LASER CUTTING MACHINE: JUSTIFICATION OF INITIAL COSTS

Dwarakish Nagaraja, BS

Thesis Prepared for the Degree of

MASTER OF SCIENCE

UNIVERSITY OF NORTH TEXAS

May 2001

APPROVED:

Ratan Kumar, Major Professor and Coordinator of
Mechanical Engineering Technology
Mark Woodruff, Manufacturing Manager, Montgomery
KONE Inc, Industrial Representative
Philip Foster, Committee Member
Roman Stemprok, Committee Member
Albert B. Grubbs, Jr, Chair of the Department of
Engineering Technology
C. Neal Tate, Dean of the Robert B. Toulouse School of
Graduate Studies

Nagaraja, Dwarakish, Laser Cutting Machine: Justification of initial costs. Master of Science (Engineering Technology), May 2001, 68 pp., 9 tables, 15 illustrations, 14 references.

The Industrial Laser is firmly established in metalcutting as the tool of choice for many applications. The elevator division of Montgomery KONE Inc., in an effort to move towards quality, ontime, complete deliveries and 100% customer satisfaction, decided to invest in new equipment to improve manufacturing processes. A huge investment is proposed for a laser-cutting machine. It is the responsibility of Manufacturing Engineering to direct the management by justifying its benefits, which includes payback time and financial gains. Factors such as common line cutting, automated material handling system and cutting time were involved in justification of the initial cost of a laser-cutting machine. Comparative statistics on appropriate factors accurately determine and justify the initial cost of a laser-cutting machine.

ACKNOWLEDGEMENT

I first wish to express my gratitude to my advisor and major professor Dr. Ratan Kumar. His encouragement and guidance throughout this work was invaluable. Dr. Kumar was available to me even during weekends and late in the evenings to answer my questions.

I also would like to thank Dr. Philip R. Foster, Associate Professor in the Department of Engineering Technology, UNT, who helped me understand the basics of Non-traditional manufacturing techniques. I also thank Dr. Roman Stemprock, Assistant Professor in the Department of Engineering Technology, UNT, who was supportive in all aspects during this work.

I wish to express my sincere gratitude to Mr. Mark Woodruff, Manufacturing Manager, KONE Inc., for providing me with the required resources for this study. I strongly believe that, without Mr. Woodruff's help, this work would not have been completed.

I would also like to thank Mr. Jani Marjamaa, an intern at KONE Inc., for helping me in creating spreadsheets for the data analysis.

Last but not the least, I would like to thank my wife for being a huge moral support during this study.

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

This study is conducted in order to justify the initial costs of a laser-cutting machine for KONE Inc. This work is a feasibility analysis based on various factors relevant to KONE Inc.'s application.

Acquisition of new equipment in a manufacturing environment is a common practice. Expensive equipment is procured to improve the efficiency of current manufacturing processes and to save overall costs. Based on the application in a particular type of industry, machinery is identified, selected, and procured. Justifying the initial cost of the machine identified and selected is essential in order to project the cost benefits and to calculate the payback time.

KONE Inc., one of the world leaders in elevators and escalators manufacturing, is basically a fabrication industry. Most of the traditional manufacturing processes such as shearing machines, press brakes and burn tables are used to make structural steel parts required to build an elevator or an escalator. Elevators are designed to customer's specific requirements. These parts should also be designed for different seismic zones of the world.

Manufacturing custom parts may be difficult with traditional equipment because it calls for different kinds of die sets, punches and other tools to be stored in house. As a result, KONE Inc. had been outsourcing most parts to various fabrication shops in the area. However, company was paying premium prices to get these parts on time. The management realized that the only solution was to invest in equipment that could fabricate most of its structural parts.

The elevator division of KONE Inc., in an effort to move towards quality, ontime and complete deliveries, and 100% customer satisfaction, decided to invest in new manufacturing equipment. It became the responsibility of Manufacturing Engineering personnel to identify the equipment needed and to justify the initial equipment procurement costs. Initial research was conducted in order to identify the equipment, which could benefit the company based on the application.

One sizable investment proposed was a laser-cutting machine. Manufacturing engineering personnel had to justify the benefits, which included the payback time and financial gains of the laser-cutting machine.

1.1 Problem Statement

The objective of this study is to justify the initial cost of the laser-cutting machine for KONE Inc.'s application by including factors such as cutting time, commonline cutting, automated material handling system, and power. A Laser-cutting machine is expensive, with several features and options attached to the base machine. Without generating statistics on these features and options, it is difficult to justify the high initial cost. Previous studies conducted for various other applications by several fabrication industries suggest the inclusion of all factors of the laser-cutting machine to justify initial costs. Comparative study on these factors would help in accurately justifying costs. This study would not only help KONE Inc. but also other elevator manufacturers and similar fabrication industries.

1.2 Purpose

The purpose of this thesis is to generate comparative statistics on common line cutting, cutting time, automated material handling and power of the laser-cutting machine to accurately justify the machine's initial costs. Laser-cutting machines come with various options. The management of KONE Inc. looks for investment payback time and cost savings after procuring the laser-cutting machine with various options.

The laser-cutting machine will reduce outsourcing, which will save the company significant costs and will provide ontime control and complete products delivery. Reduced outsourcing also helps in manufacturing schedule flexibility, which reduces dependency. It also reduces the time lost in product transfer due to shipping inconsistency. Reduction of outsourcing also helps the company in reducing split shipments of the product, which is expensive.

Traditional equipment like shearing machines and punching machines are inefficient in making complicated geometry. The procurement of the state-of -the -art laser-cutting machine will significantly improve productivity and be cost effective.

1.3 Issues addressed in the study

The issues addressed in this study are:

1. Can the initial cost of a laser-cutting machine be justified for KONE Inc.'s application?
2. Can a more powerful machine be justified for KONE Inc.'s application?

3. Can the extra investment for an automated material handling system as an option to the base laser-cutting machine be justified for KONE Inc.'s application?

4. Can faster cutting times help in justifying the initial costs of a laser-cutting machine?

1.4 Statement of Need

There are various concerns regarding the current manufacturing processes being employed at the facility (KONE Inc., McKinney, TX). These concerns lead to finding solutions relevant to KONE Inc.'s requirements.

1. <u>The shearing and punching machines currently used are inefficient</u>. The part shown in figure 1.1 is being manufactured using traditional shearing and punching machines. The geometry of the part is difficult for the traditional machines to handle. Tool changes make the process slow and inefficient. Machines being used are old, depleted and have poor repeatability and accuracy. There are no automated material handling systems attached to the current machines. Therefore, operators are involved in every operation, increasing the risk of operator injuries.

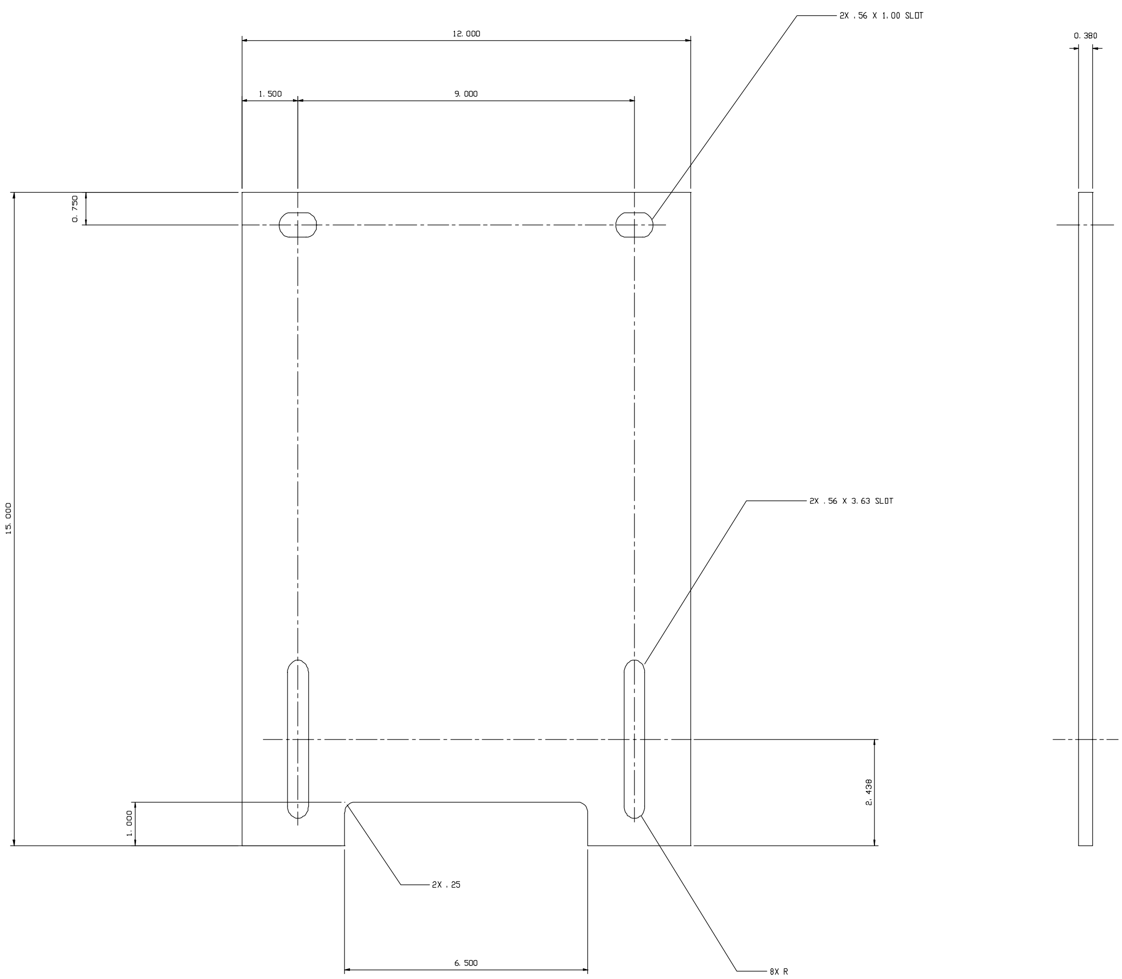

Figure 1.1: Sample part manufactured using traditional equipment

Absence of automated material handling systems also reduces the overall efficiency of the manufacturing processes as a non-value added operation such as material handling by operators is involved.

2. Product Design Flexibility is being compromised. The design engineers have to be very conservative on tolerances and geometry. If tight tolerances are absolutely required, the manufacturing of that particular part is outsourced, which is costly. With the addition of laser-cutting machine with automation, the efficiency of the process will improve and design flexibility will be greatly enhanced, as there will be no custom tooling involved. Skilled labor is required for specific part geometries, which adds operating costs. Without automation, skilled labor is being wasted for non-value-added material handling. Limiting skilled labor and eliminating unskilled labor would eventually save operating costs.

1.5 Research Methodology

Areas included in this section are equipment selection criteria, part selection techniques, identifying the major steps in conducting the study, data collection and the analysis of collected data. The method of this research is descriptive.

There are several types of non-traditional equipment that could be useful for KONE Inc.'s application. Some of them are laser-cutting machine, plasma cutting machine, and abrasive waterjet machine.

Abrasive waterjet machining is extremely noisy. It has high consumable and maintenance costs. It could also be messy due to the fact that abrasives and water used in this process could rebound. Though abrasive waterjet machining has many advantages such as low mechanical and thermal damage to the workpiece, minimal burr production during the process, it was unacceptable to the management of KONE Inc. due to the fact that it was messy and had high maintenance and consumable costs.

Thus, plasma cutting machine and laser-cutting machine were shortlisted for this study.

To determine the best-suited machine for KONE Inc.'s application, the following criteria were considered:

1. Process capability to ensure part accuracy. The manufacturing process should be efficient enough to handle batch production with high repeatability to manufacture parts with required tolerances. The process should be flexible for manufacturing parts of various thicknesses without any significant loss of time in tool changes. The parts manufactured should require minimum or no secondary operations for finishing like deburring or grinding. The process should have minimum setup times. The process should also have a safe and clean work environment.
2. Fast and reliable unmanned operation. The process should be automated in order to reduce labor. Non value added operations like material handling (loading and unloading) should be minimum. The scrap handling or disposal should be efficient. The process should be safe and reliable. Ease of use is an issue as training and retraining costs should be low.

3. Operating costs should be less. The operating costs to run and maintain the equipment should be relatively low. The initial costs of the equipment will evidently affect the operating costs. There are various factors that could affect the operating costs. Cutting speed, consumable costs and maintenance costs are a few of the factors. In order to have low operating costs, cutting speed should be high, consumable and maintenance costs should be low.

Companies of fine plasma and lasers addressed KONE Inc.'s current process and application. Sample pieces of different material thickness were cut using both fine plasma and laser. The observations were:

1. Lasers have one third the operating costs of fine plasma
2. Superior cut quality with the laser
3. Cutting time is shorter with fine plasma
4. Cutting speed drastically decreases for thicker materials with a laser
5. Fine plasma can cut thicker material (1/2" to 1") faster and efficiently without cutting edges being affected
6. Consumable costs with a laser is 1/6th the costs of fine plasma
7. Better aesthetics with a laser including cleanliness

The comparison is tabulated in table 1.1. Looking at the comparison, it was decided that a laser-cutting machine is better suited for KONE's application.

Plasma vs Laser

Selection Criteria	Laser	Fine plasma
Machine cost	-	+
Material Handling	+	0
Consumable costs	+	-
Cutting speed	-	+
Operating costs	+	-
Material thickness	0	+
Service	N/A	N/A
Aesthetics (includes cleanliness)	+	0
Secondary operations (for cutting thicker material)	+	0
Total	**2**	**1**

Table 1.1: Comparison between plasma and laser

Parts that were planned to be cut by the laser-cutting machine were identified based on the following factors: Annual usage, thickness of the material, geometry of the part, and outsourced parts. Annual usage is the total quantity required for that particular year. Thickness of the material selected for this study ranges from ¼ inch through ½inch. Parts, which require more than one operation (like shearing and punching), with many slots and holes, with offset holes and slots that could not be punched using unit tools and parts that could not be manufactured in house were selected for this study. Some parts identified are shown in the figures 1.2 and 1.3.

The decision matrix used in the part selection process is presented in chapter 3. Parts that satisfy at least two of the four factors are included in the study.

One hundred eighteen parts were identified from four thousand parts being manufactured or purchased by KONE Inc.

Mazak Corporation, a leading laser-cutting machine manufacturer provided the software to calculate the cutting time required to manufacture the selected one hundred eighteen parts. Time taken to cut these parts was calculated using the software provided. The cut time generated was used to calculate the cost of the part by adding the material cost and the overhead costs. The cut time was compared with the present time to evaluate the cost differentiation. The cost of the parts that were being outsourced was compared with the new cost to evaluate the cost differentiation.

Depreciating cost for the laser-cutting machine was calculated using the least squares method. Payback time for acquiring this machine was calculated with seven years as the life of the machine (according to the machine manufacturer). Cost savings were calculated based on cutting time comparison.

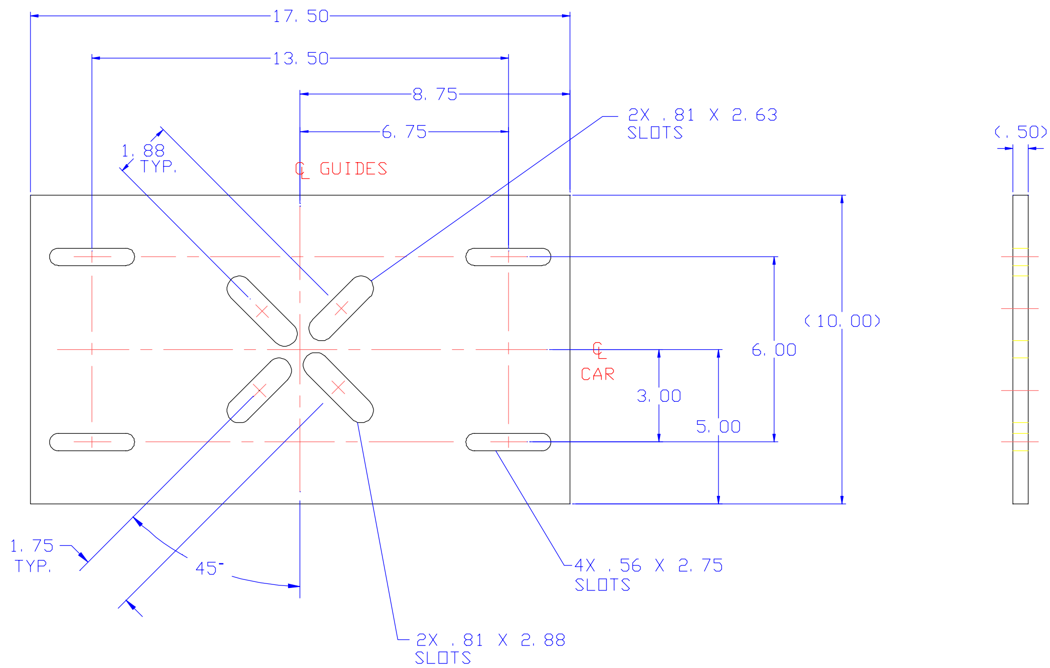

Figure 1.2: Sample part identified for analysis

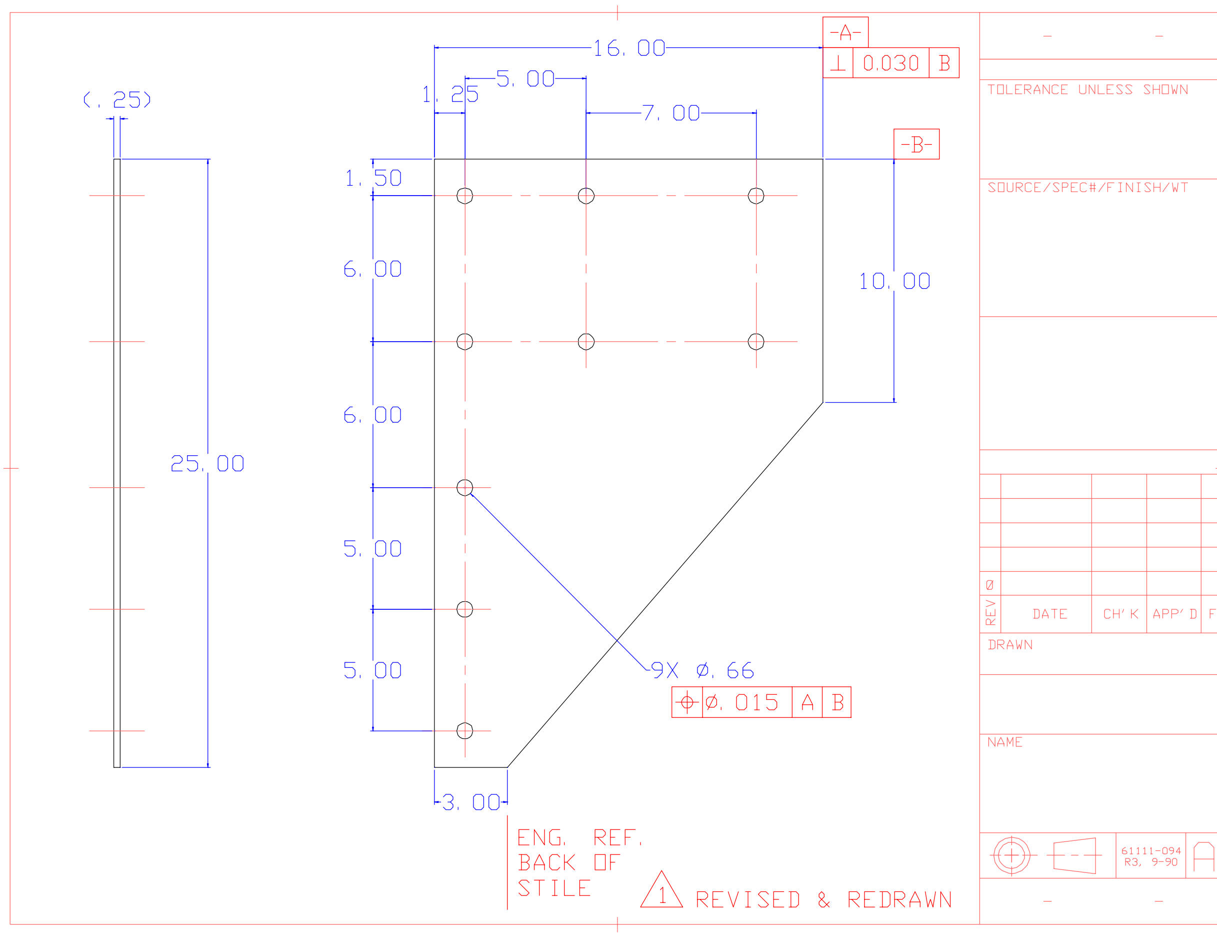

Figure 1.3: Sample part identified for analysis

Conclusions were drawn from these results to provide future research directions. Recommendations on acquiring a laser-cutting machine for the facility (KONE INC.) are based on the pay back time calculated.

1.6 Assumptions

The assumptions applying to the research performed in this thesis are.

1. Operating costs to run a 3 kW laser-cutting machine is the same as a 2 kW machine.
2. Brand names/Manufacturers of laser-cutting machines used in this research will not impact the final results.
3. Cost of labor is the same throughout the time of this study.
4. Cost of electricity and gas remain constant throughout the time of this study.
5. Operator and programmer training costs are the same as in traditional manufacturing.
6. Software provided by Mazak Inc., for calculating cutting times is reliable.
7. The present cost of parts selected for this research is accurate.
8. The scrap recycling cost is negligible.
9. The machine efficiency is 80%.

1.7 Limitations

The limitations that apply to this thesis are

1. The study is limited to KONE part designs, which uses mostly A-36 grade steel.
2. The study will be limited to the 118 parts identified. It is not feasible to include all parts that will be eventually cut on the laser-cutting machine.
3. The study limits the thickness of the material that the laser –cutting machine can handle to ½”. There are several parts ¾” thick which could be cut on the laser-cutting machine. However, low annual usage of these parts limits the inclusion of ¾” parts in this study.
4. Time involved in the justification process is not counted as an expense.

1.8 Overview

This thesis addresses the importance of accurately justifying the initial costs of a laser-cutting machine utilizing commonline cutting, cutting time, automated material handling system and machine power as factors. All these factors are discussed in terms of advantages and disadvantages. This study has been conducted in accordance to KONE Inc.’s applications, and part designs. The study also discusses the importance of including all the factors and options of the laser-cutting machine in the analysis in order to justify the high initial cost.

The purpose of research, problem statement, research questions and questions related to the research method adopted, limitations, and assumptions are discussed in chapter one. Chapter two describes the laser, laser-cutting machine, differences between plasma arc cutting and laser cutting and advantages and disadvantages of each with respect to KONE Inc.'s application. Machine power, commonline cutting, automation and cutting times are also included. Chapter three discusses the methods of analysis data collection and analysis. The actual data is also presented in this chapter. Comparison of previous costs with future cost approximation is also included in this chapter. Payback time and the cost savings are highlighted in this chapter. Chapter four provides the results of the analysis. Conclusions and recommendations are discussed in chapter five and six respectively.

CHAPTER 2

REVIEW OF LITERATURE

This chapter provides an overview of the laser and laser-cutting machine. The principles of the laser beam generation and the technology involved in the laser cutting machine is presented. Previous studies conducted on lasers and laser-cutting machines were reviewed and suggestions and recommendations from those studies were used in the current study.

2.1 LASER

The first LASER (Light Amplification by Stimulated Emission of Radiation) was developed in early 1950's. Principles of current lasers are the same as the first one developed.

A laser beam is generated in a glass tube with a mirror at each end. The laser gas is pumped into the glass and circulated by a turbine. One of the mirrors is 100 percent reflective, and the other is less than 100 percent reflective (usually seventy percent) as shown in figure 2.1. The laser gas can be a mixture of helium, carbon dioxide and nitrogen. This mixture of laser gas is commonly known as a CO_2 laser. There are several other lasing gas mixtures available and in use but, for high powered industrial lasers, the CO_2 mixture is most common.

An external energy source such as electrical power (most commonly DC power) or radio frequency (RF generator) excites the atoms in the laser gas mixture. When the atoms of the laser gas becomes excited, the stimulated gas atoms give off a photon of light. This photon excites other atoms of the laser gas giving off more photons. This forms a chain reaction.

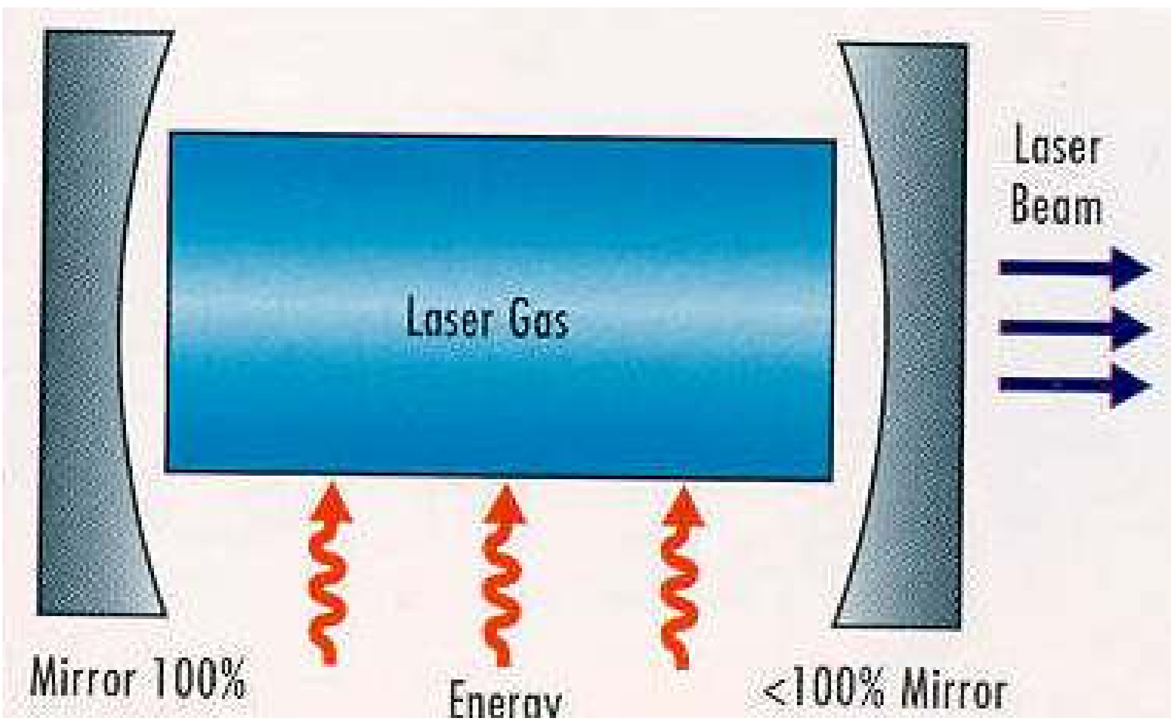

Figure 2.1: Illustration of laser working

The photons generated move back and forth between the two mirrors in the glass tube until a portion escapes through the partially reflective (less than hundred percent reflective) mirror.

Laser beam is monochromatic which means that it has the same frequency. The light beam is coherent which means the frequency is in phase. The laser beam gets its power when this monochromatic and coherent light is focussed.

The laser beam is focussed onto the workpiece to be cut. Matching the focal length of the laser beam to the depth of the cut results in maximum productivity and the best cut quality. The laser beam is “hourglass” shaped after passing through the machine as shown in fig.2.2. The maximum power concentration in the beam is at its “waist” and cuts best at that area. Focal length is measured from the lens to the center of the focus waist. Common industrial focal lengths are 5 inches for thin and sheet metals and 7.5 inches for thicker material.

A 5-inch focal length beam has a shorter ‘waist” than the focal length of a 7.5-inch focal length beam as shown in fig.2.2. In a shorter focal length beam, the angles that form the top and bottom of the hourglass are more acute. This suits the thinner gage material (16 gage – 1/8 inch). However, it may result in poor edge quality in thicker plate material (1/4 inch and above). Due to this fact, it is very important to match focal length to the material thickness.

Energy distribution is an important aspect in lasers. Mode quality in lasers is the energy distribution of the beam through its entire power curve. Mode quality describes how well the energy distribution remains reliable under different power levels.

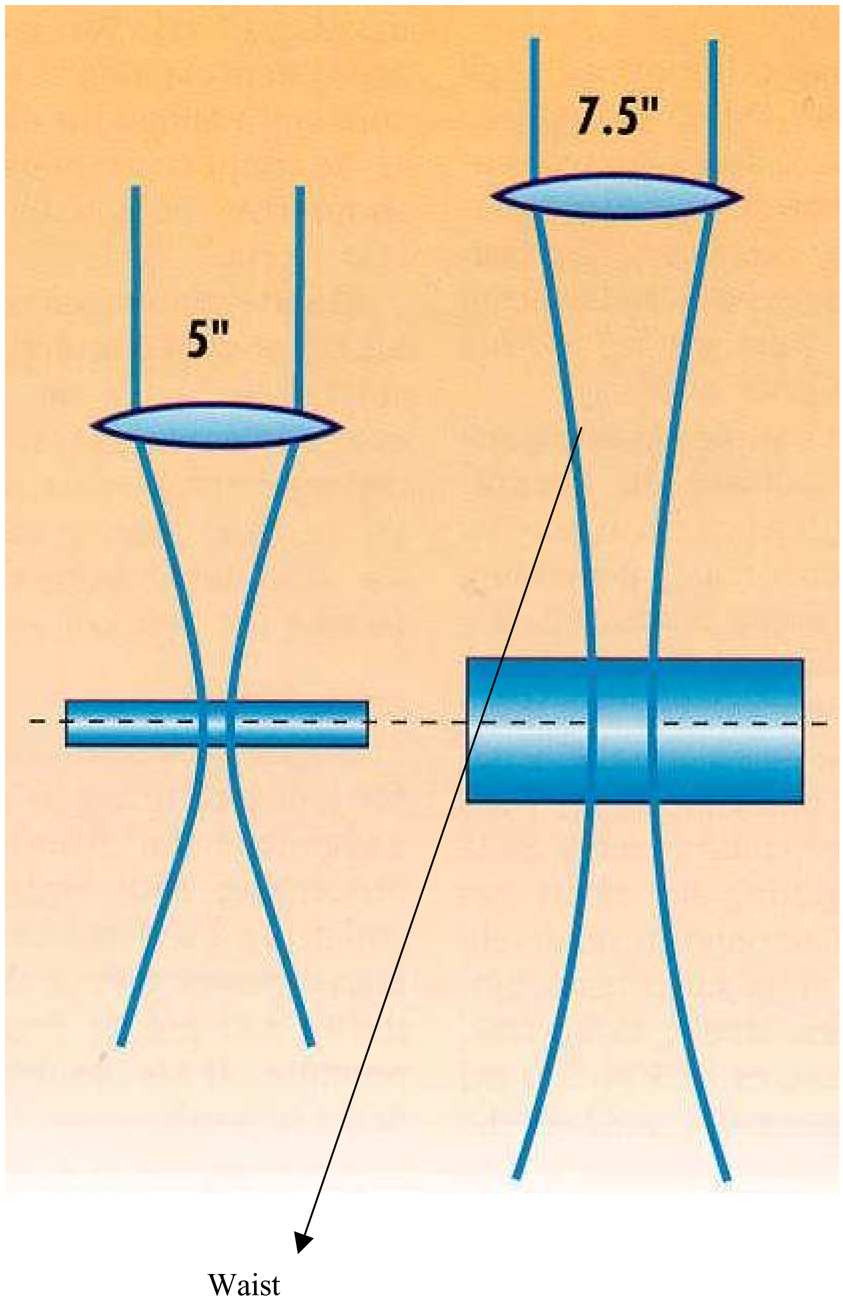

Figure 2.2: Illustration of 5” and 7.5” focal lengths

To maintain to good edge quality, it is extremely critical to maintain a stable discharge of the beam from the glass tube throughout the entire power range in high power lasers.

Stable output design is most often used to create a working beam in lasers up to 2kW. In a stable output design, the beam diverges from the glass tube in a bell curve. This is also known as Guassian mode and is shown in figure 2.3. Technically, its shape is TEM 00, which stands for transverse electromagnetic 00. A laser using an unstable design is called TEM 01 as shown in figure 2.3.

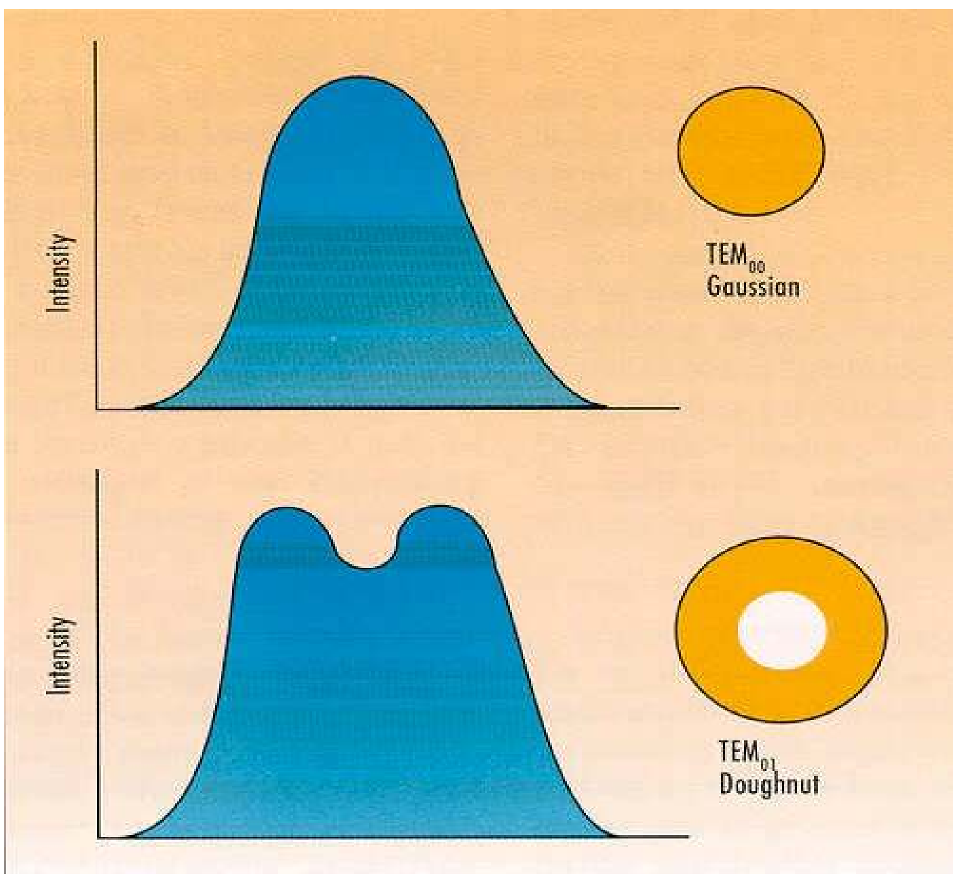

Figure 2.2: Types of laser beams

The term “unstable” does not mean inferior. It is not rare for resonators to use unstable output designs in lasers above 2kW. In an unstable design, the high power beam passes through a different area taking power from the edge of the output mirror creating a different beam profile than the stable output design. Lasers using unstable design have a smaller mirror in the center of the output mirror. In this mode, most of the laser power is around the periphery of the beam and is less concentrated in the center. TEM 01 commonly referred to as a doughnut mode, distributes the high power of the lasers over a larger area, giving consistent beam quality throughout the entire power range.

2.2 Laser-cutting machine

There are two types of industrial CO_2 lasers. CO_2 lasers excited by direct current (DC) and CO_2 lasers excited by radio frequency (RF). Industrial lasers up to 2.2 kW use DC excitation. Lasers above 2.2 kW generally use RF excitation. It is less expensive to manufacture a DC excited laser, and DC excited lasers consume less power than a RF excited laser. However, RF excitation is recommended for more powerful lasers. The main difference between the two is the electrode location. These electrodes excite the CO_2 gas mixture inside the glass cavity. The anode and cathode are located inside the glass cavity in a DC excited laser, whereas, a RF excited laser excites the gas with electrodes mounted externally to the glass cavity.

A DC excited laser gas mixture becomes more unstable at the higher end of 2.2kW. High current being pumped into the glass cavity causes the laser gas to disassociate quickly, which leads to the degradation of the output beam. The poor beam quality results in poor cutting performance of the laser-cutting machine.

As the RF excited laser will not pump high current into the gas mixture directly, it allows the beam quality to be better even at high powers of up to 10kW. Better beam quality is the main reason for RF excited lasers to be better performers in industries which cut thicker material.

Use of solid circuitry to produce the RF excitation in place of vacuum tube technology is the latest development in RF excited lasers. This solid state electronics uses lesser (approximately 50 percent) power than the traditional RF laser. Reductions in power requirements for a more powerful solid state RF laser has made the operating costs almost the same as DC excited lasers. A powerful laser with low operating costs is the main reason for fabrication shops to opt for a powerful laser, which is RF, excited. A more powerful RF excited laser can handle various material thicknesses from sheet metal to plate.

In addition to more powerful lasers, more production flexibility and higher cutting rates, production shops are looking out for more work surface area to maximize the number of parts per sheet of material. Optimum sheet utilization requires larger work tables in laser-cutting machines. Normally, worktable sizes were 96-inch by 48-inch. But, the manufacturing trend is forcing laser manufacturers to stretch worktable sizes. Some machine manufacturers are making machines with 20 feet by 10 feet worktables. These larger worktables not only help in making bigger parts but also help in better use of nesting software which would reduce the scrap.

For this research, it is important to understand the differences between processing with high power lasers and using 2kW or less. Applying the higher power gives the manufacturing plant more flexibility and higher processing speeds. Bigger worktables provide maximum sheet utilization, which translates into savings.

2.4 Features

A potential user will purchase a laser-cutting machine based on the manufacturer's specifications. Typically, after the installation the user expects the machine to cut ¾ inch material the same way it cuts ¼ inch material. When users are unable to get a consistent efficiency, frustration sets in. To avoid frustration, features, options and the variables involved in cutting thicker material should be understood properly. To achieve acceptable quality in a consistent part run, the machine should cut parts with fine striations, without burn out, and with minimal dross. Part tolerances are important with minimal heat affected zone (HAZ). To satisfy these issues, key parameters such as optics, assist gas, material quality and other cutting parameters should be strictly adhered.

1. Optics: The laser beam mode must remain stable, symmetrical, and linearly consistent throughout the entire resonator power curve. If the mode is not symmetric, the cut quality turns out poor. Beam delivery optics and the focussing lens must be aligned well and clean. For larger worktable machines, a collimator is required to ensure minimal beam divergence. A collimator is an adaptive optic (a deformable mirror), in addition to the internal optics of the machine and is typically found in high-powered DC lasers and almost all RF lasers.

2. Assist Gas: There are two types of assist gases that could be used. Oxygen and Nitrogen. Oxygen in the cut process has three basic functions.

   a. Provides energy for the exothermic reaction of iron with iron oxide. The oxygen provides 40 percent of the energy in the cut process and the laser beam provides the rest.

   b. Provides mechanical energy to expel the molten material generated while cutting.

   c. Cools the cut zone and the work piece by means of forced convection.

   Using 99.998 percent pure oxygen increases the cutting speed and improves edge quality. Oxygen flow into the cut zone is directly proportional to the flow of molten material expelled from the cut zone. Increasing nozzle diameter will reduce the gas pressure and will leave the cutting lens susceptible to splatter. Less gas flow can increase the heat build up during piercing and cutting.

3. Material quality: One of the main problems in laser cutting is adjusting plate parameters for a material batch. Quality and consistency of material vary from batch to batch. It is very hard to maintain the same parameters and achieve consistent cuts in different batches of material. Material property inconsistency is due to inconsistency in mill runs and carbon/silicon composition in the material.

Material inconsistency is a great concern for programmers. Emphasis must be placed on material consistency of especially with A-36 grade steel. The surface must be rust free and mill scale. Rust can impede the oxygen's ability to assist in the cut process, causing cut out in certain areas. Often a "laser grade" material is preferred over regular A-36 grade.

4. Cutting parameters: Cutting parameters contribute a significant value in laser cutting. There are several cutting parameters involved in laser cutting:

    a. Piercing: Piercing is a process that starts the cut. Piercing will allow the beam to blow through the material in seconds, causing splatter, which may damage the cutting lens. The programmer can control this parameter by allowing a cool down period between pulses minimizing the heat effect. Pulse piercing reduces heat effect. The size of the pierce should be small to cool down the material between pulses. The best pulse pierce frequencies are between 80-130 Hz with automatic pulse increments of 20-30 percent. Pulse cutting helps reduce heat build up during cutting. Pulse cutting could be best performed at between 200-600 Hz. Pulse cutting is less susceptible to resonant shock waves created by assist gas at higher feed rates.

    b. Cutting speed: The NC program can achieve cutting speed control. Different cutting speeds are used for different material thicknesses. As material thickness increases, cutting speed decreases. Decrease in cutting speeds maintains consistent cut quality. Very slow cut rates might lead to heat build up and create a heat-affected zone (HAZ) around the cut area.

c. Common line cutting: Parts should be nested and processed to minimize the heat-affected zone (HAZ) and reduce tension on the next part cut. Common line cutting cuts parts in alternate group sequence with individual parts alternated. Alternating depends on part contour. There is software available, which optimally nests parts to reduce the HAZ. See figure 2.4. The programmer should take extreme care in part selection when nesting is being used with common line cutting. Web thickness between nested part groups must be equal to or greater than the material thickness in order to evenly dissipate heat.

d. Focus types and position: Focussing systems automatically lower and increase the focal position according to the requirement preventing human error. Minimal heat will be induced in the part utilizing lower pulse frequencies.

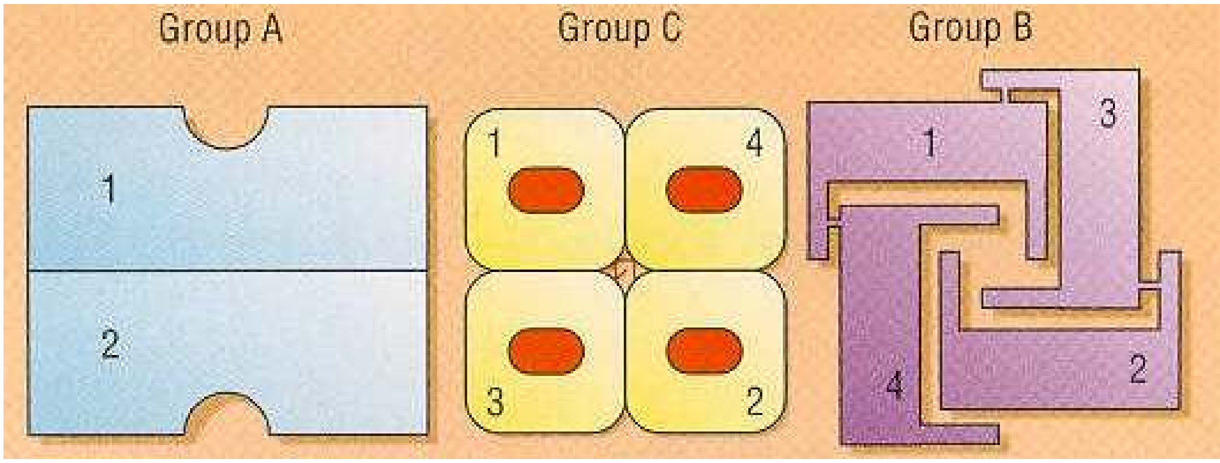

Figure 2.4: Illustration of commonline cutting and nesting

3. <u>Automated material handling</u>. This option, available with most base machines, a load and unload cell attached to the laser-cutting machine which does not require a separate controller. Automated material is an option and could be integrated to the base machine and controlled by the same controller. An automated material handling system would be extremely beneficial for production shops handling heavier gage material. The Automated material handling system makes the whole system safe and efficient and totally unmanned. Figure 2.5 shows an example of an automated material handling system that is integrated into the base laser-cutting machine.

Figure 2.5: Laser-cutting machine with automated material handling

2.5 Relevance in KONE

A significant percentage of KONE parts are structural wall and rail brackets. These bracket designs are shown in the figure 2.6. Most of the bracket designs have slots and holes, sometimes with offsets. Traditionally, these brackets were purchased by KONE from an external source due to the fact that, the manufacturing plant did not have equipment to manufacture these parts in house. With the requirement of these brackets running into thousands of pieces, it was proving expensive to purchase these brackets from an external vendor. To solve this problem, management plans to purchase equipment that has the flexibility, speed and efficiency to manufacture brackets in house.

The review of literature indicates that a laser-cutting machine would be suitable for a fabrication industry like KONE Inc. But as the equipment is relatively expensive, justifying the initial cost of the machine was absolutely required. This justification will help KONE management to invest in a laser-cutting machine to make the process efficient and to save money over time. Calculating payback time would make the justification transparent and easy for management to make a decision to purchase this equipment. The analysis and calculations of cost savings with different options are described in the next chapter.

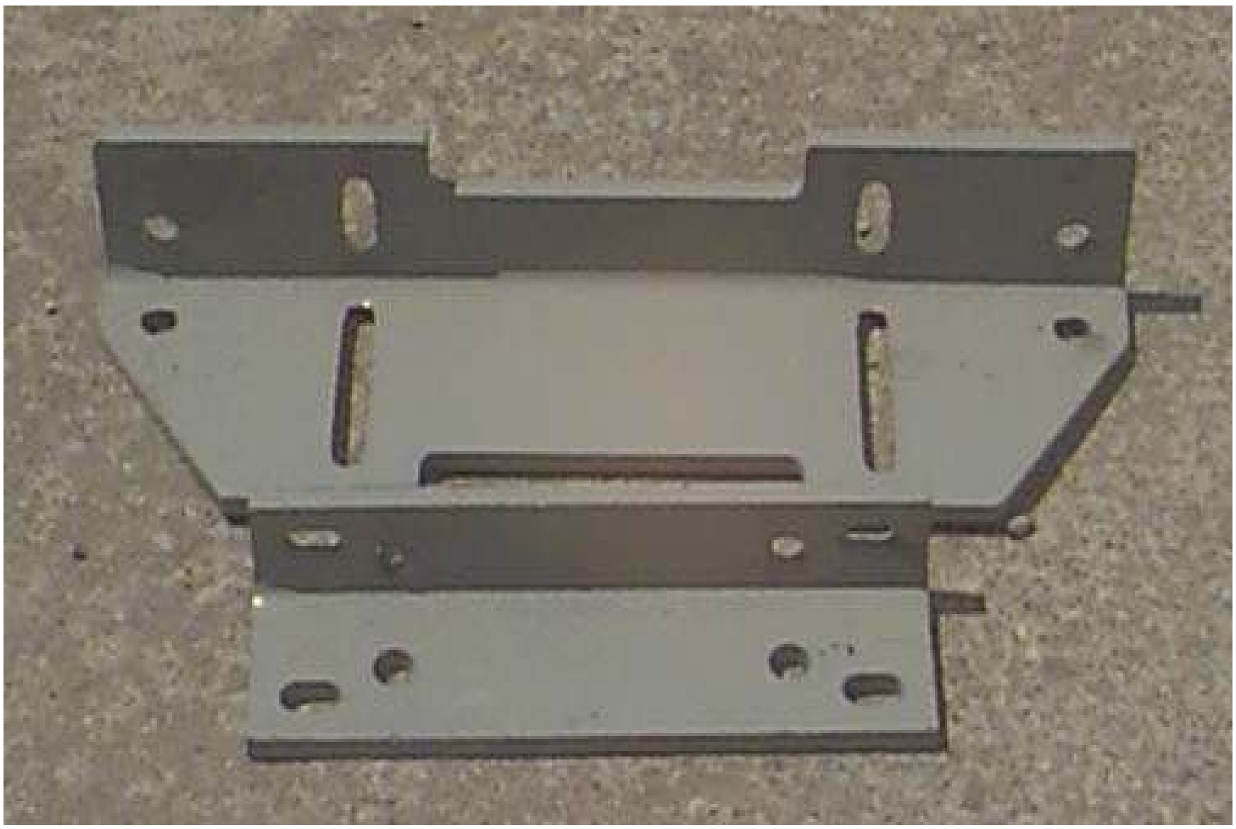

Figure 2.6: Sample of modular brackets included in the study

CHAPTER 3

DATA COLLECTION

To conduct this study, parts to be cut on the laser-cutting machine were identified from several thousand parts manufactured by KONE Inc.

This chapter explains the data collection technique and provides the calculated cutting times for selected parts. Software provided by Mazak Corporation was used to calculate cutting times.

3.1 Parts selection / Identification

Parts to be analyzed were selected according to annual usage, complicated geometry, parts that were being purchased and parts with thickness in the range of ¼ inch through ½ inch. These parts were selected mostly by visual inspection. Suggestions from several department experts were considered in the part selection process. Fabrication experts in KONE Inc. suggested some parts that were difficult to manufacture with traditional shearing and punching machines.

a. Annual usage: Annual usage was one of the main criteria for the part selection process. Any part with an annual usage of less than 600 was not considered for this study. However, KONE Inc. had several unit tools developed over a ten-year period that were being used to manufacture parts with simple designs. Though the annual usage of these parts was high, they were not considered for this study, because experts in the fabrication department believed that it would be easier to manufacture them with traditional equipment.

b. Complicated geometry: KONE Inc., in an effort to standardize the product range, was moving towards standardized European part designs. Some of the North American designs were being changed to the European design. The European part design was more complex in geometry, to reduce some of the custom designs for elevators. The new designs had more flexibility and replaced multiple parts. Research and Development engineers were designing modular brackets with complicated geometry to provide greater flexibility for construction engineers. The traditional equipment available was not capable of making these parts. A sample of the new modular bracket design is shown in figure 3.1.

c. Outsourced parts: Some of the new parts with complicated geometry were being outsourced to fabrication shops due to the lack of proper equipment or tools. Some part designs required very tight tolerances, which was impossible to achieve with the current equipment. A few of the new part designs are illustrated in figures 3.1 and 3.2.

d. Thickness: Most of the parts that are manufactured for KONE Inc. is between ¼ inch and ½ inch thick. There are parts that are more than ½ inch, but not in great quantities.

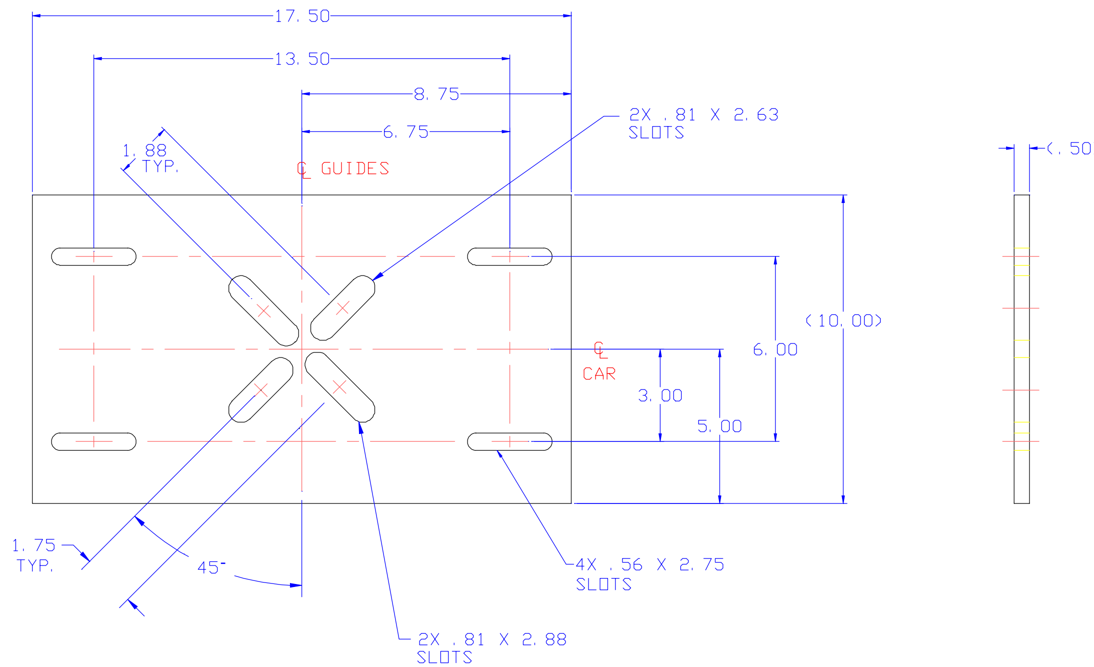

Fig.3.1: Sample of a new modular bracket.

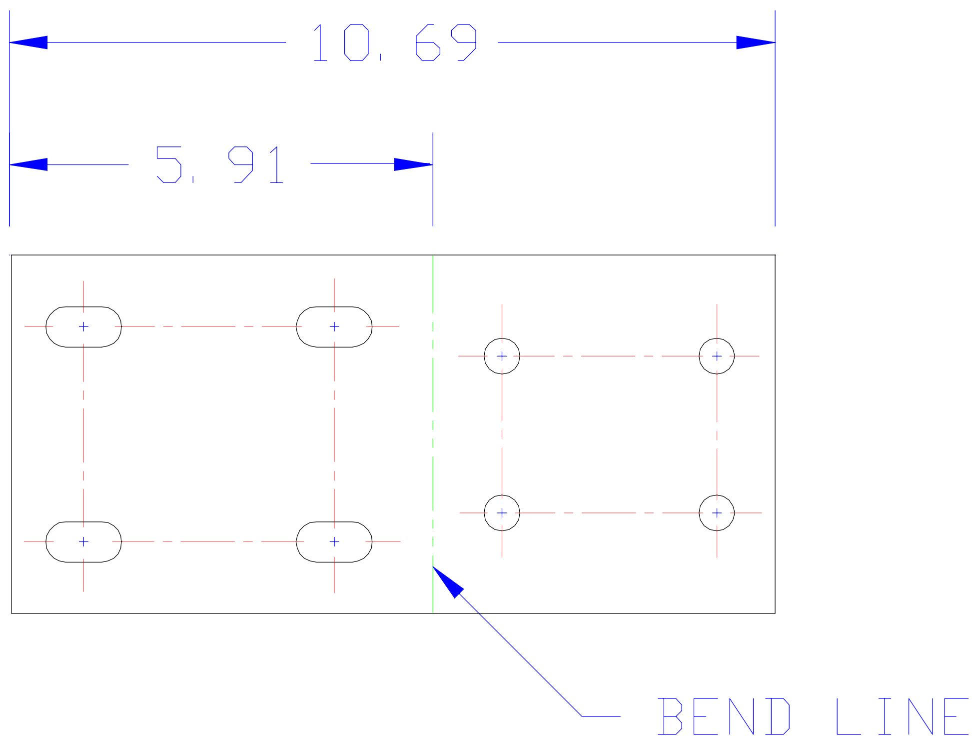

Fig.3.2: Sample of a new part design

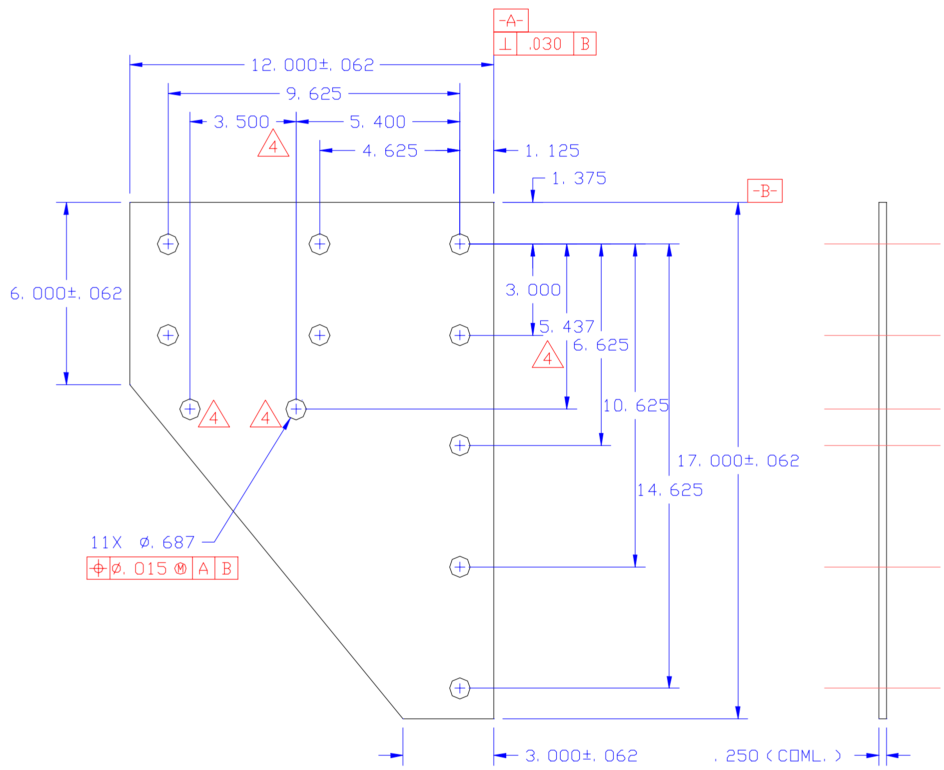

Fig.3.3: Sample of a new part design.

Considering all these factors, a decision matrix was generated to identify the parts for this study. The decision matrix is represented in figure3.4.

From the decision matrix, any part that satisfies at least two factors selected was identified as a part for this study. 118 parts were identified for this study based on the factors selected.

Part #	Annual Usage > 600	Purchased	Complicated geometry	Thickness >= 1/4" and <=1/2"
17161				
43459				
45633				
45634				
46035				
48533				
48817				
50203				
50205				
50342				
50431				
51667				
51864				
52040				
52046				
52051				
52060				
52146				
52173				
52360				
52463				
52464				
52493				
52495				
52496				
52557-001				
52557-002				
52876-002				
52904-001				
61737				
61738				
61739				
61853				
62412				
62413				
62528				
63264				
90802				
91415				
64735-001				
91653				
91655				
41831				

Part #	Annual Usage > 600	Purchased	Complicated geometry	Thickness >= 1/4" and <=1/2"
47772				
47774				
48148				
52039				
52071				
52145				
52460				
52471				
52583-001				
52583-002				
52799-001				
52842-001				
52859-001				
62391				
62449-005				
62450-005				
62965				
62973				
62975				
63278-003				
63314-002				
63314-003				
63581				
63758				
64236-001				
64534-001				
64535-001				
91383				
22514				
42990-005				
43000				
47350				
50576				
50883				
51474				
51563				
52045				
52059				
52121				
52171				
52222				
52443				
52444				

Part #	Annual Usage > 600	Purchased	Complicated geometry	Thickness >= 1/4" and <=1/2"
52533-001				
52537-001				
52567-001				
52829-001				
53225-001				
62164				
62417-006				
63455				
63457				
90362				
91377				
91398				
91399				
91400				
53176-001				
53176-002				
53177-001				
53177-002				
53177-003				
53187-001				
53187-002				
53187-003				
53178-001				
53182-001				
53181-001				
53181-002				
53181-003				
53181-004				
53181-005				
53012-001				
53012-002				
53012-003				
53012-004				
53012-005				
53179-001				
53180-001				

Fig.3.5: Decision matrix generated to identify the parts for this study.

3.2 Calculation of cutting times

After parts identification, time taken to cut these parts, using the software provided by Mazak corporation, was calculated. The software calculates an approximate cutting time when parameters (diameter of the hole, number of holes with that diameter, length and width of slots, the number of slots with those dimensions and the perimeter of the part) are provided. Power of the machine is also considered when cutting times are calculated. A sample calculation is provided for the part shown in figure 3.6.

Table 3.7 represents the time taken to cut each of the selected parts with different laser-cutting machines with different power ratings. The machines included in this study are Mazak 1500 watts and 2500 watts, Bystronic (BTL) 3000 watts, LVD 2000 watts and 3000 watts and Trumpf 3000 watts.

Sample calculation of cutting times

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	DATA			PART #	53177-001								
2	.375 HRS			RAW MATERIAL LOOKUP TABLE									
3	1			AVG DIST BTW DETAILS (POSITION DISTANCE)									
68	.375 HRS												
69	ITEM			QTY	CUTTING LENGTH	FEED RATE (IPM)	CUT TIME (SEC)	PIERCE TIME EA.	TOTAL PIERCE TIME SEC	POSITION DISTANCE	HEAD UP/DN TIME	POSITION TIME	CYCLE TIME (SEC)
70	0.690		HOLES	2	4.3	38	6.8	7.50	15.0	2	1	1.1	23.0
71	3.500		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
72	0.344		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
73	0.505		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
74	0.189		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
75	0.250		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
76	0.750		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
77	0.312		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
78	0.875		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
79	0.281		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
80	0.116		HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
81	0.690	1.500	OBRD HOLES	5	11.4	38	18.1	7.50	37.5	5	2.5	2.8	58.4
82	0.250	1.000	OBRD HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
83	0.295	0.420	OBRD HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
84	0.315	0.866	OBRD HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
85	0.671	2.257	RECT HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
86	0.345	0.345	RECT HOLES	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
87	0.450	0.600	SINGLE D	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
88	0.450	0.600	DBL D	0	0.0	38	0.0	7.50	0.0	0	0	0.0	0.0
89	16.0	5.3	PERIPHERY	1	43	38	67.4	7.50	7.5	1	0.5	0.6	75.4
90	46.0	14.50	PERIPHERY	0	0	38	0.0	7.50	0.0	0	0	0.0	0.0
91											TOTAL SEC.		156.8
92											TOTAL MIN.		2.6
93											TOTAL HOURS		0.044

Fig.3.6: Sample calculation of cutting times using the software provided by Mazak Corporation.

Cutting times

		Mazak	Mazak	BTL	LVD	LVD	Trumpf
		1500W	2500W	3000W	2000W	3000W	3000W
Part #	*Thickness*	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)
17161	1/4"	0.3	0.2	0.2	0.2	0.2	0.2
43459	1/4"	1.7	1.4	1.3	1.2	1.1	1.1
45633	1/4"	1	0.8	0.7	0.7	0.6	0.6
45634	1/4"	0.4	0.3	0.3	0.3	0.3	0.3
46035	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
48533	1/4"	0.9	0.7	0.7	0.7	0.6	0.6
48817	1/4"	1	0.8	0.7	0.7	0.6	0.6
91653	5/16"	1.3	0.8	0.8	1.0	0.8	0.8
41831	3/8"	2.4	1.4	1.6	1.8	1.4	1.4
47772	3/8"	1.1	0.6	0.7	0.8	0.6	0.6
47774	3/8"	1.8	1.1	1.2	1.4	1.1	1.1
48148	3/8"	1.8	1.1	1.2	1.4	1.1	1.1
52039	3/8"	2.4	1.4	1.6	1.8	1.4	1.4
52071	3/8"	2.6	1.5	1.8	2.0	1.5	1.5
52145	3/8"	2.4	1.4	1.6	1.8	1.4	1.4
22514	1/2"	1.5	0.9	0.9	1.0	0.8	0.8
42990-005	1/2"	2.3	1.3	1.4	1.6	1.2	1.2
43000	1/2"	5.3	3.1	3.1	3.6	2.9	2.8
47350	1/2"	4	2.3	2.4	2.7	2.2	2.1
50576	1/2"	1.3	0.8	0.8	0.9	0.7	0.7
50883	1/2"	1.5	0.9	0.9	1.0	0.8	0.8

Table 3.7: Calculated cutting times for some parts selected

The total cutting times per year is listed below in table 3.8.

Total cutting times per year

Mazak	Mazak	Bystronic	LVD	LVD	Trumpf
1500W	2500W	3000W	2000W	3000W	3000W
4790 hrs	3121 hrs	3270 hrs	3519 hrs	2881 hrs	2866 hrs

Table 3.8: Total cutting times per year

3.3 Automated material handling

Automated loading and unloading is an option which is integrated into the laser-cutting machine. This option is useful if the machine is running two or more shifts. The review of literature indicates that the option of a load and unload cell significantly increases efficiency. Manufacturers of laser cutting machines suggest automated material handling systems for fabrication shops that produce standardized products.

Laser-cutting machine efficiency is considered as the actual laser working time. Not included are loading, unloading, programming, setup and maintenance. This efficiency is also known as " green light time". Estimated efficiencies for the following features are as follows:

30-35%	Stand alone machine
45-55%	with shuttle table
70-80%	with load/unload automation
80+ %	with FMS (Flexible manufacturing system)

The total cutting times calculated for machines greater than 2500 watts, indicates 3600 hours to 4100 hours with the load and unload option (80 percent efficiency). The same machine takes 8200 hours to 9300 hours as a stand-alone system. For 4100 hours, the laser-cutting machine should run at least 16 hours a day to cut all identified parts. As Kone Inc. runs two eight hour shifts, running the machine 16 hours a day is possible only with an automated material handling system.

CHAPTER 4

ANALYSIS AND RESULTS

This chapter presents the results and comparisons of costs obtained by cutting selected parts using the laser-cutting machine. The results also indicate a suitable laser-cutting machine, which is recommended for use at KONE Inc. Cost savings calculations are presented in this chapter. Based on cost savings, payback time is calculated. The analysis method is discussed in detail and a sample calculation presented. The cost of different brand names of laser-cutting machines is presented and included in the payback time calculations.

4.1 Comparison / Correlation

After calculating cutting times for the selected parts, costs were calculated based on cutting time, labor costs, operating costs and consumable costs. Previous parts costs were taken from the KONE database. The costs were compared and savings with the laser-cutting machine were tabulated. The comparison shows the cost savings when a laser-cutting machine is used. Table 4.1 lists the calculated costs.

Table 4.1 also provides the total cost per year of individual parts based on annual usage. A sample cost calculation is provided in table 4.2 that considers the operating costs of the laser-cutting machine, including labor costs, maintenance costs and consumable costs required to run the laser-cutting machine.

Cost comparison

Part #	Thickness	Usage	Purchased	Present cost $	Laser cost $	Total Present Cost $	Total Laser cost $
17161	1/4"	5314	0	0.89	0.48	4,740.09	2,550.72
43459	1/4"	603	0	9.00	4.69	5,429.41	2,828.07
45633	1/4"	10,269	0	1.04	1.20	10,669.49	12,322.80
45634	1/4"	4,261	0	0.70	0.48	2,999.74	2,045.28
46035	1/4"	135	0	2.92	1.20	393.80	162.00
48533	1/4"	2,183	0	0.79	1.43	1,726.75	3,121.69
48817	1/4"	240	1	4.24	1.71	1,017.60	410.40
50203	1/4"	489	0	1.72	1.91	843.04	933.99
50205	1/4"	4055	0	3.81	1.96	15,449.55	7,947.80
50342	1/4"	8,595	0	0.78	0.61	6,729.89	5,242.95
50431	1/4"	120	0	17.81	6.77	2,137.20	812.40
51667	1/4"	672	0	2.73	0.69	1,833.22	463.68
51864	1/4"	844	0	4.05	2.04	3,419.04	1,721.76
52040	1/4"	1,122	0	2.24	1.53	2,511.04	1,716.66
52046	1/4"	1,252	0	3.93	2.49	4,920.36	3,117.48
64735-001	5/16"	3061	1	5.44	1.36	16,651.84	4,162.96
91653	5/16"	3095	1	6.63	1.86	20,519.85	5,756.70
41831	3/8"	1,000	0	4.88	3.17	4,884.00	3,170.00
47772	3/8"	3,323	0	3.95	1.71	13,139.14	5,682.33
47774	3/8"	1,404	0	7.08	3.91	9,936.11	5,489.64
48148	3/8"	665	0	4.97	2.74	3,301.73	1,822.10
52039	3/8"	1,082	0	4.50	4.01	4,873.33	4,338.82
52071	3/8"	1,962	0	2.48	3.05	4,855.95	5,984.10
52145	3/8"	2,892	0	4.22	4.20	12,210.02	12,146.40
22514	1/2"	302	0	1.65	1.39	496.79	419.78
42990-005	1/2"	110	0	4.33	3.67	476.08	403.70
43000	1/2"	252	1	15.50	9.27	3,906.00	2,336.04
47350	1/2"	289	0	7.40	3.87	2,138.60	1,118.43
50576	1/2"	176	0	4.31	1.24	759.26	218.24
50883	1/2"	3,228	0	1.11	1.43	3,583.08	4,616.04
51474	1/2"	464	0	2.68	2.75	1,242.13	1,276.00
53176-001	3/8"	2000	1	6.05	2.94	12,100.00	5,880.00
53176-002	3/8"	2000	1	6.05	2.94	12,100.00	5,880.00
53177-001	3/8"	800	1	7.95	3.97	6,360.00	3,176.00
53177-002	3/8"	800	1	7.95	5.00	6,360.00	4,000.00
53177-003	3/8"	800	1	7.95	6.04	6,360.00	4,832.00

Table 4.1: Sample cost comparison

Sample calculation

Labor cost	$ 14.66 / hour	=75%*$19.54 / hour
Laser running costs	$ 43.12 / hour	LVD 3000 W with load / unload automation
Cutting time	1.9 min	Calculated using software provided by Mazak.
Cost of cutting	$ 1.83	=Part cutting time/60*(labor+lasercost)
Part dimensions	7.33 inches	Dimensions of a smallest possible rectangle
	18 inches	Which includes the whole part
Number of pieces / sheet	49	Size of the sheet is 5' x 10' and 90% of the Sheet is being used. =(60"/dim 1 *120"/dim 2)*90%
Cost of raw material	$ 160.48	Cost of a 5'x 10' sheet
Material cost / piece	$ 3.27	=Cost of a sheet / number of pieces in a sheet
Efficiency	80%	With load and unload automation
Number of bends	1	Number of bends in the part
Cost of bending	$ 0.05	=Number of bends*time of operation*labor =Number*(10s/(3600s/hour))*($19.54/hour)
Laser cost / part	$ 5.61	=Laser cutting cost/Efficiency(%) +material cost+cost of bending
Present cost	$ 8.75	Present cost
Savings	35.90%	=(present cost -laser cost)/present cost *100
Usage / year	8000 pieces	Annual usage
Savings / year / part	$ 25,129.95	=usage*(present cost-lasercost)

Table 4.2: Sample calculation in detail (Part number 53182-001)

Operating costs

The Laser works:	16 hours / day 4000 hours / year			
	LVD 3000 W	Bystronic 3000 W	Mazak 2500 W	Trumpf 3000 W
Electricity cost/hr *	$ 4.70	$ 3.90	$ 4.50	$ 3.30
Compressed air cost/hr	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Gas cost/hr	$ 1.50	$ 2.30	$ 2.19	$ 0.23
Maintenance cost/hr	$ 2.20	$ 2.50	$ 4.00	$ 3.00
Consumables cost/hr **	$ 2.31	$ 3.10	$ 2.16	$ 3.00
Running cost/hr	$ 11.21	$ 12.30	$ 13.35	$ 10.03
Machine amortization cost/hr ***	$ 31.91	$ 33.30	$ 36.47	$ 29.85
Machine price	$ 638,200	$ 666,035	$ 729,395	$ 597,000
Operator cost/hr ****	$ 14.66	$ 14.66	$ 14.66	$ 14.66
Total laser operating costs / hr	$ 57.78	$ 60.26	$ 64.48	$ 54.54

* 1kWh=$0.06 (Estimate given by TU Electric)
** Lenses, mirrors etc.
*** 5 years straight line method, M/a=20%*Price/(4000hours)
**** =75%*$19.54/hour

Table 4.3: Calculation of operating costs of laser-cutting machines

LVD, Bystronic, Mazak and Trumpf are the four manufacturers of laser-cutting machines that were selected for this analysis. 2500 W and above machines were selected for this study. To calculate the operating costs, several factors (electricity costs, maintenance costs, gas cost, compressed air cost and consumable costs to run the machine) were required. The total cost of the machine with automation was required. These four machine manufacturers provided information on these factors. Table 4.3 provides the information on these costs. Five year straight-line method was used to calculate machine amortization costs. The statistician at KONE Inc. suggested the use of five-year straight-line method with twenty- percent amortization cost. The calculation was based on the following relation,

M/a = 20 % * cost of the machine / total number of working hours per year

TXU Electric provided electricity costs for this analysis. The labor rate according to KONE Inc. was $ 19.54 per hour. Seventy five percent of the operator's time is involved in running the machine, which includes setup and maintenance. The operator cost is $ 14.66 per hour. The total operating costs to run each selected machine was calculated by adding individual costs. Table 4.3 represents operating costs for the four machines selected.

4.2 Cost savings

Cost savings for all the parts selected for this study was calculated with two machines Mazak 2500 W and LVD 3000W. This was done due to the fact that most of the calculated figures had a five- percent variance. The two machines selected had difference in power and was thus considered. The sample calculations are represented in tables 4.4 and 4.5.

With cutting costs calculated, operating costs were added. This final cost is compared to the present cost available from the KONE database, the cost savings were calculated and sorted according to the machine and thickness of the material. Table 4.4 represents a sample calculation of total cost savings on a LVD 3000W machine. Table 4.5 represents a sample calculation of total cost savings on a Mazak 2500W machine.

Total cost savings for the 118 parts selected was $ 312,000. Based on the quotes provided by the selected machine manufacturers, summary of savings for three of the four machines selected was calculated and is represented in table 4.6.

Cost savings

part #	53182-001	53176-* (1,2)	53177-001	53177-002	53177-003
Cost of cutting	$ 1.83	$ 1.25	$ 1.44	$ 1.63	$ 1.83
Efficiency %	80	80	80	80	80
Secondary operations	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
Material cost	$ 3.27	1.32	$ 2.11	$ 2.90	$ 3.70
New cost/part	**$ 5.61**	**$ 2.93**	**$ 3.96**	**$ 4.99**	**$ 6.04**
Present cost	$ 8.75	$ 6.05	$ 7.95	$ 7.95	$ 7.95
Savings %	35.9	51.5	50.2	37.3	24.1
Usage/year (Pieces)	8000	4000	800	800	800
Savings/year/part	$ 25,140.00	$12,470.00	$ 3,192.00	$ 2,370.00	$ 1,530.00

Table 4.4: Sample cost savings on a LVD 3000W machine

Cost savings

part #	53182-001	53176-* (1,2)	53177-001	53177-002	53177-003
Cost of cutting	$ 2.04	$ 1.40	$ 1.61	$ 1.83	$ 2.04
Efficiency %	80	80	80	80	80
Secondary operations	$ 0.05	$ 0.05	$ 0.05	$ 0.05	$ 0.05
Material cost	$ 3.27	$ 1.32	$ 2.11	$ 2.90	$ 3.70
New cost/part	**$ 5.87**	**$ 3.12**	**$ 4.17**	**$ 5.24**	**$ 6.30**
Present cost	$ 8.75	$ 6.05	$ 7.95	$ 7.95	$ 7.95
Savings %	32.9	48.4	47.5	34.1	20.8
Usage/year (Pieces)	8000	4000	800	800	800
Savings/year/part	$ 23,040.00	$11,720.00	$ 3,022.00	$2,170.00	$1,320.00

Table 4.5: Sample cost savings on a Mazak 2500W machine

Summary of savings

	LVD 3000W	Bystronic 3000W	Mazak 2500W
Modular Brackets	$ 106,067.75 / yr	$ 93,378.28 / yr	$ 98,014.00 / yr
1/4"	$ 87,738.21 / yr	$ 78,578.58 / yr	$ 70,577.49 / yr
5/16"	$ 35,840.07 / yr	$ 35,151.35 / yr	$ 34,650.24 / yr
3/8"	$ 21,833.95 / yr	$ 17,845.23 / yr	$ 19,678.97 / yr
1/2"	$ 61,022.74 / yr	$ 58,110.51 / yr	$ 56,716.84 / yr
Total savings	$ 312,502.72 / yr	$ 283,063.95 / yr	$ 279,637.54 / yr
Machine price	$ 638,200.00	$ 670,485.00	$ 729,395.00

Table 4.6: Summary of savings

4.3 Results

The analysis conducted in the previous section indicates that the acquisition of a laser-cutting machine is justified. The payback period for a high investment value is less than two years for some of the machines selected for this study. The initial cost of the laser-cutting machine was justified for the application at KONE Inc.

The actual cutting time for some of the selected parts was actually cut on TRUMPF 3000W laser cutting machine to verify the accuracy of the analysis. The results have been tabulated in table 4.7.

The result shows that the initial evaluation of the study was conservative and in reality the actual cutting time is much lower than the calculated cutting times.
The graph shown in figure 4.1 shows the comparison between actual cutting times and calculated cutting times.

Actual cutting times vs calculated cutting times

Part #	Thickness	Actual time (min) (TRUMPF 3000 W)	Calculated time (min) using software (TRUMPF 3000W)
50205	1/4"	0.7	0.8
52463	1/4"	0.5	0.5
90362	1/2"	2	2.2
53187-001	3/8"	1.3	1.5
53178-001	1/4"	0.6	0.7
53179-001	3/8"	1.1	1.3

Table 4.7: Comparison between actual cutting times and calculated cutting times

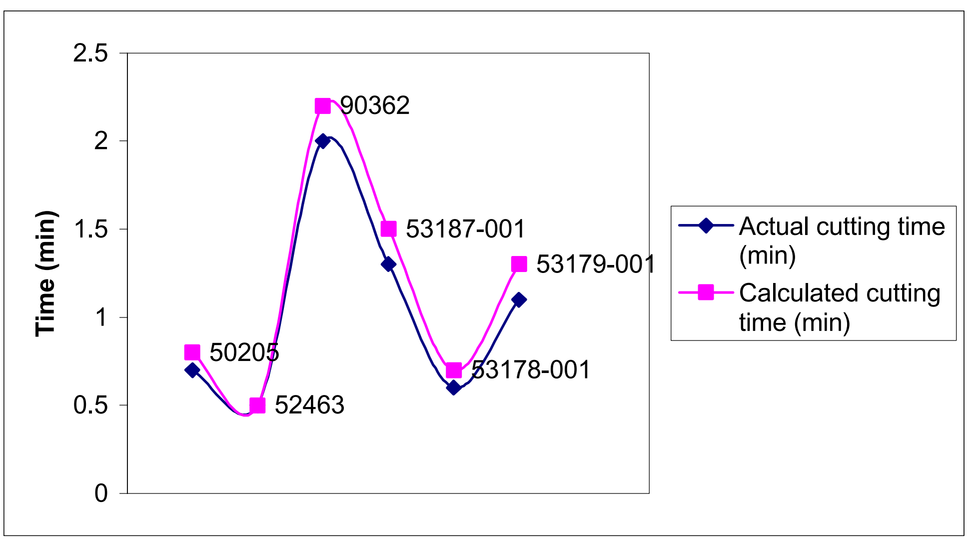

Figure 4.1: Graph showing the comparison between actual cutting time and calculated cutting time

CHAPTER 5

CONCLUSIONS

The objective of this study was to justify the initial costs of a laser-cutting machine for KONE Inc. The primary areas of concern were to identify the equipment required for Kone Inc.'s application and justify its initial cost. After looking at various non-traditional equipment, laser-cutting machine was found suitable for KONE Inc.'s application. After identifying the equipment, the parts that were going to be manufactured using the laser-cutting machine were identified using annual usage, part thickness, complicated geometry and purchased parts as criteria. Any part which could satisfy at least two of the above mentioned four criteria was considered to be a good part for this study.

Using the software provided by Mazak Corporation, a leading laser-cutting machine manufacturer, cutting times for all the one hundred eighteen parts were calculated. Based on the time taken to cut each part, the cost of the part was calculated. Raw material and labor costs were added to the cutting costs. The total cost of each part was then compared to the initial cost of the part, which was available in KONE Inc.'s database. Total cost savings for the hundred and eighteen parts was calculated. The initial cost of the laser-cutting machine with automated material handling system was then compared to the total cost savings to calculate the payback time.

Conclusions derived from this study are:

1. Laser-cutting machine is suitable for KONE Inc.'s application.
2. Substantial cost savings can be achieved in part manufacturing by using laser-cutting machine.
3. Most of the parts that were being outsourced could be manufactured in-house using the laser-cutting machine.
4. Reduction in the number of operations on the manufacturing floor can be achieved.
5. Parts with complicated geometry can be manufactured in-house with the laser-cutting machine.
6. Reduction in unskilled labor can be achieved as the laser-cutting process is automated.
7. Automated material handling system is required for KONE Inc.'s application to reduce overall costs.

CHAPTER 6

RECOMMENDATIONS

In order to accurately justify the initial costs of laser-cutting machine for other applications in various other industries, the following recommendations are proposed.

1. Various other metals should be considered for the study for fabrication shops.
2. Assist gas should be changed in order to get accurate cutting speeds for various other metals.
3. Thickness of the metal should be varied based on the application.
4. Accuracy of the software used for calculating cutting times should be checked periodically by conducting practical tests.
5. The effect of raw material and labor costs changes should be included in the study.
6. Quality of the material used for cutting should be maintained as it affects the cutting time.
7. The cost of skilled labor involved in maintaining the equipment should be considered.
8. The cost of scrap metal should be considered.
9. Various other machine manufacturers should be considered.
10. Further study must be done to find out the validity of the results obtained in this research.

APPENDIX

Calculated cutting times for the parts selected (1/4 inch material)

		Mazak	Mazak	BTL	LVD	LVD	Trumpf
		1500W	2500W	3000W	2000W	3000W	3000W
Part #	*Thickness*	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)
17161	1/4"	0.3	0.2	0.2	0.2	0.2	0.2
43459	1/4"	1.7	1.4	1.3	1.2	1.1	1.1
45633	1/4"	1	0.8	0.7	0.7	0.6	0.6
45634	1/4"	0.4	0.3	0.3	0.3	0.3	0.3
46035	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
48533	1/4"	0.9	0.7	0.7	0.7	0.6	0.6
48817	1/4"	1	0.8	0.7	0.7	0.6	0.6
50203	1/4"	0.9	0.7	0.7	0.7	0.6	0.6
50205	1/4"	1.3	1.1	1.0	0.9	0.8	0.8
50342	1/4"	0.4	0.3	0.3	0.3	0.3	0.3
50431	1/4"	2.1	1.7	1.6	1.5	1.4	1.4
51667	1/4"	0.4	0.3	0.3	0.3	0.3	0.3
51864	1/4"	0.7	0.6	0.5	0.5	0.5	0.5
52040	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
52046	1/4"	1.5	1.2	1.1	1.1	1.0	1.0
52051	1/4"	1.1	0.9	0.8	0.8	0.7	0.7
52060	1/4"	0.5	0.4	0.4	0.4	0.3	0.3
52146	1/4"	0.9	0.7	0.7	0.7	0.6	0.6
52173	1/4"	1	0.8	0.7	0.7	0.6	0.6
52360	1/4"	0.4	0.3	0.3	0.3	0.3	0.3
52463	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
52464	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
52493	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
52495	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
52496	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
52557-001	1/4"	1.9	1.5	1.4	1.4	1.2	1.2
52557-002	1/4"	2.6	2.1	1.9	1.9	1.7	1.7
52876-002	1/4"	1	0.8	0.7	0.7	0.6	0.6
52904-001	1/4"	1.4	1.1	1.0	1.0	0.9	0.9
61737	1/4"	1	0.8	0.7	0.7	0.6	0.6
61738	1/4"	0.5	0.4	0.4	0.4	0.3	0.3
61739	1/4"	1.4	1.1	1.0	1.0	0.9	0.9
61853	1/4"	0.4	0.3	0.3	0.3	0.3	0.3
62412	1/4"	0.8	0.7	0.6	0.6	0.5	0.5
62413	1/4"	1.1	0.9	0.8	0.8	0.7	0.7
62528	1/4"	0.9	0.7	0.7	0.7	0.6	0.6
63264	1/4"	1.4	1.1	1.0	1.0	0.9	0.9
90802	1/4"	0.4	0.3	0.3	0.3	0.3	0.3
91415	1/4"	0.6	0.5	0.4	0.4	0.4	0.4

Calculated cutting times for the parts selected

		Mazak	Mazak	BTL	LVD	LVD	Trumpf
		1500W	2500W	3000W	2000W	3000W	3000W
Part #	*Thickness*	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)
64735-001	5/16"	1.1	0.7	0.7	0.8	0.6	0.7
91653	5/16"	1.3	0.8	0.8	1.0	0.8	0.8
91655	5/16"	0.6	0.4	0.4	0.5	0.4	0.4

Table A.2: Calculated cutting times for 5/16" thick parts

Calculated cutting times for the parts selected

64735-001	5/16"	1.1	0.7	0.7	0.8	0.6	0.7
91653	5/16"	1.3	0.8	0.8	1.0	0.8	0.8
91655	5/16"	0.6	0.4	0.4	0.5	0.4	0.4
41831	3/8"	2.4	1.4	1.6	1.8	1.4	1.4
47772	3/8"	1.1	0.6	0.7	0.8	0.6	0.6
47774	3/8"	1.8	1.1	1.2	1.4	1.1	1.1
48148	3/8"	1.8	1.1	1.2	1.4	1.1	1.1
52039	3/8"	2.4	1.4	1.6	1.8	1.4	1.4
52071	3/8"	2.6	1.5	1.8	2.0	1.5	1.5
52145	3/8"	2.4	1.4	1.6	1.8	1.4	1.4
52460	3/8"	2.2	1.3	1.5	1.7	1.3	1.3
52471	3/8"	2	1.2	1.4	1.5	1.2	1.2
52583-001	3/8"	0.8	0.5	0.5	0.6	0.5	0.5
52583-002	3/8"	0.9	0.5	0.6	0.7	0.5	0.5
52799-001	3/8"	1.3	0.8	0.9	1.0	0.8	0.8
52842-001	3/8"	2.6	1.5	1.8	2.0	1.5	1.5
52859-001	3/8"	1.1	0.6	0.7	0.8	0.6	0.6
62391	3/8"	0.4	0.2	0.3	0.3	0.2	0.2
62449-005	3/8"	1.6	0.9	1.1	1.2	0.9	0.9
62450-005	3/8"	2.4	1.4	1.6	1.8	1.4	1.4
62965	3/8"	1.1	0.6	0.7	0.8	0.6	0.6
62973	3/8"	1.2	0.7	0.8	0.9	0.7	0.7
62975	3/8"	1.1	0.6	0.7	0.8	0.6	0.6
63278-003	3/8"	1	0.6	0.7	0.8	0.6	0.6
63314-002	3/8"	1.3	0.8	0.9	1.0	0.8	0.8
63314-003	3/8"	1.3	0.8	0.9	1.0	0.8	0.8
63581	3/8"	0.8	0.5	0.5	0.6	0.5	0.5
63758	3/8"	1.5	0.9	1.0	1.1	0.9	0.9
64236-001	3/8"	2.5	1.5	1.7	1.9	1.5	1.5
64534-001	3/8"	0.7	0.4	0.5	0.5	0.4	0.4
64535-001	3/8"	2.6	1.5	1.8	2.0	1.5	1.5
91383	3/8"	1	0.6	0.7	0.8	0.6	0.6

Table A.3: Calculated cutting times for 3/8" thick parts

Calculated cutting times for the parts selected

		Mazak	Mazak	BTL	LVD	LVD	Trumpf
		1500W	2500W	3000W	2000W	3000W	3000W
Part #	*Thickness*	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)
22514	1/2"	1.5	0.9	0.9	1.0	0.8	0.8
42990-005	1/2"	2.3	1.3	1.4	1.6	1.2	1.2
43000	1/2"	5.3	3.1	3.1	3.6	2.9	2.8
47350	1/2"	4	2.3	2.4	2.7	2.2	2.1
50576	1/2"	1.3	0.8	0.8	0.9	0.7	0.7
50883	1/2"	1.5	0.9	0.9	1.0	0.8	0.8
51474	1/2"	2.4	1.4	1.4	1.6	1.3	1.3
51563	1/2"	1	0.6	0.6	0.7	0.5	0.5
52045	1/2"	3.1	1.8	1.8	2.1	1.7	1.6
52059	1/2"	1.5	0.9	0.9	1.0	0.8	0.8
52121	1/2"	4.4	2.5	2.6	3.0	2.4	2.3
52171	1/2"	1.2	0.7	0.7	0.8	0.6	0.6
52222	1/2"	6	3.5	3.6	4.1	3.2	3.1
52443	1/2"	2.6	1.5	1.5	1.8	1.4	1.4
52444	1/2"	2.8	1.6	1.7	1.9	1.5	1.5
52533-001	1/2"	0.9	0.5	0.5	0.6	0.5	0.5
52537-001	1/2"	1.9	1.1	1.1	1.3	1.0	1.0
52567-001	1/2"	4.8	2.8	2.8	3.3	2.6	2.5
52829-001	1/2"	4.2	2.4	2.5	2.9	2.3	2.2
53225-001	1/2"	4.6	2.7	2.7	3.2	2.5	2.4
62164	1/2"	2.8	1.6	1.7	1.9	1.5	1.5
62417-006	1/2"	3.9	2.3	2.3	2.7	2.1	2.0
63455	1/2"	2.7	1.6	1.6	1.8	1.5	1.4
63457	1/2"	8.1	4.7	4.8	5.5	4.4	4.2
90362	1/2"	4.2	2.4	2.5	2.9	2.3	2.2
91377	1/2"	1.4	0.8	0.8	1.0	0.8	0.7
91398	1/2"	2.6	1.5	1.5	1.8	1.4	1.4
91399	1/2"	3.2	1.8	1.9	2.2	1.7	1.7
91400	1/2"	1.4	0.8	0.8	1.0	0.8	0.7

Table A.4: Calculated cutting times for 1/2” thick parts

Calculated cutting times for the parts selected

		Mazak	Mazak	BTL	LVD	LVD	Trumpf
		1500W	2500W	3000W	2000W	3000W	3000W
Part #	*Thickness*	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)	Time/piece (min)
53176-001	3/8"	2.2	1.3	1.5	1.7	1.3	1.3
53176-002	3/8"	2.2	1.3	1.5	1.7	1.3	1.3
53177-001	3/8"	2.6	1.5	1.8	2.0	1.5	1.5
53177-002	3/8"	2.9	1.7	2.0	2.2	1.7	1.7
53177-003	3/8"	3.3	1.9	2.2	2.5	1.9	1.9
53187-001	3/8"	2.6	1.5	1.8	2.0	1.5	1.5
53187-002	3/8"	2.9	1.7	2.0	2.2	1.7	1.7
53187-003	3/8"	3.3	1.9	2.2	2.5	1.9	1.9
53178-001	1/4"	1.2	1.0	0.8	0.7	0.7	0.7
53182-001	3/8"	3.3	1.9	2.2	2.5	1.9	1.9
53181-001	3/8"	2	1.2	1.4	1.5	1.2	1.2
53181-002	3/8"	2.2	1.3	1.5	1.7	1.3	1.3
53181-003	3/8"	2.4	1.4	1.6	1.8	1.4	1.4
53181-004	3/8"	2.7	1.6	1.8	2.0	1.6	1.6
53181-005	3/8"	3	1.8	2.0	2.3	1.8	1.8
53012-001	3/8"	2.7	1.6	1.8	2.0	1.6	1.6
53012-002	3/8"	2.9	1.7	2.0	2.2	1.7	1.7
53012-003	3/8"	3.1	1.8	2.1	2.3	1.8	1.8
53012-004	3/8"	3.3	1.9	2.2	2.5	1.9	1.9
53012-005	3/8"	3.5	2.0	2.4	2.7	2.0	2.0
53179-001	3/8"	2.3	1.3	1.6	1.7	1.3	1.3

Table A.5: Calculated cutting times for modular brackets

Cost comparison

Part #	Thickness	Usage	Purchased	Present cost $	Laser cost $	Total Present Cost $	Total Laser cost $
17161	1/4"	5314	0	0.89	0.48	4,740.09	2,550.72
43459	1/4"	603	0	9.00	4.69	5,429.41	2,828.07
45633	1/4"	10,269	0	1.04	1.20	10,669.49	12,322.80
45634	1/4"	4,261	0	0.70	0.48	2,999.74	2,045.28
46035	1/4"	135	0	2.92	1.20	393.80	162.00
48533	1/4"	2,183	0	0.79	1.43	1,726.75	3,121.69
48817	1/4"	240	1	4.24	1.71	1,017.60	410.40
50203	1/4"	489	0	1.72	1.91	843.04	933.99
50205	1/4"	4055	0	3.81	1.96	15,449.55	7,947.80
50342	1/4"	8,595	0	0.78	0.61	6,729.89	5,242.95
50431	1/4"	120	0	17.81	6.77	2,137.20	812.40
51667	1/4"	672	0	2.73	0.69	1,833.22	463.68
51864	1/4"	844	0	4.05	2.04	3,419.04	1,721.76
52040	1/4"	1,122	0	2.24	1.53	2,511.04	1,716.66
52046	1/4"	1,252	0	3.93	2.49	4,920.36	3,117.48
52051	1/4"	2,114	0	1.92	1.71	4,052.54	3,614.94
52060	1/4"	303	0	10.81	0.86	3,274.52	260.58
52146	1/4"	3,083	0	2.78	2.02	8,579.99	6,227.66
52173	1/4"	3,898	0	2.47	1.36	9,612.47	5,301.28
52360	1/4"	208	0	3.30	0.66	685.98	137.28
52463	1/4"	11427	0	4.50	1.56	51,421.50	17,826.12
52464	1/4"	10689	0	4.50	1.56	48,100.50	16,674.84
52557-001	1/4"	404	0	3.98	2.68	1,608.73	1,082.72
52557-002	1/4"	1,824	0	5.15	3.83	9,389.95	6,985.92
52876-002	1/4"	878	0	0.84	1.33	741.03	1,167.74
52904-001	1/4"	840	0	5.44	3.74	4,567.08	3,141.60
61737	1/4"	1,416	0	2.53	1.38	3,579.65	1,954.08
61738	1/4"	2,886	0	1.09	0.69	3,134.20	1,991.34
61739	1/4"	2,886	0	3.60	2.05	10,380.94	5,916.30
61853	1/4"	112	0	5.27	0.63	590.13	70.56
62412	1/4"	1,686	0	3.10	1.69	5,233.34	2,849.34
62413	1/4"	1,686	0	4.47	2.38	7,533.05	4,012.68
62528	1/4"	172	0	7.01	1.77	1,206.41	304.44
63264	1/4"	1,908	0	5.57	3.74	10,625.65	7,135.92
90802	1/4"	346	0	4.99	0.56	1,726.19	193.76
91415	1/4"	659	1	6.50	1.58	4,283.50	1,041.22

Table A.6: Cost comparison between present cost and estimated laser-cutting costs for ¼” material

Cost comparison

Part #	Thickness	Usage	Purchased	Present cost $	Laser cost $	Total Present Cost $	Total Laser cost $
64735-001	5/16"	3061	1	5.44	1.36	16,651.84	4,162.96
91653	5/16"	3095	1	6.63	1.86	20,519.85	5,756.70
91655	5/16"	3059	1	3.69	0.88	11,287.71	2,691.92

Table A.7: Cost comparison between present cost and estimated laser-cutting costs for 5/16” material

Cost comparison

Part #	Thickness	Usage	Purchased	Present cost $	Laser cost $	Total Present Cost $	Total Laser cost $
41831	3/8"	1,000	0	4.88	3.17	4,884.00	3,170.00
47772	3/8"	3,323	0	3.95	1.71	13,139.14	5,682.33
47774	3/8"	1,404	0	7.08	3.91	9,936.11	5,489.64
48148	3/8"	665	0	4.97	2.74	3,301.73	1,822.10
52039	3/8"	1,082	0	4.50	4.01	4,873.33	4,338.82
52071	3/8"	1,962	0	2.48	3.05	4,855.95	5,984.10
52145	3/8"	2,892	0	4.22	4.20	12,210.02	12,146.40
52471	3/8"	247	0	5.52	3.78	1,362.70	933.66
52583-001	3/8"	704	0	2.26	1.22	1,590.34	858.88
52583-002	3/8"	602	0	2.52	1.60	1,517.04	963.20
52799-001	3/8"	153	0	2.18	1.27	334.15	194.31
52842-001	3/8"	649	1	7.35	3.70	4,770.15	2,401.30
52859-001	3/8"	2,302	0	5.83	1.82	13,413.75	4,189.64
62449-005	3/8"	102	0	16.77	2.81	1,710.85	286.62
62450-005	3/8"	101	0	14.88	3.97	1,503.18	400.97
63278-003	3/8"	118	0	6.00	1.67	707.41	197.06
63758	3/8"	148	1	8.50	3.83	1,258.00	566.84
64236-001	3/8"	465	0	6.49	3.81	3,017.39	1,771.65
91383	3/8"	644	0	1.14	0.95	732.23	611.80

Table A.8: Cost comparison between present cost and estimated laser-cutting costs for 3/8” material

Cost comparison

Part #	Thickness	Usage	Purchased	Present cost $	Laser cost $	Total Present Cost $	Total Laser cost $
22514	1/2"	302	0	1.65	1.39	496.79	419.78
42990-005	1/2"	110	0	4.33	3.67	476.08	403.70
43000	1/2"	252	1	15.50	9.27	3,906.00	2,336.04
47350	1/2"	289	0	7.40	3.87	2,138.60	1,118.43
50576	1/2"	176	0	4.31	1.24	759.26	218.24
50883	1/2"	3,228	0	1.11	1.43	3,583.08	4,616.04
51474	1/2"	464	0	2.68	2.75	1,242.13	1,276.00
52045	1/2"	1,134	0	4.07	4.65	4,609.71	5,273.10
52059	1/2"	1,934	0	1.80	1.50	3,483.13	2,901.00
52121	1/2"	739	0	8.53	6.45	6,305.89	4,766.55
52171	1/2"	2,528	0	1.25	1.24	3,147.36	3,134.72
52533-001	1/2"	4,258	0	1.10	0.76	4,692.32	3,236.08
52537-001	1/2"	3,553	0	3.70	2.74	13,160.31	9,735.22
52567-001	1/2"	651	1	13.95	7.49	9,081.45	4,875.99
52829-001	1/2"	126	1	38.31	4.93	4,827.06	621.18
53225-001	1/2"	132	1	17.50	8.95	2,310.00	1,181.40
62164	1/2"	540	0	5.17	3.62	2,793.96	1,954.80
62417-006	1/2"	261	0	11.69	5.91	3,051.35	1,542.51
63455	1/2"	1,096	0	3.35	3.65	3,666.12	4,000.40
90362	1/2"	1,824	1	20.34	11.21	37,100.16	20,447.04
91377	1/2"	1,385	1	20.68	1.52	28,641.80	2,105.20
91398	1/2"	2,636	1	12.45	4.80	32,818.20	12,652.80
91399	1/2"	1,290	1	12.45	4.85	16,060.50	6,256.50
91400	1/2"	1,290	1	7.18	2.65	9,262.20	3,418.50

Table A.9: Cost comparison between present cost and estimated laser-cutting costs for ½” material

Cost comparison

Part #	Thickness	Usage	Purchased	Present cost $	Laser cost $	Total Present Cost $	Total Laser cost $
53176-001	3/8"	2000	1	6.05	2.94	12,100.00	5,880.00
53176-002	3/8"	2000	1	6.05	2.94	12,100.00	5,880.00
53177-001	3/8"	800	1	7.95	3.97	6,360.00	3,176.00
53177-002	3/8"	800	1	7.95	5.00	6,360.00	4,000.00
53177-003	3/8"	800	1	7.95	6.04	6,360.00	4,832.00
53187-001	3/8"	800	1	7.95	3.97	6,360.00	3,176.00
53187-002	3/8"	800	1	7.95	5.00	6,360.00	4,000.00
53187-003	3/8"	800	1	7.95	6.04	6,360.00	4,832.00
53178-001	1/4"	4500	1	8.35	4.00	37,575.00	18,000.00
53182-001	3/8"	8000	1	8.75	5.61	70,000.00	44,880.00
53181-001	3/8"	3000	1	5.70	3.23	17,100.00	9,690.00
53181-002	3/8"	1000	1	8.75	4.69	8,750.00	4,690.00
53181-003	3/8"	500	1	11.05	6.14	5,525.00	3,070.00
53181-004	3/8"	500	1	13.75	7.72	6,875.00	3,860.00
53181-005	3/8"	500	1	16.40	9.30	8,200.00	4,650.00
53179-001	3/8"	2000	1	6.50	2.98	13,000.00	5,960.00
53180-001	3/8"	2000	1	6.50	2.98	13,000.00	5,960.00

Table A.10: Cost comparison between present cost and estimated laser-cutting costs for modular brackets

CHAPTER 8

REFERENCES

1. "PC control cuts machine design time", Control Engineering, Vol. 45, No.6, Apr. 1998, p.21
2. "High-speed laser boosts production," Manufacturing-Engineering, v. 120, No3, Mar. 1998, p. 140
3. "Where to shop for laser-cutting machines," Welding-Design-and-Fabrication, v. 69, Nov. 1996, p. 34-45
4. "Laser-beam cutting expands market," Welding-Design-and-Fabrication, v. 69, Sept. 1996, p. 44
5. "New machines on the market," Welding-Design-and-Fabrication, v. 69, Feb. 1996, p. 29-30
6. Burdel. T, "Should a job shop invest in laser technology?", Welding-Design-and-Fabrication, v. 69, Feb. 1996, p. 25-26
7. Rakowski R, "Cutting system delivers big-league performance", Welding-Design-and-Fabrication, v. 69, Feb. 1996, p. 19-22
8. "Laser-beam cutting enables customization", Welding-Design-and-Fabrication, v. 68, June 1995, p. 29-30
9. Kuvin, B.F, "Spin-arc seam tracker guides turnkey robot cell," Welding-Design-and-Fabrication, v. 67, Oct. 1994, p. 21-3
10. "Laser-beam cutter carves kitchen parts", Welding-Design-and-Fabrication, v. 66, July 1993, p. 50-1

11. “Laser-fabricating center works wonders for auto-prototype maker,” Welding-Design-and-Fabrication, v. 66, Mar. 1993, p. 16

12. Ohnishi K, et al., “Motion Control for Advanced Mechatronics,” IEEE/ASME Trans. on Mechatronics, Vol. 1, No. 1, March 1996, pp. 56-67.

13. Seong H, Tomizuka M, “Robust Motion Controller Design for High-Accuracy Positioning Systems,” IEEE Trans. on Industrial Electronics, Vol. 43, No. 1, February 1996, pp. 48-55.

14. Svirko P, Zheludev N I. Polarization of Light in Nonlinear Optics. Wiley & Son (1998)