all processes into three groups: value adding (VA), necessary but non-value adding (NNVA) and non-value adding (NVA). (Hines & Rich 1997) This allows us to determine the source and causes of waste identified as non-value adding by categorising the processes within a specific construction activity. The critical path is mapped according to these categories to identify these wastes. Once wastes are identified and eliminated the new critical path is then mapped and any new wastes identified, continuing the iterative process. By continually iterating the critical path value stream mapping can not only be applied linearly but also to complex systems of processes often found in construction projects. (Braglia, Carmignani & Zammori 2006)

Seven value stream mapping tools are then used to map the types of waste identified in the value stream. The appropriate mapping tool is selected for each type of waste using a matrix showing the correlation between each waste type and the mapping tools. (Hines & Rich 1997, pp. 59-61)

The next step is the classification of waste into standard categories which can be easily quantified and compared across different processes and construction projects. One method of standardising this process is the European Waste List (EWL) which broadly classifies construction waste into; packaging, remains and soil. The estimated waste for each category can then be calculated by factoring the input quantity to predict the output quantity leftover.

This classification is specialised for European countries and include location specific data such as average wastes and technology used. This is a system which could be used to standardise measurement of waste in the Australian construction industry. (Llatas 2011, p. 1275)

Process optimisation and waste reduction can be aided using dimensional construction site management. Additional dimensions such as time, cost and waste can be applied to 3D plans of a construction site to better illustrate and plan a project. This is a complex process but one which allows waste to be prevented through planning rather than dealt with after the completion of the construction process. The Last planner System (LPS) is another method which provides a framework for the detail of planning required at each level in the construction hierarchy. This can be treated as the backbone for planning all elements of a project including the expected and actual waste created in each process. (Kamardeen 2010, p. 285; Popov et al. 2010, pp. 359,60)

This identification, classification, quantification and planning approach needs to be summarised into a form which can be used to evaluate the performance of a activity or project. This performance analysis needs to be conducted in such a way that it is standardised to both analyse projects over time and to compare different projects. Using a standardised approach this performance comparison can then be further extended to broad performance indicators for whole companies.

This process is not unlike the way in which other indicators such as environmental performance of projects and companies is rated. By extending this process to waste both contractors and clients can make better informed decisions tendering and selecting tenders for projects.

From this literature I have decided upon the following as the most important indicators and components which should be included in a monthly report to management:

- Commitment Reliability
- Overall percentage of waste
- Non-value adding waste
- Non-value but necessary waste
- Broad classifications of waste
- Origins of waste visual representation both within the schedule and on site
- Expected (planned) vs actual waste (%)
- Recommendations

Chapter 3

Method

3.1 Overview

For any company to function there needs to be a clear chain of communication from the ground up. This requires a clearly defined management structure with the access to the appropriate information necessary for decision-making at each management level. For this information to be appropriate it needs to be both reliable and summarized to the necessary level of detail. This information is usually conveyed in the form of structured reports detailing the performance of a number of key characteristics of the project. This is written to inform the next level of management who in turn then further streamline the necessary information to be passed onto the next level of management. This reporting process continues all the way up the management pyramid.

3.2 Methodology

This chapter will illustrate the chosen method to achieve the report objectives as stated in the aim. These objectives include using lean construction techniques to measure and quantify waste for concreting in construction. This will then be used to create a template for reporting waste in traditional design, tender and construct projects. To achieve this the report has been broken up into the following chapters:

- Literature review
- Questionnaire
- Reporting structure
- Case studies
- Data collection & Results
- Discussion and recommendations
- Summary, conclusions & further work

3.2.1 Literature Review

The literature review provides an overview of the information available relevant to this research project. This information has been collected for a large number of sources to provide a representative picture of what is available and what gaps are present in the current literature. This literature will be used as a knowledge base to analyze and build on for the rest of the report.

This chapter will primarily focus on evaluation and selection of methods for classification of waste from a lean construction perspective. These will be weighed up against specific criteria to justify the selection. An analysis of the effectiveness and ease of implementation of selected methods in the Australian construction industry will be conducted. This will be used to both determine which methods to use and for what types of waste they will be most effective. Utilizing this, a measurement technique and weighting scheme will be determined for each classification and a relevant unit of measurement will be determined.

3.2.2 Questionnaire

This section will outline the method used to obtain feedback on the developed reporting structures. Feedback is required to both determine the best structure and provide information whether different structures may be better for different circumstances. Feedback has been sought from a number of engineering companies working in the construction industry. These companies can be classified according to their roles on construction projects. These roles range from; owner, contract administrator, consultant and contractor. A questionnaire has been provided to easily document and compare the feedback to determine the value of each report structure.

3.2.3 Reporting structure

This section will develop a suitable report format based on the information collected in the literature review. This will be heavily reliant on the development of a classification and selection of Key Performance Indicators to measure waste.

3.2.4 Case studies

The methodology for waste reporting will be applied to the construction of the Wellcamp Airport. The particular processes studied will be taken for the construction of concrete pavements. This will include mapping the processes and identifying and classifying wastes present and summarizing the results in the proposed report format.

3.2.5 Data collection & Results

The construction processes in the chosen case studies will be analysed according to the Key Performance Indicators. Each of these KPI's have methods of measurement which involve the collection of different types of data about different facets of the project. Once this data is collected and analysed the resulting KPI's will be calculated.

3.2.6 Discussion and Recommendations

This section will provide an opportunity to discuss the effectiveness of the chosen methodology and the value of the results received by implementing the chosen structure.

3.2.6 Summary, Conclusions and Further work

The level of achievement of the project aim and objectives will be discussed and which of these achieved the expected outcomes. Based on the findings from this report future directions for research will be presented.

Chapter 4

Reporting Structure

4.1 Introduction

Project reports will ideally contain all the important statistics for management to make decisions about the health of a particular project. For this reports need to highlight any major issues while still providing a representative picture of the situation.

To ensure this is the case a questionnaire on waste reporting has been written to enable industry feedback on the development of a structure. This questionnaire has been distributed to a number of engineering professionals in the construction industry.

4.2 Development of reporting structure

This section will develop a number of potential waste reporting structures based on the literature review. An important component of this report is the ability to effectively and consistently classify the waste being reported.

4.2.1 Reporting in the Last Planner System

To establish how this waste reporting structure operates it is necessary to determine its place in the overall construction plan. For every construction process there should be a preceding planning process and a subsequent reporting process as shown in the following diagram. This planning occurs in the three forms of master plan, lookahead and weekly schedule. In respective order these determine the position of the process in the overall construction project; when it is most likely to be completed and how it will be scheduled within the week depending on other construction processes.

Figure 32 - Relationship between waste reporting, planning and the construction process itself.

As planning is conducted in the three before mentioned stages the reporting is also most effective if implemented in similar stages. Projects often have overarching waste management plans which can be added to and treated as the overall plan by which the monthly waste management plans can be measured against. The waste report being developed within this report will be used as a method of calculating and tracking weekly productivities for use by site engineers and junior management. This data can then be collated on a monthly basis for a progress report to senior management. This report will involve a simplified version showing only the KPI's, their variance from expected wastage and the overall trend for each KPI.

The developed waste reporting structure will have to be used in conjunction with the Last Planner System. This would enable a holistic approach to waste reduction by allowing an approach where recommendations and changes resulting from the waste reports can be incorporated back into planning. This process of continuous improvement is has been modelled in Figure 33.

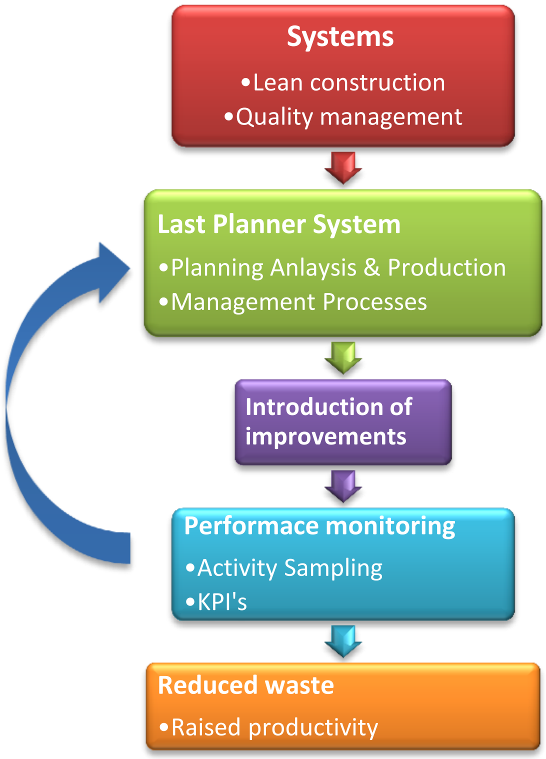


Figure 33 - Model of continuous improvement applied to waste reduction. (HARRIS 2006, p. 39)

4.2.1 Selection of Waste Classification

An extensive list of wastes has been listed in the literature review. To categorise these a number of classifications have been reviewed and developed. This section will provide reasons for a selection to be used as a basis of the reporting structure. The major classifications developed in the literature review are as follows:

- European Waste List (EWL)
- Management structure
- PESTLE
- Project Management
- Source
- Process

The two major themes emerging from these classifications are classification according to the type of waste and classification according to the people responsible.

The methods of classification presented in the literature review can be integrated together to provide an overview of the types of waste present in any process. This method of classification would use the following process:

1. What is the stage of the construction project?
   (procurement, materials handling, operational etc)
2. What is the specific process being conducted?
   (formwork, reinforcement assembly, pouring etc)
3. Is the waste – a material, due to a lack of information or take up time?

This process can be used as a tool for consistently reporting what types of waste are present on site.

The biggest challenge is defining a waste classification which is easily defined into categories encompassing elements which are integral to each and every construction process on site. These also need to be easily defined and quantified at a site level to enable an efficient and reliable flow of data. For this reason the final waste classification will need to be presented in the form of performance indicators for the respective waste groups.

Other concepts introduced throughout the literature review can be used as performance indicators. The concept of Supply Chain Management introduced the pull system which aims for reduction and ultimate elimination of inventory. From this it can be gathered that the inventory required on site is an important indicator of wastes present within the supply chain and potentially the ordering processes of the companies involved.

Commitment reliability provides an overall indicator of the company's ability to keep its promises and meet deadlines. However, this indirectly gives us an indicator of whether the company is being wasteful. It the project is behind and deadlines are not being met we can assume that some wasteful process is to blame or at least much waste will be generated during these delays.

4.2.2 KPI's

The most integral part of any project reporting structure is the development of performance indicators. Key performance indicators (KPI's) are a measurement of performance of a particular activity or endeavor. To develop a useful KPI it must satisfy three conditions. The indicator must be an important contributor to the project making it 'key to its success. The KPI must be quantified or measured in some way. The KPI must give an indication of the present and future performance of what is being measured. Each of these KPI's will be measured by a number of different methods discussed in the literature review. Some of the indicators will be simply measure by the loss in production or the lost time due to the particular issue. (Ngoc 2014, pp. 5-6)

From the waste lists and classifications presented in the literature review five major KPI's can be synthesized:

1. Commitment Reliability
2. Transformation
3. Quality
4. Inventory
5. Design

4.2.2.1 Commitment reliability

Commitment Reliability can be used as an overarching measure of waste for the project. This indicator compares planned performance to actual performance to give % reliability.

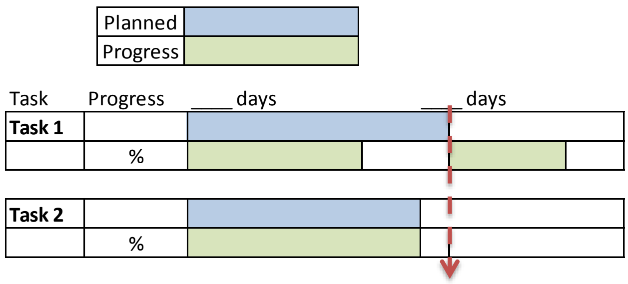


Figure 34 - Example template for visually representing commitment reliability.

4.3.2.2 Transformation

Transformation or process waste includes wastes such as transportation, waiting and idle time and the utilization of available resources. This wastage is measured by utilization in the form of Random Activity Sampling (RAS). This method involves recording utilization results for the specific process over the course of a day and averaging to calculate a final utilization %.

Random Activity Sample

Total labour:

Time	Working
6:00 AM	
7:00 AM	
8:00 AM	
9:00 AM	
...	

Efficiency %

Figure 35 - Data tabulation for Random Activity Sampling of a process

A more detailed approach is used to calculate the process wastes in the form of a Flow Process Chart. This breaks the process up into steps which are classified according to the type of operation being performed and whether it is value-adding, non-value adding or non-value adding but necessary. Data is then collected for each step including the machinery and crew required, time taken and the distance travelled. This data is then collated to give an overall waste % for the process.

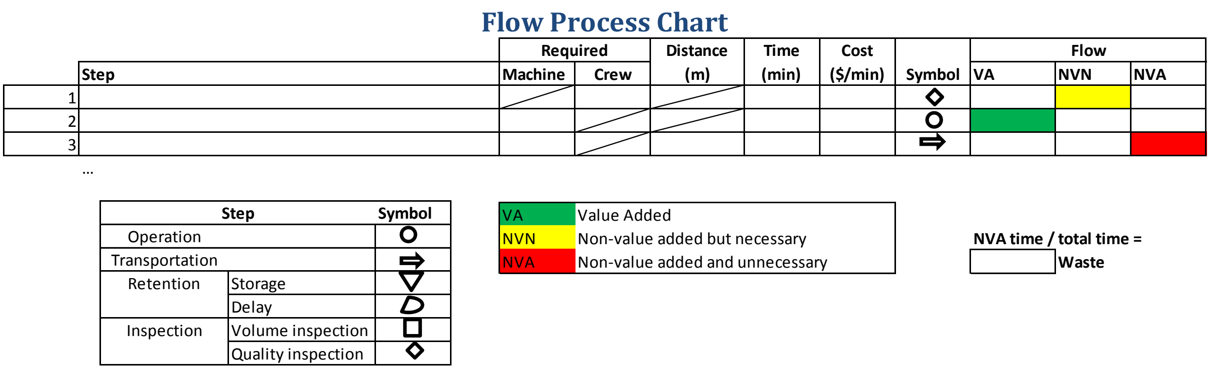


Figure 36 - Template Flow Process Chart

If the process displays a high level of waste it can be further analyzed using a Multiple Activity Chart (MAC). This is another form of process mapping which provides a visual representation of the process. This makes it easy to identify wasted time and to determine a cycle time which we will aim to reduce. Once this cycle time is identified a critical path can be determined identifying which activities need to be re-scheduled or moved.

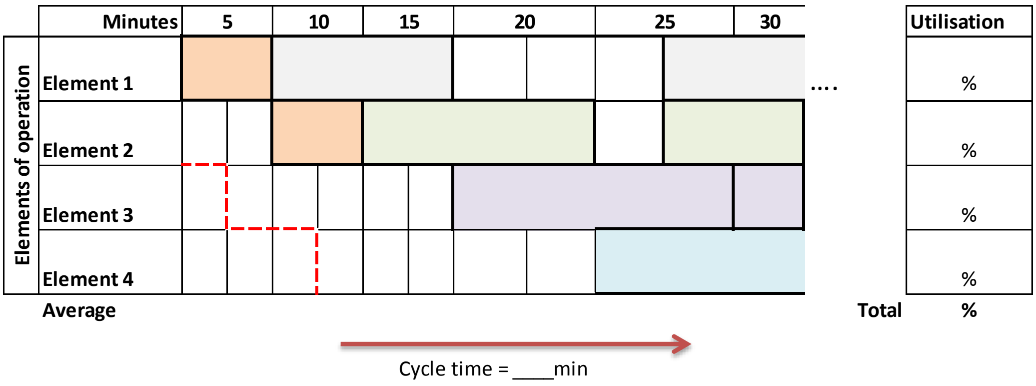


Figure 37 - Example template for a Multiple Activity Chart.

4.2.2.3 Quality

Quality is a measurement of the time and resources taken up by activities such as inspections, defects and work improvement notices. This is measured as the time taken by quality / total process time as a percentage.

4.2.2.4 Inventory

Inventory waste which occurs when an unnecessary amount of material and products are on site wasting space and increasing the possibility of damage before use. The waste Is calculated by the amount of materials present on site divided by the actual amount of materials required for that day or days being observed.

4.2.2.5 Design

Design waste is a result of poorly detailed or errors in plans which result in constructability concerns. This includes section will analyze sources of waste such as requests for information, design and detailing errors and the resulting constructability concerns.

4.2.3 Reporting structure

The following report template has been developed using the specified KPI's. The most useful correlating measurement techniques have been suggested as methods of measurement to judge the performance of each KPI to the expected performance.

KPI	Waste	Method of measurement	Unit	Result
Commitment reliability		Actual/Planned	%	🟢
Transformation (process waste)	Utilisation	RAS, MAC	%	🟡
	Transport time	FPC	%	🟢
Quality	Inspections	Waste time/total time	%	
	Defects		No.	🔴
Inventory waste	Material stock	Daily need / total materials	%	🟡
Design waste	RFI		No.	🟢

RAS	Random Activity Sampling
MAC	Multiple Activity Chart
FPC	Flow Process Chart

🟢	Improved
🟡	No change
🔴	Worse

Figure 38 - Waste reporting structure for quantification of Key Performance Indicators.

4.3 Reporting Structures

For the purpose of this research reporting structures will be developed for weekly and monthly timeframes. A weekly waste report template has been provided below and a more detailed monthly report can be found in Appendix B.

Weekly Site Waste Report

FOR

Construction Project

6/10/14 – 12/10/14

1 Progress Overview:

(Progress of projects and current activities being conducted. Summary of current works and works completed since previous report. Any major decisions or changes influencing waste generation.)

2 Key Performance Indicators:

KPI	Waste	Method of measurement	Unit	Result
Commitment reliability		Actual/Planned	%	
Transformation (process waste)	Utilisation	RAS, MAC	%	
	Transport time	FPC	%	
Quality	Inspections	Waste time/total time	%	
	Defects		No.	
Inventory waste	Material stock	Daily need / total materials	%	
Design waste	RFI		No.	

RAS	Random Activity Sampling
MAC	Multiple Activity Chart

Improved
No change

3 Open Issues:

(Any newly discovered non-value adding processes and potential solutions.)

4 Closed Issues:

(Any issues raised in the last report and implemented solutions)

5 Photos:

(Annotated photographs illustrating issues, changes and initiatives implemented on site.)

6 Recommendations:

(Explanations for any changes in waste generation and any initiatives taken to remedy this. Comments of KPI's.)

7 Conclusions:

(Reiteration of major points and outputs from report.)

Appendix A – Random Activity Sampling (RAS)

Appendix B – Flow Process Chart (FPC)

Appendix C – Multiple Activity Chart (MAC)

Chapter 5

Case studies

5.1 Overview of Wellcamp Airport Construction

Wellcamp Airport is situated 20 minutes west of Toowoomba and is currently being constructed by a locally based company Wagners. This Airport is due for completion in November this year with flights expecting to start on the 19th of the month. The airport consists of a Terminal facility and a 3750m runway able to take aircraft up to a Boeing 747. In addition to this there will be a number of buildings, taxiways and aprons to cater for the flow of aircraft. The airport will be accessed from the Toowoomba – Cecil Plains Rd via a 4.3km dual carriageway ring road which will also connect onto the future Toowoomba Bypass.

The construction of this facility can be broken up into; earthworks, building, pavements, concreting and services. This chapter will present a number of case studies of these construction processes with a focus on construction of concrete pavements.

As part of the runway construction a large area of high-strength concrete pavements are being constructed. A concrete turning node will be built at the end of the runway to provide large aircraft room to maneuver. This area is constructed from concrete to provide a surface that has both an acceptable friction factor and a robust surface which can cope with the force imposed by turning planes. Another concrete pavement will be laid in front of the terminal as an apron for planes to park while boarding passengers.

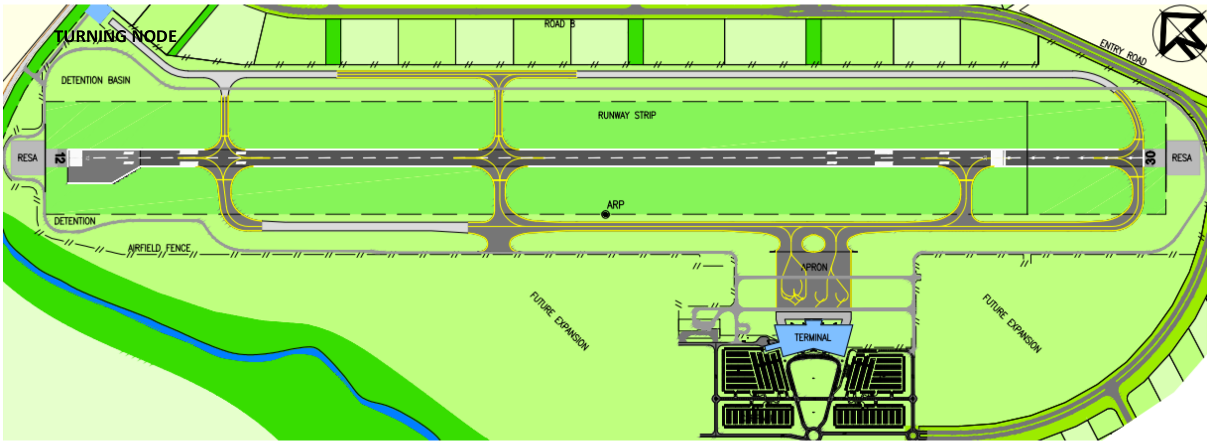


Figure 39 - Layout of airport with the turning node pictured on the far left end of the runway and the apron located in front of the terminal (Wagners Constructions).

These areas are being laid using a concrete paver and as a trial for the Wagners new Environmentally Friendly Concrete (EFC). This concrete does not contain Portland cement and instead uses blast furnace slag and fly ash to create a geopolymer binder. This mix gives the concrete performance advantages and has been proven to reduce carbon emissions by 80-90%. The pavements encompass an area of almost 54,000m2 and will use in excess of 23,000m3 of concrete.

5.2 Concrete paving

5.2.1 The Process

The concrete pavement is being constructed using a specially designed paving machine which places, vibrates and screeds the concrete. The paving machine used was a GOMACO GP-4000 which has the ability to pave widths ranging from 3.66 to 15.24m wide. The paving process involves a complicated cyclic process repeated each paving run. The turning node is divided up into a number of straight runs 4.5m wide which allow the machine to pave up to 200m in a straight line depending on the particular run. The Apron, however, is divided up into runs of 5m wide which allows paving of 80m runs with a current rate of 240m per day.

The paver uses string lines to give an offset from the pavement surface. Using this string line the paver is able to self-level as it moves down the run keeping the concrete surface height consistent with the design gradient.

The process is similar to other concreting operations with primary difference being the automation of a number of processes usually performed by physical labor. As with any other large concreting operation the process is supplied by 6 – 9 concrete trucks on turnaround from the onsite batch plant. Having a batch plant on site reduces transport times enabling the use of dump trucks instead of agitator trucks. This increases the supply efficiency as dump trucks can be loaded quicker, can dump their load quicker and take less time to wash out. This time saving multiplied by the average of 64 loads/day makes a huge difference the overall project cost and schedule. The use of dump trucks is also made possible by the utilization of the paving machine which only requires trucks to dump the concrete on the ground in front of the machine.

This project is also the first to use a paving machine to build concrete pavements on an airport. This coupled with the use of an experimental concrete provides a number of engineering challenges both known and unknown. Prior to the commencement of this project a number of test runs were undertaken on the Wagners hanger. This process has allowed the paving crew to continually refine to process to what is now an efficient and viable process. Some of the learnings which occurred as part of this process will be discussed in the next section.

The photographs below illustrate the steps involved:

Step 1 - Conducting scratch test before concreting can commence.

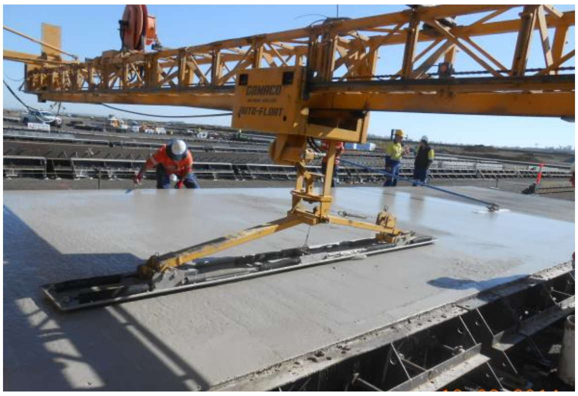
Step 2 – Setting up paver for run.

Step 3 – Dump truck tipping concrete in front of paver

Step 4 – Full range of testing showing compression cylinders and flexural beams.

Step 5 – Paver pushes concrete forward vibrating the concrete into place.

Step 6 – Concrete is screened by paving machine.



Step 7 – Concrete screened and broomed by hand.

Step 8 – Concrete sprayed with curing compounds.

Step 9 – Completed concrete run.

Step 10 – Softcutting concrete surface to induce cracking.

Step 11 – Cleaning out sawcuts .

Step 12 – Covering with geofabric to enable curing in optimum conditions.

5.2.2 Waste KPI's

The following sections will calculate the Key Performance Indicators for the concreting process. From this the process can be evaluated both over time and against other processes to determine the performance regarding waste.

Commitment Reliability

The commitment reliability of a project can be measured as a percentage by Actual progress/Planned progress:

$$commitment\ reliability = \frac{actual}{planned}$$

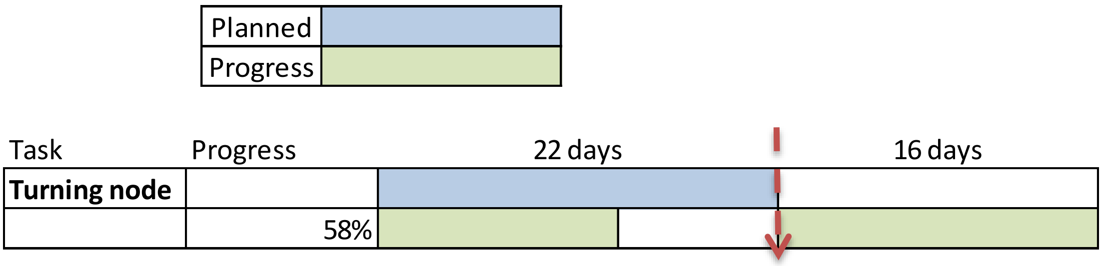


Figure 40 - Commitment reliability calculation of the paving of the turning node.

The turning node was planned to take 22 days, however, the program stretched out to 38 days. From this it can be calculated that the project completed 58% of the planned work within the 22 days giving the project an overall commitment reliability of 58%.

Transformation waste

The utilisation levels of the operation were determined by Random Activity Sampling (RAS). This sample was conducted over one hour during paving:

This sample gives a very low efficiency for the paving crew. However, in this case the efficiency of the labour force is not necessarily representative of the output of the operation as the paver is continuously moving forward finishing the concrete. To measure the efficiency of the paver the length of stops within the same period can be measured.

Total workers: 10
Total plant: 1

Time:	Labour working:	Plant working:
8:50	7	1
9:05	7	1
9:14	6	1
10:04	3	0
11:27	7	1
11:37	5	1
11:47	8	1
11:53	0	0
12:02	8	1
12:30	0	0
12:49	4	1
12:54	1	0
13:06	7	1
13:40	5	0
Average	48.57%	64.29%
Average Utilisation:		56.43%

Figure 41 - Example of RAS sampling taken over one day of paving.

The utilisation of the paving operation was measured on two different days using this method. Over this period the paving crew had an overall efficiency of 54% while the paver itself had a much higher efficiency of 71%. This is as expected as the efficiency of the process is determined by the paver placing concrete while the crew is there to tend to the paver.

		Utilisation
Elements of operation	**Testing**	45%
	Truck 1	100%
	Truck 2	93%
	Truck 3	87%
	Truck4	81%
	Truck 5	71%
	Truck 6	60%
	Paver	66%
	Paving crew	54%
	Average	**73%**

Figure 42 - Utilisation rates of the elements in the concreting process.

Each utilisation is calculated from the start of the concrete pour. Note that the paver needs a minimum of two trucks to tip before paving can begin in order to keep up production. There is an average utilisation of 73% when the productivities of the pavement crew are incorporated into the result.

So what does this mean for the efficiency of the crew? The crew efficiency is still relevant as although it doesn't directly correlate to the output it is tells us that the machine does not need this many crew. The fact that there appears to be 2 too many crew shows that they are not unproductive but do not have enough work. This is an interesting finding and could be further investigated as a recommendation.

Transportation Waste

The best evaluation of the waste due to transportation is by using a Flow Process chart. This enables processes to be classified into types of operation and whether or not they add value. As the time taken for each process is recorded the total time wasted by transportation can be calculated. This can be divided by the overall time to undertake the work activity to give the % of time taken up by transportation.

Concrete Paving for 3 trucks of concrete

	Step	Required Machine	Required Crew	Distance (m)	Time (min)	Cost ($/min)	Symbol	Flow VA	Flow NVN	Flow NVA
1	ACG scratch test for formwork height		2		14	42.96	◇		■	
2	Truck Batched	Truck			4	42.96	O	■		
3	Truck drives to site	Truck		4500	9	42.96	⇨			■
4	Truck tips concrete on ground in front of paver	Truck	1		0.5	42.96	O	■		
5	Concrete tested				5	42.96	◇		■	
6	Truck moves to wash out area	Truck		100	1	42.96	⇨			■
7	Truck washes out	Truck			5	42.96	O		■	
8	Returns to batching plant	Truck		4400	9	42.96	⇨			■
9	Paves pushes concrete forward	Paver				42.96	O	■		
10	Truck Batched	Truck			4	42.96	O	■		
11	Truck drives to site	Truck		4500	9	42.96	⇨			■
12	Truck tips concrete on ground in front of paver	Truck	1		0.5	42.96	O	■		
13	Concrete tested				5	42.96	◇		■	
14	Truck moves to wash out area	Truck		100	1	42.96	⇨			■
15	Truck washes out	Truck			5	42.96	O		■	
16	Returns to batching plant	Truck		4400	9	42.96	⇨			■
17	Paves pushes concrete forward	Paver				42.96	O	■		
18	Truck Batched	Truck			4	42.96	O	■		
19	Truck drives to site	Truck		4500	9	42.96	⇨			■
20	Truck tips concrete on ground in front of paver	Truck	1		0.5	42.96	O	■		
21	Concrete tested				5	42.96	◇		■	
22	Truck moves to wash out area	Truck		100	1	42.96	⇨			■
23	Truck washes out	Truck			5	42.96	O		■	
24	Returns to batching plant	Truck		4400	9	42.96	⇨			■
25	Paves pushes concrete forward	Paver				42.96	O	■		
26	Alcohol compound sprayed on surface by paver	Paver				42.96	O	■		
27	Paver screens surface	Paver				42.96	O	■		
28	Screened by hand		2			42.96	O	■		
29	Broomed		2			42.96	O	■		
30	E11 compound sprayed on by hand		1			42.96	O		■	
31	Curing compound sprayed on by hand		1			42.96	O		■	
32	Softcut joints	Saw	1		7	42.96		■		
33	Covered with geofabric		2		4	42.96			■	
					125.5			20.5	44	57 Min
								14	10	9 No. ti

NVA time / total time =
47% Waste

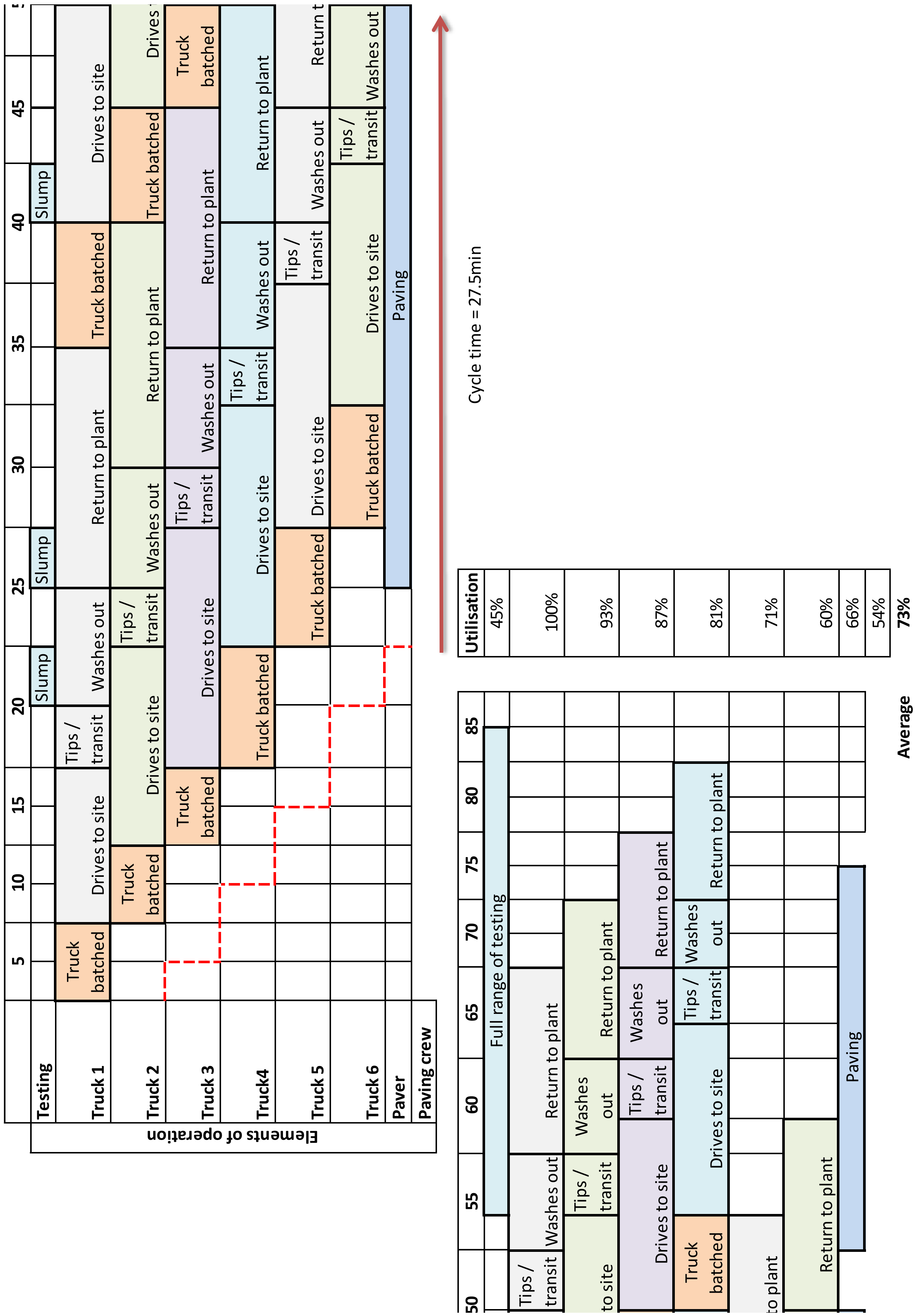
Step		Symbol
Operation		O
Transportation		⇨
Retention	Storage	▽
	Delay	D
Inspection	Volume inspection	□
	Quality inspection	◇

VA	Value Added
NVN	Non-value added but necessary
NVA	Non-value added and unnecessary

Figure 43 - FPC for the concrete paving process running for a duration of three truck deliveries.

An interesting note is that there is no step for rejecting trucks based on slump tests. Slump is considered an important indicator for the characteristics of concrete and must be within a certain tolerance from the design slump. However, in this case EFC is still an experimental product and has no proven correlation between strength and slump and therefore no guide tolerance.

It is evident from the flow process chart that there is a high proportion of waste. In this case a Multiple Activity Chart will be used to further map this process to determine possible solutions for this wastage.


Elements of operation
Testing
Truck 1
Truck 2
Truck 3
Truck4
Truck 5
Truck 6
Paver
Paving crew
Truck batched
Drives to site
Tips / transit
Washes out
Return to plant
Slump
Drives to site
Paving
Full range of testing
Cycle time = 27.5min
Utilisation
45%
100%
93%
87%
81%
71%
60%
66%
54%
73%
Average

A multiple activity chart of the concrete paving process is another method of determining utilisation as well as a visual representation of the processes involved. This enables the cycle time to be determined which for this example is 35 minutes. It is clear that this cycle is determined by the trucks and their batching and turnaround time. An interesting feature of this concreting process is the use of dump trucks to transport concrete. This enables quicker batching, tipping and washout times, therefore reducing the cycle time.

Quality

There are a number of tests and inspections required before, during and after concrete placement. Inspections correspond to the three hold points required for each concrete pour:

- Use of a scratch template (checks depth of formwork)
- Notice of intention to place concrete
- Placement of Dowel bars

Each of these requires an ACG (Airport Consultancy Representative) to be present and either witness the test or inspects the formwork or dowel bars. From observation the scratch test takes an average of 14 minutes before each pour, however, the waste time comes from waiting for an ACG representative which can take upwards of an hour if poorly coordinated. The inspection of dowel bars also takes a similar amount of time.

List of checks required by Wagner's personnel

- Fastening of dowel bars
- Formwork height
- Paving bay free from debris
- Timing of concrete trucks
- Concrete testing results

On-site concrete testing also takes approximately 5 minutes per slump which is conducted on the first 2 trucks and every third truck thereafter. A complete range of testing is conducted is conducted on four concrete batches per lot which takes 30 minutes for each set. For the purposes of this operation a lot is considered one day which is an average of 200m lineal paving with 7 hours or 420 minutes of paving time. This equates to 450m3 per day which is approximately 64 concrete batches of which 23 will need to be tested.

Time (min)		
Inspection	**Testing**	**Paving**
14	115	
14	120	
60		
88	235	420

Waste = Waste time / total time

Waste **43%**

In addition to this the following statistics should be noted:

- Defects 109
- WIN's (Work Improvement Notices) 2

The defects were classified as joints, cracks, honeycombing or surface/texturing. Work improvement notices have also been included as these are issued as remedial actions for non-conformances.

To achieve the desired quality the concrete must be soft cut after placement to induce cracking. This is ideally started 5 hours after a pour and takes approximately 16 hours to complete three 80m runs or one days paving. Another issue affecting the quality of the saw cuts is the residue left behind after cutting. The saw built for this task cuts downwards leaving the residue inside the cut as opposed to an upwards cutting blade which would throw the residue outwards. To remove this the saw must be pulled back along each cut while a blower-vac is used to blow the residue away. The extra process requires a second operator and an increase in the time required for each cut.

Photo 1 - Spalling between concrete slabs.

Photo 2 – Air voids extending into slab.

Inventory waste

The three major inventory items used for the paving are formwork, dowels and the ingredients to make concrete. The batch plant supplying concrete also supplies concrete to the construction of the terminal, a bridge and the perimeter fence. The concrete mixes for these structures require similar mix designs and therefore use the same ingredients. However, as the concrete paving uses EFC the inventory of the materials at any one time can be quantified as follows:

Table 4 - Inventory of materials kept on site used in concrete production.

Material	Inventory (t)
40mm	6,500
Sand	4,500
Slag	600
Flyash	200
Activators	150
Total	**11,950** t

The tonnage of concrete used per day can be calculated as follows:

Concrete density of 2.4t/m3

Use 240 x 0.5 x 5 = 600m3

600 x 2.4 = **1440t per day**

With a daily demand of 1440t per day this is enough for little over a week. Compared to most batch plants this is an excessive supply. However, space is not an issue on site allowing storage of materials which need to be trucked in from a metropolitan area.

Design waste

Over the length of the project a total of 16 Requests for Information (RFI's) have been raised. The RFI's covered a number of categories ranging from methods for measuring evaporation rate to the necessary concrete strength required to run the paver over new pavements. The most common type of RFI was seeking advice on repairs to the concrete surface, joints and to remediate cracks. There was a total of 6 of this type of RFI making it evident that there has been a number of issues with the concrete corresponding to the large amount of defects.

Constructability concerns

The concrete is poured in numbered runs 4.5m wide which are further divided into square bays 4.5m long. An expansion joint has been dsigned through the turning node on the northern end. This posed a problem to the paving team as at least one bay needed to be left in each run to have the time and space to install the joint.

The installation of expansion joints requires the paver to stop just before the bay and wait for formwork to be placed in front of it on both sides of the open bay. This takes approximately 1 hour to complete before the paver can continue. This process will be discussed further in the next case study.

Reporting of Results

The results of the analysis are presented in the following table. These results are representative of the concreting process thus far:

Table 5 - Waste Reporting Summary for the concreting process.

KPI	Waste	Method of measurement	Unit	Result
Commitment reliability		Actual/Planned	%	58
Transformation (process waste)	Utilisation	RAS, MAC	%	73
	Transport time	FPC	%	47
Quality	Inspections	Waste time/total time	%	43
	Defects		No.	109
Inventory waste	Material stock	Daily need / total materials	%	12
Design waste	RFI		No.	16

RAS	Random Activity Sampling
MAC	Multiple Activity Chart
FPC	Flow Process Chart

5.3 Hand Pours

As part of the turning node and apron a number of expansion joints need to be installed laterally and longitudinally across the pavements. These required the paver to skip this bay and continue paving at the next bay to allow for the installation of the expansion joint once the concrete is cured.

5.3.1 The Process

Once the paver has passes and the concrete has cured any concrete must be removed from inside the bay and the internal formwork must be removed. Once the area is clear the foam expansion joint can be installed. Once this is completed the bay takes approximately 40 minutes to hand pour. Compared to paving this is a very expensive and time consuming operation with a rate of 15m3/hr   compared to 77m3/hr for the paver.

The following photos show the installation of formwork across a run. This process is used so that a bay can be left open for the installation of an expansion joint.

Step 1– Paver is stopped while formwork is lowered into place with an excavator

Step 2 – Positioning form

Step 3– Installed formwork which paver can move over

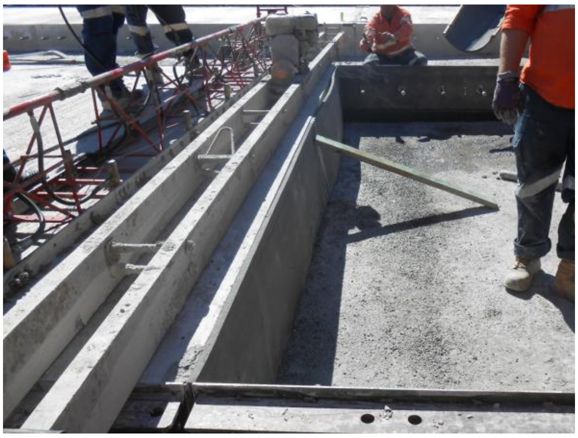
Step 4 – Paver moving over skipped bay

The actual process of conducting a hand pour is outlined in the following photos:

Step 1– Hand pour bay after paver has passed

Step 2 – Cleaned face of slab for installation of expansion joint

Step 3 - Placement of foam expansion joint.



Step 4 - Placing concrete against expansion joint.

Step 5 – Vibrating concrete into place.

Step 6 – Pouring bay using chutes on two concrete trucks.

Step 7 – Placing concrete using a vibrating screed. 	Step 8 – Screeding surface 
Step 9 – Smoothing finnish . 	Step 10 – Brooming surface 

5.3.2 Waste KPI's

The following sections will calculate the Key Performance Indicators for the concreting process. From this the process can be evaluated both over time and against other processes to determine the performance regarding waste.

Commitment Reliability

The commitment reliability of a project can be measured as a percentage by Actual progress/Planned progress:

$$commitment\ reliability = \frac{actual}{planned}$$

IT was expected that three had pours would be achieved per day when paving was not underway. This has been consistently achieved giving the process an overall commitment reliability of 100%.

Transformation waste

The utilisation levels of the operation were determined by Random Activity Sampling (RAS). This sample was conducted over one day of hand pours and gave an average utilisation of 43%.

Waste due to transportation:

Hand Pour for 2 concrete trucks

	Step	Required Machine	Required Crew	Distance (m)	Time (min)	Cost ($/min)	Symbol	Flow VA	Flow NVN	Flow NVA
1	Truck Batched	Truck			8		○			
2	Truck drives to site	Truck		4500	9		⇨			
3	Truck pours concrete	Truck	1		14		○			
4	Concrete tested				5		◇			
5	Truck moves to wash out area	Truck		100	1		⇨			
6	Truck washes out	Truck			10		○			
7	Returns to batching plant	Truck		4400	9		⇨			
8	Apply alcohol		1		1	6.8	○			
9	Screed concrete	Truck	4		30	6.8	○			
10	Spray alcohol	Truck	1	4500	5	6.8	○			
11	Broom surface	Truck	2		20	6.8	○			
12	Spary with EP21/11		1		5	0.33	○			
13	Wait	Truck		100	10	0.33	D			
14	Spray curing compound	Truck	1		1	0.33	○			
15	Truck Batched	Truck			8		○			
16	Truck drives to site	Truck		4500	9		⇨			
17	Truck pours concrete	Truck	1		14		○			
18	Concrete tested				5		◇			
19	Truck moves to wash out area	Truck		100	1		⇨			
20	Truck washes out	Truck			10		○			
21	Returns to batching plant	Truck		4400	9		⇨			
22	Apply alcohol		1		1	6.8	○			
23	Screed concrete	Truck	4		30	6.8	○			
24	Spray alcohol	Truck	1	4500	5	6.8	○			
25	Broom surface	Truck	2		20	6.8	○			
26	Spary with EP21/11		1		5	0.33	○			
27	Wait	Truck		100	10	0.33	D			
28	Spray curing compound	Truck	1		1	0.33	○			
					256			84	102	70 Min
								6	10	12 No. times

NVA time / total time = 27% Waste

Step		Symbol
Operation		○
Transportation		⇨
Retention	Storage	▽
	Delay	D
Inspection	Volume inspection	□
	Quality inspection	◇

VA	Value Added
NVN	Non-value added but necessary
NVA	Non-value added and unnecessary

Figure 45 - FPC over a duration of two hand pours; each with two trucks arriving and placing at the same time.

As with the concrete paving process a large amount of waste was evident from the FPC which calls for further analysis. A multiple activity chart representing three hand pours has been constructed to better analyse the source of waste. It is quickly evident that there is a extensive cycle time of 70 minutes per bay. This cycle is measured from the batching of the truck to the last application of curing compound. It is also evident that there are a number of elements which are very inefficient and much less efficient than the paving process.

Time (min)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
Testing					Slump									Slump									
Elements of operation: Truck 1	Truck batched		Drives to site		Tips / transit		Washes out		Return to plant		Truck batched		Drives to site	Tips / transit		Washes out		Return to plant		Truck batched		Drives to site	
Truck 2	Truck batched		Drives to site		Tips / transit		Washes out		Return to plant		Truck batched		Drives to site	Tips / transit		Washes out		Return to plant		Truck batched		Drives to site	
SEC crew					Work, screed, broom bay 1									Work, screed, broom bay 2									
Wagners crew													EP21 /11	Curing agent								EP21 /11	

Cycle time = 70min

120	125	130	135	140	145	150	155	160	165	Utilisation
Slump										16%
Tips / transit	Washes out		Return to plant							100%
Tips / transit	Washes out		Return to plant							100%
Work, screed, broom bay 2										77%
Curing agent								EP21 /11	Curing agent	9%

Figure 46 - MAC of processes over the duration of multiple concrete pours.

Quality

There were no defects directly attributed to hand pours, however, in some cases the need for hand pours was the result of defects.

Inventory waste

The materials used for hand pours are the same as the paving process, however, the amount used for hand pours is insignificant.

Table 6 - Inventory of materials kept on site used in concrete production.

Material	Inventory (t)
40mm	6,500
Sand	4,500
Slag	600
Flyash	200
Activators	150
Total	**11,950** t

The tonnage of concrete used per day can be calculated as follows:

Concrete density of 2.4t/m3

Use 12.5 x 3 x 0.5 x 5 = 94m3

94 x 2.4 = **225t per day**

The demand for 3 hand pours uses only 1.8% of the inventory at the plant which is insignificant compared to the paving operation.

Design waste

3 of the 16 RFI's directly correlated to the execution of hand pours.

Reporting of Results

The summary of results from the analysis is presented in the following table:

Table 7 - Summary of waste KPI's for hand pours.

KPI	Waste	Method of measurement	Unit	Result
Commitment reliability		Actual/Planned	%	100
Transformation (process waste)	Utilisation	RAS, MAC	%	43
	Transport time	FPC	%	27
Quality	Inspections	Waste time/total time	%	0
	Defects		No.	0
Inventory waste	Material stock	Daily need / total materials	%	1.8
Design waste	RFI		No.	3

RAS	Random Activity Sampling
MAC	Multiple Activity Chart
FPC	Flow Process Chart

5.4 Formwork Assembly

Normally the use of a paving machine such as the GOMACO would negate the need for formwork as the machine acts as its own formwork whilst the concrete is being placed. However, for this operation each run needs to be fixed to the next so that the entire pavement surface acts as one slab. This is of course with the exception of the designed expansion joints. To do this dowel bars have been used to lock the concrete runs together. These are 32mm round bars placed at a minimum spacing of 250 and a maximum spacing of 450. These dowels also need to be placed a distance of 600mm from the ends of each slab. The formwork has been introduced purely as a system of holding the dowels in place. This is only needed for every second pour as the 'infill' runs between two completed runs already have dowel bars protruding for the concrete on each site. This means that for these infill runs no formwork is needed and formwork installation only occurs for every second run. This saves a lot of time as the formwork installation process is complicated, time consuming and subject to rigorous testing and inspection.

Figure 47 - The run in the middle is currently supporting the formwork for the runs either side. Once each side is completed and the formwork is removed the middle run will be paved as an infill run.

5.4.1 The Process

Formwork is transported to site by truck and unloaded by an excavator or forklift. From here an excavator is used to move formwork and place them in position along the runs. Two laborers follow this process and position the formwork longitudinally using survey marks and string lines and vertically by packing the ends to the marked RL. Then holes are drilled to bolt the forms down. Once in place another crew packs each of the fastening points between the ends enabling the forms to be fastened down with bolts. A forklift carries the dowels down the run as two laborers place them into each position in the formwork on either side of the run. This process is then repeated with the collars where the laborers simply place the collars on the formwork where they are used by the next crew to fix the dowel bars into place.

Step 1– Overview of formwork installation process.

Step 2– Excavator lifting forms into place.

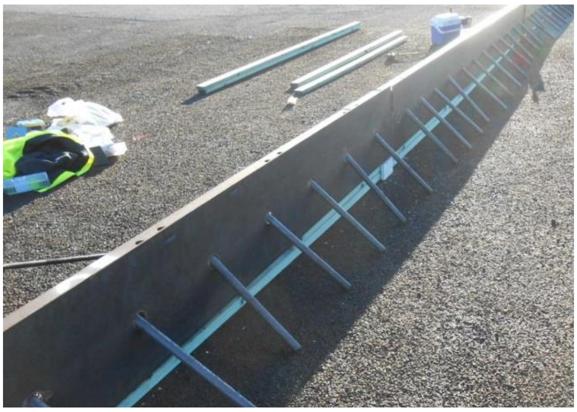
Step 3– Moving generator for drill along run.

Step 4– Transporting dowels down run usinf forklift.

Step 5– Packers installed to height and forms bolted down on top

Step 6– Installation of triangle crack inducers on bottom and sides of slab.

Step7– Dowel bars inserted into formwork



Step 8 – Scratch test to check formwork height

Step 9 – Finnished formwork run ready for paving

Step 10– Removal of formwork 1 day after paving

5.4.2 Waste KPI's

The following sections will calculate the Key Performance Indicators for the process of formwork installation. These KPI's can then be measure over time, compared to similar processes and compared to the planned performance.

Commitment Reliability

The commitment reliability of this project can be measured as a percentage by Actual progress/Planned progress:

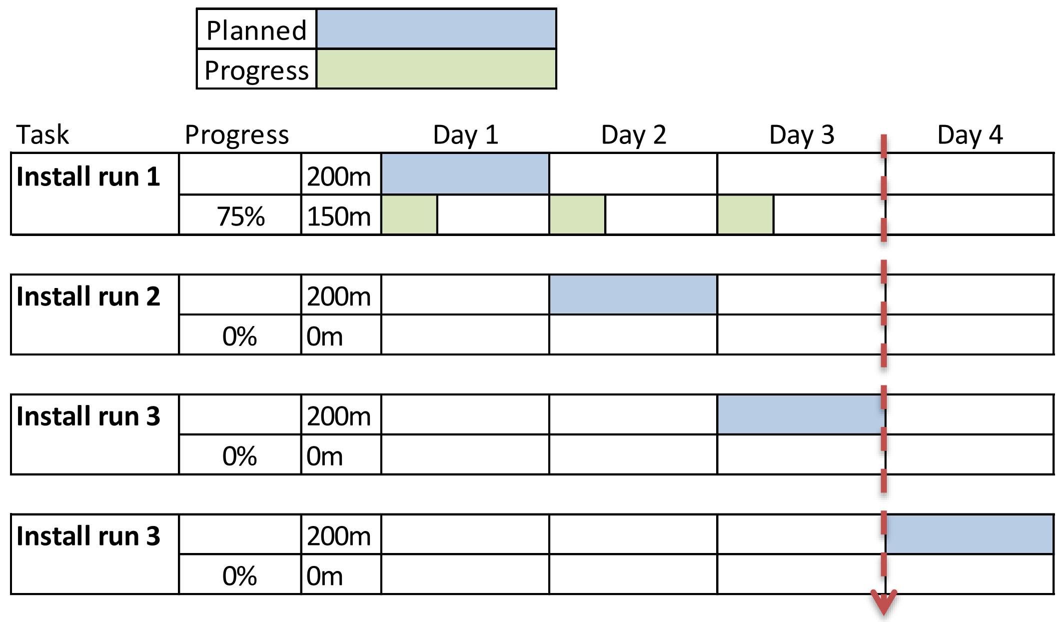


Figure 48 - Calculation of commitment reliability showing the work planned each day and the actual progress at the end of each day.

The commitment reliabilities for the three day progress review are as follows:

Run 1 = 75% (a majority of this task has been completed)

Run 2 = 0% (this task has not been attempted)

Run 3 = 0% (this task has not been attempted)

Run 4 = __ (this task is not planned to commence until the next day)

It is evident that while a majority of the first task has been completed this has been at a cost to tasks 2 & 3. The average commitment reliability of the project is 25%.

The labour required for the installation of formwork was drastically underestimated by management at the beginning of the project. It was originally assumed that 6 labourers would be able to install one run (two sides) of formwork per day. However, this ended up taking 4 days per run. The solution to this was to gradually increase the number of labourers until it was possible to achieve one run per day. To achieve this target a total of 30 labourers split into dayshift and nightshift have been used.

Transformation waste

The utilisation levels of the operation were determined by Random Activity Sampling (RAS). Two samples were conducted over two days of formwork assembly:

The first study was conducted on the 8th of October which sampled a total of 17 workers and 4 plant. The plant being two forklifts, a bobcat and an excavator. Over a course of almost 4 hours the labour had an overall efficiency of 53% with the plant only utilised 25% of the time.

The second sample was taken on the 14th of October and with a labour force of 12 and the same four plant. This study gave an average utilisation of approximately 47% for both labour and plant.

Combining these results we obtain an average utilisation of 43% for the entire operation. Obviously this number may not be entirely representative of the efficiencies of individual processes but gives a broad indication of the overall wastage.

Transportation Waste

The installation of formwork requires transportation of different types of materials using a number of machines:

As with the concrete paving process a large amount of waste was evident from the FPC which calls for further analysis.

Installation of 3 forms

	Step	Required Machine	Required Crew	Distance (m)	Time (min)	Cost ($/min)	Symbol	Flow VA	Flow NVN	Flow NVA
1	Excavator loads truck at storage area	Excavator	1		16	4	○			
2	Truck takes forms to run	Truck		100	9	4	○			
3	Form inspected for defects				1	4	◇			
4	Excavator lifts form 1 into place	Excavator	1		2	4	⇨			
5	Place forms level and straight (pack ends)		2		5	4	○			
6	Drill holes for bolts into seal		1		18	4	○			
7	Move generator down run	Forklift		10	2	4	⇨			
8	Install packers to height		2		22	4	○			
9	Fasten down forms with bolts		1		17	4	○			
10	Clean concrete out of dowel holes		1		13	4	○			
11	Dowel bars inserted into formwork	Forklift	2		4	4	○			
12	Collars placed on formwork	Forklift	2		3	4	○			
13	Dowel bars locked in with collars		2		18	4	○			
14	Excavator lifts form 2 into place	Excavator	1		2	4	⇨			
15	Place forms level and straight (pack ends)		2		5	4	○			
16	Drill holes for bolts into seal		1		18	4	○			
17	Move generator down run	Forklift		10	2	4	⇨			
18	Install packers to height		2		22	4	○			
19	Fasten down forms with bolts		1		17	4	○			
20	Clean concrete out of dowel holes		1		13	4	○			
21	Dowel bars inserted into formwork		2		7	4	○			
22	Collars placed on formwork	Forklift	2		3	4	○			
23	Dowel bars locked in		2		18	4	○			
24	Excavator lifts form 3 into place	Excavator	1		2	4	⇨			
25	Place forms level and straight (pack ends)		2		5	4	○			
26	Drill holes for bolts into seal		1		18	4	○			
27	Move generator down run	Forklift		10	2	4	⇨			
28	Install packers to height		2		22	4	○			
29	Fasten down forms with bolts		1		17	4	○			
30	Clean concrete out of dowel holes		1		13	4	○			
31	Dowel bars inserted into formwork		2		7	4	○			
32	Collars placed on formwork	Forklift	2		3	4	○			
33	Dowel bars locked in		2		18	4	○			
34	Formwork Inspected				20	4	◇			
35	Scratch test				6	4	◇			
							No. times	9	15	7
							Min	120	187	54

Step		Symbol
Operation		○
Transportation		⇨
Retention	Storage	▽
	Delay	D
Inspection	Volume inspection	□
	Quality inspection	◇

VA	Value Added
NVN	Non-value added but necessary
NVA	Non-value added and unnecessary

NVA time / total time =
15% Waste

Figure 49 - FPC for the installation of three forms.

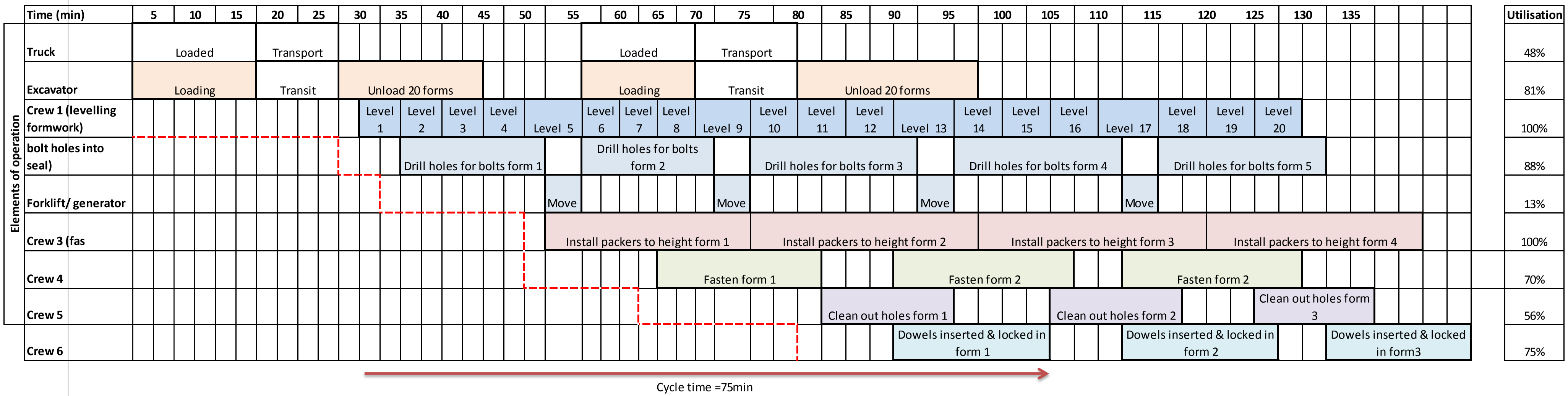


Figure 50 - MAC showing the various elements of the formwork installation process.

Quality

There have been a number of quality issues arising from the formwork assembly methodology. The formworks when delivered to site were out of tolerance and required each form to be ground back into shape. During pouring most of the quality issues have arisen from the placement of dowel bars. In some instances these have been bent but most cases have arisen from poorly fixed collars. This allows the dowel bars to either fall into or out of the concrete pour due to the vibrations of the paving machine.

Photo 1 – Dowel bar vibrated into concrete slab.

Photo 2 –Dowel bar pushed out of slab.

Each runs formwork is inspected before the commencement of concrete placement. This inspection is dependent on when the paving is initiated and does not interrupt the work flow of the formwork installation. For this reason there is no inspection time directly attributed to the installation of formworks.

Inventory waste

The formwork used has been manufactured from the Wagners workshop in town reducing the lead time and potential problems with ordering. A total of 2km was manufactured at the start of the project. With an average run length of 200m this is enough to form up 5 runs assuming both sides need to be formed up. Using the current method each day a minimum of three runs of formwork are needed: one to be paved, one being formed up and a third which cannot be stripped until the next day. Realistically it takes more than a day to form each run so a fourth set needs to be utilised for the formwork to be able to stay behind the paver. This means that only 1600m of the 2000m on site is being used at any point in time correlating to wastage of 20%.

The 32mm dowel bars need to be ordered from China with a two month lead time. For this reason the total order of 28,000 dowels was placed before the start of the project to avoid issues. However, this means that a huge inventory of dowels needs to be kept on site which takes up space and can increase the risk of damage. Fortunately on this particular site, space is not an issue and dowel bars are a particularly robust product. Assuming one run is paved per day 552 dowels will be used per day giving a daily inventory wastage of approximately 98% which will reduce over time to 0% as the supply is used up.

Design waste

To date a total of 2 RFI's have been raised regarding the formwork and dowel bars.

Constructability concerns

The formwork was built in 4.5m lengths to cater for the 4.5m wide runs on the turning node. However, due to the overall dimensions of the apron it was determined that 5m width runs would be necessary and therefore 5m lengths of formwork would be required. To achieve this additional 500mm sections of formwork were manufactured and bolted to the existing formwork.

Reporting of Results

The waste KPI’s discussed have been summarised quantitatively in the table below:

Table 8 - Summary of waste KPI's for the installation of formwork.

KPI	Waste	Method of measurement	Unit	Result
Commitment reliability		Actual/Planned	%	25
Transformation (process waste)	Utilisation	RAS, MAC	%	43
	Transport time	FPC	%	15
Quality	Inspections	Waste time/total time	%	0
	Defects		No.	0
Inventory waste	Material stock	Daily need / total materials	%	98
Design waste	RFI		No.	2

RAS	Random Activity Sampling
MAC	Multiple Activity Chart
FPC	Flow Process Chart

5.5 Sample Weekly Waste Report

From these case studies we have developed a detailed description of each of the processes involved in the construction of the Concrete pavements for the airport. This information coupled with the report format were used to create a Weekly Waste Report of the concrete paving operation for the week of the 12th of October.

Weekly Site Waste Report

FOR

Construction Project

6/10/14 – 12-10/14

1 Progress Overview:

The construction of the concrete apron has progressed into its fourth week of paving with just over a quarter completed. Due to the recent open day a transition pavement between the taxiway and the apron has been constructed to facilitate airplane movements. This is particularly complex process to transition from the rigid concrete pavement to a flexible pavement.

Due to the impending deadline for the CASA (Civil Aviation Authority) audit production has been stepped up. More labourers and engineering staff have been recruited to achieve this. Some of these will be dropping back to conduct repairs on the placed concrete.

2 Key Performance Indicators:

To estimate the wastage the following KPI's have been measured:

KPI	Waste	Method of measurement	Unit		Result
Commitment reliability		Actual/Planned	%	Green	100
Transformation (process waste)	Utilisation	RAS, MAC	%	Yellow	56
	Transport time	FPC	%	Green	47
Quality	Inspections	Waste time/total time	%		54
	Defects		No.	Red	1
Inventory waste	Material stock	Daily need / total materials	%	Yellow	12
Design waste	RFI		No.	Green	0

RAS	Random Activity Sampling
MAC	Multiple Activity Chart
FPC	Flow Process Chart

Green	Improved
Yellow	No change
Red	Worse

3 Open Issues:

1. **Saw cut night crew:** For best quality saw cutting needs to be performed 5 hours from placement. To achieve this saw cutting night crew could be utilised as most pours finish in the afternoon.
2. **Cracks:** Thirteen transverse cracks formed in one of the runs - far more than ever before. This is thought to be attributed to a delay in saw cutting and covering with geofabric.

4 Closed Issues:

1. **Hand pours:** Due to a change in methodology the need for hand pours has been eliminated. This has been achieved by paving every second run on the same side of the expansion joints. This has improved efficiencies greatly as SEC crews no longer need to be taken off the paver every few days.
2. **Outsourcing cartage:** Previously concrete cartage needed to be outsourced when agitator trucks were needed for hand-pours. Now that hand pours are no longer necessary this will not occur again.
3. **Saw Cuts residue:** The design of the saw used cuts into the concrete laving residue inside the cuts which later cements together again. Now the saw is run back over the cut while a blower-vac blows away the residue.
4. **Dowel bar movement*:*** The vibration of the paving machine has caused dowel bars to move. To prevent this it is now mandatory for engineers to check every dowel before the pour.

4 Photos:

Photo 1 - Placing formwork for an expansion joint.

Photo 2 - Outsourcing concrete cartage to Boral for hand-pours.

Photo 3 – Placement of concrete in front of terminal.

Photo 4 – Installation of the end-of-run formwork.

Photo 5 – Softcut surface to induce cracking. And placement of geofabric to slow curing.

Photo 6 – Collar vibrated off dowel bar which has fallen into the pour.

5 Summary & Recommendations:

The paving plan for the apron required 200 lineal meters a day, however, SEC is currently averaging three 80m runs with a total of 240m. This gives the program a 100% commitment reliability as the promised work has been completed in the allotted time. The batching plant holds a capacity of 11,000t of materials which is a little over a week's supply with the current usage of 1440t of concrete per day or 12% of inventory.

The paving process has undergone a number of changes resulting from learnings developed over the months since commencement. In the past week a number of key solutions have been developed to a range of issues. The major improvement being the elimination of hand-pours through a change in paving layout.

Utilisation of labour and plant is 56% while transportation time still accounts for 47% of the total time of each cycle. It is obvious the movement of trucks is more time consuming than the turning node which was closer to the on-site batch plant. As the labourers are tending to the paving machine utilisation cannot be directly correlated to productivity in this case.

There has been no RFI's this week which contrasts to last week's 4 RFI's due to the commencement of crack repairs on completed pavement. The one defect was recorded for the 13 cracks on run 33 potentially due to the delay in saw cutting.

6 Conclusions:

Paving has increased in productivity and is achieving a bettor quality outcome than ever before. This consistency has improved the commitment reliability and reduced RFI's. However, issues such as transportation times and underutilisation of labour are still prevalent.

Appendix A – Random Activity Sampling (RAS)

PROJECT: Wellcamp Airport Construction

OPERATION: Concrete Paving

STUDY NO.: 2

STUDY TYPE: Random Activity Sample (RAS)

DATE: 9/10/2014

Start time: 8:45 Finnish Time: 14:00

WEATHER CONDITIONS: Overcast

NOTES:

Total workers: 10
Total plant: 1

Observations

Time:	Labour working:	Plant working:	Notes:
8:50	7	1	
9:05	7	1	
9:14	6	1	
10:04	3	0	Cleaning and resetting
11:27	7	1	
11:37	5	1	
11:47	8	1	
11:53	0	0	Truck not arrived
12:02	8	1	
12:30	0	0	Truck not arrived
12:49	4	1	
12:54	1	0	Truck not arrived
13:06	7	1	
13:40	5	0	End of paving
Average:	48.57%	64.29%	**Average Utilisation:** 56.43%

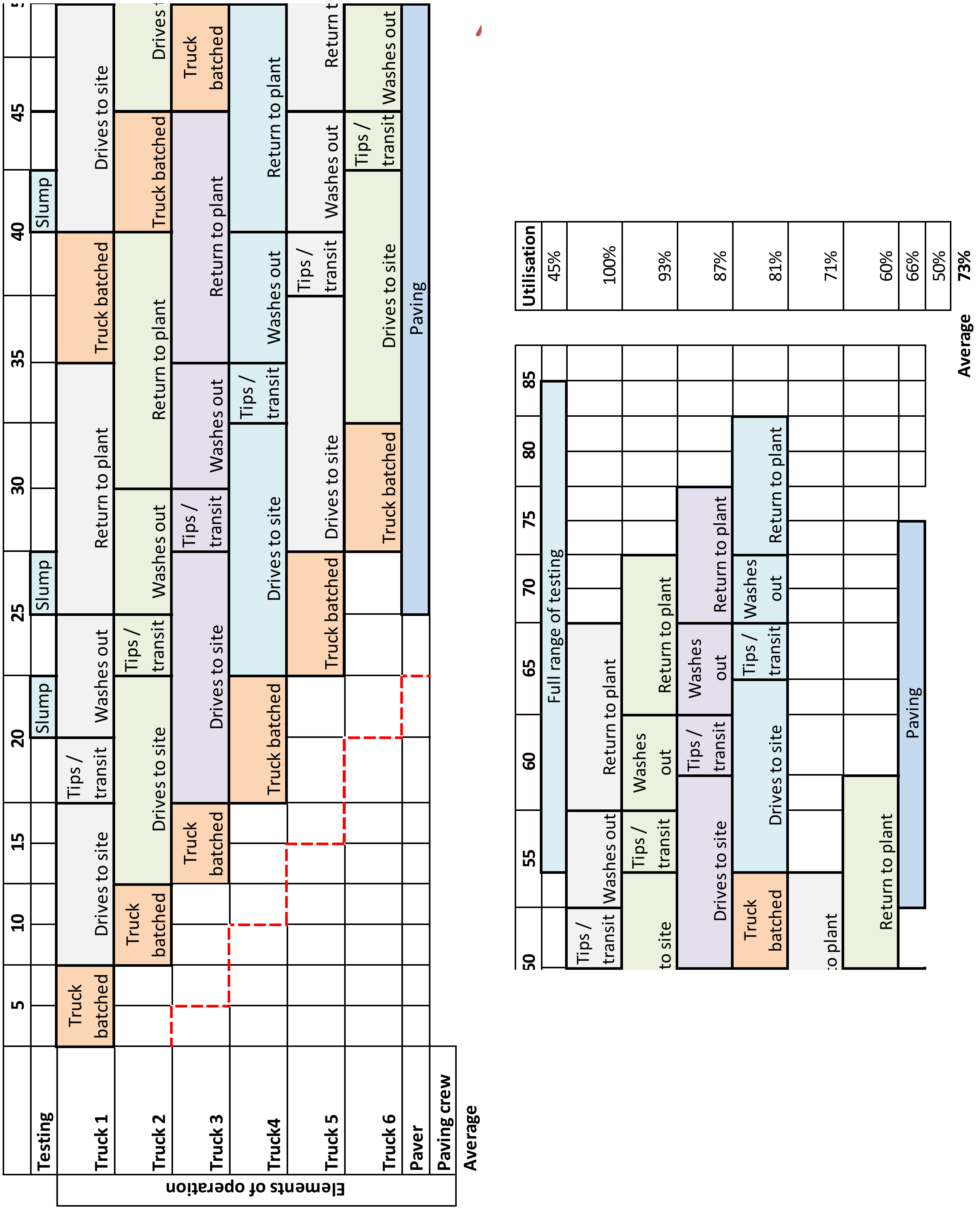
Concrete Paving for 3 trucks of concrete

	Step	Required Machine	Crew	Distance (m)	Time (min)	Cost ($/min)	Symbol	Flow VA	NVN	NVA
1	ACG scratch test for formwork height		2		14	42.96	◇			
2	Truck Batched	Truck			4	42.96	○			
3	Truck drives to site	Truck		4500	9	42.96	⇨			
4	Truck tips concrete on ground in front of paver	Truck	1		0.5	42.96	○			
5	Concrete tested				5	42.96	◇			
6	Truck moves to wash out area	Truck		100	1	42.96	⇨			
7	Truck washes out	Truck			5	42.96	○			
8	Returns to batching plant	Truck		4400	9	42.96	⇨			
9	Paves pushes concrete forward	Paver				42.96	○			
10	Truck Batched	Truck			4	42.96	○			
11	Truck drives to site	Truck		4500	9	42.96	⇨			
12	Truck tips concrete on ground in front of paver	Truck	1		0.5	42.96	○			
13	Concrete tested				5	42.96	◇			
14	Truck moves to wash out area	Truck		100	1	42.96	⇨			
15	Truck washes out	Truck			5	42.96	○			
16	Returns to batching plant	Truck		4400	9	42.96	⇨			
17	Paves pushes concrete forward	Paver				42.96	○			
18	Truck Batched	Truck			4	42.96	○			
19	Truck drives to site	Truck		4500	9	42.96	⇨			
20	Truck tips concrete on ground in front of paver	Truck	1		0.5	42.96	○			
21	Concrete tested				5	42.96	◇			
22	Truck moves to wash out area	Truck		100	1	42.96	⇨			
23	Truck washes out	Truck			5	42.96	○			
24	Returns to batching plant	Truck		4400	9	42.96	⇨			
25	Paves pushes concrete forward	Paver				42.96	○			
26	Alcohol compound sprayed on surface by paver	Paver				42.96	○			
27	Paver screens surface	Paver				42.96	○			
28	Screened by hand		2			42.96	○			
29	Broomed		2			42.96	○			
30	E11 compound sprayed on by hand		1			42.96	○			
31	Curing compound sprayed on by hand		1			42.96	○			
32	Softcut joints	Saw	1		7	42.96				
33	Covered with geofabric		2		4	42.96				
					125.5			20.5	44	57 N
								14	10	9 N

NVA time / total time =
47% Waste

Step		Symbol
Operation		○
Transportation		⇨
Retention	Storage	▽
	Delay	D
Inspection	Volume inspection	□
	Quality inspection	◇

VA	Value Added
NVN	Non-value added but necessary
NVA	Non-value added and unnecessary


Elements of operation
Testing
Truck 1
Truck 2
Truck 3
Truck4
Truck 5
Truck 6
Paver
Paving crew
Average
Truck batched
Drives to site
Tips / transit
Washes out
Return to plant
Slump
Paving
Full range of testing
Utilisation
45%
100%
93%
87%
81%
71%
60%
66%
50%
73%

Chapter 6

Industry Feedback

6.1 Aim

From the literature review it was established that the following areas required further investigation:

- Major causes of waste in construction
- Effectiveness of waste management plans
- Commitment reliability of projects
- Prevalent waste types

It was also apparent that there needed to be some sort of evaluation on the Waste Classification and Reporting Structure Developed. The following areas of the reporting structure will be evaluated by the interviewees:

- Structure and coverage
- Suitability of methods of waste measurement
- Feasibility of implementation
- Importance of data collected

6.2 Format

Obtaining feedback will take the form of a face to face interview. This will begin with a general introduction into the aim of the research and a background on lean construction and the context of waste. A sample waste report for a specific process will then be used to explain the structure and waste measurement methods and KPI's. The process will then culminate with the interviewee filling out the accompanying questionnaire.

The areas of interest outlined in the aim will be investigated by the use of 'tick and flick' rating system. This gives the participant the ability to either incrementally rate their response 1 – 5 or whether they agree, disagree or maintain a neutral position to the question asked. This method makes it quick and easy for the participant to answer the questions. The format also allows the results to be easily correlated and compared and allows the development statistical averages. A comments section was provided for the participants to provide feedback on the survey to potentially improve the effectiveness of this particular data collection method.

6.3 Target Group

The questionnaire has been aimed towards Engineers in Management roles on large construction sites. To gain a balanced and more representative view of responses the candidates have been chosen from a number of different companies and from a variety of roles within the middle to senior management tiers. These companies have projects including; civil, building, electrical installations and airport construction. The interviewees chosen are listed as follows:

1. Project Manager – Probuild *(Grand Central shopping centre reconstruction)*
2. Senior Project Engineer – Seymour Whyte Constructions *(Toowoomba Range Remediation)*
3. Manager Energy Services –Wagners *(Santos electrical infrastructure refit)*
4. Contracts Administrator/Project Engineer – Wagners *(Wellcamp Airport)*

The number of interviewees selected has been chosen to give an indication of the views on lean construction and waste in the construction industry at this time. To provide a statistically significant sample would require a large number of professions to be interviewed. For the purpose of this research this is considered outside the scope and as a potential future direction for more in-depth study.

6.4 Method

The feedback will be gathered in the form of a structured interview accompanied by a questionnaire. The interview will begin with a background into the research being conducted and provide an introduction to lean construction with a focus on defining 'waste'. The example reporting structure will be introduced and the structure and relevance of each section explained. Throughout this process the relevant sections on the questionnaire will be completed.

The interview structure is as follows:

Interview Structure

1 Introduction to research being conducted:

- Background
- Need
- Aim

3 minutes

2 Introduction to Lean construction:

- Overview
- JIT production
- Value Stream Mapping

5 minutes

3 Defining Waste:

- Definition
- Types
- Classification
- Methods of measurement

5 minutes

4 Overview of waste reporting structure:

- Structure
- Process used in specific example
- Key Performance Indicators
- Applications

10 minutes

5 Questionnaire:

- To be filled out by Interviewee

10 minutes

6.3 Questionnaire

The following questionnaire was used to gauge the interviewee's responses:

Lean Construction to reduce waste

Project topic: Measurement of waste in Concrete Construction using Lean Construction Methodologies

Questionnaire background

This research aims to develop a suitable format for the measurement, classification and reporting of wastes from a lean construction perspective. To complement this research this questionnaire has been developed to better understand the current situation of waste reporting in the construction industry.

The concept of lean is focused on; elimination of waste, maximisation of customer value and increasing workflow. For the purpose of this questionnaire waste is considered any wasteful or non-value adding activity in a construction process.

Instructions

Tick the box that is most representative of you views of each question and provide comments if desired.

Remark: *This questionnaire aims only to assess current views on waste reporting within the construction industry. This questionnaire is NOT to assess people and their work or knowledge.*

Participant Information

Name (optional): ____________________________

Position: ____________________________

Date: ____________________________

Questions

1.0	Lean Construction			
		Agree	Neutral	Disagree
1.1	Are you familiar with the Lean construction/production concept?	☐	☐	☐
1.2	On your current project is concrete batched on site or delivered?	☐	☐	☐
1.3	Do you believe it is reasonable to apply techniques from manufacturing to construction to increase productivities?	☐	☐	☐
1.4	Project progress reports often report on cost, progress and safety - but rarely do we report on waste. Is this the case?	☐	☐	☐
1.5	On your current project is there an effective waste management plan in place?	☐	☐	☐

2.0 Waste & waste-reducing strategies

2.1 In your opinion which of the following aspects of a project cause wastage?

(1 significant source of waste - 5 non-waste causing)

	1	2	3	4	5
Transportation	☐	☐	☐	☐	☐
Inspections	☐	☐	☐	☐	☐
Waiting/idle time	☐	☐	☐	☐	☐
Unnecessary inventory	☐	☐	☐	☐	☐
Overordering or ordering error	☐	☐	☐	☐	☐
RFI's (Requests for information)	☐	☐	☐	☐	☐
Constructability concerns	☐	☐	☐	☐	☐
Design errors	☐	☐	☐	☐	☐
Defects	☐	☐	☐	☐	☐
Lack of waste management plan	☐	☐	☐	☐	☐
Safety concerns	☐	☐	☐	☐	☐

3.0 Report Content & Structure

In your opinion how would you rate the effectiveness of the following report characteristics:

	(1 agree - 5 disagree)	1	2	3	4	5
3.1	Is the content included relevant to the construction works?	☐	☐	☐	☐	☐
3.2	Is the structure logical and easy to follow?	☐	☐	☐	☐	☐

4.0 Tools and Techniques

In your opinion how would you rate the effectiveness of the following waste reporting tools:

	(1 not-useful - 5 very effective)	1	2	3	4	5
	Commitment reliability is the measure of a projects ability to meet it's goals. % reliable = actual progress/planned progress					
4.1	How would you rate your current projects commitment reliability?	☐	☐	☐	☐	☐
4.2	Do you believe commitment reliability is an effective indicator of wastage or inefficiency within a project?	☐	☐	☐	☐	☐
	Random Activity Sampling (RAS) records the % of the labourforce working at random intervals throughout the day giving an overall utilisation %.					
4.3	Do you think RAS would be effective as a method of determining utilisation of labour and plant on site?	☐	☐	☐	☐	☐
	Construction activities can be classified according to their ability to add 'value' to the final product being produced.Three categories being: ***value-adding, non-value adding and value-adding but necessary.***					
4.4	Is this an effective way to categorise all construction activities?	☐	☐	☐	☐	☐
	A Flow Process Chart (FPC) (attached to the report) has been used to categorise the process steps according to these 3 classifications and the type of operation. Data is collected for each step and collated to give an overall waste %					
4.5	Do you think FPC is an effective analysis technique for identifying wastage on site?	☐	☐	☐	☐	☐
	A Multiple Activity Chart (MAC) (attached to the report) has been used to analyse a specific process to visually represent waste time.					
4.6	Do you think MAC would be an effective mapping technique for identifying wastage on site?	☐	☐	☐	☐	☐

5.0 Frequency

		Weekly	Monthly	Quarterly
5.1	What fequency/s should the wastage be reported?	☐	☐	☐
5.2	What frequency are other project progress reports (cost/progress/safety) conducted?	☐	☐	☐

		Daily	Weekly	Monthly
5.4	How frequently should the following techniques be used?			
	Commitment Reliability	☐	☐	☐
	Random Activity Sampling (RAS)	☐	☐	☐
	Flow Process Chart (FPC)	☐	☐	☐
	Multiple Activity Chart (MAC)	☐	☐	☐

		Supervisor	Site Eng	Env Eng	PM
5.3	Who should be responsible for waste reporting?	☐	☐	☐	☐

		Tick
5.4	What should this report be called:	
	Waste management report	☐
	Site waste Report	☐
	Continuous Improvement Report	☐
	Other ______________________________	☐

6.0 Feasibility

		Agree	Neutral	Disagree
6.1	Could lean construction techniques help generate cost savings on this site?	☐	☐	☐
6.2	Do you believe it would be feasible to implement a waste reporting program on your current project?	☐	☐	☐

Do you have any comments/feedback on the survey?

____

____

____

____

6.4 Results

The results for each question are outlined below. The completed questionnaires are located in Appendix D for reference.

1.0 Lean Construction

Question 1.1

Q: Are you Familiar with the lean construction/production concept?

A: Two out of the four respondents were familiar with lean construction.

Question 1.2

Q: On your current project is concrete batched on site or delivered?

A: Two of the projects had concrete delivered and the other two batched concrete on site.

Question 1.3

Q: Do you believe it is reasonable to apply techniques from manufacturing to construction to increase productivities?

A: Three of the respondents agreed that it is reasonable with the other disagreeing.

Question 1.4

Q: Project progress reports often report on cost, progress and safety - but rarely do we report on waste. Is this the case?

A: Only one respondent agreed with the rest disagreeing.

Question 1.5

Q: On your current project is there an effective waste management plan in place?

A: One respondent had an effective plan, one was neutral and the remaining two did not have a plan.

2.0 Waste & waste reducing Strategies

Question 2.1

Q: In your opinion which of the following aspects of a project cause wastage?

A: The results have been summarised in the following table:

Table 9 - Quantification of the significance of different sources of waste.

Type of Waste	Respondent's scores				Average
	Manager Energy Services	Senior Project Engineer	Contracts Administrator	Project Manager	
Transportation	5	1	1	3	2.5
Inspections	5	5	3	5	4.5
Waiting/idle time	1	1	1	3	1.5
Unnecessary inventory	3	3	3	4	3.3
Over ordering and ordering error	2	3	1	1	1.8
RFI's (Requests for information)	3	3	2	4	3.0
Constructability concerns	3	3	2	3	2.8
Design errors	4	3	3	2	3.0
Defects	2	4	3	2	2.8
Lack of waste management plan	4	3	4	3	3.5
Safety concerns	1	5	4	4	3.5

3.0 Report Content & Structure

Question 3.1

Q: Is the content included relevant to the construction works?

A: Three respondents believed that the content I very relevant while one was undecided.

Question 3.2

Q: Is the structure logical and easy to follow?

A: All four respondents agree that the structure was very logical and easy to follow.

Question 3.3

Q: Any suggestions for improvement?

A: No suggestions were offered by any of the respondents.

4.0 Tools and Techniques

Question 4.1

Q: Do you believe commitment reliability is an effective indicator of wastage or inefficiency within a project?

A: The responses were 3,4,5,5 with an average of 4.25. This means that CR is effective.

Question 4.2

Q: Do you think RAS would be effective as a method of determining utilisation of labour and plant on site?

A: The responses were 5,5,5,5 with an average of 5. This means that RAS is very effective.

Question 4.3

Q: Is Value Adding an effective way to categorise all construction activities?

A: The responses were 5,5,4,3 with an average of 4.25. This means that Value Adding is effective.

Question 4.4

Q: Do you think the FPC is an effective technique for identifying waste on site?

A: The responses were 5,5,5,3 with an average of 4.5. This means that FPC is very effective.

Question 4.5

Q: Do you think MAC would be an effective mapping technique for identifying wastage on site?

A: The responses were 5,5,5,4 with an average of 4.75. This means that MAC is very effective.

5.0 Frequency

Question 5.1

Q: What frequency/s should the wastage be reported?

A: Two respondents stated that it should be reported weekly and monthly while one picked weekly and one picked monthly.

Question 5.2

Q: What frequency are other project progress reports (cost/progress/safety) conducted?

A: Two respondents stated weekly and monthly while the other two only reported waste monthly.

Question 5.3

Q: How frequently should the following techniques be used?

- Commitment Reliability
- Random Activity Sampling (RAS)
- Flow Process Chart (FPC)
- Multiple Activity Chart (MAC)

A: The following table outlines the frequencies suggested by the interviewees:

Table 10 - Suggested waste measurement frequencies for each technique.

Technique	**Respondants scores**			
	Manager Energy Services	Senior Project Engineer	Contracts Administrator	Project Manager
Commitment Reliability	**D W**	**D W**	**M**	**W**
Random Activity Sampling	**D W**	**M**	**W**	**W**
Flow Process Chart	**D W**	**M**	**W**	**M**
Multiple Activity Chart	**D W**	**M**	**W**	**W**

(D - Daily, W - Weekly, M - Monthly)

Question 5.4

Q: Who should be responsible for waste reporting?

A: Two respondents agreed that everyone (Supervisor, Site Eng, Env Eng, PM) should report waste while one respondent believed it up to the site engineers and another that it is up to supervisors.

Question 5.5

Q: What should this report be called?

A: This question was introduced late into the questionnaire, therefore only one respondent was able to answer this question. This person agreed that it should be called the Site Waste Report.

6.0 Feasibility

Question 6.1

Q: Could lean construction techniques help generate cost savings on this site?

A: Three respondents agreed with this statement while one was neutral.

Question 6.2

Q: Do you believe it would be feasible to implement a waste reporting program on your current project?

A: All respondents agreed that this would be feasible.

6.5 Discussion

The interviews produced a generally positive response with the respondents approving of the waste measurement techniques. There was very useful feedback and comments on each section of the questionnaire which will be discussed as follows.

6.5.1 Lean Construction

An interesting result was that 2 out of 4 participants were familiar or at least had heard of the concept of Lean Construction. A majority of the participants agreed that it is reasonable to apply techniques from manufacturing to construction to increase efficiencies. Only half of the respondents had a waste management plan on their current project, however, a majority of respondents stated that there waste some form of waste reporting or tracking.

6.5.2 Waste & waste reducing Strategies

The three **most** significant sources of waste were

1. Waiting/Idle time
2. Over ordering and ordering error
3. Transportation

The three **least** significant sources of waste were

1. Inspections
2. Lack of waste management plan
3. Safety concerns

The ability for interviewees to list additional factors that they believed to be significant sources of waste of site gave valuable insight. The additional sources listed were:

- Recruitment and retraining of employees for different roles and
- Poor Materials control
- Lack of Experience
- No set out (survey)
- Wet weather

6.5.3 Report Content & Structure

All those interviewed rated the relevance of report content and the logical layout of the report highly and had no suggestions for improvement. The report was based on a standard progress report format which is tried and tested and familiar to most construction professionals. This may have helped the acceptance of the chosen structure.

6.5.4 Tools and Techniques

This section required the explanation of each of the methods used for data collection. Commitment reliability received a mixed review. One respondent noted that CR is not always representative of waste and does not account for issues out of the person's control.

The respondents agreed that the methods of commitment reliability, RAS, FPC and MAC were very effective at identifying waste on site. However, there were some different opinions regarding the application of value-adding as a classification of processes on site. All respondents agreed that all processes fit into the three categories but not what types of waste are classified as non-value adding. One of the respondents stated that processes such as transportation are in fact not non-value adding and should perhaps be categorized differently as they are a requirement of the process. Another respondent stated that perhaps the category of non-value adding could be renamed to better reflect the processes it covers.

6.5.5 Frequency

All the respondents agreed that other project progress reports are conducted monthly and that waste reporting should be treated the same. One of the respondents commented that on their current project the progress is reported weekly to the project manager and monthly to the board of directors. The same respondent noted that initially wastage should be reported weekly then once the process is well established the reporting should be reduced to monthly. The Contracts Administrator stated that the frequency for waste reporting is job specific depending on the type of construction.

There were differing opinions on how often the waste measurement techniques should be used. The Manager of Energy Services suggested that all the methods could be used on a daily basis and reported at the end of each week. The Senior Project Engineer believed that commitment reliability would be useful at evaluating waste on a daily and weekly basis but the other more complex methods would only need to be reported monthly. These answers followed no trend and seemed to be very biased towards each person's experience and the company they work for.

6.5.6 Feasibility

All respondents agreed that lean construction techniques could save costs on construction sites. One respondent noted that while this would most likely be the case there would need to be a cost/benefit analysis to prove this before implementation. This would compare the costs of a particular person monitoring wastage to the cost-savings that could be developed. In the case that waste reporting is a shared responsibility this would have to incorporate the accumulated time each individual spends on planning and monitoring per day. Each respondent also agreed that it would be feasible to implement a waste reporting program on their current project. One respondent mentioned that this would still be difficult as companies would not be willing to spend the money to introduce this. A majority of the respondents believed that reporting should be conducted by site engineers and supervisors out on site in each area. The benefit of this is that these people know their particular area of site and will be better able to report waste comprehensively. Another respondent stated that it is everyone's responsibility and is required at every level.

6.5.7 Additional Comments

There were a number of constructive comments provided in addition to the questionnaire.

- All respondents noted that waste can never be completely eliminated and that in the ever-changing construction industry this will always be the case.
- A large amount of manpower is required for planning which will help to reduce waste. This is especially important at the beginning of the project
- Perhaps an extra person is needed on projects to report wastes across all the different areas of a project.
- Reporting is difficult to implement as companies do not want to spend the money.
- Construction time can be classified according to the three W's; walking, waiting and working. At any one time every person on site will be doing one of these three.
- Everyone is responsible for reporting waste at different level.

Chapter 7

Conclusions

7.1 Summary

This research has conducted a study into the quantification of all wastes present in particular construction process. This has been conducted from a lean construction perspective where waste has been defined as any non-value adding process or activity. The processes chosen were concrete paving, hand-pouring concrete and the installation of formwork. The types of wastes present in the construction industry have been researched and a comprehensive list collated. A number of waste classifications have been evaluated to organise these wastes into manageable groups. These classifications were also selected on their usability and the potential techniques of measurement.

A suitable format for waste reporting has been established and trialled in a construction environment. This has been evaluated by Professional Engineers in management positions within the construction industry. From this evaluation improvements can be made to this structure and a future direction for this research has been determined.

7.2 Review of the Problem

The aim of this research was to study the application of lean construction methodologies to the Australian construction industry. To achieve this, the report examined production processes involved in construction and identified and measured waste. This was specifically applied to concreting processes.

The biggest question to be asked is whether the project has achieved the goals and objectives determined at the beginning of research. These are both a guide and a measure of the overall success of the research project:

1 **Investigate current methodologies for construction of concrete structures and the types of waste present.**

The types of waste found in construction has been thoroughly researched and the types identified from multiple sources have been evaluated and incorporated into a comprehensive list.

2 **Identify lean construction techniques for reducing waste**

A number of lean construction techniques such as; Just in Time delivery, Value Stream Mapping and Supply Chain Management have been introduced and evaluated in the Literature Review.

3 Establish techniques for measuring waste and a framework to implement these.

The literature review has analysed number of lean construction techniques which can be used for mapping, classifying and measuring construction wastes. The Use of Transformation flow value and the 7 Value Stream Mapping tools has been identified as very important. The waste report developed utilises commitment reliability, random activity sampling, flow process charts and multiple activity charts as waste measurement techniques.

4 Select specific processes to study and measure waste.

The specific process of concrete paving, had pours and formwork installation have been selected. These have been studied using case studies of these processes on the Wellcamp Airport construction site.

5 Synthesise a suitable format for waste reporting.

Formats for waste reports have been developed for both weekly and monthly timeframes. These reports centre around the KPI's developed from the literature review.

6 Seek feedback from construction industry professionals on KPI's

Structured interviews with Professional Engineers and an accompanying questionnaire have been used to evaluate the report structure and KPI's from an industry perspective.

7 Use waste classifications and corresponding remedial actions for report recommendations

The report recommendations have been based on the issues and resulting wastes that have occurred over the period of the report. The associated recommendations have been based on the standard remedial actions for the particular waste classifications.

8 Conduct a case study for concreting

Three detailed case studies have been conducted on different types of concreting activities. This has involved mapping the processes, applying waste classifications and application of the report format.

7.3 Conclusion

In summary the respondents believed the lean construction techniques and waste report to be very beneficial to improving construction process on site. However, there were some concerns about the cost/benefit ratio of implementing the controls and collecting the data as compared to the cost of the waste. This appeared to be the major obstacle in implementation as the initial cost and time required for implementation would be quite high. This indicates that a cost/benefit analysis of waste reporting would be a very useful direction for further research.

The varying responses from different construction sites highlights the fact that the integration of these lean construction techniques may need to be customized to fit different types of construction management scenarios.

The following recommendations have been developed for improving the waste reporting process:

- The waste report will be presented monthly while wastes will be measured on a weekly basis using CR, RAS, FPC & MAC.
- A cost/benefit analysis will need to be conducted to determine feasibility.
- Waste reporting wouldn't occur unless there is a requirement to do so.

This research project has achieved all the objectives outlined in the project specification. Construction waste has been effectively classified and measured in a construction environment. This data collected has been synthesized into a format which is deemed both usable and useful by construction industry professionals.

7.4 Limitations of the study

This study was limited to the depth of research required for an undergraduate dissertation. For this reason the scope of work was limited to make the project achievable in the allocated timeframe of two semesters.

This dissertation focuses on the construction phase of projects and does not consider other phases such as design and planning. This has been further constrained to concrete construction and has only conducted research, case studies and industry feedback directly related to this process.

7.5 Further Work

There are a number of possibilities for further work on this project. Firstly this method of process analysis, classification and reporting can be applied to other types of concreting activities and other fields of construction such as earthworks, pavement construction and structures. Once this method has been further refined and tested on different construction processes the effect of its implementation can be better determined. This will measure how informative the reporting is to management and whether effective recommendations can be determined from data collected. The ultimate test will be whether this method increases overall efficiencies in construction processes over time.

Another avenue to be explored is the possibility of modification of standards or legislation to include waste reporting. One method would be to make reporting a requirement from major government infrastructure clients such as the Department of Transport and Main Roads in Queensland. This government body acts as a client and contracts road infrastructure projects to private construction companies. As part of these contracts the companies need to comply with building standards and report on elements of the project such as environmental compliance. The best way to integrate waste reporting would be to introduce a requirement for this into contracts awarded by the Department of Transport and Main Roads.

One of the main points raised in the interviews was the need for a cost/benefit analysis to prove the feasibility of the approach in a monetary form. This cost/benefit analysis would need to determine the costs of implementing waste reporting and determine a monetary value of the wastes eliminated.

Appendices

Appendix A – Project Specification

ENG4111

Research Project Specification

For: George Watson

Topic: Application of lean construction methodologies in concrete construction processes to measure and reduce waste.

Supervisor: Vasantha Abeysekera

Project Aim: Examine production processes and measure waste with the aim of improving performance. In order to do this it is necessary to focus on a specific group of processes – in this case concreting with associated work such as formwork and rod reinforcement.

Objectives: Issue 2, 4th September 2014

1. Investigate current methodologies for construction of concrete structures and the types of waste present. This will focus on the construction phase of traditional design, tender and construct projects.
2. Identify lean construction techniques for reducing waste
3. Establish techniques for measuring waste and a framework to implement these.
4. Select specific processes to study (foundations, culvert, bridge pier etc) and measure waste.
5. Synthesise suitable format for waste reporting based on literature review
6. Seek feedback from construction industry professionals on Key Performance indicators for waste
7. Use waste classifications and corresponding remedial actions for report recommendations
8. Conduct a case study for concreting including classification of wastes, process mapping and application of reporting formats.

Appendix B – Monthly Site Waste Report Template

Monthly Site Waste Report

FOR

Construction Project

Contract No:

October 2014

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Table of Contents

1 Project Overview

(Progress of projects and current activities being conducted. Summary of current works and works completed since previous report. Any major decisions or changes influencing waste generation.)

2 Implementation of Waste management Plan

(Overview of waste management for the construction project and the process for continuous improvement of the processes and plan.)

Figure 1 – Continuous improvement for waste reduction.

3 Key Performance Indicators

The following Key Performance Indicators (KPI's) have been used to measure waste:

KPI	Waste	Method of measurement	Unit	Result
Commitment reliability		Actual/Planned	%	
Transformation (process waste)	Utilisation	RAS, MAC	%	
	Transporting waste	FPC	%	
Quality	Inspections	Waste time/total time	%	
	Defects		No.	
Inventory waste	Material stock	Daily/ total materials	%	
Design waste	RFI		No.	
	Design errors		$	

3.1 Commitment Reliability

(Explanation of KPI, how it is measured, changes to the result and corresponding reasons.)

3.2 Transformation waste

(Explanation of KPI, how it is measured, changes to the result and corresponding reasons.)

3.3 Quality waste

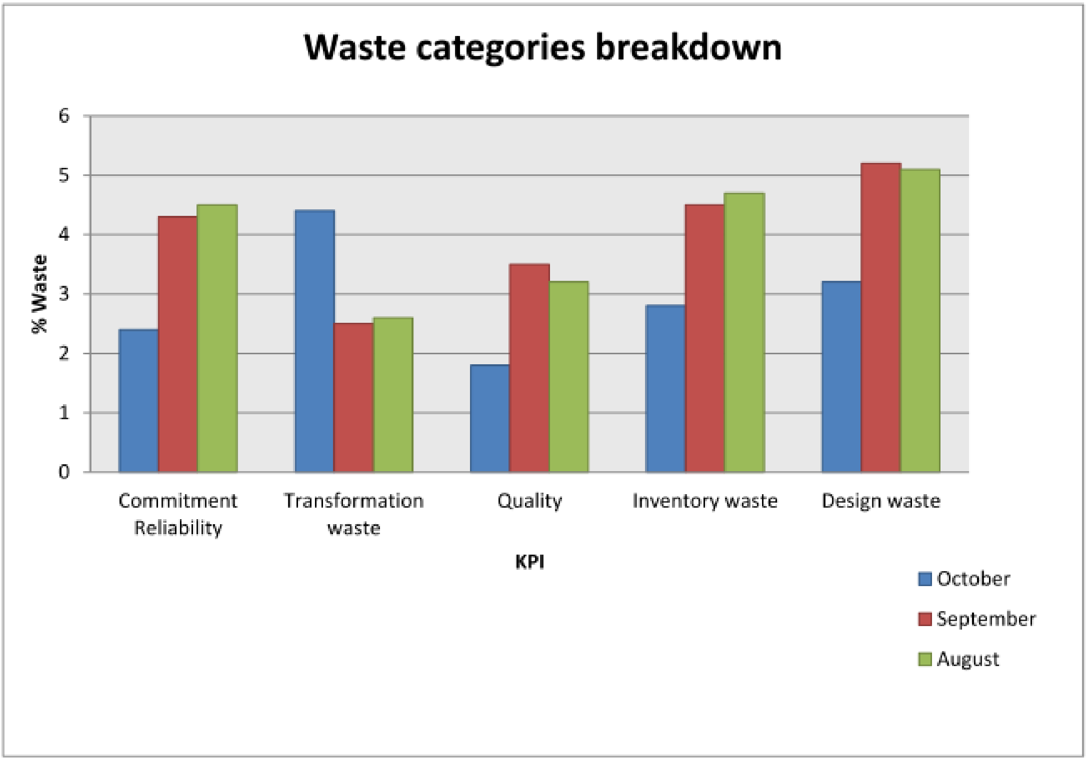
(Explanation of KPI, how it is measured, changes to the result and corresponding reasons.)

3.4 Inventory waste

(Explanation of KPI, how it is measured, changes to the result and corresponding reasons.)

3.5 Design waste

(Explanation of KPI, how it is measured, changes to the result and corresponding reasons.)



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4 Open Issues

(Any newly discovered non-value adding processes and potential solutions.)

1. ...
2.

4 Closed Issues:

(Any issues raised in the last monthly report and implemented solutions.)

1. ...
2.

5 Photos

(Annotated photographs illustrating issues, changes and initiatives implemented on site.)

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6 Recommendations

(Explanations for any changes in waste generation and any initiatives taken to remedy this. Review and improvement of the Waste Report)

6 Conclusions

Appendix A – Waste Management Plan

Appendix B – RAS Template

Appendix C – FPC Template

Appendix D – MAC Template

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Appendix C – RAS field sampling sheets

PROJECT: Wellcamp Airport Construction

OPERATION: Formwork installation

STUDY NO.: 1

STUDY TYPE: Random Activity Sample (RAS)

DATE: 8/10/2014

Start time: 8:00 Finnish Time: 11:45

WEATHER CONDITIONS:

Sunny, Low wind

NOTES:

Total workers: 17
Total plant: 4

Observations

Time:	Labour working:	Plant working:	Notes:
8:08	12	2	Excavator idle
8:22	9	1	
8:55	8	1	
9:07	10	0	
9:53	10	1	Forklift
10:15	8	2	
10:32	4	0	Smoko
11:25	12	1	Bobcat
11:40	8	1	
Average:	52.94%	25.00%	**Average Utilisation:** 38.97%

PROJECT: Wellcamp Airport Construction

OPERATION: Concrete Paving

STUDY NO.: 2

STUDY TYPE: Random Activity Sample (RAS)

DATE: 8/10/2014

Start time: 8:00 Finnish Time: 11:45

WEATHER CONDITIONS:

Sunny, Low wind

NOTES:

Total workers: 10

Total plant: 1 (Paver)

Observations

Time:	Labour working:	Plant working:	Notes:
8:08	8	1	
8:21	4	0	Waiting for trucks
8:55	5	1	
9:07	7	1	
9:53	4	0	Paver setting up
10:15	2	1	Paver starting
10:32	8	1	
11:25	9	1	
11:40	7	1	
Average:	60.00%	77.78%	**Average Utilisation:** 68.89%

PROJECT: Wellcamp Airport Construction

OPERATION: Hand Pours

STUDY NO.: 3

STUDY TYPE: Random Activity Sample (RAS)

DATE: 16/09/2014

Start time: 10:05 Finnish Time: 15:15

WEATHER CONDITIONS:

Fine and sunny

NOTES:

1 boral truck contracted in for cartage

Total workers: 7
Total plant: 0

Observations

Time:	Labour working:	Plant working:	Notes:
10:05	0		Waiting for truck
10:20	2		Pouring concrete
10:45	2		
11:30	4		Vibrating concrete
11:51	5		3rd vibrator needed
12:15	4		
12:52	3		
13:05	3		
13:21	4		Screeding surface
13:35	3		
13:55	2		Brooming
14:12	2		
14:42	4		
14:55	4		
15:10	2		

Average: 42.86% **Average Utilisation:** 42.86%

PROJECT: Wellcamp Airport Construction

OPERATION: Formwork

STUDY NO.: 4

STUDY TYPE: Random Activity Sample (RAS)

DATE: 14/10/2014

Start time: 8:45 Finnish Time: 13:55

WEATHER CONDITIONS:

Overcast

NOTES:

Total workers: 12

Total plant: 4 (Paver)

Observations

Time:	Labour working:	Plant working:	Notes:
8:49	8	3	
9:05	7	2	
9:15	6	2	
10:04	6	1	
11:18	7	2	
11:25	8	1	
11:37	4	1	
11:47	3	2	
11:53	4	1	
12:02	5	2	
12:30	8	2	
12:49	5	3	
12:54	6	1	
13:06	2	3	
13:40	6	1	
Average:	47.02%	46.43%	**Average Utilisation:** 46.73%

PROJECT: Wellcamp Airport Construction

OPERATION: Paving

STUDY NO.: 5

STUDY TYPE: Random Activity Sample (RAS)

DATE: 14/10/2014

Start time: 8:45 Finnish Time: 14:00

WEATHER CONDITIONS:

Overcast

NOTES:

Total workers: 10
Total plant: 1

Observations

Time:	Labour working:	Plant working:	Notes:
8:50	7	1	
9:05	7	1	
9:14	6	1	
10:04	3	0	Cleaning and resetting
11:27	7	1	
11:37	5	1	
11:47	8	1	
11:53	0	0	Truck not arrived
12:02	8	1	
12:30	0	0	Truck not arrived
12:49	4	1	
12:54	1	0	Truck not arrived
13:06	7	1	
13:40	5	0	End of paving
Average:	48.57%	64.29%	**Average Utilisation:** 56.43%

Appendix D – Questionnaire Feedback Forms

University of Southern Queensland | Faculty of Health, Engineering and Sciences

Lean Construction to reduce waste

Project topic: Measurement of waste in Concrete Construction using Lean Construction Methodologies

Questionnaire background

This research aims to develop a suitable format for the measurement, classification and reporting of wastes from a lean construction perspective. To complement this research this questionnaire has been developed to better understand the current situation of waste reporting in the construction industry.

The concept of lean is focused on; elimination of waste, maximisation of customer value and increasing workflow. For the purpose of this questionnaire waste is considered any wasteful or non-value adding activity in a construction process.

Instructions

Tick the box that is most representative of you views of each question and provide comments if desired.

Remark: *This questionnaire aims only to assess current views on waste reporting within the construction industry. This questionnaire is NOT to assess people and their work or knowledge.*

Participant Information

Name (optional): ____________________

Position: Manager Energy Services

Date: 18/10/14

Questions

1.0	Lean Construction	Agree	Neutral	Disagree
1.1	Are you familiar with the Lean construction/production concept?	☐	☐	☒
1.2	On your current project is concrete batched on site or delivered?	☐	☐	☐
1.3	Do you believe it is reasonable to apply techniques from manufacturing to construction to increase productivities?	☒	☐	☐
1.4	Project progress reports often report on cost, progress and safety - but rarely do we report on waste. Is this the case? *If required, cautiously*	☐	☐	☒
1.5	On your current project is there an effective waste management plan in place?	☐	☐	☒

2.0 Waste & waste-reducing strategies

2.1 In your opinion which of the following aspects of a project cause wastage?

(1 significant source of waste - 5 non-waste causing)

	1	2	3	4	5
Transportation	☐	☐	☐	☐	☒
Inspections	☐	☐	☐	☐	☒
Waiting/idle time	☒	☐	☐	☐	☐
Unnecessary inventory	☐	☐	☒	☐	☐
Overordering or ordering error	☐	☒	☐	☐	☐
RFI's (Requests for information)	☐	☐	☒	☐	☐
Constructability concerns	☐	☐	☒	☐	☐
Design errors	☐	☐	☒	☒	☐
Defects	☐	☒	☐	☐	☐
Lack of waste management plan	☐	☐	☐	☒	☒
Safety concerns	☒	☐	☐	☐	☐
Other	*Poor materials control*				

Three w's of construction
- walking
- working
- waiting

3.0 Report Content & Structure

In your opinion how would you rate the effectiveness of the following report characteristics:

	(1 agree - 5 disagree)	1	2	3	4	5
3.1	Is the content included relevant to the construction works?	☑	☐	☐	☐	☐
3.2	Is the structure logical and easy to follow?	☑	☐	☐	☐	☐
3.3	Any suggestions for improvement?					

4.0 Tools and Techniques

In your opinion how would you rate the effectiveness of the following waste reporting tools:

(1 not-useful - 5 very effective)

		1	2	3	4	5
	Commitment reliability is the measure of a projects ability to meet it's goals. % reliable = actual progress/planned progress					
4.1	Do you believe commitment reliability is an effective indicator of wastage or inefficiency within a project?	☐	☐	☐	☐	☑
	Random Activity Sampling (RAS) records the % of the labourforce working at random intervals throughout the day giving an overall utilisation %.					
4.2	Do you think RAS would be effective as a method of determining utilisation of labour and plant on site?	☐	☐	☐	☐	☑
	*Construction activities can be classified according to their ability to add 'value' to the final product being produced. Three categories being: **value-adding, non-value adding and value-adding but necessary.***					
4.3	Is this an effective way to categorise all construction activities?	☐	☐	☐	☐	☑
	A Flow Process Chart (FPC) (attached to the report) has been used to categorise the process steps according to these 3 classifications and the type of operation. Data is collected for each step and collated to give an overall waste %					
4.4	Do you think the FPC is an effective technique for identifying waste on site?	☐	☐	☐	☐	☑
	A Multiple Activity Chart (MAC) (attached to the report) has been used to analyse a specific process to visually represent waste time.					
4.5	Do you think MAC would be an effective mapping technique for identifying wastage on site?	☐	☐	☐	☐	☑

NVA
Some handling
– Transport

5.0 Frequency

		Weekly	Monthly	Quarterly
5.1	What fequency/s should the wastage be reported?	☑ (then)	☑	☐
5.2	What frequency are other project progress reports (cost/progress/safety) conducted?	☑ (PM)	☑ (Board)	☐

		Daily (used)	Weekly (frequently)	Monthly
5.4	How frequently should the following techniques be used?			
	Commitment Reliability	☑	☑	☐
	Random Activity Sampling (RAS)	☑	☑	☐
	Flow Process Chart (FPC)	☑	☑	☐
	Multiple Activity Chart (MAC)	☑	☑	☐

		Supervisor	Site Eng	Env Eng	PM
5.3	Who should be responsible for waste reporting?	☐	☑	☐	☐

6.0 Feasibility

		Agree	Neutral	Disagree
6.1	Could lean construction techniques help generate cost savings on this site?	☑	☐	☐
6.2	Do you believe it would be feasible to implement a waste reporting program on your current project?	☑	☐	☐

Do you have any comments/feedback on the survey?

Difficult to implement as companies do not want to spend money
Identify how

Lean Construction to reduce waste

Project topic: Measurement of waste in Concrete Construction using Lean Construction Methodologies

Questionnaire background

This research aims to develop a suitable format for the measurement, classification and reporting of wastes from a lean construction perspective. To complement this research this questionnaire has been developed to better understand the current situation of waste reporting in the construction industry.

The concept of lean is focused on; elimination of waste, maximisation of customer value and increasing workflow. For the purpose of this questionnaire waste is considered any wasteful or non-value adding activity in a construction process.

Instructions

Tick the box that is most representative of you views of each question and provide comments if desired.

Remark: *This questionnaire aims only to assess current views on waste reporting within the construction industry. This questionnaire is NOT to assess people and their work or knowledge.*

Participant Information

Name (optional): Kieran Convery

Position: Contract Administrator / Project Engineer

Date: 17/10/14

Questions

1.0 Lean Construction

		Agree	Neutral	Disagree
1.1	Are you familiar with the Lean construction/production concept?	☑	☐	☐
1.2	On your current project is concrete batched on site or delivered?	☐	☐	☐
1.3	Do you believe it is reasonable to apply techniques from manufacturing to construction to increase productivities?	☑	☐	☐
1.4	Project progress reports often report on cost, progress and safety - but rarely do we report on waste. Is this the case?	☐	☐	☑
1.5	On your current project is there an effective waste management plan in place?	☐	☐	☑

2.0 Waste & waste-reducing strategies

2.1 In your opinion which of the following aspects of a project cause wastage?

(1 significant source of waste - 5 non-waste causing)

	1	2	3	4	5
Transportation	☑	☐	☐	☐	☐
Inspections	☐	☐	☑	☐	☐
Waiting/idle time	☑	☐	☐	☐	☐
Unnecessary inventory	☐	☐	☐	☐	☐
Overordering or ordering error	☑	☐	☐	☐	☐
RFI's (Requests for information)	☐	☑	☐	☐	☐
Constructability concerns	☐	☑	☐	☐	☐
Design errors	☐	☐	☑	☐	☐
Defects	☐	☐	☑	☐	☐
Lack of waste management plan	☐	☐	☐	☑	☐
Safety concerns	☐	☐	☐	☑	☐
Other	Recruitment & retraining employees for different roles.				

3.0 Report Content & Structure

In your opinion how would you rate the effectiveness of the following report characteristics:

	(1 agree - 5 disagree)	1	2	3	4	5
3.1	Is the content included relevant to the construction works?	☑	☐	☐	☐	☐
3.2	Is the structure logical and easy to follow?	☐	☑	☐	☐	☐

3.3 Any suggestions for improvement?

____

4.0 Tools and Techniques

In your opinion how would you rate the effectiveness of the following waste reporting tools:

	(1 not-useful - 5 very effective)	1	2	3	4	5
	Commitment reliability is the measure of a projects ability to meet it's goals. % reliable = actual progress/planned progress					
4.1	Do you believe commitment reliablity is an effective indicator of wastage or inefficiency within a project?	☐	☐	☐	☑	☐
	Random Activity Sampling (RAS) records the % of the labourforce working at random intervals throughout the day giving an overall utilisation %.					
4.2	Do you think RAS would be effective as a method of determining utilisation of labour and plant on site?	☐	☐	☐	☐	☑
	*Construction activities can be classified according to their ability to add 'value' to the final product being produced. Three categories being: **value-adding, non-value adding and value-adding but necessary.***					
4.3	Is this an effective way to categorise all construction activities?	☐	☐	☐	☑	☐
	A Flow Process Chart (FPC) (attached to the report) has been used to categorise the process steps according to these 3 classifications and the type of operation. Data is collected for each step and collated to give an overall waste %					
4.4	Do you think the FPC is an effective technique for identifying waste on site?	☐	☐	☐	☐	☑
	A Multiple Activity Chart (MAC) (attached to the report) has been used to analyse a specific process to visually represent waste time.					
4.5	Do you think MAC would be an effective mapping technique for identifying wastage on site?	☐	☐	☐	☐	☑

5.0 Frequency

		Weekly	Monthly	Quarterly
5.1	What fequency/s should the wastage be reported?	☑	☑	☐
5.2	What frequency are other project progress reports (cost/progress/safety) conducted?	☐	☑	☐

		Daily	Weekly	Monthly
5.4	How frequently should the following techniques be used?			
	Commitment Reliability	☐	☐	☑
	Random Activity Sampling (RAS)	☐	☑	☐
	Flow Process Chart (FPC)	☐	☑	☐
	Multiple Activity Chart (MAC)	☐	☑	☐

		Supervisor	Site Eng	Env Eng	PM
5.3	Who should be responsible for waste reporting?	☑	☐	☐	☐

6.0 Feasibility

		Agree	Neutral	Disagree
6.1	Could lean construction techniques help generate cost savings on this site?	☑	☐	☐
6.2	Do you believe it would be feasible to implement a waste reporting program on your current project?	☑	☐	☐

Do you have any comments/feedback on the survey?

Waste Reporting frequency is job specific. Eg. earthworks will be more frequent.

Feasibility – Need a case study of Cost/Benefit of a person monitoring wastage

Lean Construction to reduce waste

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The concept of lean is focused on; elimination of waste, maximisation of customer value and increasing workflow. For the purpose of this questionnaire waste is considered any wasteful or non-value adding activity in a construction process.

Instructions

Tick the box that is most representative of you views of each question and provide comments if desired.

Remark: *This questionnaire aims only to assess current views on waste reporting within the construction industry. This questionnaire is NOT to assess people and their work or knowledge.*

Participant Information

Name (optional): ____________________

Position: Senior Project Engineer

Date: 21/10/14

Questions

1.0	Lean Construction	Agree	Neutral	Disagree
1.1	Are you familiar with the Lean construction/production concept?	☑	☐	☐
1.2	On your current project is concrete batched on site or (delivered?)	☐	☐	☐
1.3	Do you believe it is reasonable to apply techniques from manufacturing to construction to increase productivities? depends on design	☐	☐	☑
1.4	Project progress reports often report on cost, progress and safety - but rarely do we report on waste. Is this the case?	☐	☐	☑
1.5	On your current project is there an effective waste management plan in place?	☑	☐	☐

2.0 Waste & waste-reducing strategies

2.1 In your opinion which of the following aspects of a project cause wastage?

(1 significant source of waste - 5 non-waste causing)

	1	2	3	4	5
Transportation (cost of maintenance)	☑	☐	☐	☐	☐
Inspections (ensure producing quality product)	☐	☐	☐	☐	☑ needed
Waiting/idle time	☑	☐	☐	☐	☐
Unnecessary inventory	☐	☐	☑	☐	☐
Overordering or ordering error	☐	☐	☑	☐	☐
RFI's (Requests for information)	☐	☐	☑	☐	☐
Constructability concerns	☐	☐	☑	☐	☐
Design errors	☐	☐	☑	☐	☐
Defects	☐	☐	☒	☑	☐
Lack of waste management plan	☐	☐	☑	☐	☐
Safety concerns	☐	☐	☐	☐	☑
Other					

3.0 Report Content & Structure

In your opinion how would you rate the effectiveness of the following report characteristics:

	(1 agree - 5 disagree)	1	2	3	4	5
3.1	Is the content included relevant to the construction works?	☑	☐	☐	☐	☐
3.2	Is the structure logical and easy to follow?	☑	☐	☐	☐	☐
3.3	Any suggestions for improvement?					

____

4.0 Tools and Techniques

In your opinion how would you rate the effectiveness of the following waste reporting tools:

	(1 not-useful - 5 very effective)	1	2	3	4	5
	Commitment reliability is the measure of a projects ability to meet it's goals. % reliable = actual progress/planned progress					
4.1	Do you believe commitment reliability is an effective indicator of wastage or inefficiency within a project?	☐	☐	☑	☐	☐
	Random Activity Sampling (RAS) records the % of the labourforce working at random intervals throughout the day giving an overall utilisation %.					
4.2	Do you think RAS would be effective as a method of determining utilisation of labour and plant on site?	☑	☐	☐	☐	☐
	*Construction activities can be classified according to their ability to add 'value' to the final product being produced. Three categories being: **value-adding, non-value adding and value-adding but necessary.***					
4.3	Is this an effective way to categorise all construction activities?	☐	☐	☑	☐	☐
	A Flow Process Chart (FPC) (attached to the report) has been used to categorise the process steps according to these 3 classifications and the type of operation. Data is collected for each step and collated to give an overall waste %					
4.4	Do you think the FPC is an effective technique for identifying waste on site?	☑	☐	☐	☐	☐
	A Multiple Activity Chart (MAC) (attached to the report) has been used to analyse a specific process to visually represent waste time.					
4.5	Do you think MAC would be an effective mapping technique for identifying wastage on site?	☑	☐	☐	☐	☐

5.0 Frequency

		Weekly	Monthly	Quarterly
5.1	What fequency/s should the wastage be reported?	☐	☑	☐
5.2	What frequency are other project progress reports (cost/progress/safety) conducted?	☐	☑	☐

		Daily	Weekly	Monthly
5.4	How frequently should the following techniques be used?			
	Commitment Reliability	☑	☑	☐
	Random Activity Sampling (RAS)	☐	☐	☑
	Flow Process Chart (FPC)	☐	☐	☑
	Multiple Activity Chart (MAC)	☐	☐	☑

		Supervisor	Site Eng	Env Eng	PM
5.3	Who should be responsible for waste reporting?	☑	☑	☑	☑

		Tick
5.4	What should this report be called:	
	Waste management report	☐
	Site waste Report	☑
	Continuous Improvement Report	☐
	Other ______________________	☐

6.0 Feasibility

		Agree	Neutral	Disagree
6.1	Could lean construction techniques help generate cost savings on this site?	☐	☑	☐
6.2	Do you believe it would be feasible to implement a waste reporting program on your current project? (similar already implemented)	☑	☐	☐

Do you have any comments/feedback on the survey?

- Commitment Reliability can also highlight issues out of the persons control
  ↳ not always representing wastage
- Everyone is responsible for reporting waste at different levels

University of Southern Queensland
Faculty of Health, Engineering and Sciences

Lean Construction to reduce waste

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Questionnaire background

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The concept of lean is focused on; elimination of waste, maximisation of customer value and increasing workflow. For the purpose of this questionnaire waste is considered any wasteful or non-value adding activity in a construction process.

Instructions

Tick the box that is most representative of you views of each question and provide comments if desired.

Remark: *This questionnaire aims only to assess current views on waste reporting within the construction industry. This questionnaire is NOT to assess people and their work or knowledge.*

Participant Information

Name (optional): Steven Dalton

Position: Project Manager

Date: 27/10/14

Questions

1.0 Lean Construction

		Agree	Neutral	Disagree
1.1	Are you familiar with the Lean construction/production concept?	☐	☑	☐
1.2	On your current project is concrete batched on site or delivered?	☐	☐	☑
1.3	Do you believe it is reasonable to apply techniques from manufacturing to construction to increase productivities?	☑	☐	☐
1.4	Project progress reports often report on cost, progress and safety - but rarely do we report on waste. Is this the case?	☑	☐	☐
1.5	On your current project is there an effective waste management plan in place?	☐	☑	☐

2.0 Waste & waste-reducing strategies

2.1 In your opinion which of the following aspects of a project cause wastage?

(1 significant source of waste - 5 non-waste causing)

	1	2	3	4	5
Transportation	☐	☐	☑	☐	☐
Inspections	☐	☐	☐	☐	☑
Waiting/idle time	☐	☐	☑	☐	☐
Unnecessary inventory	☐	☐	☐	☑	☐
Overordering or ordering error	☑	☐	☐	☐	☐
RFI's (Requests for information)	☐	☐	☐	☑	☐
Constructability concerns	☐	☐	☑	☐	☐
Design errors	☐	☑	☐	☐	☐
Defects	☐	☑	☐	☐	☐
Lack of waste management plan	☐	☐	☑	☐	☐
Safety concerns	☐	☐	☐	☑	☐
Other	Lack of experience				

No set out

Over excavation

Wet weather, erosion

3.0 Report Content & Structure

In your opinion how would you rate the effectiveness of the following report characteristics:

	(1 agree - 5 disagree)	1	2	3	4	5
3.1	Is the content included relevant to the construction works?	☐	☐	☑	☐	☐
3.2	Is the structure logical and easy to follow?	☑	☐	☐	☐	☐

3.3 Any suggestions for improvement?

4.0 Tools and Techniques

In your opinion how would you rate the effectiveness of the following waste reporting tools:

(1 not-useful - 5 very effective)

Commitment reliability is the measure of a projects ability to meet it's goals. % reliable = actual progress/planned progress

Random Activity Sampling (RAS) records the % of the labourforce working at random intervals throughout the day giving an overall utilisation %.

*Construction activities can be classified according to their ability to add 'value' to the final product being produced. Three categories being: **value-adding, non-value adding and value-adding but necessary.***

A Flow Process Chart (FPC) (attached to the report) has been used to categorise the process steps according to these 3 classifications and the type of operation. Data is collected for each step and collated to give an overall waste %

A Multiple Activity Chart (MAC) (attached to the report) has been used to analyse a specific process to visually represent waste time.

		1	2	3	4	5
4.1	Do you believe commitment reliability is an effective indicator of wastage or inefficiency within a project?	☐	☐	☐	☐	☑
4.2	Do you think RAS would be effective as a method of determining utilisation of labour and plant on site?	☐	☐	☐	☐	☑
4.3	Is this an effective way to categorise all construction activities?	☐	☐	☐	☐	☑
4.4	Do you think the FPC is an effective technique for identifying waste on site?	☐	☐	☑	☐	☐
4.5	Do you think MAC would be an effective mapping technique for identifying wastage on site?	☐	☐	☐	☑	☐

5.0 Frequency

		Weekly	Monthly	Quarterly
5.1	What fequency/s should the wastage be reported?	☑	☐	☐
5.2	What frequency are other project progress reports (cost/progress/safety) conducted?	☑	☑	☐

		Daily	Weekly	Monthly
5.4	How frequently should the following techniques be used?			
	Commitment Reliability	☐	☑	☐
	Random Activity Sampling (RAS)	☐	☑	☐
	Flow Process Chart (FPC)	☐	☐	☑
	Multiple Activity Chart (MAC)	☐	☑	☐

		Supervisor	Site Eng	Env Eng	PM
5.3	Who should be responsible for waste reporting?	☑	☑	☑	☑

6.0 Feasibility

		Agree	Neutral	Disagree
6.1	Could lean construction techniques help generate cost savings on this site?	☑	☐	☐
6.2	Do you believe it would be feasible to implement a waste reporting program on your current project?	☑	☐	☐

Do you have any comments/feedback on the survey?

The biggest cause of waste is experience ie over ordering and lack a accountability.

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