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Abstract	Woodlam is the leading plywood furniture manufacturer in South Africa, experiencing steady growth in the last few years. Due to the increasing cost of electricity in South Africa it has become important for companies within the manufacturing industry to find methods to optimize their electricity consumption. This enables these manufacturers to reduce operating costs. Globalization and market pressures also make it necessary to find a means to reduce the cost of production in order to increase profit and remain competitive both locally and internationally. Addressing this problem correctly results in a more profitable business model while allowing production capacity to meet the customer demand. This report includes a literature review to understand key concepts, electricity data

	collection and analysis, solution research and design of the approach to solving the problem as well as the evaluation and validation of the proposed improvements. This report outlines the importance of finding an effective solution to rising electricity manufacturing costs and depicts the methodology and steps necessary to obtain the desired optimal solution. An in-depth study was conducted to provide insight into the manufacturing process. Electricity tariffs and solution approaches were also examined from which an operations research mixed integer linear programming model (MILP) was selected. This model was then formulated to achieve the desired financial benefits that can be achieved through the intelligent scheduling of operations. The monetary and environmental results of the (MILP) model depict that by scheduling the production of the machinery has the ability to assist the production manager to reduce the electricity cost by avoiding peak electricity tariff time periods. The validation process to determine the success of the project is also outlined.
Category	Operations Research
Sensitive Parts	N/A

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1 Executive Summary

Woodlam is the leading plywood furniture manufacturer in South Africa, experiencing steady growth in the last few years. Due to the increasing cost of electricity in South Africa it has become important for companies within the manufacturing industry to find methods to optimize their electricity consumption. This enables these manufacturers to reduce operating costs. Globalization and market pressures also make it necessary to find a means to reduce the cost of production in order to increase profit and remain competitive both locally and internationally. Addressing this problem correctly results in a more profitable business model while allowing production capacity to meet the customer demand.

This report includes a literature review to understand key concepts, electricity data collection and analysis, solution research and design of the approach to solving the problem. As well as the evaluation and validation of the proposed improvements. This report outlines the importance of finding an effective solution to rising electricity manufacturing costs and depicts the methodology and steps necessary to obtain the desired optimal solution. An in-depth study was conducted to provide insight into the manufacturing process. Electricity tariffs and solution approaches were also examined from which an operations research mixed integer linear programming model (MILP) was selected. This model was then formulated to achieve the desired financial benefits that can be achieved through the intelligent scheduling of operations. The results of the (MILP) model depict that by scheduling the production of the machines the business has the ability to assist the production manager to reduce the electricity cost. This is achieved by avoiding peak electricity tariff time periods. The validation process to determine the success of the project is also outlined. Further development of the project should incorporate the inclusion of the model into the Enterprise Resource Planning System of the business. As well as further development of the model for a more holistic approach accounting for labor costs, tardiness penalties and scheduling of multiple machines.

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chairs & components since 1991

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4 Abbreviations

MILP – Mixed Integer Linear Program
AI - Artificial Intelligence
ML - Machine Learning
NP - Nondeterministic Polynomial Time Problems
SVM - Neural Networks Support Vector Machines
ES – Expert system
TOU – Time of Use
MOL – Metering Online
LP – Linear programming

1 Introduction

1.1 Organization Description

Woodlam was established in 1991 as a division of a manufacturing company. The current owner acquired the business in January 2001 and since then the company has experienced significant growth, becoming the largest local furniture manufacturer of its kind.

Woodlam's core business has traditionally been to manufacture components for office seating and hospitality chair industries. In recent years, they have also expanded into the restaurant furniture market. Flexibility and design capability are key aspects for the success of this business. Production of plywood components is achieved by the use of 57 hydraulic molding presses and a 5 axis CNC milling machine. All of these machines require a substantial amount of electricity to operate.

1.2 Project Background

The wooden furniture sector is becoming increasingly competitive, as more and more producers enter the global market. As a consequence, world prices of all goods that can be imported are declining (Kaplinsky, Morris, & Readman, 2002) . This in turn applies pressure on local industries to implement innovative solutions to stay competitive and continue to maintain and expand their customer base. One of the main challenges facing manufacturing industries in South Africa is the cost and consumption of electricity. This is due to a lack of electricity for the required demand, general inflation and poor municipal planning. This results in the need for very cost effective and efficient electricity usage plans.

2 Problem Statement

During Woodlam's early years the company's electricity consumption tariff costs were low, and the business grew. However, in recent years these electricity charges have dramatically increased, presenting a problem for the furniture business. The high cost of electricity means that the cost per unit of product will be high and could potentially be undercut by opposition and decreased profit. Therefore, in order to remain competitive and improve profitability, a cost saving solution needed to be identified and developed.

3 Project Aims & Rationale

The main goal of this project was to formulate a sustainable method to continuously monitor Woodlam's electricity consumption, while maintaining the production capacity of the factory.

4 Project Objectives

The objectives of this project are to:

- Find a means of metering electricity usage.
- Determine which machines use the most electricity and at what time of day.
- Generate possible solutions to optimize the manufacturing process to reduce electricity costs.
- Select and develop the best means to reduce the electricity consumption cost.

5 Project Scope, Approach and Deliverables

5.1 Scope

The aim of this project is to create a successful solution to reduce the electricity consumption of the Woodlam factory by utilizing an understanding of electricity pricing within manufacturing and operations research techniques. The focus area of this project is specifically on the production management of plywood furniture and how the production process can be scheduled to optimize the electricity production cost.

The Project is subdivided into three components, namely:

- Research into the timber furniture industry:
    1. Background and history of electricity in South Africa.
    2. Current challenges such as tariff rates.
    3. The current operational costs and manufacturing process.
    4. The role that electricity plays in this industry.
- Solution Development:
    1. Investigating production planning, management accounting and operations research in order to find the most effective solutions.
    2. Solution selection.
    3. Solution verification.
- Delivery and presentation of the final project

5.2 Exclusions

Due to the fact that the focus area of this project is on production management and more specifically the production planning and control activity, all other activities that make up production management such as: facility location, material handling, product design, process design, material management, quality control and maintenance, are excluded.

5.3 Assumptions

The manufacturing process makes use of 57 heated hydraulic presses to mold the plywood into the desired form. There are two different types of presses utilized: a conventional oven heating system as seen in Figure 1 and a microwave heating system as seen in Figure 2. Both the microwave and oven presses use approximately the same amount of electricity. In order to assess the electricity usage of the machines it is necessary to meter one machine of each type to confirm that the electricity usage is approximately the same and then apply the usage data collected in this sample to the hydraulic press used for a specific production run.

FIGURE 1: ELEMENT HEATED PLYWOOD PRESS

FIGURE 2: HIGH FREQUENCY HEATED PLYWOOD PRESS

6 Research Methodology/Approach

The methodology followed in order to find the optimal solution is broken down into four main steps namely:

1. Studying and understanding the problem.
2. Solution research and solution generation.
3. Selection and development of the solution.
4. Evaluation and conclusion.

6.1 Studying and Understanding the Problem

Fact-finding is the formal process of using interviews, research, questionnaires and other techniques to collect information about systems, requirements and preferences (Kothari, 2004) . The most effective means of research and fact finding involves a literature study and as such are presented below.

6.1.1 Literature Study

A literature study was performed in order to gain knowledge on the history of electricity costs in South Africa. Solutions and techniques that have been used in instances in the past were researched. The literature is used to provide insight into:

- Power generation and supply in South Africa.
- The different tariff rates at specific times of day in South Africa and how these affect production scheduling.
- The methods and equipment required to make furniture. Enabling a better understanding of the flow and processes of plywood manufacturing and to provide insight into the cost per unit.
- Methods of optimizing the electricity consumption.
- Management accounting to understand the manufacturing costs, production planning and operations research to reduce the cost of electricity consumption.

6.2 Alternate Solution Generation

The literature review was used to generate and understand production planning and operations research techniques that are utilized in order to reduce the consumption cost of electricity. As well as other potential solutions that engineers in industry have used to solve similar problems in the past were also investigated.

6.3 *Selection and Research Design*

Alternatives solutions were researched and the smart electricity meters were used to determine where and when exactly the majority of the electricity was being consumed in the production cycle. The model was developed in order to reduce the manufacturing cost.

6.4 *Evaluation and Conclusion*

A solution has been developed whereby the scheduling of production has been optimized. A validation approach through testing and then comparison to the current system in place is proposed. Using tools like management accounting a conclusion on whether the changes are beneficial and in line with the project deliverables is made. The results are presented in this report.

7 Literature Review

7.1 *Overview*

The literature reviewed in this report was focused on five main factors namely:

- The plywood furniture industry in South Africa and its manufacturing process.
- The electricity generation, supply and cost breakdown in South Africa.
- Methods used to obtain a solution.
- Management Accounting cost and effect.

7.2 *The Plywood Furniture Industry in South Africa*

According to (Pogue, 2008) the wooden furniture industry in South Africa relies on sawn timber inputs for the primary processing, as well as metal and other secondary inputs. As a result, it is not purely a secondary wood beneficiation sector but it is directly linked to the sawn timber and forestry industries. The wooden furniture sector is broken down into five subdivisions namely:

- Cane Furniture
- Wood bedroom furniture
- Wood kitchen furniture
- Wood office furniture
- Other wood furniture

Woodlam products fall into both the “wooden office furniture” as well as “other wood” furniture categories. The configuration of wooden furniture imports is shown in Figure 3. The graph indicates that there is a very weak correlation when comparing imports to the exchange rate. It is evident that the Rand appreciation since 2002 seems to occur simultaneously with an increase of wooden furniture imports. Wooden furniture imports experienced substantial growth at an annual rate of 17.6% between 1994 and 2005. In 2005: the category classified as “other wood “made up the majority share of the imports at 57%. Therefore, showing how drastically the import market impacts Woodlam. Wooden “bedroom furniture” accounted for 21% of all the imports. This was followed by the other category affecting Woodlam “Wooden office furniture” that accounted for 10%. Last is “cane and kitchen furniture” that represented 9% and 3% respectively. When compared side by side with export trends over the same time period, the relative share of “other wooden furniture” imports increased and these were slightly compensated for by marginal decreases in the import of “wooden office” and bedroom furniture (Pogue, 2008) .

Process improvements need to be implemented in order to promote expansion into the global furniture value chain (Moodley, 2001). In this regard, it is a necessity to promote manufacturing cost reduction and optimization. The decreasing balance of global commerce in wood furniture and accumulated values of all the sectors imports and exports are represented in Figure 4. The strong increasing trend of imports are depicted in Figure 4. Furniture imports have resulted in a rapid decrease in the sectoral ratio of trade with 2005 experiencing a trade deficit for the year. These trends would appear to suggest that domestic wood furniture is under pressure from global competitors.

The Wooden Furniture Industry is predominately made up of small and medium enterprises.(Pogue, 2008) estimates that of the approximate 1,085 wood furniture manufactures in South Africa, about 95% are estimated to be small and medium enterprises. Companies such as these are located around urban centers in all the main provinces with the three main locations being the Western Cape, Kwazulu-Natal and Gauteng. From roughly 1994 these manufactures have shifted their focus from concentrating solely on the local market to an increasing focus on export markets that bring opportunities with higher volumes and greater variety (Moodley, 2001).

The Wooden Furniture sector can drastically benefit from applying principles of manufacturing cost reduction. This can be achieved by optimizing electricity consumption in order to facilitate its integration into the global furniture value chain (Moodley, 2001) . In this regard, there is a need identified to develop and incorporate lean manufacturing operations. The job creation opportunity represented by the success of small and medium enterprise structures within industry has encouraged its development by government.

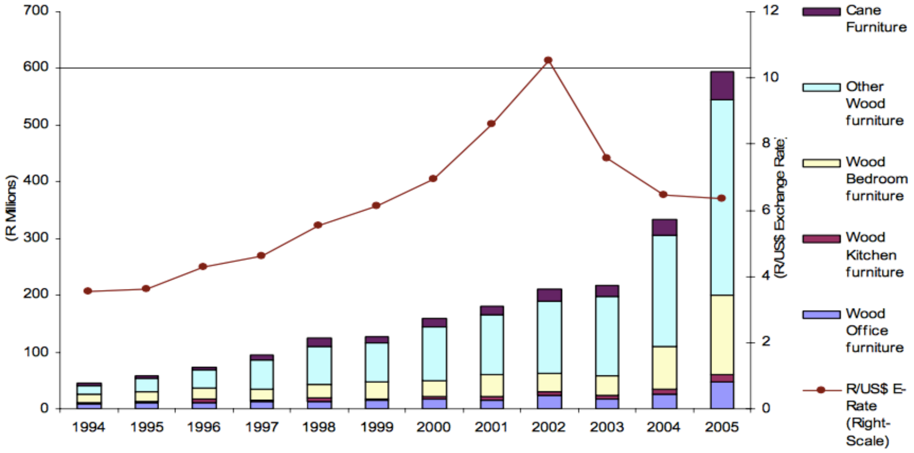


FIGURE 3: COMPOSITION OF WOODEN FURNITURE IMPORTS IN SOUTH AFRICA

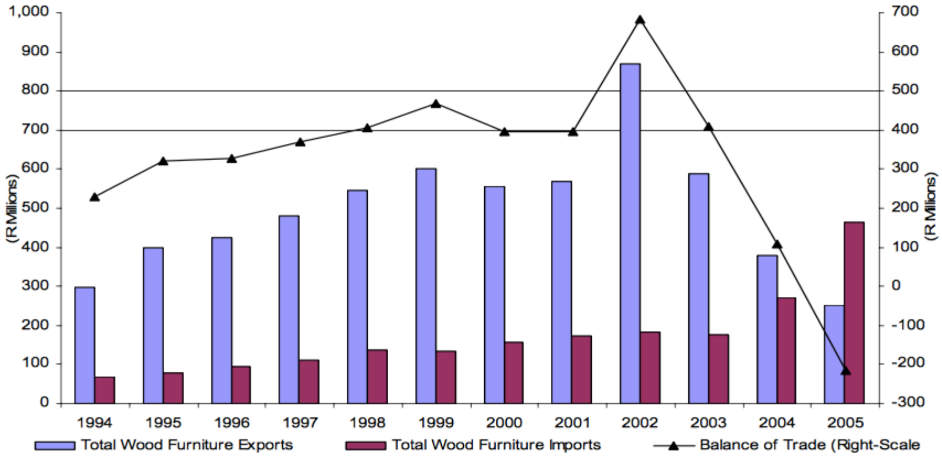


FIGURE 4: THE BALANCE OF IMPORTS AND EXPORT VALUE OF WOODEN FURNITURE IN SOUTH AFRICA

7.3 Curved Plywood Presses

The manufacturing process for plywood furniture starts when the facility receives veneer sheets form suppliers. Veneer sheets refer to thin slices of wood, usually thinner than 3 mm. The correct number of sheets are selected for a particular run of plywood and the process of laying up and gluing the pieces together with rollers follows.

The first piece of veneer is laid flat and is run through a glue roller, a coat of glue is applied to the upper surface. The shorter pieces of veneer that make up the core are then laid horizontally on top of the glued back. The entire sheet is sent through the glue roller for a second time. The final sheet of veneer that will be on the surface is then placed on top of the glued center, and the sheet is stacked alongside other plywood sheets that will be sent into press.

The glued sheets are then put into a hydraulic press. Presses can handle between three and forty sheets at a time. Once in the press the sheets are pushed together under a pressure of around 110-200 psi. Hot presses heat the male and female sections of the die to a temperature of around 109.9-157.2° C. The pressure and heat enables the wood to cure quickly and properly for maximum strength. After a period of between 3 to 35 minutes the wood is removed from the press.

The rough shaped wooden sheets are then sent to a CNC milling machine, saws and sanders in order to smooth both the front and back of the shape. Small deviations in quality are manually sanded. The finished sheets are then painted or varnished with the desired finish, packaged and shipped.

Curved plywood presses differ considerably in construction depending on the degree of curvature that is required for the product. Presses that need to make 90-degree bends will need to apply pressure from multiple sides of the wooden panel. The most common curved product in the furniture industry are the back and seat panels of chairs. These products have a limited degree of curvature. For chairs with little complexity the components can be manufactured with any type of press with the aid of matched male and female dies.

Due to the problems involved with heating, many curved plywood presses are operated cold. (Jackson, Kent, & Casselman, 1927) states that the notable exception is the press that is operated with high frequency heating. In this case, the male and female dies are covered with a sheet of aluminum. The two sheets are connected with the high frequency generator and act as electrodes. Due to the complexity of the product line offered, Woodlam makes use of this heated press and a press that uses elements to heat the dies.

8 The Electricity Cost and Supply Breakdown in South Africa

8.1 Supply and Availability of Electricity

The energy supply sector in South Africa is traditionally dominated by coal. This is due to the large number of coal deposits found in the country. (Eskom, 2017) states that roughly 77% of all electricity needs in South Africa are catered for by coal. This is unlikely to change due to a lack of sustainable alternatives at the present time. Recent data estimates performed by Eskom estimate the coal reserve of the country as being in the order of 53 billion tons and with our present production rate there should be almost 200 years of coal supply left.

According to (Basson, 2007) during the 1970s and 1980s the Apartheid government undertook public infrastructure projects in which electricity generation capacity formed part of. The resulting surplus electricity availability meant that when the change in government occurred, no future development plans were implemented and the delayed decision in 2004 by government to fund the building of a new power station did not give enough time to Eskom to prevent the crisis. Eventually demand caught up and exceeded the supply.
According to (Eskom, 2017) the post-apartheid government implemented a policy of selling power at lower rates than the cost in order to utilize the excess capacity. In recent years, this policy has drastically changed to impose expensive penalties in an attempt to limit consumption.

Eskom states that the power system in South Africa has greatly improved since the demand capacity crisis in 2008. Due to rigorous plant maintenance, there has been an increase in plant availability which has increased from 70,7% to 77.3% meaning that an additional 3103 MW have been added to the grid.

Eskom states that it currently has a surplus of 5 600 MW at peak, due to improved plant performance and new additional capacity that can meet any increase in demand until 2021. Due to an increasing demand electricity supply will still remain tight and the improvements and maintenance are funded by the tariff policies. Potentially contributing to driving up electricity prices.

As a solution to reducing rolling blackouts experienced in past years, the government and Eskom introduced hiked tariff policies in order to limit the maximum consumption of heavy industry to 90% of their peak demand (NERSA, 2008). In the crisis period starting from 1988 and stretching unto 2008, (Inglesi-Lotz, 2011) shows that the electricity tariff increases did not keep trend with inflation. The reason for this is in part due to the government introducing a policy in the past to keep electricity costs low for underprivileged communities. The problem was also caused due an oversupply of electricity by Eskom that occurred in the 1990s resulting in the company not investing in the expansion of capacity in the 2000s. The years 1988 to 2007 saw electricity tariffs raised by an alarming 223%, inflation over the course of this period was 335%.

From the electricity crisis experienced in 2008 onwards, it is clear to see a sharp inflection of the electricity tariffs experienced in South Africa. During the period ranging from 2007 until 2015, electricity tariffs were raised by 300%, inflation over the course of this period accounted for 45%. Therefore, Tariffs were tripled in the space of 8 years. An additional increase of 9.58% was experienced for 2015. This increase along with the initial 12.69% increase that was approved by NERSA means that over the period of 9 years, South Africa experienced total increases of 335%.

Additional increases for 2016 and 2017 are imposed by the 8% per annum that has already been accepted by NERSA as well as a proposed additional 9% per annum, means South Africa will see a total increase in electricity tariffs of 495%, which is drastic by comparison to the 74% that inflation incurs in the same time period. Therefore, in the space of 10 years electricity costs will have increased 5-fold.

As the demand has reached capacity, Eskom has had to raise domestic tariff prices by massive margins in order to raise capital investment for capacity expansion. In order to maintain and expand, Eskom's request for a 16% increase was declined and only 8% was granted in the period from 2014 to 2016. Due to the cash constraints experienced by Eskom it is however likely that increases of 15% - 25% will be granted as depicted in Figure 5 (Go Solar, 2017).

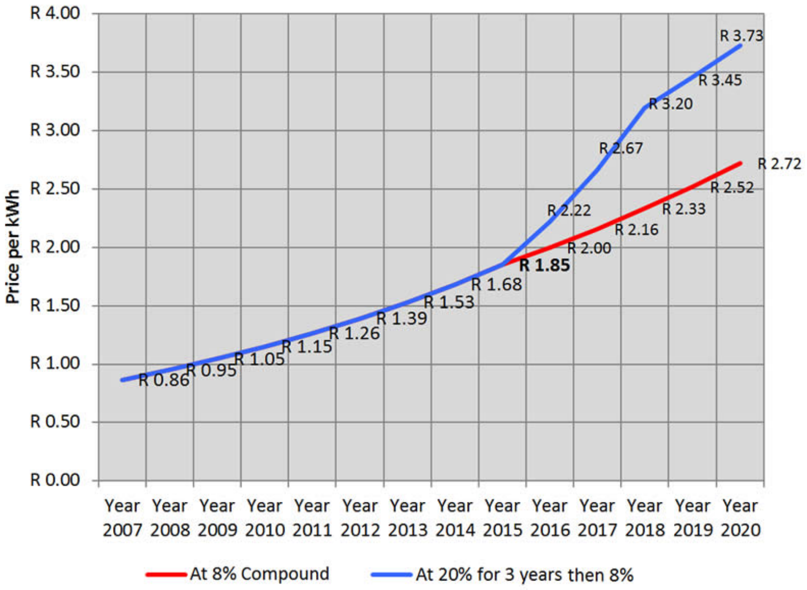


FIGURE 5: AN AVERAGE PER KWH PRICE OF R1,85 SHOWN FOR DOMESTIC CONSUMPTION GREATER THEN 600 KWH/MONTH

The implications of this increased tariff hike weigh heavily on South African industry, especially in the manufacturing sector where the use of heavy machinery, such as heated hydraulic presses, demands large amounts of power to function.

As stated by(Shrouf, Ordieres-Meré, García-Sánchez, & Ortega-Mier, 2014) the rising cost of energy is one of the important factors associated with increased production costs at manufacturing facilities, which encourages decision-makers to tackle this problem in different manners. One important step in this trend is to reduce the energy consumption costs of production systems. By making decisions at machine level to determine the launch times for job processing, idle time, shut down time, “turning on” time, and “turning off” time. A scheduling model enables the operations manager to implement the least expensive production scheduling during a production shift.

8.2 Cost of Electricity

Most of the manufactures and in the City of Johannesburg use the “Large Customer/ Industrial Time of Use” tariff package. This tariff is applicable to business consumers with supply capacities exceeding 100 kVA and who elect to reduce their demand during peak and standard periods and who can reallocate all or part of their load by load management and load shifting capability. Minimum demand charge is determined as follows:

- The measured peak period demand, or;
- A demand of 70 kVA, or;
- A demand based on the 80% average of the three highest demands recorded over the preceding 12 months

Consumers are further split into three categories namely:

1. Low Voltage: ≤ 1000 V
2. Medium Voltage: > 1000 V and ≤ 33 000 V
3. High Voltage: > 33 000 V

As can be seen in Figure 6, the structure of the tariff schedule is additionally split into two seasons. Firstly, a high demand season (from June to August) due to the winter season where the electric capacity demand experiences a drastic increase and a Low demand season (from September to May) during the summer period. Alternate rates are also applied on weekends and weekdays to promote customers to move operations to hours when there is little demand. The cost structure based on time of use can be seen in Figure 7.

- Weekdays
  PEAK: 07h00-10h00 and 18h00-20h00
  STANDARD: 06h00-07h00 with 10h00-18h00 and 20h00-22h00
  OFF-PEAK: 22h00-06h00
- Saturdays
  PEAK: none
  STANDARD: 07h00-12h00, and 18:00-20h00
  OFF-PEAK: 12h00-18h00, and 20h00-07h00
- Sundays & Public Holidays
  All hours are OFF-PEAK

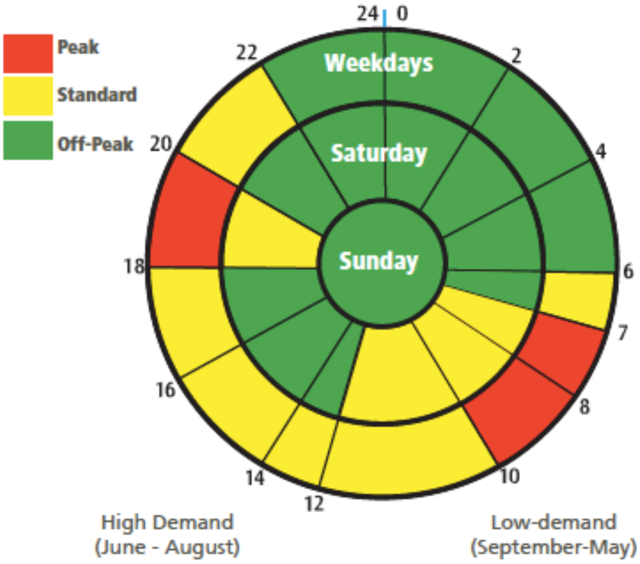
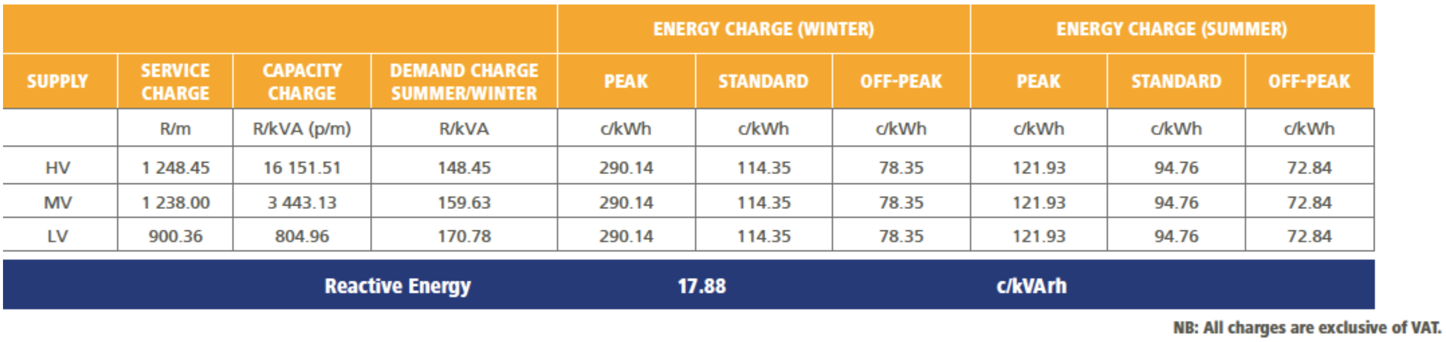


Figure 6: Energy Peak Demand Structure



				ENERGY CHARGE (WINTER)			ENERGY CHARGE (SUMMER)		
SUPPLY	SERVICE CHARGE	CAPACITY CHARGE	DEMAND CHARGE SUMMER/WINTER	PEAK	STANDARD	OFF-PEAK	PEAK	STANDARD	OFF-PEAK
	R/m	R/kVA (p/m)	R/kVA	c/kWh	c/kWh	c/kWh	c/kWh	c/kWh	c/kWh
HV	1 248.45	16 151.51	148.45	290.14	114.35	78.35	121.93	94.76	72.84
MV	1 238.00	3 443.13	159.63	290.14	114.35	78.35	121.93	94.76	72.84
LV	900.36	804.96	170.78	290.14	114.35	78.35	121.93	94.76	72.84
		Reactive Energy			17.88			c/kVArh	

NB: All charges are exclusive of VAT.

Figure 7: The Cost Breakdown Of Industrial Customers

9 Production Planning Solution Approaches

In order to optimize the electric consumption cost of manufacturing the heated hydraulic presses at Woodlam will need to be scheduled in a manner that ensures the smallest amount of electricity is used, while production is still able to satisfy customer demand. Scheduling is the process of arranging, optimizing and controlling workloads in a manufacturing process. Scheduling is utilized in order to allocate plant and machinery resources, plan human resources, plan production processes and purchase materials. Scheduling seeks to minimize both production time and costs by allocating machines and people to perform certain takes at certain times. Production scheduling aims to maximize the efficiency of the operation and reduce costs.

9.1 Operations Research Scheduling

The aim of this project is to focus on how the manufacturing production process can be manipulated in order to reduce the production costs of electricity. Production management is defined as coordinating and controlling the activities required to make a product, typically involving effective control of scheduling, cost, performance, quality, and waste management.

Production planning in a manufacturing company entails the identification of the various production activities and sequencing their execution in a logic and efficient manner. It makes use of the available resources, materials and production capacity. The functions that make up production planning consist of both planning and scheduling.

Operations research is a branch of mathematics that deals with the application of scientific methods and techniques to reach an optimal solution or solutions to assist management with decision making. (Yadav & Malik, 2014) has emphasized the importance of operations research due to the growth of the global market and increased competition. In this competitive environment businesses need to aim to achieve a combination of low cost, high quality and rapid availability. Operations research provides an optimal solution to help a business to achieve its targets.

(Yadav & Malik, 2014) shows that the main tool used in operations research is the use of a model. A model refers to the easy depiction of a problem whereby the basic or the most important features of the problem under consideration are deliberated. A number of mathematical programming models exist for problem solving with the use of operations research techniques.

Operations research models, although common in industry, government, and education, have not been widely used in manufacturing but this is changing as the complexity of problems increases (McCallum, 1986) . Managers can no longer depend on experience alone but need the help of decision support tools.

(McCallum, 1986) states that the operations research models used can be constructed and revised much quicker and in a cheaper fashion than physical prototypes. Models also allow a wider range of tests to be analyzed. Operations research has been successfully and effectively applied in areas such as production scheduling, inventory management and control, resource allocation, and production layout and design.

The three most important phases in solving a problem using operations research techniques are outlined by (Yadav & Malik, 2014) and depicted in Figure 8, they are the:

- Decision Phase: this is where the problem aim and variables are selected. The values of a number variables with the correct measurement, and the selection of an appropriate model are identified.
- Research Phase: this phase is the longest and most important phase. It involves data collection, formulation/prediction of potential outcomes and the analysis of available information.
- Planning and Action phase: this is the final stage where data collected in the research phase is applied and the results are analyzed for future decisions and recommendations.

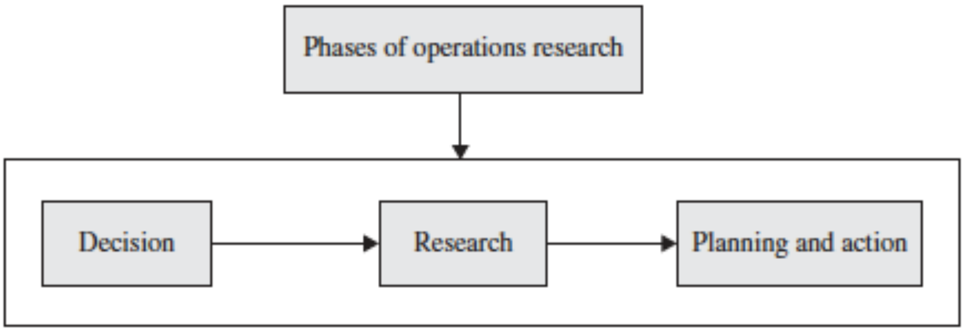


FIGURE 8: PHASES OF OPERATIONS RESEARCH

9.1.1 *Models and Applications*

There are a number of different models at the disposal of industry to find an optimal solution to operations research problems. (Yadav & Malik, 2014) lists them as:

- Non-linear programming
- Linear programming
- Dynamic programming
- Integer programming
- Geometric programming
- Multi-objective programming
- Mixed Integer Linear Programming

There are also stochastic process models such as Queuing Theory and stastical models like Regression Analysis.

Operations research provides an effective base to make management decisions. It is also universally accepted that operations research techniques are important in the field of engineering.

Electricity in South Africa is charged by time of use tariffs, this makes the timing of a production run is very important. A few papers have researched scheduling problems that are time dependent. Examples are found in steel production, resource allocation, maintenance scheduling, and national defense. (Aghelinejad M, Ouazene Y, & Yalaoui A, 2016) presents two mathematical models used to reduce the total energy consumption cost of a manufacturing system. This paper looks at simultaneously optimizing the processing of jobs and the utilization of the machines.

When the electricity consumption cost is taken into account, the decision maker has to decide on the timing and the length of the turn on and turn off process in order to optimize the sequencing of jobs. In different studies shown by (Aghelinejad M et al., 2016) authors looked at the minimization of energy costs alongside classic scheduling objectives like the total completion time. An example would be “Yildirim and Mouzon” who presented a model to minimize energy consumption and processing time by changing the state of the machinery (i.e. off, idle or operational). Another example given by (Aghelinejad M et al., 2016) is “K. Fang “who made a model of job shop scheduling that considers the machine operations that affect peak power load, energy usage and even the carbon footprint created.

(Moon, Shin, & Park, 2013) show in their research paper that since industrial electricity tariff schedules usually include time of use rates, for example a higher rate during the day then at night and on weekends is profitable for customers to shift their electricity demand periods to ones with lower rates thereby making economic savings.

After assessing all the above-mentioned research papers it is evident that scheduling using operations research is one of the most effective and well documented solutions to an electricity optimization problem with electricity costs dependent on the time of use.

9.2 Machine Learning

Machine learning is applied to operational research and is a type of artificial intelligence (AI) that enables computers to learn without being programmed. Machine learning allows computers to self-adjust when they are exposed to a new set of data. The outcome of the program applied by the computer is dependent on the input data that the AI has been exposed to.

(Florez-Revuelta & Chaaraoui, 2016) states that machine learning is mainly separated into two broad categories, namely supervised and unsupervised learning. Supervised learning is applicable when the computers training data is typically available, therefore most classification and regression algorithms fall within this category. Decision Trees, Neural

Networks Support Vector Machines (SVM) and Bayesian Networks can also be used under supervised learning. Unsupervised learning consists predominantly of clustering algorithms, such as k-means. Clustering can be used to derive insights into the nature and patterns of the data it is brought into contact with.

In reality the border line between supervised and unsupervised learning is blurred. This results in the emergence of other categories combining the two, such as semi-supervised learning which results in larger hybrid algorithms.

In the last 10-15 years, there have been large developments in the realm of artificial intelligence and considerable effort has been devoted to applying AI methods to scheduling. (Aytug, Bhattacharyya, Koehler, & Snowdon, 1994) states that when developing AI logic the problem domain is encoded in some structure i.e. rules, logic frames or scripts, and then manipulated in order to solve the problem presented. methods are seen as flexible enough to capture idiosyncratic knowledge while providing an automated means to use this knowledge as well as providing a way to study how people perform scheduling.

Artificial Intelligence models are often referred to as knowledge-based systems. Expert Systems (ES) are defined by (Aytug et al., 1994) as a special branch of knowledge-based systems where the system encompasses the knowledge of a human expert.
Due to the development of technological capabilities, processing power and software that is becoming readily available and easily accessible the development of machine learning has also taken leaps in its evolutionary development. This in turn means the possibilities for potential applications are endless from fraud detection to the prediction of equipment failures.

Although no specific examples are readily available for time of use electricity manufacturing cost optimization, problem research has been performed about the advantages and challenges of machine learning applications within manufacturing.(Wuest, Weimer, Irgens, & Thoben, 2016a) outlines them.

9.2.1 Advantages of Machine Learning in Manufacturing

The main advantage of machine learning is the fact that the models are able to solve NP (nondeterministic polynomial time) problems. A problem is assigned to the NP class if it is solvable in polynomial time by a nondeterministic Turing machine. This often occurs in intelligent manufacturing systems. ML provides a means to increase the understanding of the overall domain. It is accepted that ML enables manufactures to reduce cycle time and scrap as well as improve resource utilization in certain NP-hard manufacturing problems. Furthermore, ML provides powerful tools for continuous quality improvement in a large and complex process (Wuest, Weimer, Irgens, & Thoben, 2016).

Therefore, due to the fact that manufacturing systems are dynamic, shifting and usually complex the machine learning algorithms provide both an opportunity for learning as well as being able to adapt to change automatically to a certain extent or provide decision support to business owners. (Simon, 1983)

9.2.2 *Challenges Associated with Machine Learning in Manufacturing*

One of the main challenges associated with ML and manufacturing is obtaining both accurate and relevant data. This becomes a problem because the availability, quality, and composition play a role in the performance of the ML algorithm. The extent to which the performance of the algorithm is effected depends on a number of factors, which include the model itself and the set parameters. Due to the need for relevant data, the collected data is often pre-processed which has a critical impact on the results. Pre-processing data consists of tasks such as normalizing or filtering. It is a frequent problem that values of certain variables are unavailable or absent in the data (Wuest et al., 2016).

Another challenge associated with ML is the understanding of the results. The format or illustration of the results are relevant for the interpretation. The specifications of the chosen algorithm itself such as parameter settings are also important. Therefore, certain distinct limitations (depending on the algorithm selected) have the ability to play a large impact on the result (Wuest et al., 2016) .

After researching the above-mentioned research papers and information I believe it is possible and viable to implement machine learning into electricity optimization whereby the algorithm selected would learn which times of day to avoid heated hydraulic press utilization and when to start the equipment or leave it idling. As new data becomes available i.e. an increase or shift of the tariff rates, the model would adjust the schedule and the decision maker of Woodlam would be able to implement the changes.

9.3 *Management Accounting and Activity Based Costing*

A well-developed manufacturing strategy is becoming increasingly important to many manufacturing organizations. A major factor in the manufacturing strategy is how products and services compete in the relevant markets.

(Timothy D Fry, Daniel C Steele, & Brooke A Saladin, 1995) state that the primary role of management accountants in manufacturing operations is to provide a financial analysis of management decisions that affect production activities.

The primary concern of management accounting is cost accounting. This particular form of accounting was developed in the 19th century following the industrial revolution. It was and is used as a tool to provide essential information for manufacturing products such as textiles and steel.

The relevance of management accounting to this project is the cause and effect analysis. It is important that the proposed optimization model takes into account all the manufacturing and penalization costs associated with mass producing wooden furniture components. The analysis of the effects caused on other sections of the manufacturing process by the changes proposed can be used to further assist the business owner to decide on whether to implement the changes to the production set up. The management accounting can also be used as a tool to help determine the validity of the optimization model.

(Turney, 1992) states that activity based costing can be used as a performance measurement. Performance management plays an important role in strategy execution. It is used to measure goal accomplishment, provide feedback on performance, predict future performance, and trigger analysis and actions to correct problems that become evident. These benefits will only occur, however, if relevant and accurate performance measures are available for inclusion in performance management.

10 Solution Design/Development

10.1 Understanding the Process of Production/ Current Operation

In order to apply the model, the first step was to understand the production process that needed to be followed to manufacture the wooden furniture. The production process can be seen in Figure 9. Woodlam only makes use of hot presses instead of a combination as depicted in the Figure 9. As with any production process the system is made up of three elements as can be seen in Figure 10.

FIGURE 9: WOODEN PLYWOOD PRODUCTION PROCESS

FIGURE 10: ELEMENTS OF PRODUCTION

10.1.1 Inputs

The Inputs that are required for the process of wooden furniture manufacture are:

1. Wooden veneer sheets
2. Binding resin
3. Electricity
4. Human resources

10.1.2 Process

The process consists of a number of activities that require machinery, those activities are:

1. Gluing the veneer sheets together.
2. Hot pressing the wood sheets in the hydraulic press mold.
3. Shaping with the CNC milling machine.
4. Finishing activities.

10.1.3 Outputs

Once the process has been completed the desired outputs emerge from the system ready for the next stage of the supply chain. The outputs are:

1. Plywood furniture and furniture components
2. Offcuts

These elements all needed to be considered in order to provide the most comprehensive approach and to ensure that the data collected is accurate and relevant to the model. Generally, Job requests and orders are received by the administration department. Once a job is accepted it is ready for processing. The jobs cards are sent to the production manager along with any special requests. The production manager then schedules the production of the wooden components on a first come first serve basis. This in turn results in jobs being run as soon as possible with little regard for electricity consumption.

11 The Model Approach

This chapter of the document describes the development of the analytical model to be used to schedule and optimize the electricity consumption manufacturing cost.

The approach used to formulate the analytical model was a mixed integer linear programming model (MILP). There has been a substantial amount of research conducted on electricity cost reduction through scheduling and there is evidence that this approach has worked in similar instances in the past.(Shrouf et al., 2014) showed a MILP that can be utilized in order to produce a production schedule reducing the cost of the electricity used. This was used as the framework for the model generation.

11.1 Data Gathering and Analysis

In order to formulate the solution, data had to be gathered and analyzed for the inputs and parameters. The data that was required included:

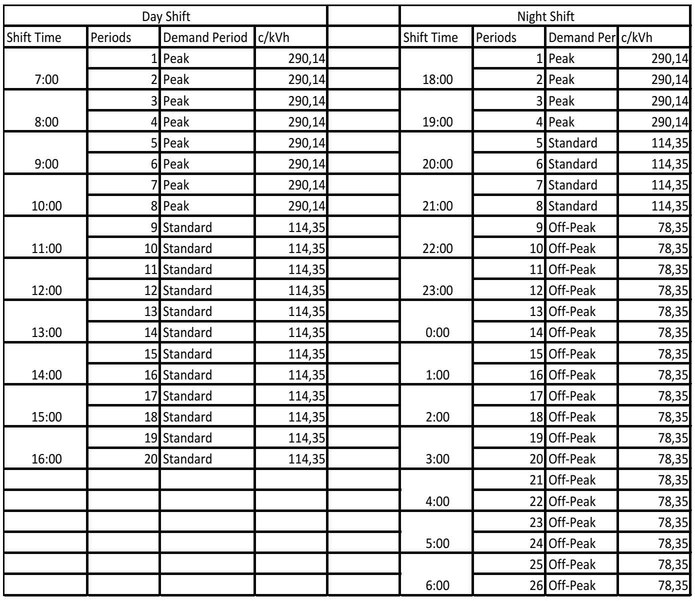
11.1.1 Duration of a Production Shift

The standard production schedule set up at the factory consists of a day shift that starts at 7:00 in the morning and ends at 17:00 in the afternoon with an hour set aside for lunch. Factory staff spit lunch into two sessions, from 12:00 to 12:30 and 12:30 to 13:00. This is so that production can continue without turning the presses off and on again. A day shift is split into 20 time periods due to the fact that the power metering system is measured in half hour increments. This is a standard day to day schedule and can change if there are deadlines or if there is a sudden increase in the demand at any given point in time. The factory has the capability to run both a night time and day time shift. In the event that a night shift occurs, production starts at 18:00 and ends at 06:00 the following morning with one hour set aside for breaks (24 Periods). Therefore, the time of a production shift is specified by the production manager.

11.1.2 Price per Time Period

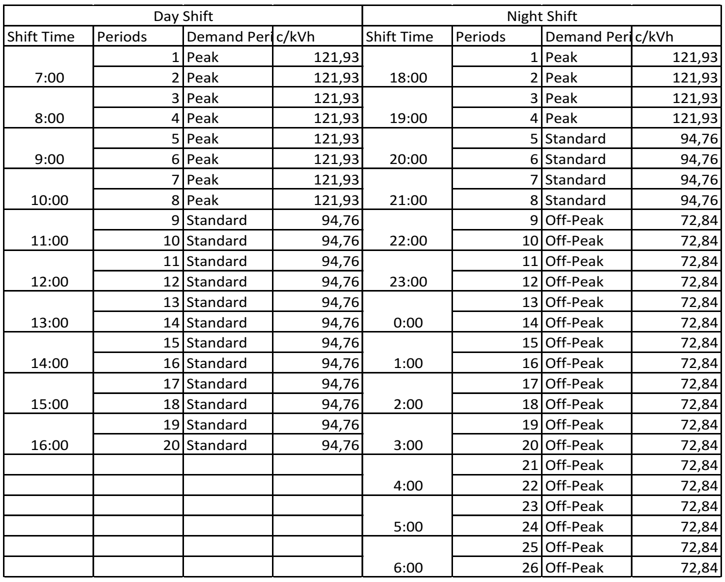
As previously stated there are numerous pricing plan structures in place established by the City of Johannesburg. Woodlam specifically falls under the “Large Customer/ Industrial TOU” tariff division. The Focus of this project is on reducing the electricity consumption. Therefore, the “Energy Charges” section of the online document presented by (City Power Johannesburg, 2017) show the figures relevant to the application of the model. The price for time of use tariffs for 2016/2017 are presented in Table 1 and Table 2. These can be updated for either the winter or summer pricing season that is relevant when determining the production schedule.

TABLE 1 : TOU ELECTRICITY TARIFF PRICES WINTER



Day Shift					Night Shift			
Shift Time	Periods	Demand Period	c/kVh		Shift Time	Periods	Demand Per	c/kVh
7:00	1	Peak	290,14		18:00	1	Peak	290,14
	2	Peak	290,14			2	Peak	290,14
8:00	3	Peak	290,14		19:00	3	Peak	290,14
	4	Peak	290,14			4	Peak	290,14
9:00	5	Peak	290,14		20:00	5	Standard	114,35
	6	Peak	290,14			6	Standard	114,35
10:00	7	Peak	290,14		21:00	7	Standard	114,35
	8	Peak	290,14			8	Standard	114,35
11:00	9	Standard	114,35		22:00	9	Off-Peak	78,35
	10	Standard	114,35			10	Off-Peak	78,35
12:00	11	Standard	114,35		23:00	11	Off-Peak	78,35
	12	Standard	114,35			12	Off-Peak	78,35
13:00	13	Standard	114,35		0:00	13	Off-Peak	78,35
	14	Standard	114,35			14	Off-Peak	78,35
14:00	15	Standard	114,35		1:00	15	Off-Peak	78,35
	16	Standard	114,35			16	Off-Peak	78,35
15:00	17	Standard	114,35		2:00	17	Off-Peak	78,35
	18	Standard	114,35			18	Off-Peak	78,35
16:00	19	Standard	114,35		3:00	19	Off-Peak	78,35
	20	Standard	114,35			20	Off-Peak	78,35
					4:00	21	Off-Peak	78,35
						22	Off-Peak	78,35
					5:00	23	Off-Peak	78,35
						24	Off-Peak	78,35
					6:00	25	Off-Peak	78,35
						26	Off-Peak	78,35

TABLE 2 : TOU ELECTRICITY TARIFF PRICES SUMMER



Day Shift				Night Shift			
Shift Time	Periods	Demand Peri	c/kVh	Shift Time	Periods	Demand Peri	c/kVh
7:00	1	Peak	121,93	18:00	1	Peak	121,93
	2	Peak	121,93		2	Peak	121,93
8:00	3	Peak	121,93	19:00	3	Peak	121,93
	4	Peak	121,93		4	Peak	121,93
9:00	5	Peak	121,93	20:00	5	Standard	94,76
	6	Peak	121,93		6	Standard	94,76
10:00	7	Peak	121,93	21:00	7	Standard	94,76
	8	Peak	121,93		8	Standard	94,76
11:00	9	Standard	94,76	22:00	9	Off-Peak	72,84
	10	Standard	94,76		10	Off-Peak	72,84
12:00	11	Standard	94,76	23:00	11	Off-Peak	72,84
	12	Standard	94,76		12	Off-Peak	72,84
13:00	13	Standard	94,76	0:00	13	Off-Peak	72,84
	14	Standard	94,76		14	Off-Peak	72,84
14:00	15	Standard	94,76	1:00	15	Off-Peak	72,84
	16	Standard	94,76		16	Off-Peak	72,84
15:00	17	Standard	94,76	2:00	17	Off-Peak	72,84
	18	Standard	94,76		18	Off-Peak	72,84
16:00	19	Standard	94,76	3:00	19	Off-Peak	72,84
	20	Standard	94,76		20	Off-Peak	72,84
				4:00	21	Off-Peak	72,84
					22	Off-Peak	72,84
				5:00	23	Off-Peak	72,84
					24	Off-Peak	72,84
				6:00	25	Off-Peak	72,84
					26	Off-Peak	72,84

11.1.3 *Job Processing Times*

The job processing time was required to determine the number of time periods necessary to produce an individual product type. There are a variety of molds that can fit into any of the hot-pressing machines therefore, job types are separated according to the number of wooden veneer sheets that the product is comprised of. This information had to be gathered through the use of time studies. The results of the average processing time for each product thickness are presented in Table 3. The standard deviation was also included to analyze the consistency of the processing times. To use this data in the model the time taken in seconds had to be converted into time periods or a fraction of a 30-minute time period.

Each plywood component has the possibility of two finishes. First, it can be a rough face finish in which case it would be fitted with upholstery at a later stage in the production process. Secondly the plywood component can have face sheeting. In which case, extra caution has to be taken when applying resin and pressing the wood. As a result, when face sheets are required there is an addition of one minute to the processing time of the component.

Table 3 : Processing Time for Each product type based on veneer sheets

Product type ID	Veneer Sheets	Avg process time seconds	Std Deviation	Avg Process Time (Periods)
1	3	241	3,606	0,13
2	4	273	5,686	0,15
3	5	361	6,557	0,20
4	6	375	5,000	0,21
5	7	425	5,000	0,24
6	8	452	5,859	0,25
7	9	463	3,786	0,26
8	10	544	9,292	0,30
9	11	597	6,083	0,33
10	12	705	4,509	0,39
11	13	831	13,650	0,46
12	14	960	12,503	0,53
13	15	1116	17,039	0,62
14	16	1201	13,051	0,67
15	17	1261	3,786	0,70
16	18	1268	4,000	0,70
17	19	1275	5,000	0,71
18	20	1290	2,082	0,72
19	21	1384	1,732	0,77
20	22	1444	4,041	0,80
21	23	1480	0,577	0,82
22	24	1498	2,517	0,83
23	25	1562	5,686	0,87
24	26	1625	5,000	0,90
25	27	1660	3,000	0,92
26	28	1670	2,082	0,93
27	29	1809	3,055	1,01
28	30	1876	6,083	1,04
29	31	1920	4,509	1,07
30	32	1950	5,000	1,08
31	33	2040	0,577	1,13

11.1.4 Power Consumption of Hot-Press Machine

The Hydraulic Hot- Press machine has a number of operating states that it can be in during a production shift. There are also transition periods present when a press is heating up or shutting down. These various states consist of different electricity consumption patterns. In order to record this information accurately, the power profiles of the machines needed to be recorded. The best method to obtain and analyze this data was through the use of a smart electricity meter as stated by (O'Driscoll, Óg Cusack, & O'Donnell, 2013). These were supplied by a company called MOL (Metering Online) for the duration of the project and can be seen in Figure 11. The meters were linked remotely to an online profile. Separate production runs were monitored continuously for two months. The results were downloaded as csv folders as well as power consumption graphs. An example of the power consumption graph used is shown in Figure 12. These were then analyzed and the average power consumption for each state was calculated to provide the power consumption associated with each state. The states identified include:

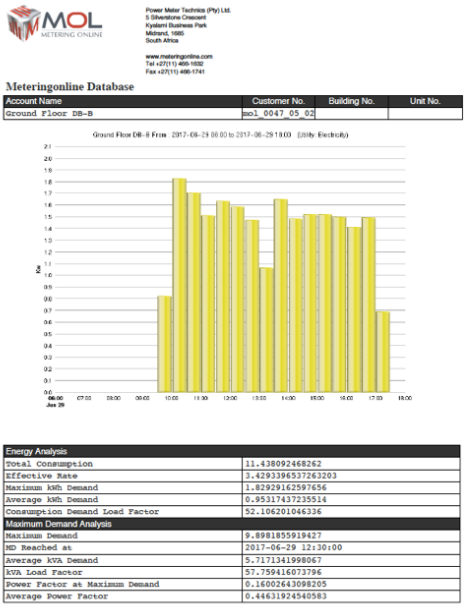
- Operating/Processing
- Idling
- Shut Down

The two relevant transition states identified were:

- Start up (from shutdown to operating)
- Shut down (from operating to shut down

The results can be seen in Table 4.

FIGURE 11: MOL SMART ELECTRICITY METER



MOL
METERING ONLINE

Power Meter Technics (Pty) Ltd.
5 Silverstone Crescent
Kyalami Business Park
Midrand, 1685
South Africa

www.meteringonline.com
Tel +27(11) 466-1632
Fax +27(11) 466-1741

Meteringonline Database

Account Name	Customer No.	Building No.	Unit No.
Ground Floor DB-B	mol_0047_05_02		

Ground Floor DB-B From : 2017-06-29 06:00 to 2017-06-29 18:00 (Utility: Electricity)

Energy Analysis	
Total Consumption	11.438092468262
Effective Rate	3.4293396537263203
Maximum kWh Demand	1.82929162597656
Average kWh Demand	0.95317437235514
Consumption Demand Load Factor	52.106201046336
Maximum Demand Analysis	
Maximum Demand	9.8981855919427
MD Reached at	2017-06-29 12:30:00
Average kVA Demand	5.7171341998067
kVA Load Factor	57.759416073796
Power Factor at Maximum Demand	0.16002643098205
Average Power Factor	0.44631924540583

FIGURE 12: ELECTRICITY CONSUMPTION GRAPH FOR A TYPICAL PRODUCTION RUN

TABLE 4: AVERAGE ELECTRICITY CONSUMPTION FOR EACH PRESS STATE

Machine State	Power Consumption kW
Processing/Working	1,82
Idle	0,98
OFF	0
Turning On	0,42
Turning Off	0,28

11.1.5 Transition State and Time Periods

When the hydraulic presses are switched on at the beginning of a production shift they require a certain amount of time in order for the elements in the mold to heat up. Once the required temperature is reached the thermostat notifies the operator and production can start. The time required for the presses to heat up is not always consistent and the average of the “turning on” time was taken. This information was collected and analyzed with the use of the smart power meters. The “shutdown” transition times were also analyzed in the same manner. The average transition times are represented in Table 5. Only two transitions are considered when changing between operating states. The transitions between idle and shutdown are not considered. Due to the fact that there are two possible ways that the press can shut down namely:

- From processing to shutdown directly or
- From processing to idle and then to shutdown

The second transition is more expensive then the first and is therefore not considered. The same process occurs when turning the machine from shutdown to processing.

TABLE 5: THE PROCESSING TIME OF TRANSITION STATES OF THE PRESS

Transition	Avg Time (minutes)	Period
Shutdown - Processing	30	1
Processing - Shutdown	15	0,5

11.2 Assumptions and Constraints of the Model

- Due to the fact that the presses use approximately the same amount of electricity they are seen as 57 individual machines. These machines have a set job in each production run and as a result a production schedule is set for each machine individually by the production manager at the start of each shift. Woodlam only operates 4 or 5 presses on average at the same time.
- The presses have three states at any point, namely ON, OFF or IDLE. Each of these states has a specific amount of electricity consumption related to it.
- There is the possibility of two separate transition states as discussed prior in the data analysis section of the report. These states also have electricity consumptions.
- The number and size of jobs have to be input by the production manager as this can change regularly and is not constant at any point in time.
- Only one job can be performed on a hydraulic press at any point.
- There is no pre-emption in the model (a job must be completed before the next job can begin)

- The production shift is split into time periods. This is due to processing time and the data handling capabilities of the smart control meters. Each period has a TOU electricity cost associated with it.
- In the first and last period of each shift the press must be in the shutdown/OFF state.
- There are no breakdowns, this is due to the fact that the 57 presses can be utilized and a mold is specific to a particular job. In the event of a breakdown the mold can be interchanged to another press and production can continue.

11.3 The Analytical Mathematical Model

A combination of the mathematical models used by (Shrouf et al., 2014) and (MohammadMohsen, Yassine, & Alice, 2016) have been used to reduce the number of binary variables required and achieve a MILP that is able to solve the scheduling problem most effectively.

The model formation starts by presenting the necessary variables, sets and parameters. The objective function of the model is also shown.

Let:
s: states of the machine (OFF, Idle, ON) (I = 1,2,3 means machine is ON; OFF or idle respectively).
n: number of jobs
T: total number of periods
E_S: amount of energy that machine consumes during state s
E_{SS}: amount of energy consumption when the machine is transiting from state s to state s'
C_p: cost of energy in period p
t_j: processing time of job j (in number of periods)
$t_{ss:}$ number of periods that must elapse when machine switches from state s to state s'

Decision variables:

$$\alpha_{s,p}: \begin{cases} 1 \text{ if the machine is in state s during period p} \\ 0 \; otherwise \end{cases}$$

$$\beta_{ss,p}: \begin{cases} 1 \; if \; machine \; is \; in \; transition \; from \; state \; s \; to \; state \; s' \; in \; time \; period \; p \\ 0 \; otherwise. \end{cases}$$

$$y_{j,p}: \begin{cases} 1 \; if \; job \; j \; is \; being \; processed \; in \; period \; p \\ 0 \; otherwise. \end{cases}$$

The Model explanation is as follows:

Objective Function:

Equation (1) Depicts the objective function. This takes into consideration the electricity consumption which is dependent on which state the machine is operating in as well as the electricity price for each period.

1. $Min \sum_{p=0}^{T} C_{\text{p}} \left(\sum_{s=1}^{k} Es \; . \alpha_{s,p} + \sum_{s=1}^{k} \sum_{s'=1}^{k} E_{ss'} . \beta_{ss'p} \right)$

Subject To:

Equation (2) ensures that a press can only process a job when in the “ON” state.

2. $\sum_{j=1}^{n} y_{j,p} = \alpha_{1,p}\ ;\ \forall p = 0, \ldots, T$

Equation (3) makes sure that during each time interval the press is either in a state or transitioning between two states.

3. $\sum_{s=1}^{k} \alpha_{s,p} + \sum_{s=1}^{k} \sum_{s'=1}^{k} \beta_{ss'p} = 1\ ;\ \forall\ p = 0, \ldots, T$

Equations (4) and (5) are established to limit the possible state of the press based on what transition or state the press was in during the previous period.

4. $\sum_{s\prime=1\ /\ tss=0}^{k} \alpha_{s',p+1} + \sum_{s=1\ /\ tss''\geq 1}^{k} \sum_{s\prime\prime=1}^{k} \beta_{ss'',p+1}\ ;\ \forall p = 0, .., T-1;\ s = 1, .., k$

5. $\beta_{ss'p} \leq \beta_{ss',p+1}\ \alpha_{s,p+1}\ ;\ \forall p = 0, .., T-1;\ s = 1, .., k;\ s' = 1, .., k;\ t_{ss'} \geq 1$

Equations (6) and (7) set both the upper and lower limits of periods so that the press can be in a transition state. This ensures that an operation lasts for a specified number of periods.

6. $\sum_{p+1}^{p+t_{ss'}} \beta_{ss',p'} \geq (\alpha_{s,p} + \beta_{ss',p+1} - 1).t_{ss'}\ ;\ \forall p = 0, .., T-1;\ s = 1, .., k;\ s' = 1, .., k;\ t_{ss'} \geq 1$

7. $\beta_{ss',p'} + \beta_{ss',p+t_{ss}} \leq 1\ ;\ \forall p = 0, .., T - t_{ss'};\ s = 1, .., k;\ s' = 1, .., k;\ t_{ss'} \geq 1$

Equation (8) is used to ensure that only one job can be performed during any given time period.

8. $\sum_{j=1}^{n} y_{j,p} \leq 1\ ;\ \forall p = 0, .., T$

Equation (9) Allows a job to begin processing if the job preceding jobs are complete.

9. $t_j . y_{j',p} \leq \sum_{p'=0}^{p} y_{j,p'}\ ;\ \forall p = 0, .., T';\ j = 1, .., n;\ j' = 1, .., n;\ j' > j$

Equation (10) ensures that there is no pre-emption of the jobs.

10. $\sum_{p\prime=1}^{p-t_j} y_{j,p'} + \sum_{p'=p+t_j}^{T} y_{j,p'} \leq T . (1 - y_{j,p'})\ ;\ \forall\ p = 0, \ldots, T - t_j - 1\ ;\ j = 1, \ldots, n$

Equation (11) ensures all jobs must be completed during the production shift.

11. $\sum_{p=1}^{T} y_{j,p} \geq t_j\ ;\ \forall j = 1, \ldots, n$

Equations (12) and (13) ensure binary variables.

12. $\alpha_{s,p}\ ;\ \beta_{s,p} \in \{0,1\}$

13. $y_{j,p} \in \{0,1\}$

11.4 Running the Model

The Computer Program used to run the MILP is LINGO. The main purpose of LINGO is to enable the user to quickly formulate an input model, solve the problem, analyze the correctness or the relevance of the model based on the solution. After these steps, minor modifications can be implemented and the process can be repeated(LINDO SYSTEMS, 2017) . The main version of LINGO includes a graphical user interface (GUI). Due to the limitations of the student version available, only the command line interface was used. The LINGO model analytical MILP model formulation can be seen in Appendix 3.

11.4.1 Model Run Scenarios

After generation of the model, three different cases were simulated and the results compared. The different scenarios take into account different types of production runs based on:

- Summer or Winter electricity costing seasons.
- The number jobs and type of orders in each production run.
- Number of periods available in the alternate production shifts.

The three different cases were taken from production orders during 2017 and simulated for the model. These were selected to ensure a variety of order sizes were selected. The relevance of this being that production orders vary according to customer demand. The model needs to be capable of scheduling a production run for a low number of products with long processing times or a high number of products with short processing times. A summary of the three cases are shown below in Table 6:

Table 6: Scenario Descriptions

Parameters	Scenario 1			Scenario 2			Scenario 3		
Season	Winter			Summer			Winter		
Shift	Day and Night Shift			Day and Night Shift			Day and Night Shift		
Number of 30 Minute Time Periods Available	45			45			45		
Electricity Cost for each Time Period	Table 8 , Page 34			Table 10 , Page 35			Table 12 , Page 36		
Number of Products in Order	2			4			10		
Veneer Sheets for Each Job in Production Order	Description	Order quantity	tal Processing Time (Periods)	Description	Order quantity	tal Processing Time (Periods)	Description	Order quantity	tal Processing Time (Periods)
(Order Quanties and Details Can be Seen in Appendix 3)	1. Curved Chair Back - 11 PLY	22	10	1. High Chair Back - 16 PLY	12	7	1. Back Board 1 - 11 PLY	9	3
	2. Straight Chair Back - 9 PLY	96	24	2. Seat - 4 PLY	73	10	2. Seat Board 1 - 9 PLY	8	2
				3. Chair Back 1 - 20 PLY	4	3	3. Seat Board 2 - 9 PLY	12	3
				4. Chair Back 2 - 9 PLY	20	5	4. Back Board 2 - 16 PLY	6	4
							5. Seat Board 3 - 16 PLY	6	4
							6. Shell - 6 PLY	12	2
							7. Seat Board 3 - 20 PLY	6	2
							8. Seat Back - 5 PLY	20	4
							9. Headboard - 9 PLY	26	7
							10. Arm - 30 PLY	1	1
Processing Time for Each Job Based on Number of Sheets		Table 3 , Page 28			Table 3 , Page 28			Table 3 , Page 28	

12 Results

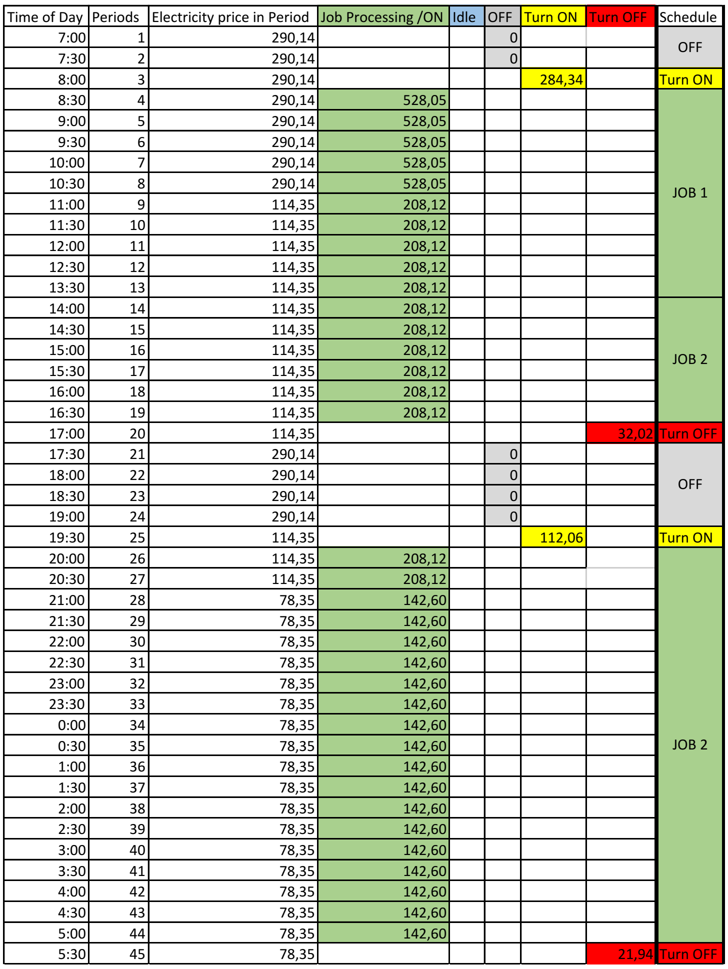
12.1 Scenario 1

In scenario 1, the production schedule for the hydraulic press is shown in Table 8. The description of the schedule and cost saving of the production run are shown in Table 7 below. In order to avoid the peak tariff costs experienced in the first periods the press is only started in period 3. Job 1 is processed until it is complete and Job 2 begins production immediately afterwards. Job 2 is temporarily stopped because the press is shut down in period 20 to avoid the high evening electricity tariff price. Job 2 then continues to be processed until it is complete at the end of the shift and the press is turned off. By avoiding these high tariff periods, there is a 16% saving to the cost of electricity for this production run.

TABLE 7: SCENARIO 1 SCHEDULE DESCRIPTION AND COST SAVING ON PRODUCTION RUN

Periods that the Hydraulic Press 'Turns ON'	3 and 25
Periods that the Hydraulic Press 'Turns OFF'	20 and 45
Periods that the Hydraulic Press 'Runs'	JOB 1 - 4 to 13 JOB 2 - 14 to 19 and 26 to 44
Periods that the Hydraulic Press 'Idles'	0
Periods that the Hydraulic Press is 'OFF'	1,2 and 21 to 24
Electricity Cost to Run Production with No Adjusted Scheduling	R10 439,86
Electricity Cost to Run Production with the MILP to Adjust the Production Schedule.	R8 860,18
Cost Saving on Production Run	R1 633,68
The Electricity Cost Saving Ratio	0,16

TABLE 8: SCHEDULE PRODUCED BY SCENARIO 1



Time of Day	Periods	Electricity price in Period	Job Processing /ON	Idle	OFF	Turn ON	Turn OFF	Schedule
7:00	1	290,14			0			OFF
7:30	2	290,14			0			
8:00	3	290,14				284,34		Turn ON
8:30	4	290,14	528,05					JOB 1
9:00	5	290,14	528,05					
9:30	6	290,14	528,05					
10:00	7	290,14	528,05					
10:30	8	290,14	528,05					
11:00	9	114,35	208,12					
11:30	10	114,35	208,12					
12:00	11	114,35	208,12					
12:30	12	114,35	208,12					
13:30	13	114,35	208,12					
14:00	14	114,35	208,12					JOB 2
14:30	15	114,35	208,12					
15:00	16	114,35	208,12					
15:30	17	114,35	208,12					
16:00	18	114,35	208,12					
16:30	19	114,35	208,12					
17:00	20	114,35					32,02	Turn OFF
17:30	21	290,14			0			OFF
18:00	22	290,14			0			
18:30	23	290,14			0			
19:00	24	290,14			0			
19:30	25	114,35				112,06		Turn ON
20:00	26	114,35	208,12					JOB 2
20:30	27	114,35	208,12					
21:00	28	78,35	142,60					
21:30	29	78,35	142,60					
22:00	30	78,35	142,60					
22:30	31	78,35	142,60					
23:00	32	78,35	142,60					
23:30	33	78,35	142,60					
0:00	34	78,35	142,60					
0:30	35	78,35	142,60					
1:00	36	78,35	142,60					
1:30	37	78,35	142,60					
2:00	38	78,35	142,60					
2:30	39	78,35	142,60					
3:00	40	78,35	142,60					
3:30	41	78,35	142,60					
4:00	42	78,35	142,60					
4:30	43	78,35	142,60					
5:00	44	78,35	142,60					
5:30	45	78,35					21,94	Turn OFF

- Cost of Each machine state seen in cells = Electricity Price in Period x Electricity Consumption (Table 4, Page 29)

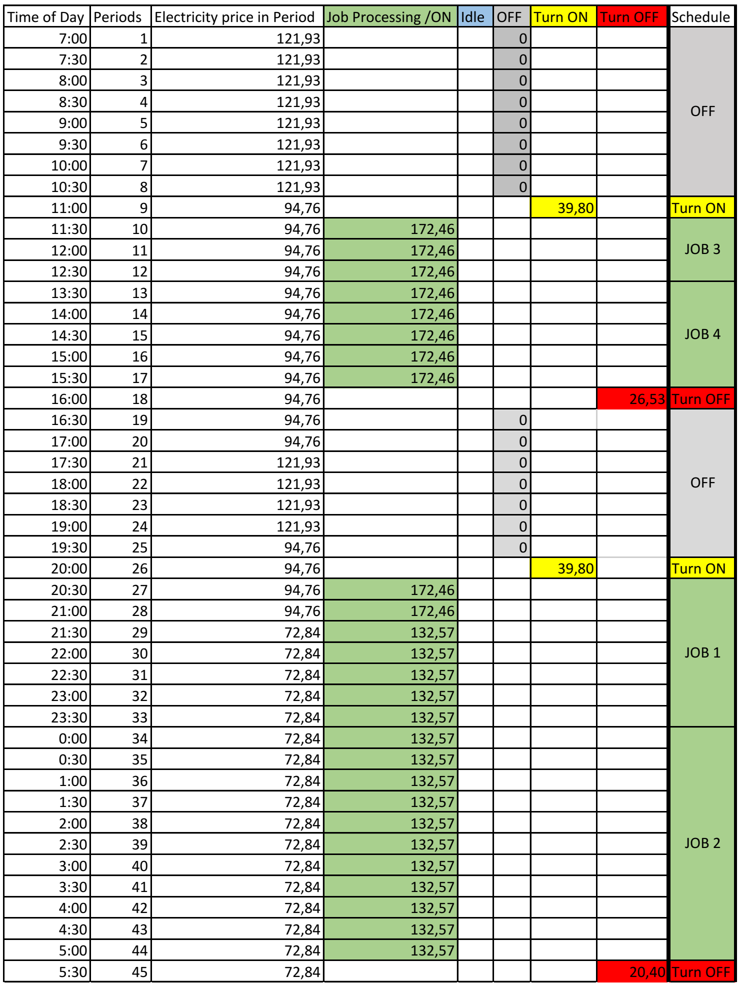
12.2 Scenario 2

The production schedule for scenario 2 is shown in Table 10. The description of the schedule and cost improvement are shown in Table 9 below. The press remains shut down for the first 8 periods in order to avoid peak tariff demand pricing. The two shorter jobs occur first so that they can be completed in the shortest time and both are fully processed in a time period that has lower electricity tariff rates. The machine then requires one period to start up before processing job 3. After Job 3 the machine directly starts processing job 4. The press then turns 'OFF' and remains shut down to avoid peak evening tariff costs. In period 26 the press is turned back 'ON' and resumes processing jobs 1 and 2 for the remainder of the production shift. These longer jobs are scheduled for the cheapest time period where there is the most time to compete the production run. By running the production set up in this manner there is a 20 % cost saving when compared to processing jobs 1 to 4 as soon as possible throughout the day.

TABLE 9: SCENARIO 2 SCHEDULE DESCRIPTION AND COST SAVING ON PRODUCTION RUN

Periods that the Hydraulic Press 'Turns ON'	9 and 26
Periods that the Hydraulic Press 'Turns OFF'	19 and 45
Periods that the Hydraulic Press 'Runs'	JOB 1 - 27 to 33
	JOB 2 - 34 to 44
	JOB 3 - 10, 11 and 12
	JOB 4 - 14 to 18
Periods that the Hydraulic Press 'Idles'	9
Periods that the Hydraulic Press is 'OFF'	1 to 8 and 20 to 26
Electricity Cost to Run Production with No Adjusted Scheduling	R5 067,79
Electricity Cost to Run Production with the MILP to Adjust the Production Schedule.	R4 051,36
Cost Saving on Production Run	R1 016,42
The Electricity Cost Saving Ratio	0,2

TABLE 10 : SCHEDULE PRODUCED BY SCENARIO 2



Time of Day	Periods	Electricity price in Period	Job Processing /ON	Idle	OFF	Turn ON	Turn OFF	Schedule
7:00	1	121,93			0			OFF
7:30	2	121,93			0			
8:00	3	121,93			0			
8:30	4	121,93			0			
9:00	5	121,93			0			
9:30	6	121,93			0			
10:00	7	121,93			0			
10:30	8	121,93			0			
11:00	9	94,76				39,80		Turn ON
11:30	10	94,76	172,46					JOB 3
12:00	11	94,76	172,46					
12:30	12	94,76	172,46					
13:30	13	94,76	172,46					JOB 4
14:00	14	94,76	172,46					
14:30	15	94,76	172,46					
15:00	16	94,76	172,46					
15:30	17	94,76	172,46					
16:00	18	94,76					26,53	Turn OFF
16:30	19	94,76			0			OFF
17:00	20	94,76			0			
17:30	21	121,93			0			
18:00	22	121,93			0			
18:30	23	121,93			0			
19:00	24	121,93			0			
19:30	25	94,76			0			
20:00	26	94,76				39,80		Turn ON
20:30	27	94,76	172,46					JOB 1
21:00	28	94,76	172,46					
21:30	29	72,84	132,57					
22:00	30	72,84	132,57					
22:30	31	72,84	132,57					
23:00	32	72,84	132,57					
23:30	33	72,84	132,57					
0:00	34	72,84	132,57					JOB 2
0:30	35	72,84	132,57					
1:00	36	72,84	132,57					
1:30	37	72,84	132,57					
2:00	38	72,84	132,57					
2:30	39	72,84	132,57					
3:00	40	72,84	132,57					
3:30	41	72,84	132,57					
4:00	42	72,84	132,57					
4:30	43	72,84	132,57					
5:00	44	72,84	132,57					
5:30	45	72,84					20,40	Turn OFF

- Cost of Each machine state seen in cells = Electricity Price in Period x Electricity Consumption (Table 4, Page 29)

12.3 Scenario 3

In scenario 3 the schedule can be seen in Table 12. The description of the schedule and cost improvement are shown in Table 11 below. This case depicts that on certain occasions there are varied orders with large differences in the quantities ordered. Production of Job 1 only starts in the 4th period after the press has been turned 'ON' to avoid the initial high demand tariff. After job 1 is complete the press idles this is to ensure that the minimum amount of electricity is consumed in this high cost period. The consumption associated with turning 'OFF' and 'ON' again as well as the time constraints make idling the most feasible option. Jobs 6, 8, 3 and 2 are then processed for periods 9 to 19. The press is then shut down for four periods to avoid the high evening tariffs before starting up and continuing with the production of the rest of the jobs for the remainder of the time shift. By applying the production schedule, there is a 21% electricity cost saving for the production run.

TABLE 11: SCENARIO 3 SCHEDULE DESCRIPTION AND COST SAVING FOR PRODUCTION RUN

Periods that the Hydraulic Press 'Turns ON'	3 and 24
Periods that the Hydraulic Press 'Turns OFF'	20 and 45
Periods that the Hydraulic Press 'Runs'	JOB 1 - 4,5 and 6
	JOB 2 - 18 and 19
	JOB 3 - 15,16 and 17
	JOB 4 - 36 to 39
	JOB 5 – 40 to 43
	JOB 6 - 7 and 8
	JOB 7 – 27 and 28
	JOB 8 – 11 to 14
	JOB 9 – 29 to 35
	JOB 10 - 44
Periods that the Hydraulic Press 'Idles'	9 and 10
Periods that the Hydraulic Press is 'OFF'	1 to 8 and 20 to 26
Electricity Cost to Run Production with No Adjusted Scheduling	R10 210,93
Electricity Cost to Run Production with the MILP to Adjust the Production Schedule.	R8 083,63
Cost Saving on Production Run	R2 131,30
The Electricity Cost Saving Ratio	0,21

TABLE 12: SCHEDULE PRODUCED BY SCENARIO 3

Time of Day	Periods	Electricity price in Period	Job Processing /ON	Idle	OFF	Turn ON	Turn OFF	Schedule
7:00	1	290,14			0			OFF
7:30	2	290,14			0			
8:00	3	290,14				121,86		Turn ON
8:30	4	290,14	528,05					JOB 1
9:00	5	290,14	528,05					
9:30	6	290,14	528,05					
10:00	7	290,14		112,06				IDLE
10:30	8	290,14		112,06				
11:00	9	114,35	528,05					JOB 6
11:30	10	114,35	528,05					
12:00	11	114,35	208,12					JOB 8
12:30	12	114,35	208,12					
13:30	13	114,35	208,12					
14:00	14	114,35	208,12					
14:30	15	114,35	208,12					JOB 3
15:00	16	114,35	208,12					
15:30	17	114,35	208,12					
16:00	18	114,35	208,12					JOB 2
16:30	19	114,35	208,12					
17:00	20	114,35					32,02	Turn OFF
17:30	21	290,14			0			OFF
18:00	22	290,14			0			
18:30	23	290,14			0			
19:00	24	290,14				121,86		Turn ON
19:30	25	114,35	208,12					JOB 2
20:00	26	114,35	208,12					
20:30	27	114,35	208,12					JOB 7
21:00	28	78,35	142,60					
21:30	29	78,35	142,60					JOB 9
22:00	30	78,35	142,60					
22:30	31	78,35	142,60					
23:00	32	78,35	142,60					
23:30	33	78,35	142,60					
0:00	34	78,35	142,60					
0:30	35	78,35	142,60					
1:00	36	78,35	142,60					JOB 4
1:30	37	78,35	142,60					
2:00	38	78,35	142,60					
2:30	39	78,35	142,60					
3:00	40	78,35	142,60					JOB 5
3:30	41	78,35	142,60					
4:00	42	78,35	142,60					
4:30	43	78,35	142,60					
5:00	44	78,35	142,60					JOB 10
5:30	45	78,35					21,94	Turn OFF

- Cost of Each machine state seen in cells = Electricity Price in Period x Electricity Consumption (Table 4, Page 29)

12.4 Effect on Production Costs

The summary of the economic effect of the production scheduling approaches represented in scenarios 1,2 and 3 can be viewed in Table 13. This figure depicts the ratio of production cost savings per production run of the “improved” production schedule compared to the “standard” production plan of processing jobs as soon as possible and in the order in which they arrive. These results depict individual saving percentages of 15.57, 20.06 and 20.86 respectively. The average cost saving ratio for all three cases is 19%. This becomes substantial to the entire production cost when a number of heated hydraulic presses are being utilized in the facility and the cost saving scheduling model approach is applied. The overall production cost is thus reduced as a result of the decrease in the electricity consumption cost. This figure may change according to the number of time slots available and the specific production demand placed on the press at any given point in time.

Table 13 : Cost Comparison Between 'Model’ and 'Standard’ Approach

MODEL SCENARIO	Energy Cost (As soon as Possible Schedule)	Energy Cost (Model Schedule)	Difference (Rand)	Electricty Cost Saving (%)
1	10493,86	8860,18	1633,68	15,57
2	5067,79	4051,36	1016,42	20,06
3	10214,93	8083,63	2131,30	20,86

12.5 Effect on the Environment

By scheduling the production of the hydraulic presses in this manner, the results are not only monetary but also have positive environmental effects. By scheduling production in time periods where the electricity demand is low, the minimum possible demand pressure is placed on the grid. This results in the use of more sustainable energy systems such as uninterrupted power supplies or solar panels to assist to supply electricity which in turn reduces carbon emissions to be implemented.

13 Solution Validation

A means of measuring the power consumption of the presses was found through the use of smart electricity meters. These can be used going forward to monitor any changes in consumption as the machines age or if Woodlam would like to make any further comparisons. In order to validate whether the model used to schedule the production of plywood furniture is successful, the production manager needs to implement and apply the solution model for a set duration of time. The results would be recorded, documented and assessed. The success of the solution can be determined by comparing the current electricity production cost to the one experienced by the new approach. In order to determine the success of the project the results of the solution would have to reflect that there was a reduction in the electricity consumption cost of the hydraulic hot press machinery, while maintaining the production capacity of the factory.

14 Conclusion and Recommendations

14.1 Conclusion

The wooden furniture sector continually experiences increases in global competition and increasing electricity costs as a result of inflation, lack of electricity supply and poor municipal planning. After completion of a thorough study regarding the need, benefits and approaches to reducing the electricity production costs of manufacturing. Woodlam is now able to apply a MILP model in order to assist management to optimize the scheduling of the production so as to avoid peak tariff demand hours. This enables the company to minimize the electricity consumption costs of running a heated hydraulic mold press. Once the model has been implemented and the production manager has allocated the required inputs, LINGO will provide the user with a production schedule results. This will assist with decisions about the exact time allocated to start machinery up and likewise when to shut down or keep it remaining idle.

As seen in the literature study, examples in the past have shown success in implementing mixed linear programming models in order to schedule production. The implementation of a decision-making tool such as this will increase the profitability of the business by reducing the electricity portion of the production cost.

The benefits of having the ability to adjust or reduce the cost of energy used for production by scheduling, makes the model dynamic and the economic benefits of its use are clearly visible.

It is also important to note that this model is limited to only produce a production schedule for one machine at a time. This means that the production manager still has a large input. Further project work should include the application of the model into the Enterprise Resource Planning System of the business. In conjunction with the application of the base model the program should be further developed. This will ensure a more holistic model is used, thus combining the scheduling of all the hydraulic presses within the facility, the tardiness penalty costs of production and overtime labor costs for night shifts. This will further optimize the entire production operation and reduce the electricity costs even further.

14.2 Recommendations

14.2.1 Metaheuristic / Genetic Algorithm Approach

When formulating an analytical integer programming model for a problem such as a shop floor scheduling problem, it is considered to be Non-Deterministic Polynomial Time problem. The solving time required by the computer may be a limiting constraint. For the current production capacity at Woodlam, the production runs are small enough to ensure that the analytical model provides a scheduling solution. In the event that jobs become too big or more variables are introduced, the time frame required might detract from the useful aspect of the model.

In order to provide a model solution, metaheuristics such as Genetic Algorithms should be considered. Metaheuristics, unlike other models allow us to develop solutions for large scaled problems in a reasonable amount of time. There is however no guarantee that the global optimum solution will be found.(MohammadMohsen et al., 2016) .

Genetic Algorithms are a version of a metaheuristic model that can help solve this particular problem(MohammadMohsen et al., 2016) .

14.2.2 More Specialized Meters

For this project, the smallest increment the meters could incorporate were 30 minute periods. On small production orders this can detract from the accuracy of the scheduling. For this reason, it would be beneficial in future work to invest in meters that can analyze smaller time periods to have more precise production schedules.

14.2.3 Human Error and Costs

The solution approach of this model did not take into account the overtime costs associated with labour as well as the unpredictability of the human element. This can be particularly volatile in South Africa and should be considered by the production manager when scheduling production on weekends and during night shifts.

15 References

- Aghelinejad M, Ouazene Y, & Yalaoui A. (2016). Machine and production scheduling under electricity time varying prices. *IEEE International Conference on Industrial Engineering and Engineering Management, 2016-December*, 992-996.
- Aytug, H., Bhattacharyya, S., Koehler, G. J., & Snowdon, J. L. (1994). A review of machine learning in scheduling. *IEEE Transactions on Engineering Management, 41*(2), 165-171.
- Basson, J. (2007). SOUTH AFRICA'S FERRO ALLOYS INDUSTRY - PRESENT STATUS AND FUTURE OUTLOOK., 1 -22.
- City Power Johannesburg. (2017). ***TARIFF INFO READ MORE ABOUT CITY OF JOHANNESBURG TARIFFS*** Retrieved 08/02, 2017, from https://www.citypower.co.za/customers/Pages/Tariff-Info.aspx
- Eskom. (2017). *Coal power.* Retrieved 04/28, 2017, from http://www.eskom.co.za/AboutElectricity/ElectricityTechnologies/Pages/Coal_Power.aspx
- Florez-Revuelta, F., & Chaaraoui, A. (2016). *Active and assisted living - technologies and applications* Institution of Engineering and Technology.
- Go Solar. (2017). *<B>Electricity prices in south africa 'Historical & projected'</B>.* Retrieved 05/01, 2017, from http://www.payasyougosolar.co.za/electricity-prices-in-south-africa-historical-projected/
- Inglesi-Lotz, R. (2011). The evolution of price elasticity of electricity demand in south africa: A kalman filter application. *Energy Policy, 39*(6), 3690-3696.
- Jackson, R. P., Kent, G. C., & Casselman, E. J. (1927). No title. *Molded Plywood,*

- Kaplinsky, R., Morris, M., & Readman, J. (2002). The globalization of product markets and immiserizing growth: Lessons from the south african furniture industry. *World Development, 30*(7), 1159-1177. doi://dx.doi.org.uplib.idm.oclc.org/10.1016/S0305-750X(02)00029-3
- Kothari, C. R. (2004). *Research methodology: Methods and techniques* New Age International.
- LINDO SYSTEMS, I. (2017). ***LINGO documentation.*** Retrieved 08/20, 2017, from http://www.lindo.com/index.php/ls-downloads?id=112:lingo-documentation&catid=82
- McCallum, C. J. (1986). Operations research in manufacturing. *AT&T Technical Journal, 65*(4), 4-16.
- MohammadMohsen, A., Yassine, O., & Alice, Y. (2016). Machine and production scheduling under electricity time varying prices. *Industrial Systems Optimization Laboratory (ICD, UMR 6281, CNRS) Universit´e De Technologie De Troyes, France,* , 992-993,994,995,996.
- Moodley, S. (2001). Impact of electronic commerce on small exporting firms in the south african wooden furniture manufacturing sector. *Journal of Information Technology Impact, 2*(3), 89-104.
- Moon, J., Shin, K., & Park, J. (2013). Optimization of production scheduling with time-dependent and machine-dependent electricity cost for industrial energy efficiency. *The International Journal of Advanced Manufacturing Technology, 68*(1-4), 523-535.
- NERSA. (2008). *Annual report 2007/2008*. www.nersa.org.za: National Energy Regulator Of South Africa.
- Pogue, T. (2008).
A sectoral analysis of wood, paper and pulp industries in south africa *1*(1), 49-50,51,52,53.

- Shrouf, F., Ordieres-Meré, J., García-Sánchez, A., & Ortega-Mier, M. (2014). Optimizing the production scheduling of a single machine to minimize total energy consumption costs. *Journal of Cleaner Production, 67*, 197-207.
- Simon, H. A. (1983). Why should machines learn? In J. C. R. Michalski (Ed.) *Machine learning* (pp. 25) Charlotte, NC: Tioga Press.
- Timothy D Fry, Daniel C Steele, & Brooke A Saladin. (1995). The role of management accounting in the development of a manufacturing strategy. *International Journal of Operations & Production Management, 15*(12), 21.
- Turney, P. B. (1992). Activity based costing. *Management Accounting Handbook"(4 Th Edition), Edited by C.Drury, Butterworth-Heinemann and CIMA,*
- Wuest, T., Weimer, D., Irgens, C., & Thoben, K. (2016a). Machine learning in manufacturing: Advantages, challenges, and applications. *Production & Manufacturing Research, 4*(1), 23-45.
- Wuest, T., Weimer, D., Irgens, C., & Thoben, K. (2016b). Machine learning in manufacturing: Advantages, challenges, and applications. *Production & Manufacturing Research, 4*(1), 23-45.
- Yadav, S. R., & Malik, A. K. (2014). *Operations research*. New Delhi, India: Oxford University Press.
- O'Driscoll, E., Óg Cusack, D., & O'Donnell, G. E. (2013). The development of energy performance indicators within a complex manufacturing facility. The International Journal of Advanced Manufacturing Technology, 68(9-12), 2205-2214.

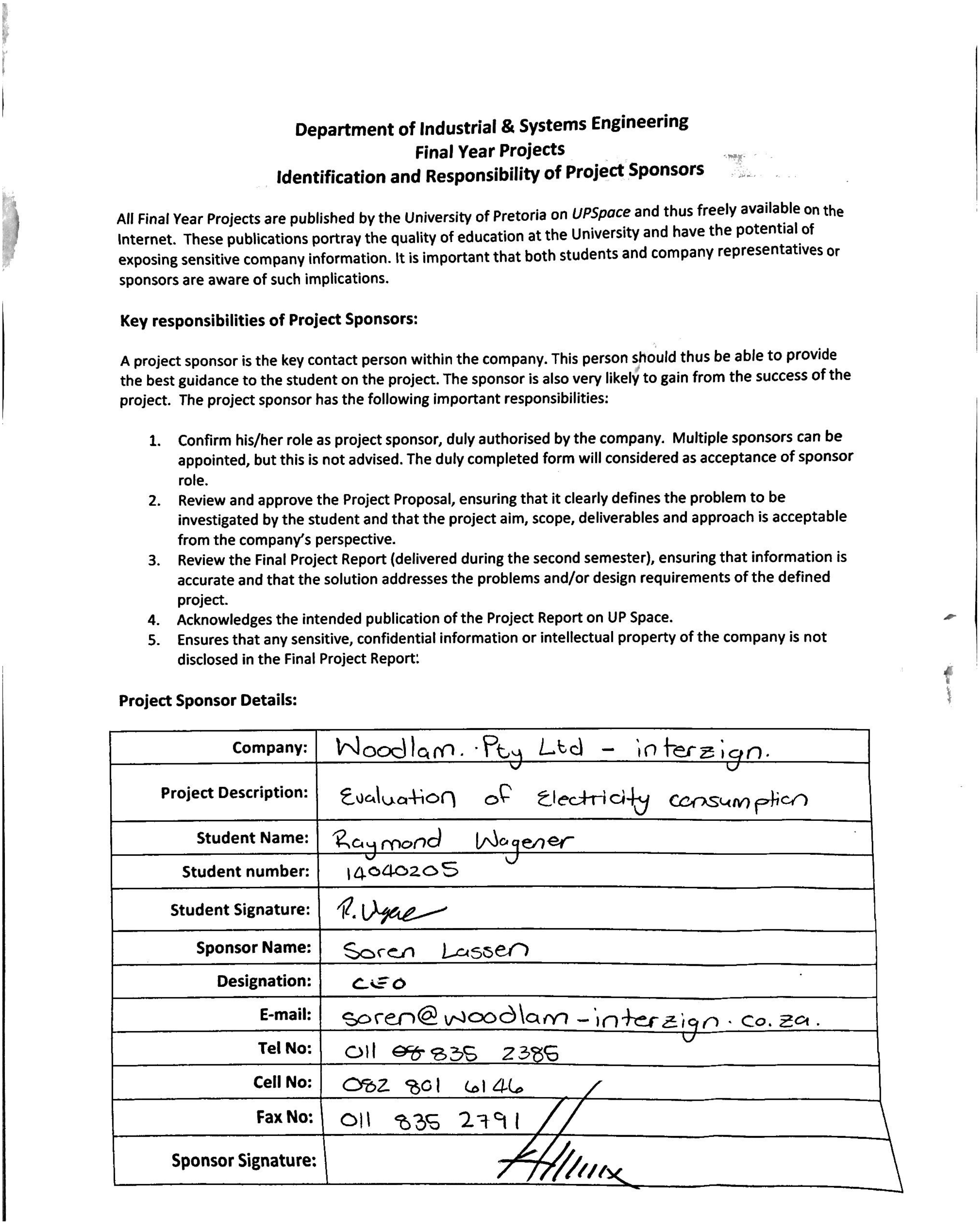
16 Appendix A: LINGO CODE

Electricity Cost Reduction model:

```
sets:

s /1,2,3/: Es;! 1 = ON , 2 = IDLE , 3 = OFF ;
Trans(s,s): Ess, tss , tran;
j/1,2,3,4,5,6,7,8,9,10/ :t ;
p/1..45/:Cp;

alpha(s,p): a;
beta(Trans,p): b;
Yb(j,p): y;

endsets


data:


Cp=
121.93,121.93,121.93,121.93,121.93,94.76,94.76,94.76,94.76,72.84,72.84,72.84,72.84,72.84,72.84,72.84,72.84,72.84,72.84,
72.84,72.84,72.84,72.84,72.84,72.84,72.8;
t = 2,4,8,7,9,11,7,6,9,10 ;

Es = 1.7 ,0.9 ,0 ;
Ess = 0 0 0.5
0 0 0
0.2 0 0 ;
tss = 0 0 0.5
0 0 0
1 0 0 ;

! processing time in periods;
! Periods ;
!Electricity cost during each period ;

Enddata

min=@sum(p(i):Cp(i)*(@sum(s(h):Es(h)*(a(h,i))+@sum(s(k):@sum(s(l):Ess(k,l)*(b(k,l,i)))))));

@for(p(i):
@sum(j(h):
y(h,i))=a(1,i);
);

@for(p(h):
(@sum(s(i):a(i,h))+@sum(s(i):@sum(s(k):b(i,k,h))))=1;
);




@for(p(i) | i #LT# 45 :
@for(s(h):
a(h,i)<=@sum(s(o)|tss(h,o)#EQ#0:a(h,i+1))+(@sum(s(u):@sum(s(z)|tss(h,z)#GT#1 :b(h,z,i+1))))));



@for(p(i) | i #LT# 45 :
@for(s(h):
@for(s(u)|tss(h,u)#GT#1:b(h,u,i) <= b(h,u,i+1) + a(u,i+1))));


@for(p(i) | i #LT# 45 :
```

```
@for(s(h):
@for(s(u)|tss(h,u)#GT#1: @sum( p(v) | v #GT# (i+1) #AND# v #LT# (i+tss(h,u)): b(h,u,v)) >= (a(h,i) + b(h,u,i+1) - 1)*
tss(h,u))));


@for(p(i):
@for(s(h):
@for(s(u)|tss(h,u)#GT#1 #and# i #LT# 45 - tss(h,u): b(h,u,i) + b(h,u,i+tss(h,u)) <= 1 )));



@for(p(i):
@sum(j(h):
y(h,i)) <= 1 );


@for(p(i):
@for(j(h):
@for(j(u)| u #GT# h : (t(h) * y(u,i)) <= (@sum(p(k): y(h,k))))));


@for(p(i):
@for(j(u) | i #LT# 10 - t(u)-1 : (@sum(p(v)| v #GT# 1 #and# v #LT# i-t(u) : y(u,v)))+ @sum(p(v)| v #GT# i+t(u) #AND# v
#LT# 45 : y(u,v) ) <= 10 * (1- y(u,i))));


!@for(j(u):
@sum(p(i) : y(u,i)) >= t(u));


@for(j(v):
@for(p(i): @bin( y(v,i))));


@for(s(k):
@for(s(l):
@for(p(i):
@bin(b(k,l,i));
);
);
);
@for(p(i):
@for(s(h):
@bin(a(i,h));
);
);

END MODEL
```

17 Appendix B: Sponsorship Form



Department of Industrial & Systems Engineering
Final Year Projects
Identification and Responsibility of Project Sponsors

All Final Year Projects are published by the University of Pretoria on *UPSpace* and thus freely available on the Internet. These publications portray the quality of education at the University and have the potential of exposing sensitive company information. It is important that both students and company representatives or sponsors are aware of such implications.

Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide the best guidance to the student on the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.

Project Sponsor Details:

Company:	Woodlam. Pty Ltd - interzign.
Project Description:	Evaluation of Electricity consumption
Student Name:	Raymond Wagener
Student number:	14040205
Student Signature:	
Sponsor Name:	Soren Lassen
Designation:	CEO
E-mail:	soren@woodlam-interzign.co.za.
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Sponsor Signature:	

18 Appendix C: Production Orders

PRODUCTION LIST Scenario 1

Order Date	CUSTOMER	Customer Order Number	Order AMT	PRODUCT
06-Jul	ARUZAFUSION	PIETER02-01	22	GALAXY MIDBACK WITH SLOT NO T-NUTS 11PLY
06-Jul	ARUZAFUSION	PIETER02-01	96	GALAXY MIDBACK NO SLOT 9 PLY STRAIGHT CUT

PRODUCTION LIST Scenario 2

Order Date	CUSTOMER	Customer Order Number	Order AMT	PRODUCT
20-Feb	KARO MANUFACTURING	45399	12	OMEGA HIGHBACK 16 PLY
20-Feb	KARO MANUFACTURING	45462	73	EURO SEAT 4 PLY
20-Feb	KARO MANUFACTURING	28833	4	OMEGA MIDBACK 20 PLY
20-Feb	KARO MANUFACTURING	45431	20	GENERIC MIDBACK 9 PLY

PRODUCTION LIST Scenario 3

Order Date	CUSTOMER	Customer Order Number	Order AMT	PRODUCT
10-May	BFM CHAIR DIVISION - BIDOFFICE	PO063731	9	LINYA MIDBACK BACK BOARD 11 PLY
10-May	BFM CHAIR DIVISION - BIDOFFICE	PO063731	8	DAZZLE TYPIST SEAT BOARD 9 PLY
10-May	BFM CHAIR DIVISION - BIDOFFICE	PO063731	12	DASHING SEAT BOARD 9PLY
10-May	BFM CHAIR DIVISION - BIDOFFICE	PO063731	6	DASHING BACK BOARD 16PLY
10-May	BFM CHAIR DIVISION - BIDOFFICE	PO063731	6	BUZZ OPERATOR SEAT BOARD 16PLY
10-May	BFM CHAIR DIVISION - BIDOFFICE	PO063731	12	2700 ARMCHAIR SHELL 6PLY
10-May	BFM CHAIR DIVISION - BIDOFFICE	PO063731	6	RE-LAX SEAT BOARD 20 PLY
10-May	CRIMSON MOON FURNITURE MNF	1994	20	T800 HIGH BACK 5 PLY
10-May	CRIMSON MOON FURNITURE MNF	1994	26	GENESIS HB UNCUT 9 PLY
10-May	CRIMSON MOON FURNITURE MNF	1900 REPLACEMENT	1	UTILITY ARM 30 PLY