

**A Calculation Concept to Reduce Manufacturing Cost on  
Laser Sintering Machines**

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Dissertation submitted in fulfilment of the requirements of the degree

**MAGISTER TECHNOLOGIAE:  
ENGINEERING: MECHANICAL**

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Bloemfontein, January 2008

## DECLARATION

I, Anton Johannes Starz, do hereby declare that this research project submitted to the Central University of Technology for the degree Magister Technologiae: Engineering Mechanical, is my own independent work that has not been submitted before to any institutions by myself or any other person in fulfilment of the requirements for the attainment of any qualification.

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Anton J. Starz

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Date

## ACKNOWLEDGEMENTS

I wish to acknowledge the following people and institutions for their contributions whilst I was working on this project:

- A special thank you to Prof. Dr. DJ de Beer who invited me to write my final thesis of my German study in 2002 at the Science Park in Bloemfontein. During this time we he offered me the opportunity to write this master thesis at the CRPM and supported me with guidance and supervision.
- Prof. M. Truscott for her help, guidance and supervision.
- Mr. LJ Barnard for his help and support during this project.
- Mr. GJ Booysen for his assistance, help and teamwork all the time.
- Messrs. M. Potgieter, D. du Preez, M. Steyn and D. Mauchline for their continuous support. They also introduced me to the South African culture, which enriched my life and broadened my vision for my future.

„Nichts auf der Welt ist mächtiger als  
eine Idee, deren Zeit gekommen ist.“

Nothing on earth is mightier than an idea, which time is come

**Victor Hugo**

Wer zu spät an die Kosten denkt,  
der ruiniert sein Unternehmen.

Wer immer zu früh an die Kosten denkt,  
tötet die Kreativität.

Who thinks too late about costs has ruined its company.

Who thinks always too early about costs kills the creativity.

**Philip Rosenthal, German Entrepreneur (1916-2001)**

## SUMMARY

A company's ability to produce products faster and more economically may lead to a competitive edge in the international market. The reduction of development costs and shortened development time will undeniably depend on effective organisational structures that are based on effective information- and communication techniques and manufacturing technologies. An innovative manufacturing technology that impacts on rapid product development is Rapid Prototyping (RP). The Centre for Rapid Prototyping and Manufacturing (CRPM) works closely with South African companies, supporting them with common mechanical engineering solutions and specialising in the manufacturing of prototypes. One of the options offered in the manufacture of prototypes is the Laser Sintering (LS) process. It is however, difficult to determine the product cost for the building volume used to manufacture the prototypes. Prototypes from different clients can be manufactured at the same time in the same process. The problem however, is how to calculate the costs for each prototype and to offer the clients an accurate quotation for the manufacture of the prototype. Therefore, it is necessary to design a calculation concept, which includes all accrued costs and allocate these to the different parts/prototypes. As it is problematic to calculate the manufacturing cost of prototypes, it is necessary to analyse all the effects, parameters and influences on the manufacturing process in order to determine the manufacturing time, and ultimately the machine costs. This is needed to calculate the total cost of one platform and the cost of each individual part. The project, through various experiments determined how to allocate the costs, through a correlation between part volume and platform height. The aim of the study was to determine a calculation concept to estimate the total platform cost

and the cost of each individual part. Furthermore, the estimated cost was compared with the actual cost to determine the deviation between the calculation methods, and lead to a calculation concept that can be used to predict and reduce the manufacturing costs. The results obtained from the research were used for an exact calculation and reduction of prototype unit costs manufactured on LS machines, which gave three basic advantages:

- Manufacturing costs were reduced to benefit clients, which meant that they could invest more in the design of new prototypes and products, to improve customer satisfaction
- Prototype manufacturing on expensive RP machines could be optimised by using more prototypes and lower costs for entering the market.
- The calculation risk could be minimised, which lowered the risk of losing money on a project and resulted in better planning for available resources.

## **OPSOMMING**

'n Maatskappy se vermoë om produkte vinniger en meer ekonomies te produseer, kan tot 'n kompeterende voordeel in die internasionale mark lei. Reduksie in ontwikkelingskoste en korter ontwikkelingstyd sal oontenseglik van effektiewe organisatoriese strukture afhang, wat weer op effektiewe inligting- en kommunikasie strukture, asook vervaardigingstechnologieë gebaseer is. Snelvervaardiging (SV) is 'n innoverende tegnologie wat op snel produkontwikkeling kan impakteer. Die Sentrum vir Snelprototipering en Vervaardiging (CRPM) werk nou saam met en ondersteun Suid-Afrikaanse maatskappye om hulle met oplossings vir algemene meganiese ingenieursoplossings by te staan deur spesialisasie in die vervaardiging van prototipes. Een opsie wat deur CRPM aangebied word, is die Laser Sintering (LS) proses. Dit is egter moeilik om die produkkoste van 'n bou-volume wat gebruik word om 'n prototipe te vervaardig, te bereken. Prototipes van verskillende kliënte kan in een oplaag (en een proses) vervaardig word. Dit is egter problematies om die koste van elke prototipe te bepaal, en aan elke kliënt, akkurate kwotasie vir die vervaardiging van 'n prototipe te lewer. 'n Berekeningskonsep wat alle uitgawes insluit wat vir die vervaardiging van 'n spesifieke prototipe aangegaan word, was dus noodsaaklik. Aangesien dit problematies is om die vervaardigingskoste van 'n prototipe te bereken, was dit nodig om al die effekte, parameters en invloed op die vervaardigingsproses te analiseer, ten einde die vervaardigingstyd en uiteindelik die masjienkoste te bepaal. Laasgenoemde is weer gebruik om die koste per platform en uiteindelik die koste van elke onderdeel te bepaal. Die navorsingsprojek het tot metodes gelei om die koste van individuele onderdele te bepaal, deur middel van 'n

korrelasie tussen tussen onderdeel-volume en platformhoogte. Die doel van die studie was om 'n berekeningsmodel te ontwikkel om totale platformkoste, asook die koste van elke onderdeel te bepaal. Die geskatte koste was voorts met die werklike koste vergelyk om die afwyking tussen die berekeningsmetodes te bepaal, en het tot 'n model gelei wat gebruik kan word om vooruitskattings te maak en vervaardigingskoste te verlaag. Resultate wat behaal is, is gebruik om 'n eksakte berekening en reduksie van prototipering-eenheidskoste wat met behulp van LS tegnologie vervaardig word, en wat die volgende drie basiese voordele bied:

- Vervaardigingskoste is tot voordeel van die kliënt besnoei, wat beteken dat groter investering in die ontwerp van nuwe prototipes en produkte tot bevrediging van die kliënt gemaak kon word.
- Prototipe-vervaardiging op duur SV masjiene kon geoptimeer word deur meer prototipes per oplaag te vervaardig, en wat tot laer produksiekoste vir marktoegang gelei het.
- Die berekeningsrisiko kon geminimaliseer word, wat beteken het dat die risiko om kapitaal op 'n projek te verloor, verlaag word en wat tot beter beplanning vir die beskikbare infrastruktuur gelei het.

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## **ABBREVIATIONS**

3D	Three Dimensional
CAD	Computer Aided Design
CKF	Cost Key Figure
EOS	Electrical Optical Systems GmbH, Planegg/München, D
GF	Glass-Filled
Hplat	Part or platform height
HT	Platform height - manufacturing time
LLM	Layer Laminate Manufacturing
LS	Laser Sintering
MHR	Machine Hourly Rate
MT	Manufacturing Time
MT P1	Manufacturing time for one part
MT P2	Manufacturing time for two parts
NP	Number of parts
PR	Production Rate
PV	Production Volume, Parts Volume
RM	Rapid Manufacturing
RP	Rapid Prototyping
RPD	Rapid Product Development
RT	Rapid Tooling
SLA	Stereo Lithography Apparatus
.STL	Stereo Lithography Language
TC	Total Costs
TPV	Total Platform Volume

V part	Volume of part
V plat	Volume of platform
VUF	Volume Utilisation Factor
VUR	Volume Utilisation Rate
VF	Volume Factor

# CHAPTER 1

## REDUCTION OF MANUFACTURING COSTS ON LS MACHINES

### 1.1 INTRODUCTION

The globalisation of the markets is causing an increase in national and international competition between companies. One way in which local companies and institutions remain competitive is to be creative and flexible in their market. It is therefore necessary to improve their position in the marketplace by establishing the product first and have a leading edge on competitors. In this context, it is important to use and develop new prototypes economically. Therefore it is a basic requirement to reduce development costs and shorten the development time within a good organisational structure, utilising good information- and communication techniques and manufacturing technologies. An excellent way to manufacture prototypes is to use different Rapid Prototyping (RP) methods [27]. Figure 1.1 reflects the major industrial sectors that are now taking advantage of the technology.

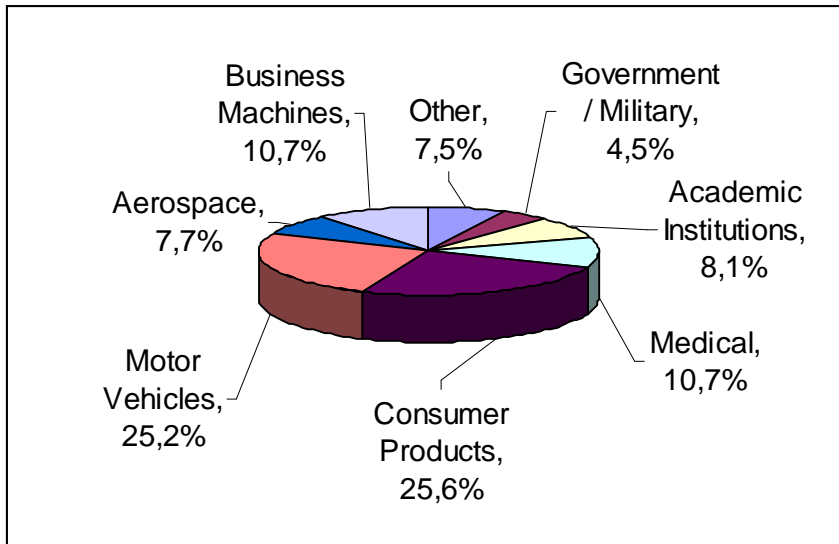


Figure 1.1 Industries being served by RP Technologies [29]

## 1.2 PROBLEM STATEMENT

The Centre for Rapid Prototyping and Manufacturing (CRPM) works closely with South African companies, supporting them with common mechanical engineering solutions and specialising in manufacturing prototypes. One of the options offered in the manufacture of prototypes is the Laser Sintering (LS) process. The prototypes are grown on two LS machines, namely the EOSINT P 380 and EOSINT S 700. It is however, difficult to determine the product cost for the building volume used to manufacture the prototypes. Prototypes from different clients can be manufactured at the same time in the same process. The problem however, is how to calculate the costs for each prototype and to offer the clients an accurate quotation for the manufacture of the prototype. Therefore, it is necessary to design a calculation concept, which includes all accrued costs and allocate these to the different parts/prototypes.

### **1.3 AIM OF STUDY**

There is no accurate usable software available on the market to calculate the manufacturing cost of prototypes. Therefore, it is necessary to analyse all the effects, parameters and influences on the manufacturing process in order to determine the manufacturing time. The manufacturing time multiplied by the machine hourly rate results in the machine costs. This is needed to calculate the total cost of one platform and the cost of each individual part. Experiments will be conducted to determine how to allocate the costs, as there should be a correlation between part volume and platform height. The aim of the study will be to determine a calculation concept to estimate the total platform cost and the cost of each individual part. Furthermore, the estimated cost will be compared with the actual cost to determine the deviation between these two calculation methods. The calculation concept will be used to predict and reduce the manufacturing costs in the future.

### **1.4 HYPOTHESIS**

To calculate the manufacturing time it is necessary to find a correlation with a physical property. This physical property can be platform height, volume and area, which can differ from the material and machine used. Furthermore, the material consumption and waste rate must be determined. The material consumption can be calculated by the build volume multiplied by the specific mass. The waste rate differs between different materials and/or platforms. It must be determined which material percentage rate can be reused for the next manufacturing process and what the waste rate for each platform is.

The results are used to design a calculation concept by only entering a few physical properties. The manufacturing cost is calculated by using the entered data and multiplying it by the data table values. To simulate the resulting costs the entered data can be changed and the manufacturing cost minimised. This can be done either by optimising parts to a platform or placing the parts to get the lowest platform costs.

## **1.5 SCOPE OF STUDY**

The results obtained from the research can be used for an exact calculation and reduction of prototype unit costs manufactured on LS machines, which will give three basic advantages:

- The manufacturing costs can be reduced and the lower costs passed on to the client. This means that the clients save money and can invest more in the design of new prototypes and products, which will in turn result in customer satisfaction.
- The prototype manufacturing on expensive RP machines can be optimised, by using more prototypes and lower costs for entering the market. Furthermore, wear of the RP machines can be reduced and the durability increased.
- The calculation risk can be minimised, which means that the possibility of losing money on a project is minimised and better planning of the resources is possible.

## 1.6 MASTER THESIS STRUCTURE

The Master thesis structure is based on the analysis of Rapid Manufacturing (RM) in CRPM. It describes the different prototyping technologies and focuses especially on the LS process. It furthermore describes the application of the software and the manufacturing process on LS machines. The analysis involved both machines and materials used. Machine utilisation and hourly rate calculations are investigated to analyse the influence on the manufacturing costs. All the accrued costs are calculated in a Microsoft Excel-based calculation concept. The overhead costs are also determined on a cost allocation sheet to complete the calculation concept. Case studies involved methods to reduce manufacturing costs in the day-to-day operations. The evaluated results give an overview of the manufacturing process and its costs. Figure 1.2 represents a schematic diagram, which outlines the structure of the thesis.

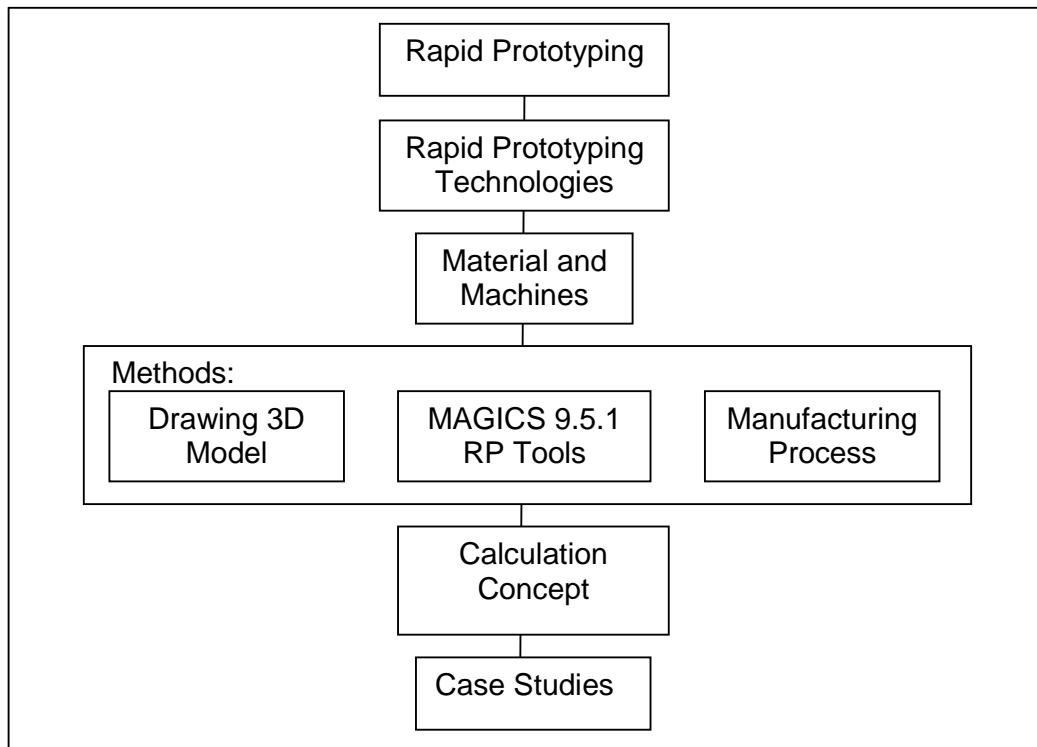


Figure 1.2 Structure of Master Thesis

# CHAPTER 2

## RAPID PROTOTYPING TECHNOLOGIES

The RP technologies will be divided into solid, liquid and gaseous basic material, which can be plastic, metal, paper or sand and can be used as wire, single- or multi component powder or foil. The basic materials dictate the physical process, which will be set in a workable condition and transferred in a workable process to a solid form [27].

### 2.1 RAPID PROTOTYPING, TOOLING AND MANUFACTURING

RP is the collective term for new additive manufacturing methods. These allow the manufacturing of parts, which are built up layer-by-layer – as opposed to the material removal process. In addition the manufacturing of special forms and shapes, e.g. a hollow ball or a ship in a bottle are nearly impossible to manufacture with traditional methods.

Rapid Tooling (RT) has the goal to manufacture tools and moulds through the application of RP technology, which includes pattern making and mould making. The conceptual formulation of RT differs from RP. The CAD data must be generated under manufacturing conditions and for further applications like casting and injection moulding. For these techniques the construction must include mould separation and part ejection, as well as shrinkage factors. The fast availability of tooling makes RT an important factor in the product development and manufacturing process chain. Rapid Prototyping Tools have nearly the same

characteristics as tools made of aluminium or steel. It will depend on the product application whether a laser sintered tool or a steel tool is used.

Rapid Manufacturing (RM) or Rapid Production entails the utilisation of RP technology to manufacture batch parts. With RP technology, a number of parts can be manufactured and parts can be easily changed or adjusted. The advantage of RM is the ability of manufacturing complex products and increasing individuality of the parts. A further application is the production of spare parts. Figure 2.1 shows the application of RP, RT and RM in product development [15].

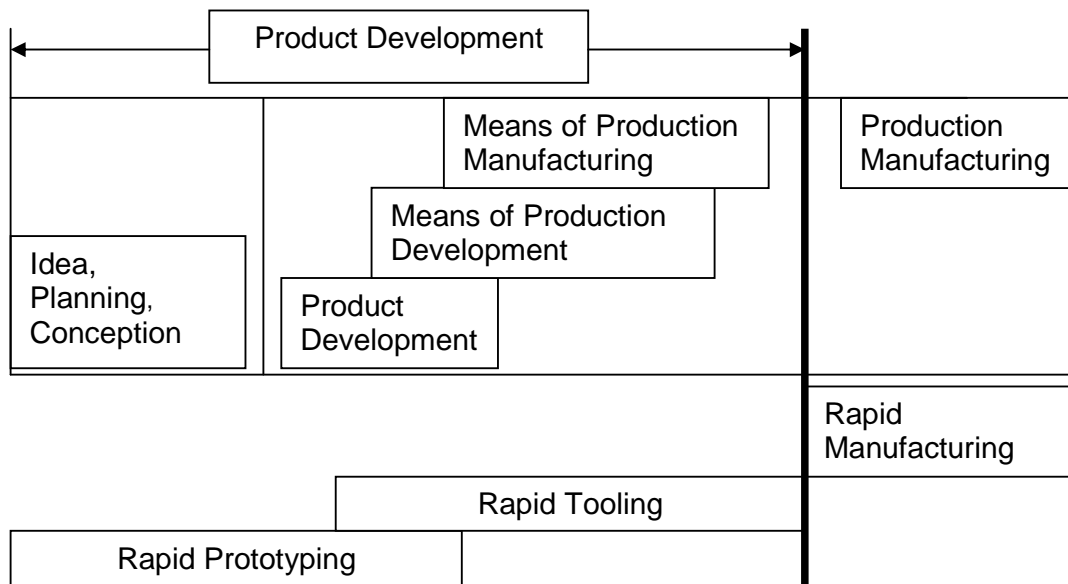


Figure 2.1 Application of RP, RT and RM in the Product Development [15]

### **2.1.1 Advantages and Disadvantages of RP**

The fundamental advantages and disadvantages of RP are transferred over to RM. The benefits of RM must be balanced against its present substantial limitations. Unless there is an overwhelming need for a specific advantage that RM provides, the balance currently favours a conventional approach. However, as technical problems on many fronts are solved, the balance can be expected to tip in favour of RM with greater frequency. The driving force to solve these problems comes from the early adopters whose present applications already possess an overwhelming balance in favour of additive fabrication [18].

### **2.1.2 Geometric Freedom**

Essentially all additive fabrication technologies provide the ability to fabricate with unbounded geometric freedom. It is their most important advantage over subtractive methods and their main reason to exist. Geometric freedom, however comes with several limitations using today's technology. The speed of fabrication compared to standard manufacturing methods is much slower. By some estimates, existing mass production methods are 10 to 1000 times faster [28]. The finishes and accuracy are also not on par with conventional technology. Secondary operations may be required, such as support removal and hand-finishing. In a production situation where multiple parts are fabricated, secondary operations can add up and become time-consuming. There are also part size limitations at present, which are more restrictive than those of standard methods [19].

### **2.1.3 RP with Laser Sintering (LS) Machines**

The application of LS is the ideal solution for fully functional prototypes and series. The polyamide material allows the production of strong, durable parts that can be used for extensive functional testing. Sintered products have mechanical properties comparable to those of injection moulded PA 12 [30] parts. Typical applications are snap fits but it is also possible to produce working hinges. Polyamide parts with glass filling have much higher thermal resistance and are perfectly suited for lighting elements and ventilation systems or products that require high thermal loads. Apart from their use as test products, the functional LS parts often need to be used at the same time for a visual/aesthetical control or dimensional checks.

LS is an interesting and cost-effective alternative to injection moulding. With the EOSINT P 700 machine, which has a large build area, a series of small pieces can be built in one single LS process. This dramatically decreases the price, as the costs of an LS part depend on its volume. The cost is defined by the amount of powder it takes to build it and not by the initial investment in an injection moulding tool. Moreover, a series of LS parts are available in a few days. There is no need for high start-up investments, no long lead times to produce a mould and injection mould the parts and no difficulties in case of complex parts [22].

## **2.2 STEREO LITHOGRAPHY APPARATUS (SLA)**

SLA is the best known RP system. It is an additive manufacturing process, which uses a laser beam directed by computer onto the surface of a photo curable liquid plastic (resin) to produce copies of solid or surface models.

There are several industrially applied systems using SLA techniques. The most representative system is the SLA from 3D Systems (Valencia, California, USA). It consists of four main components: the slice computer, the control computer, the process chamber and the laser unit. The slice computer reads the triangulated CAD model and cuts it into thin slices according to process parameters. The input for the slice computer is usually a so-called .STL (Stereo Lithography Language) file, which is generated on a CAD workstation. Thereafter, the control computer reads the file provided by the slice computer and allows moving and rotating the different parts of the machine (elevator, sweeper, mirrors, etc.) during the manufacturing period. The process chamber is the "heart" of the system. Initially, the elevator is located at a distance from the surface of the liquid equal to the thickness of the first layer. The laser beam will then scan the surface following the geometry of the slice. The liquid is a photo polymeric fluid which, when exposed to the UV laser beam, solidifies by low energy absorption. When the laser beam has completely "written" the first layer, the elevator is moved downwards and the following layers are produced as the first. Finally, the part is removed from the vat and completely cured in a special UV post-cure apparatus. Because the part is built in a liquid environment and the interior of the part contains liquid, it is necessary to add support structures. These are used to hold the parts in place while the layers are being built and to maintain the structural integrity of the part.

The support structures attach the part to the elevator platform (a perforated steel plate) and have to be removed when the part is completely manufactured [25].

Figure 2.2 shows a schematic diagram of the SLA [1].

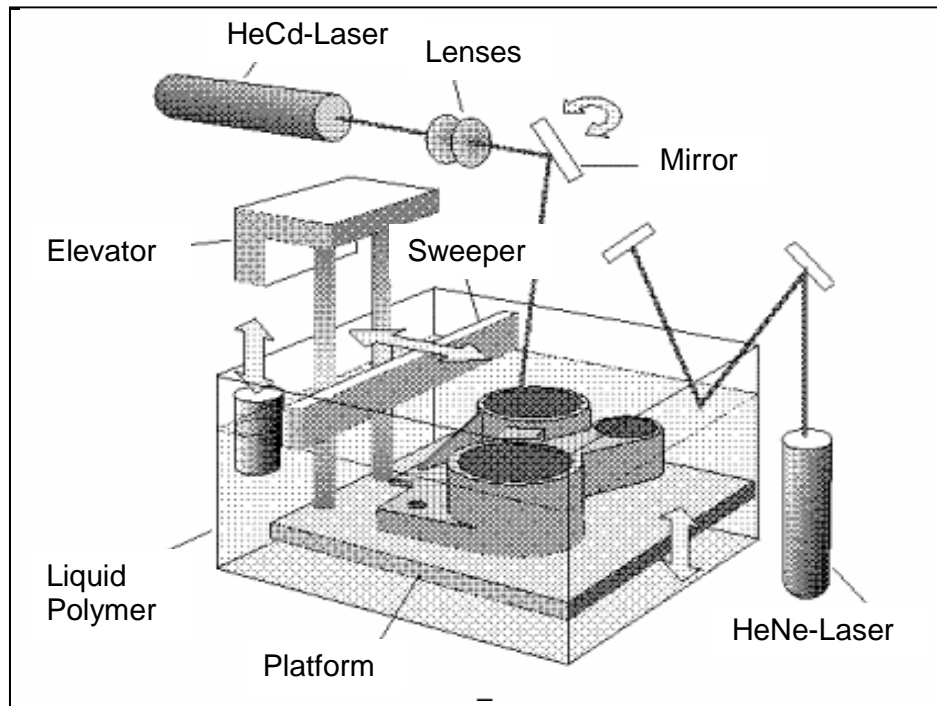


Figure 2.2 Schematic Diagram of SLA [1]

### 2.2.1 Application Range

Typical usage may include:

- Parts used for functional tests.
- Tools that can be used for pre-series production tests.
- Manufacturing of medical models.
- Manufacturing of electro-forms for Electro Discharge Machining (EDM).
- Form-fit functions for assembly tests [25].

- Prototypes for vacuum casting.

### **2.2.2 Advantages**

- It is possible to manufacture parts that are impossible to produce conventionally in a single process.
- Continuous unattended operation for 24 hours.
- High resolution.
- Any geometrical shape can be made with very little limitations [25].

### **2.2.3 Disadvantages**

- Need of sophisticated sequence of processes.
- Necessity to have support structures (SLA).
- Accuracy not in the range of mechanical part manufacturing.
- Restricted areas of application due to given material properties.
- Labour requirements for post-processing, especially cleaning [25].

### **2.3 LASER SINTERING (LS)**

LS is an additive manufacturing process based on sintering, using a laser beam controlled by a computer onto the surface of metallic or non-metallic powders selectively to produce copies of solid or surface models.

The process operates on the layer-by-layer principle. At the beginning a very thin layer of heat fusible powder is deposited in the working space container. Powder is then preheated to setpoint using infrared heaters. The CO<sub>2</sub>-laser then sinters the powder. The sintering process uses the laser to raise the temperature of the powder to a point of fusing without actually melting it. As the process is repeated, layers of powder are deposited and sintered until the object is complete. The powder is transferred from the powder cartridge feeding system to the part cylinder (the working space container) via a counter rolling cylinder, a scraper blade or a slot feeder. In the unsintered areas, powder remains loose and serves as natural support for the next layer of powder and object under fabrication. No additional support structure is required. An LS system also contains an atmosphere control unit that houses the equipment to filter gas recirculated from the process chamber. It maintains a set temperature of the air flowing into the process chamber.

Theoretically, all thermoplastic materials are usable in the sintering process, implying the materials are able to fuse superficially, returning to their previous volume and specific value after the solidification. Important material properties are low melting temperature and thermal conductivity. These properties are

important to limit the sintering process locally [26]. Figure 2.3 shows a schematic diagram of the LS process [20].

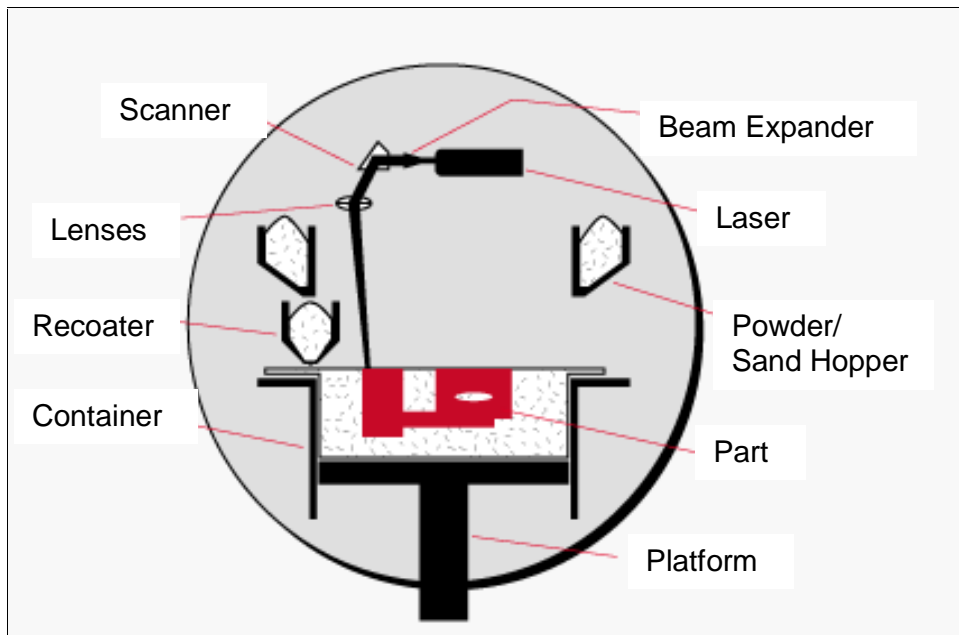


Figure 2.3 Schematic Diagram of LS Process [20]

### 2.3.1 Application Range

Typical usage may include:

- Visual representation models.
- Functional and tough prototypes.
- Cast metal parts (by use of wax).
- Short run and soft tooling [26].

### **2.3.2 Advantages**

- Numerous materials can be used such as polycarbonate, polyvinyl chloride (PVC), nylon, cronin<sup>®</sup> sand for building sand casting cores, metal and polystyrene for investment casting; virtually any material that has decreased viscosity upon heating can potentially be used.
- The part prototypes do not require any post-curing except when Ceramics 5.2 is used.
- Production from powder to part, is generally a same day process.
- There is no need to create structures to support overhanging geometry, saving time during creation of the part, as well as after removing it from the machine [26].

### **2.3.3 Disadvantages**

- During solidification, it may happen that additional powder hardens on the outer surface. This results in a raw appearance of the part surface.
- It is necessary to provide the process chamber continuously with nitrogen to assure safe material sintering.
- Toxic gases emitted from the fusing process have to be handled carefully (especially with PVC).
- The roughness is most visible when parts contain gradual sloping surfaces and a stair step effect created by the layer-by-layer process, becomes increasingly visible [26].

## **2.4 LAMINATED OBJECT MANUFACTURING (LOM™)**

LOM™ is a RP technique for manufacturing of 3D objects based on 3D geometrical data. The starting point is sliced data of the object, which is used for controlling a laser beam that cuts the contours of foil materials. During the process, these foils will be glued together and the desired model is created layer-by-layer. The computer that runs the system is capable of slicing a 3D solid model into thin 2D cross-sections. The thickness of each cross-section is equal to the thickness of the material used in the process. The mechanical part of the system contains an unwinding and rewinding roll connected by a ribbon of sheet material, routed through several idler rollers. These rolls store and supply the material. The laminated part is grown on a platform capable of a vertical incremental movement under the action of a stepping motor. Above the platform there is a heated roller, capable of heating and compressing the ribbon on the stack of laminations on the platform. As a result of a single reciprocal motion of the heated roller the ribbon material is bound to the top of the stack. An X-Y positioning table carries two mirrors that reflect a CO<sub>2</sub> laser beam and a lens that focuses the beam on the upper surface of the laminated stack in order to cut the top layer. Scrap pieces remain on the platform as the part is being built. They are diced by the laser beam into cross hatched squares and serve as a support structure for the part. The product comes out of the machine as a rectangular block containing the part and the cubes, due to a cross hatch cut by the laser and are separated easily from the part. The LOM™ parts have the look, and characteristics of wood [24]. Figure 2.4 shows a schematic diagram of the LOM™ process.

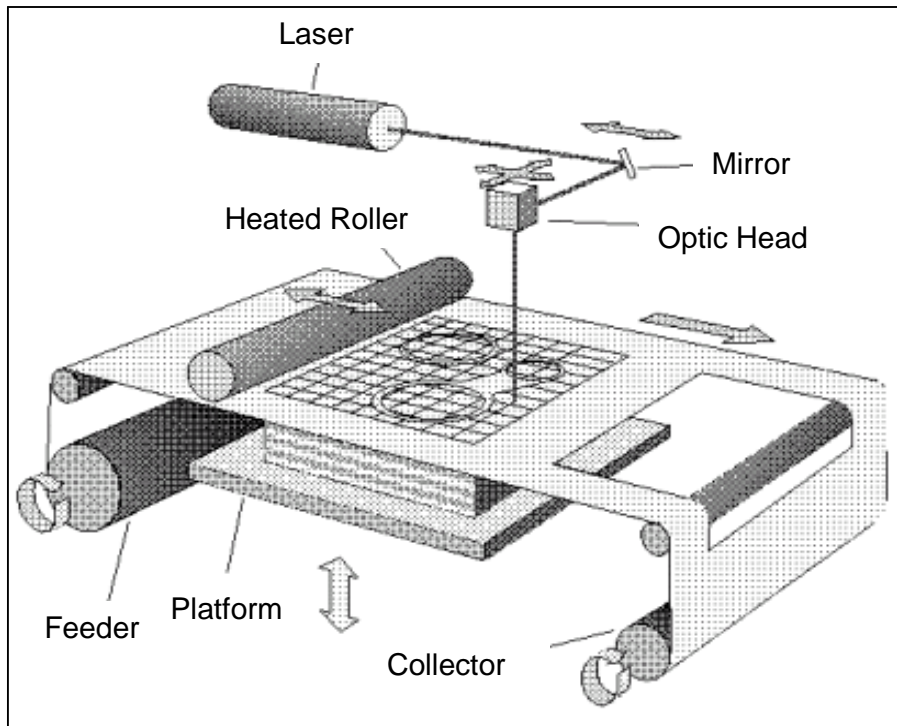


Figure 2.4 Schematic Diagram of LOM™ Process [1]

### 2.4.1 Application Range

Typical usage may include:

- Used for large bulky models such as sand casting patterns [24].

### 2.4.2 Advantages

- A variety of organic and inorganic materials can be used such as paper, plastic, composites, etc.
- The costs are relatively low.
- The process is much faster than competing techniques.

- The process produces virtually no internal stress and associated undesirable deformation.
- LOM™ Slice has the robust capacity of dealing with imperfect .STL files, created with discontinuities, in which the surfaces of .STL objects are not closed completely.
- Best suited for building large parts, these machines have the largest workspace on the market today [24].

#### **2.4.3 Disadvantages**

- The stability of the objects is limited by the bonding strength of the glued layers.
- Hollow parts, like bottles, cannot be built [24].
- Rough stairstep surfaces.

### **2.5 FUSED DEPOSITION MODELLING (FDM)**

The FDM system from Stratasys, USA, consists of the main 3D Modeller unit, slicing software and a workstation. The process starts with the creation of a part with a CAD system as a solid or surface model. The model is then converted into a .STL file and sent to the FDM slicing software. There the .STL file is sliced into thin cross-sections of a desired resolution. Supports are created if required by the geometry and are sliced as well. The sliced model and supports are converted to

a file that contains actual instruction codes for the FDM machine. The FDM machine follows the principle of a three axis CNC-machine. A nozzle, controlled by a computer guides the specific molten material in the X- and Y-planes. The material leaves the heated nozzle in a liquid form, which hardens immediately at the ambient temperature. For this reason, it is fundamental for the FDM process that the temperature of the liquid modelling material is balanced just above the solidification point. A spool of modelling filament with a diameter of 1.27 mm feeds the FDM head. It can be changed to a different material in a short period. Within the building of the desired object the material is extruded and then deposited in ultra thin layers from the lightweight FDM machine layer-by-layer. Recently, Stratasys changed its working principle by using a double extruder head (similar to that of Sanders machines). One nozzle carries the build material, while the other carries a support wax, which can easily be removed afterwards. This allows more complex parts to be built [23].

### **2.5.1 Application Range**

Typical usage may include:

- Conceptual modelling.
- Fit, form and functional applications and models for further manufacturing procedures.
- Investment casting [23].

### **2.5.2 Advantages**

- Quick and low cost generation of models.
- There is no danger of possible exposure to toxic chemicals, lasers, or a liquid polymer bath.
- The system does not waste material during or after producing the model and does not require clean-up.
- Materials can be changed quickly [23].

### **2.5.3 Disadvantages**

- Restricted accuracy due to the shape of the material used: wire of 1.27 mm diameter [23].

## **2.6 THREE DIMENSIONAL PRINTING (3DP™)**

The method is reminiscent of LS, except that the laser is replaced by an inkjet head. The multi-channel jetting head (A) deposits a liquid adhesive compound onto the top layer of a bed of powder object material (B) (Figure 2.5). The particles of the powder become bonded in the areas where the adhesive is deposited. Once a layer is completed the piston (C) moves down by the thickness of a layer. As in SLA or LS, the powder supply system (E) is similar in function to the build cylinder. In this case the piston moves upward incrementally to supply powder for the process and the roller (D) spreads and compresses the powder on the top of the build cylinder. The process is repeated until the entire object is completed within the powder bed. After completion the object is elevated and the extra powder brushed away leaving a so-called "green" object. Parts must usually

be infiltrated with a hardener before it can be handled without much risk of damage. The 3DP™ process has been licensed to several companies. Several additional companies have either optioned or licensed the technology for applications ranging from filtration to figurines. Z Corp. however, is the only licensee that addresses the RP market directly. Z Corp uses the process to create conceptual models out of starch, plaster and other types of powders. The company introduced a colour-capable system in 2000, and greatly improved that technology in 2004 with the introduction of a 24-bit colour system. Figure 2.5 shows the schematic diagram of 3DP™ system [17].

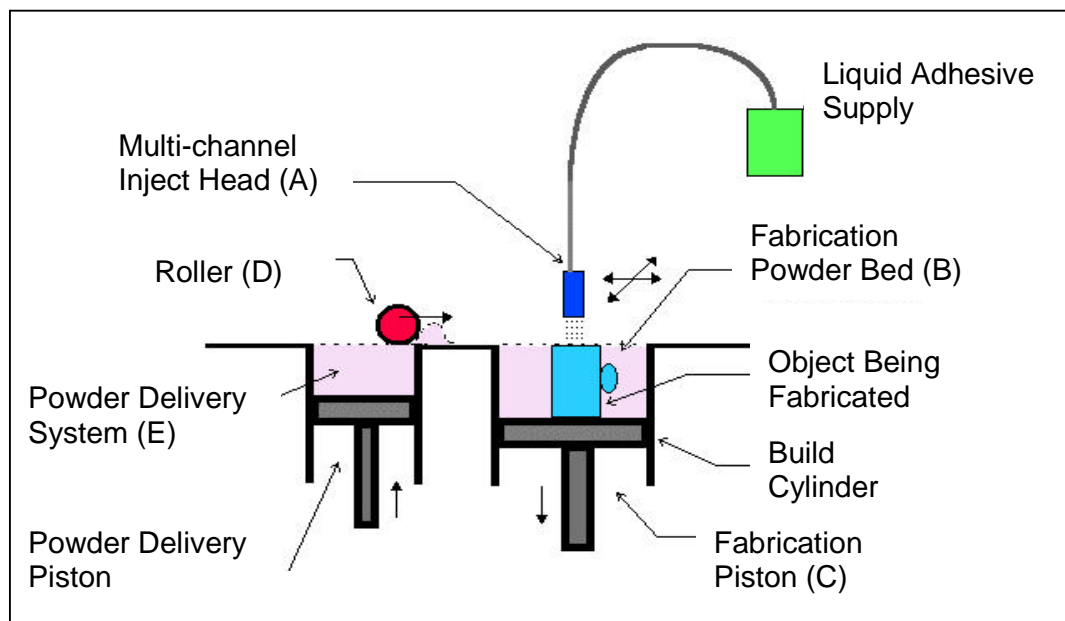


Figure 2.5 Schematic Diagram of 3DP™ [17]

## 2.7 PRODUCTION TECHNIQUES

Figure 2.6 shows the classified overview of production techniques according to the aggregate state of original material. The basic criteria differ between non-metal- and metal materials. Furthermore it is divided into three aggregate states

namely gas, liquid and solid. The solid aggregate state is divided into wire, powder and laminate. The prototype requirements determine the production technique and material to be used. The material can be bound by coagulate, amalgamate or baking.

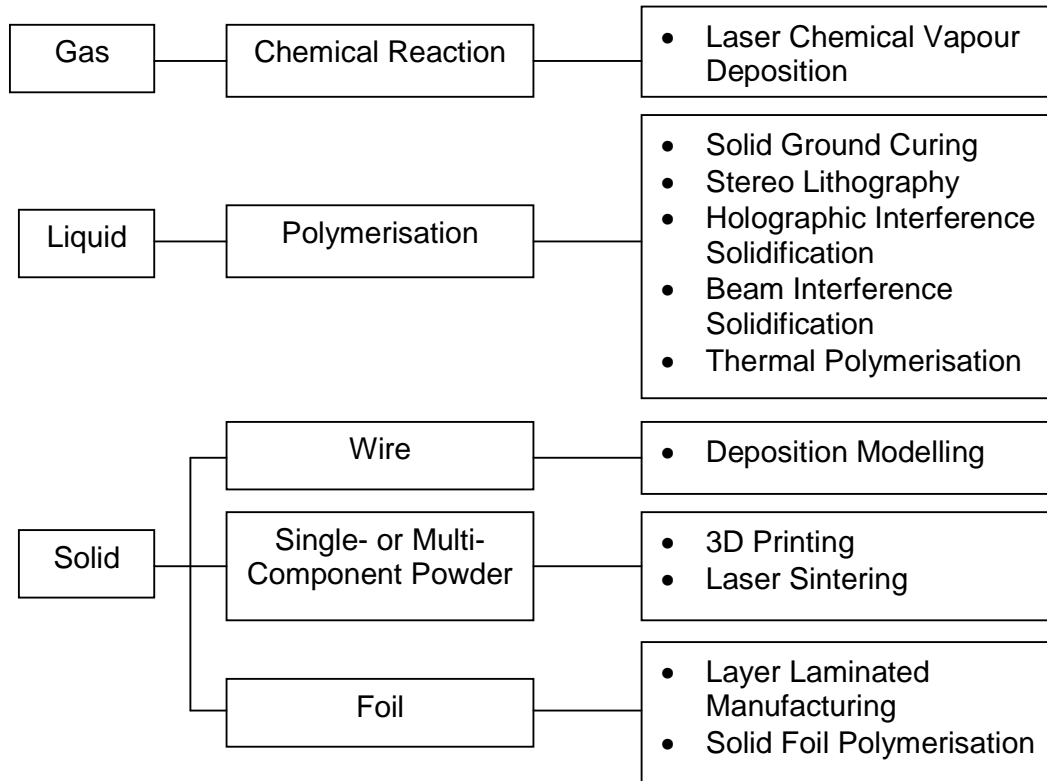


Figure 2.6 Classifying the Manufacturing Techniques according to the Aggregate State of Original Material [1]

Depending on the part's development phase, the model and the material obtains different properties. It depends whether it is a concept model, ergonomic model, function model or technical prototype. The RP production techniques are influenced by characteristics such as fast and cheap concept model production, high accurate and filigree cast models, flexible material range to manufacture function models and a special applicability for tool manufacturing (tooling) [3].

## CHAPTER 3

### LASER SINTERING PROCESS

The LS process describes work-flow to manufacture prototypes with LS machines. The work-flow is divided into four phases. Phase one imports the digital 3D model from a CAD data base. To use the geometrical data, the CAD data are transferred in phase two into a .STL standard format. The generated file is transferred to work in the software programme Magics 9.5.1. Magics 9.5.1 is used for the positioning of the parts, compiling the multi-build platform, adjustment and checking of the parts, placing the parts, saving and exporting the data. Furthermore, the generated platform described by the .STL file must be divided into layers (slices) using the EOS software programme RP-Tools. The result is a sliced platform, which in the LS process builds up the parts by the layer-by-layer principle. The .SLI files generated in this way are copied to the process computer, loaded into a job file and then saved. Material and machine parameters are also saved in the job file. A job file can contain one or more .SLI files. The manufacturing process describes phase three. It includes the work-flow before the RP machine starts and during the building phase. Phase four describes the work-flow after the building phase. It includes the cleaning and checking of the parts. The manufacturing work-flow process is shown in Figure 3.1.

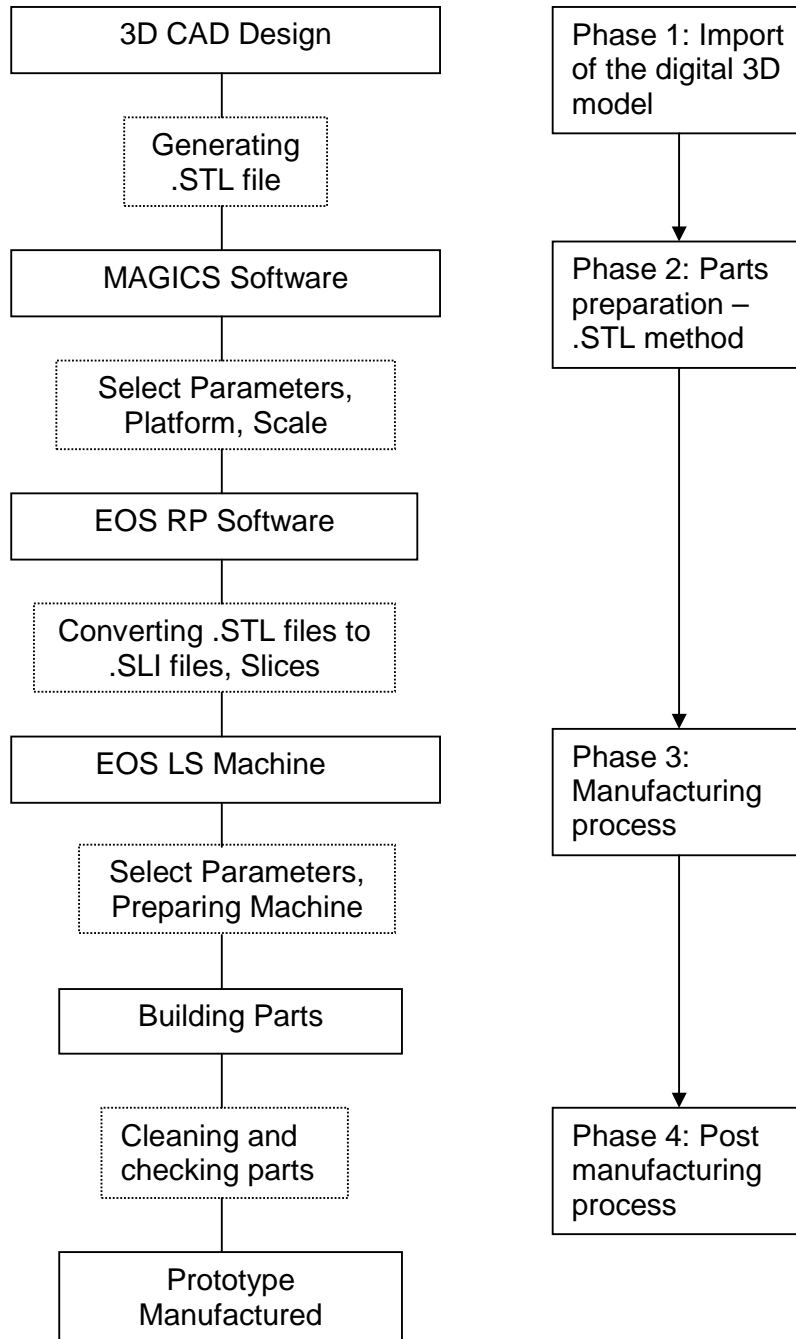


Figure 3.1 Manufacturing Work-flow Process

### 3.1 Magics 9.51

The software programme Magics 9.5.1 is used for 3D nesting of parts on the platform. The parts are opened and loaded in the software to multiply and place them. After checking and saving the platform, the data are prepared to be

exported to the EOS RP-Tools software programme. All important Magics 9.5.1 functions are available in the menu, shortcuts and the button toolbar. The buttons are described with a small text, which appears when the cursor moves over them. Figure 3.2 shows the working surface together with menu and toolbars in Magics 9.51.

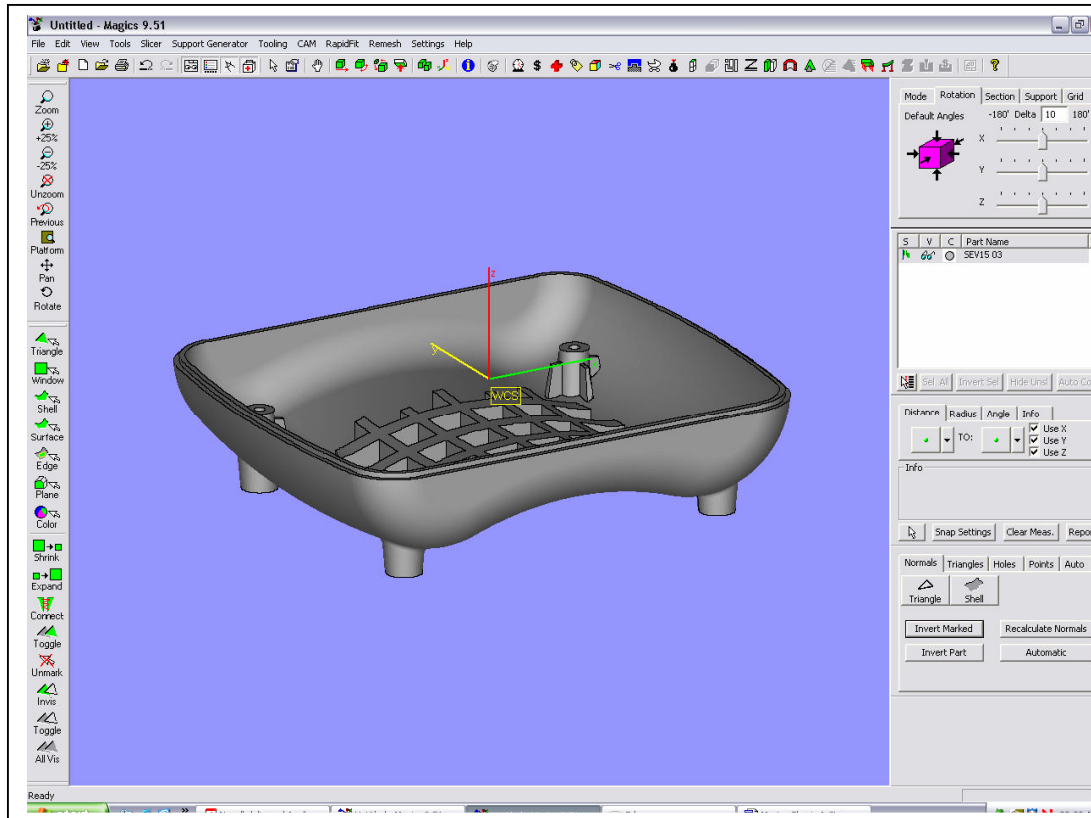


Figure 3.2 Magics 9.51 Menu and Toolbars

### 3.1.1 Load Part

This command loads a part on the current platform from a selected location. Magics 9.5.1 accepts the .STL file format as input. To load several parts at the same time, the CTRL or the SHIFT button is used.

### **3.1.2 Save Platform**

When a platform is prepared in Magics 9.5.1, it can be saved to disk in order to load it again at later stage. The files are saved as .pff files. The .pff file contains all the platform information, i.e. the machine settings, the different parts and the position of each part on the build platform. The platform file has to be saved in a selected directory. All the parts on the platform are saved in the same location as the platform file. This way, platforms can easily be replaced or copied to another directory.

### **3.1.3 Select Parts**

Every time the user clicks a selection tag, this tag will turn green and the others will turn grey. In selecting multiple parts, there are two options. The first option is the selection window, which can be dragged over the tags of several parts. The second option is to select multiple tags by clicking them with the CTRL or SHIFT button held down.

### **3.1.4 Pick and Place Principle**

This command allows translating and rotating selected parts on a platform by mouse movements. The part can be selected by first clicking on the icon and then clicking on the part. The pick and place tags will appear. There are nine tags on a selected part in the pick and place mode. One translation tag is a filled green

circle located in the centre of the part. Eight rotation tags are the hollow green tags located on the corners of the bounding box.

### **3.1.5 Pick and Place Translation**

When the cursor is positioned above the circle in the middle of the part, it will change to the translation cursor. Pressing the left mouse button will translate the part. If several parts are selected, the parts will all move in the same direction and the same distance.

### **3.1.6 Pick and Place Rotation**

When the cursor is positioned above the hooks around the part, it will change to the rotation cursor. Pressing the left mouse button will rotate the part. If several parts are selected, the parts will all rotate by the same angle.

### **3.1.7 Translate**

With the translate command, the selected parts can be moved over a distance in a certain direction. The X-, Y- and Z- value of the translation have to be defined. The user has the option to translate a part away from its current position with a relative coordinate (relative translation) or an absolute position (absolute placement) can be entered.

### **3.1.8 Rotate**

With the rotate command, the selected parts can be rotated by entering the rotation angle values around X-, Y- and Z-axis in degrees. The positive rotation sense is counter - clockwise. The original Z position can be maintained.

### **3.1.9 Rescale Parts**

A part can be rescaled with different factors in the three main directions. The factor is a multiplying value for the dimensions in that direction. A factor greater than 1 results in an enlargement of the part whilst a factor smaller than 1 results in shrinkage of the part.

### **3.1.10 Analyse**

The analysis page is the key-step in the fixing wizard. It is used to detect errors in the .STL file. Based on the analysis, the fixing wizard will advise an action. This advice can be used as a guideline throughout the fixing process.

### **3.1.11 Duplicate Parts**

This command duplicates the selected parts. The new part automatically gets the name of the original part preceded by "copy\_#\_of\_part name" where # is a number and part name is the name of the original part.

### 3.1.12 Info and Properties

The info and properties command displays the properties of all the information about the desired part. The following is included:

- The minimum and maximum coordinates (X, Y, Z) of the part and the delta value; the difference between both is calculated.
- The number of triangles, marked triangles and invisible triangles are given.
- The number of bad edges and bad contours are displayed.
- The number of shells can be calculated by pushing the analyse button.
- The total volume of the part is calculated.
- The total surface of the part is calculated.
- The status of the .STL part is indicated. If no modifications are made to the loaded part, the status is "Not Changed". In the other case, the status is "Changed". Figure 3.3 shows the info and properties window of a part.

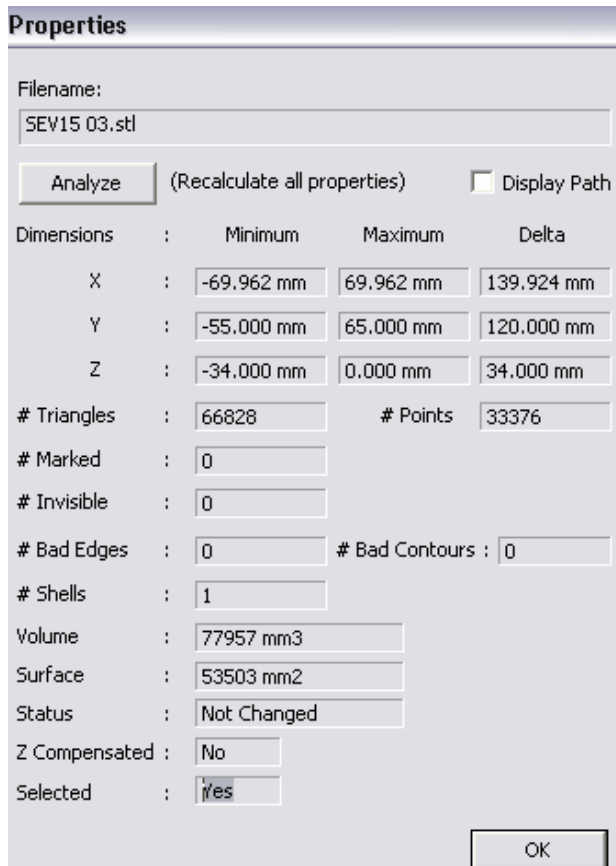


Figure 3.3 Info and Properties Window

### 3.1.13 Hollow Part

The result of the hollow part operation is one .STL file with two shells: the original shell and a new one that gives the part a certain thickness. The new shell is built from triangles whose size is determined by the parameter's smallest detail.

### 3.1.14 Automatic Placement

This command will nest the loaded parts on the building platform. There are two options, namely bounding box based or geometry based nesting. While loading parts it can also be prompted to make this choice.

### **3.1.15 Collision Detection**

Magics 9.5.1 can detect whether there is a collision (intersection of triangles of different parts). The intersecting triangles are marked in the Marked Triangles Colour (default green).

### **3.1.16 Merge**

Shells can be merged to be one .STL part. This function is used to save all loaded parts as one. This is the inverse operation of Convert Shells to Parts.

## **3.2 EOS RP-TOOLS**

The EOS RP-Tools are needed to prepare the platform for the machine. The merged and rescaled platform is loaded into the Software. The platform is then sliced into 0.15 mm thick layers.

Using the EOS software RP-Tools the data are prepared with various modules:

- Data format conversion
- Slicer SLI viewer
- Skin-core generation

The prepared data must be transferred to the process computer [6].

## **3.3 EOSINT LS MATERIALS**

The company EOS offers a wide range of different materials to manufacture parts on EOS LS machines. On the EOSINT P 380 machine it is possible to sinter parts from the materials PrimeCast 100, Polyamide (PA) and ALUMIDE®. On the

EOSINT S 700 machine it is possible to sinter parts from different laser sand materials. Most of the parts are manufactured using PA and sand material. Table 3.1 shows two different LS materials and their application.

Table 3.1 LS Materials and their Applications [3]

Material		Application
Plastic	Polystyrene Polyamide Glass filled PA	Precision casting-master patterns Vacuum casting Sand casting patterns Technical prototypes Injection moulding tools Functional prototypes Test parts
Sand	Crystal sand (SiO <sub>2</sub> ) Zircon sand (ZrSiO <sub>4</sub> )	Mould and cores for sand casting

### 3.3.1 PrimeCast 100

A typical application for the PrimeCast 100 material is the production of lost patterns for the casting process. Generally PrimeCast 100 is also suitable for shell casting, however special measures against shell cracking are necessary. Another application for PrimeCast 100 is the production of master patterns for vacuum casting. The recommended layer thickness is 0.15 mm and the bulk density is approximate 0.59 – 0.63 g/cm<sup>3</sup> [13].

### 3.3.2 Fine Polyamide (PA 2200)

PA 2200 allows for the production of fully functional prototypes with high mechanical and thermal resistance. The use of PA powder with glass filling (PA-GF) has much higher thermal resistance and is typically used for functional tests

with high thermal loads. Polyamide LS parts have excellent long-term stability and are resistant against most chemicals. Polyamide LS parts can be made watertight by impregnation. PA 2200 material is certified as biocompatible and not harmful to health or the environment. It is suitable for use in all EOSINT P systems with a fine polyamide option. The recommended layer thickness is 0.15 mm. Unexposed powder can be reused. Used powder must be mixed with fresh powder dependent on the number of cycles reused in order to guarantee constant process parameters and consistent part quality. The bulk density is approximate 0.435-0.445 g/cm<sup>3</sup> [12].

### **3.3.3 ALUMIDE®**

ALUMIDE® is an aluminium-filled polyamide 12-powder, which allows metallic-looking, non-porous components to be machined easily and is resistant to high temperatures [21]. A typical application for ALUMIDE® is the manufacture of stiff parts of metallic appearance for applications in automotive manufacture (e.g. wind tunnel tests or parts that are not safety relevant), for small production runs, for illustrative models (metallic appearance), for education- and jig manufacture, amongst others [2]. ALUMIDE® can be finished by grinding, polishing or coating. A further advantage is the finishing employing machining procedures such as milling, drilling, and turning that cause small tool abrasions. To ensure a consistent quality of parts, it is recommended to use new powder only. The recommended layer thickness amounts to 0.15 mm [2]. The bulk density is approximate 0.63 – 0.68 g/cm<sup>3</sup> [9].

### **3.3.4 Ceramics 5.2**

Ceramics 5.2 is a phenolic resin-coated aluminium silicate sand (synthetic mullite). This sand has been developed and optimised for use in the Direct Croning Process (DCP®). The material is suited for generative fabrication of complex sand cores and sand moulds for all casting applications. Due to its high heat capacity and low thermal expansion this Ceramics 5.2 can especially be used for high temperature casting. Ceramics 5.2 can be used in all EOSINT S systems. The recommended layer thickness is 0.2 mm and the average bulk density is 1.69 g/cm<sup>3</sup> [11].

## **3.4 EOSINT LS MACHINES**

The analysed machines are the EOSINT P 380 and EOSINT S 700. Both machines work with the same LS principle and therefore the method of analysis is similar. The research analysis was first performed on the EOSINT P 380 machine. The results were then used for the manufacturing time calculation for the EOSINT S 700 machine. The EOSINT P 380 is a one laser system and EOSINT S 700 is a two laser system, which grow the prototype independently of each other. Figure 3.4 shows the EOSINT S 700 machine.



Figure 3.4 LS Machine EOSINT S 700

### 3.4.1 EOSINT P 380

With various different building materials, LS technology offers a broad range of applications: fully functional prototypes, series components, mould or tool inserts for plastic and metal parts.

EOSINT P systems build plastic parts from PA or polystyrene directly from CAD data, without support structures and in a short period of time. The system allows for the efficient production of fully functional parts up to a size of 340 mm x 340 mm x 620 mm. Through intelligent exposure strategies and process control, EOSINT P systems offer a high building speed and excellent part

quality. Further parts can be added to be built during the building process as well. High process integration and automation guarantee minimum turn-around times. Thus an EOSINT P system combines the flexibility of a Rapid Technology with the automation and efficiency of mass production and is used for RM. Technical information of EOSINT P 380 is shown in Table 3.2 [10].

Table 3.2 Technical Data EOSINT P 380 [10]

<b>Technical Data</b>	
Effective building volume	340 mm x 340 mm x 620 mm (B x D x H)
Building speed (material-dependent)	10 - 25 mm height/h
Layer thickness (material-dependent)	Typically 0.15 mm
Support structure	Not necessary
Laser type	CO <sub>2</sub> , 50 W
Precision optics	F-theta lens
Scan speed	5 m/s
Power supply	32 A
Power consumption (nominal)	4 kW
Nitrogen generator	Integrated (optional)
Compressed air supply	Minimum 5000 hPa ; 6 m <sup>3</sup> /h
Dimensions	
Process cabinet	1250 mm x 1300 mm x 2150 mm (B x D x H)
Control terminal	610 mm x 820 mm x 1785 mm (B x D x H)
Recommended installations	
Space	4700 mm x 3700 mm x 3000 (B x D x H)
Weight	Approx. 800 kg
Data preparation	
PC	Current Windows operation system
Software	EOS RP Tools; Magics RP; Expert Series
CAD interface	.STL, CLI
Network	Ethernet
Certification	CE

### **3.4.2 EOSINT S 700**

The EOSINT S 700 is the only double-laser sintering system world-wide for the processing of Croning® moulding material. Using the Direct Cast method, the system builds cores and moulds directly from CAD data for the production of sand castings – fully automatically, with a building speed of up to 2500 cm<sup>3</sup>/h and without any tooling. Sand parts of any complexity are built layer-by-layer, with high accuracy, detailed resolution and surface quality, up to a build volume of 720 mm x 380 mm x 380 mm.

The resulting cores or core packages are not only realised with significant savings in time and costs compared to conventional technologies, but usually consist of less parts, which can thus be assembled faster and more precisely. Technical information of EOSINT S 700 is shown in Table 3.3 [14].

Table 3.3 Technical Data EOSINT S 700 [14]

<b>Technical Data</b>	
Effective building volume	720 mm x 380 mm x 380 mm
Building speed (material-dependent)	Up to 2500 cm <sup>3</sup> /h
Layer thickness	0.2 mm
Laser type	2 x 100 W, CO <sub>2</sub>
Precision optics	2 x F-theta lens, 2 x high speed-scanner
Scan speed	3.0 m/s
Power supply	32 A
Power consumption (nominal)	6 kW (average), 12 kW (maximum)
Compressed air supply	Minimum 6000 hPa ; 15 m <sup>3</sup> /h
Dimensions	
Process cabinet	1400 mm x 1400 mm x 2150 mm (B x D x H)
Control cabinet	610 mm x 800 mm x 1830 mm (B x D x H)
Switchgear cabinet	810 mm x 870 mm x 2150 mm (B x D x H)
Recommended installations Space (without IPCM)	4.5 m x 4.6 m x 2.7 m (B x D x H)
Weight	Approx. 2200 kg
Data preparation	
PC	Current Windows operation system
Software	EOS RP Tools; Magics RP; Expert Series
CAD interface	.STL, Optional converter to all standard formats
Network	Ethernet
Certification	CE

### 3.5 OPERATION EOSINT P 380 MACHINE

Before the machine can be started, it is necessary to set up the machine. It is important that all steps must be done accurately; otherwise the machine is not running optimally, producing waste parts.

### **3.5.1 Compartments**

The front part of the EOSINT P 380 is divided into the top machine compartment, closed by the front valve. This compartment contains the process chamber with radiant heater and recoater, two dispensers, two powder supply bins for material and an emergency stop button. The bottom machine compartment is closed by two front doors. This compartment contains the exchangeable frame system with lifting device and building platform. The exchangeable frame contains the parts already sintered, surrounded by the powder. It can be removed completely with the aid of the lifting trolley provided for this purpose [4].

### **3.5.2 Cleaning**

All chambers must be cleaned with a vacuum cleaner. The recoater, especially its blades, must be free of old material. The lens must be cleaned with a lens cleaning paper and ethanol.

### **3.5.3 Material Supply**

The machine contains two material cartridges on the top left and right hand sides to provide material for the recoater. Both must be taken out to be filled with material powder and closed with the lid. The cartridges must be replaced with the openings in the lid facing the back of the machine. The cartridges are to be secured by locking the metal clip in an upward position and the fluidisation supply connected.

### **3.5.4 The Recoater**

The recoater is located in the process chamber. It is permanently fixed in a vertical position and moves horizontally in both directions (from left to right and from right to left) over the top edge of the exchangeable frame. With each travel movement a new layer of material is applied. The build platform is automatically lowered into the exchangeable frame by thickness of one layer [8].

### **3.5.5 Collector Bins**

Excess powder falls through the overflow into the collector bins that are located to the left and right in the bottom machine compartment. The collector bins must be manually emptied upon completion of the build.

## **3.6 COMPUTER SETTINGS**

Before the machine is ready to start, some build settings must be done and the new platform must be uploaded and saved.

### **3.6.1 Select Material**

The material settings must be made to select the material. The path is:

Options – HW/Parameters – Prog. Files – EOS – PSV – Config. – Default job.

Select – Alumide – PA 2200 Technikon 2. job – e.g. PA 2200

### **3.6.2 Chamber Settings**

By opening the “Adjust” table and Hardware Interface (HWI) window, the following settings must be done:

- Temperature process chamber setting 179 °C
- Heating process chamber on
- Temperature removal chamber setting 120 °C
- Heating removal chamber on
- Nitrogen supply on
- Fan on

Here it is also possible to adjust, fill and move the recoater. It is necessary to put some material layers in the process chamber during the warm-up phase. The bin bottom can be lifted to adjust and to cover with some material layers.

### **3.6.3 Load and Save New Platform**

The path to upload the new platform into the Software Load platform:

R: Rapid: Client & Supplier

The platform is saved in the folder:

Save As – Rapid – Platform SLS – Month

### **3.6.4 Surface finish**

There are two main options, amongst others, to manufacture parts in order to obtain a better surface finish.

- Sorted: The laser sinters the part without interruption of the laser beam as shown in Figure 3.5. This causes a surface mark, although the manufacturing time is faster than when it is unsorted.

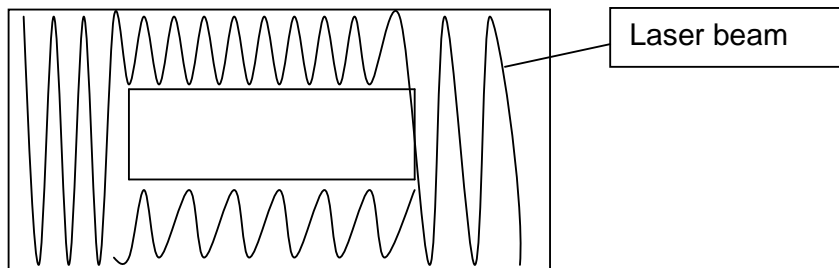


Figure 3.5 Sorted Surface Finish

- Unsorted: The laser sinters the part and interrupts the laser beam by sintering a layer area as shown in Figure 3.6. This results in the best surface finish, but the manufacturing time is longer than when it is sorted.

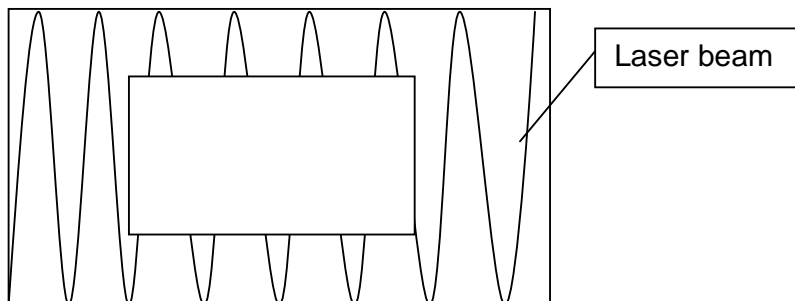


Figure 3.6 Unsorted Surface Finish

### **3.6.5 Start**

Before the machine can be started, the laser must be switched on. Then the “start” button on the main menu can be pressed and the machine starts its manufacturing process independently.

## **3.7 BUILDING PHASE**

The EOSINT P 380 offers an alternative to produce parts rapidly from powder (e.g. plastic) with complex geometries, without the usage of tooling. As with all RP systems, CAD data are used as input to directly build parts with complex 3D geometries on the EOSINT P 380. The basic principle comprises the sintering of plastic powder using a CO<sub>2</sub> laser. A radiant heater regulates the building area temperature to defined value below the melting temperature of the powder. During the LS process, the plastic powder is preheated and then heated to a temperature above the melting point with exposure to the laser beam. A solid body is produced by this heating and subsequent cooling. Density and residual porosity of the part produced depend on the exposure parameters and the exposure strategy. The shrinkage that occurs is compensated for by scaling the 3D models. In each layer the cross-section of the parts is exposed using the laser beam. The exposure parameters are selected to enable the exposed areas to bond to the preceding layer, which has already been solidified. In this way 3D parts are produced layer-by-layer [5]. All sensitive components in the optics compartment (laser, scanner electronics) are temperature controlled by cooling or heating. Using the nitrogen generator, nitrogen obtained from the air is supplied to the process chamber. The inert gas atmosphere created in this way prevents damage to the powder due to atmospheric oxygen in the process chamber. A

lens-cleaning nozzle keeps the F-theta lens clear of dirt. At the start of the building process the building platform is moved to its homing point. The recoater is filled with plastic powder and applies approximate a 5 mm thick base layer to the build platform (warm-up cycle). During this process the recoater is filled again, the building platform lowered one layer thickness and a new layer of plastic powder applied. The computer controlled laser beam then exposes the contours and the areas enclosed by the contours in accordance with the part data defined. The final build height is produced by the continuous repetition of layer-by-layer application of exposure [7]. After the manufacture, the platform is placed on a cleaning table to separate the loose material from the parts. The cleaning process is performed by a brush, compressed air and glass beads. The cleaned parts are checked for manufacturing and surface errors.

# CHAPTER 4

## DEVELOPING A NEW CALCULATION CONCEPT

This chapter describes the existing product cost calculation used by the CRPM. It also evaluates the cause of the error and disadvantage of the existing calculation procedure.

### 4.1 STATUS QUO ANALYSIS OF EXISTING CALCULATION PROCESS

The client sends the CAD drawing of the proposed prototype to the CRPM. With the drawing details and information, a quotation can be generated. Drawing details such as part height and the orientation are important. The client states whether the part must be manufactured in its original height or placed as flat as possible, depending on the part functions. Part areas that face the laser will be stronger and more accurate. If manufacturing process results in a higher platform, more material is required and machine running time increases. For a quotation or pre-calculation, all this information must be included. The quotation is for every single part and not for the total platform. The total platform can include numerous parts from different clients. For example: If the first part has a height of 34 mm, the machine has an average build-height of approximately 17 mm per hour. For this part the machine needs two hours manufacturing time. If the second part has a height of 51 mm, the machine needs three hours manufacturing time. In total the calculated manufacturing time for these two parts results in five hours. Therefore, a separate calculation is done for each part. The quotation furthermore includes the material cost, labour cost, profit, VAT and postage.

#### 4.1.1 Error Sources

Calculating the parts separately produces errors. By estimating individual parts, the material usage calculation is much higher and the machine running time is longer than for a nested platform with numerous parts. Therefore the calculation for one single manufactured part is more expensive than for a nested manufactured one. As an example consider the data for platform “gf08” shown in Table 4.1.

Table 4.1 Data for Platform “gf08”

<b>Material</b>	<b>Separate Calculated Time (minutes)</b>	<b>MAGICS 9.5.1 Time (minutes)</b>	<b>Actual Manufacture Time (minutes)</b>	<b>EOS PSW Time Calculated (minutes)</b>
Polyamide PA 2200	2220	1375	1796	1775

The total separate calculated time for each part was 2220 minutes. The deviation in this case is 424 minutes to the actual manufacturing time. The total calculated time in Magics 9.5.1 is 1375 minutes. The deviation in this case is 421 minutes to the actual manufacturing time. The software used to calculate parts and platforms has too large a deviation to use for cost estimates. Calculating this platform with the calculation system, the deviation is 21 minutes. The result of the single part calculation method and Magics 9.5.1 calculation is that it is too inaccurate and ineffective for cost estimation. These calculation methods calculate the manufacturing time, but they do not include material costs and overhead costs to get the total manufacturing cost. Therefore it is necessary to develop a new calculation concept.

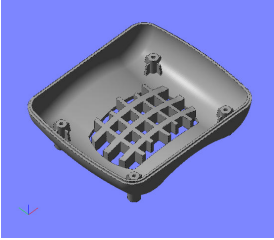
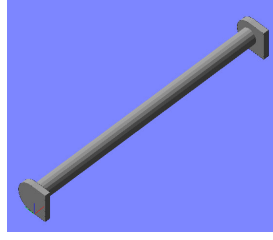
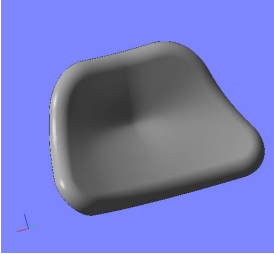
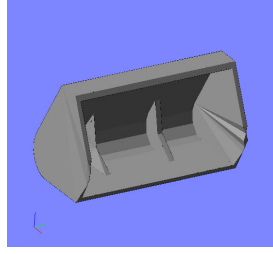
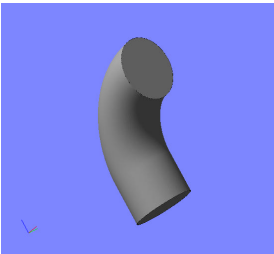
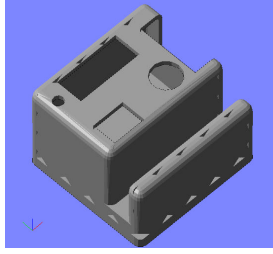
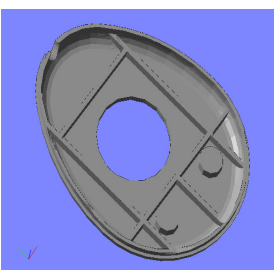
## **4.2 MEASUREMENT RESULTS**

The measurement results describe the work-flow of the Magics 9.5.1 software calculation and the work-flow to develop a method to calculate the manufacturing time for the EOSINT P 380 machine. For all the tests a variety of small, medium and large parts were used, in order to cover a wide range of measurements. With these results it is possible to get empirical values and it helped to understand the manufacturing time calculation in Magics 9.5.1 software and the EOSINT machines. Results are important for developing a new manufacturing time calculation concept, which is independent and simple to use. The Magics 9.5.1 calculation is completely different to the EOSINT. The Magics 9.5.1 software uses different parameters for its calculation than the EOSINT machines. The EOSINT machines do include the manufacturing time of one platform, the exposure layers, recoating time, process chamber heating time and material properties. The deviations in results between the two calculation types were tested. These tests showed that the Magics 9.5.1 software has an acceptable result only under special circumstances, compared with EOSINT machines. In most tests the results differ considerably.

### **4.2.1 Analysed Parts**

Table 4.2 gives an overview of analysed parts used for the measurements and to calculate the first results. These parts are completely different in volume, height and shape. The part properties are also added. Therefore a wide and different range in measurement results is guaranteed.

Table 4.2 Data of Analysed Parts

<p>SEV 1503</p> 	<p>Volume: 77 957mm<sup>3</sup> Area: 53 503 mm<sup>2</sup> Z-Height: 34 mm</p>	<p>Part 01</p> 	<p>Volume: 20 mm<sup>3</sup> Area: 81 mm<sup>2</sup> Z-Height: 2 mm</p>
<p>SEV 1507</p> 	<p>Volume: 33 704 mm<sup>3</sup> Area: 12 973 mm<sup>2</sup> Z-Height: 23 mm</p>	<p>SEV 1501</p> 	<p>Volume: 271 565 mm<sup>3</sup> Area: 111 023 mm<sup>2</sup> Z-Height: 100 mm</p>
<p>SEV 1511</p> 	<p>Volume: 52 969 mm<sup>3</sup> Area: 8478 mm<sup>2</sup> Z-Height: 30 mm</p>	<p>SEV 1504</p> 	<p>Volume: 40 862 mm<sup>3</sup> Area: 41 723 mm<sup>2</sup> Z-Height: 40 mm</p>
<p>Mouse TB</p> 	<p>Volume: 10 566 mm<sup>3</sup> Area: 11 884 mm<sup>2</sup> Z-Height: 8 mm</p>		

#### **4.2.2 Manufacturing Time Calculated in Magics 9.5.1**

The result in Table 4.3 shows the time development as calculated in Magics 9.5.1. The experimental calculations were repeated 15 times, starting by one and ending by 15 parts. Magics 9.5.1 calculate all the parts with the following parameters:

- Fixed Time
- Volume
- Project Area
- Surface and
- Delta Z

After the manufacturing time for one part is calculated, the following parts have a linear time development. This is clarified by showing the results in a chart. All the manufacturing times are calculated in minutes. For example the part SEV 1503 in Magics 9.5.1 needs a manufacturing time of 297 minutes for one part and for two parts 314 minutes. The deviation is 17 minutes with a rounding factor of one minute.

Table 4.3 Calculated Manufacturing Time for Analysed Parts using  
Magics 9.5.1

Number of Parts	Manufacturing Time (minutes)						
	SEV 1503	SEV 1507	SEV 1511	Mouse TB	Part 01	SEV 1501	SEV 1504
1	297	68	83	27	4	508	107
2	314	86	95	35	4	550	122
3	332	105	108	44	4	591	137
4	349	123	121	52	4	633	151
5	367	142	134	61	4	675	166
6	384	161	147	69	4	717	180
7	402	179	160	78	4	758	195
8	419	198	173	86	5	800	210
9	436	278	186	94	5	842	224
10	454	296	199	106	5	1356	239
11	471	315	212	112	5	1398	254
12	489	333	225	121	5	1439	268
13	506	352	237	129	5	1481	283
14	524	370	250	168	5	1523	297
15	541	389	263	176	5	1565	312

In Figure 4.1 the time development is relatively linear. For certain parts, for example SEV 1501, it is evident that there is a larger time difference between nine and 10 parts. All nine SEV 1501 parts are placed on the platform with the same height. For 10 parts, there is not enough space on the platform area, so one part must be placed above the previous nine parts. The space between these two levels and the new height results in the new manufacturing time. The new platform height is calculated by using the following equation:

$$\text{Platform height} = \text{parts height} + \text{distance parts} + \text{parts height} \quad (1)$$

That means that the height for nine parts, the space between the two blocks of parts result in a total platform height calculated by equation (1):

$$204 \text{ mm} = 100 \text{ mm} + 4 \text{ mm} + 100 \text{ mm}$$

The time development for parts 10 to 15 is again almost linear. The time deviation for 10 parts to 15 parts is nearly the same time as calculated for part one to part nine. For example, the value for one part SEV 1501 is 508 minutes. It is linear to nine parts, which need 842 minutes. When the starting time is added to the time for nine parts the result is 1350 minutes. The deviation of 6 minutes results from the space between these two layers.

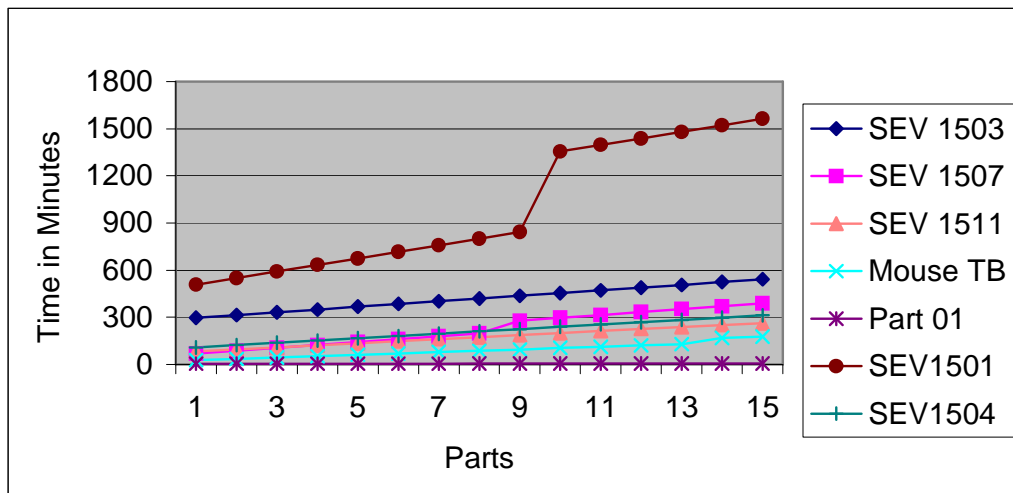


Figure 4.1 Manufacturing Time Calculated in Magics 9.5.1

### **4.2.3 Time Deviation - Parts Turned at 90°**

Table 4.4 shows the manufacturing time and the deviation by rotating the parts at 90°. For example, part SEV 1503 has a new height of 120 mm by turning it through 90°. The analysis clearly shows that up to seven parts of the original placement have a shorter manufacturing time than when placed at 90°. From eight parts to 12 parts it is better to turn the parts at 90° with a height of 120 mm instead of 34 mm. The deviation shows that the time development and the minutes to be decreased. In example SEV 1511 there is no break-even point, which implies that it is always better to place the parts at 90°. For example for SEV 1504 the manufacturing time is the same as for one part. For two and three parts it is better to place them in the original height. When manufacturing more than four parts per platform it is always better to place the parts at 90°.

Table 4.4 Manufacturing Time in Magics 9.5.1 of Analysed Parts Turned at 90°

Number of Parts	Manufacturing Time SEV 1503 (minutes)		Manufacturing Time SEV 1511 (minutes)		Manufacturing Time SEV 1504 (minutes)	
	Height 34 mm	Turned at 90°	Height 30 mm	Turned at 90°	Height 40 mm	Turned at 90°
1	110	297	113	83	508	508
2	142	314	123	95	404	550
3	205	332	133	108	491	591
4	300	349	143	121	821	633
5	328	367	213	134	907	675
6	359	384	224	147	993	717
7	391	402	234	160	1323	758
8	422	419	244	173	1410	800
9	545	436	254	186	1496	842
10	576	454	264	199	1826	1356
11	608	471	274	212	1913	1398
12	639	489	285	225	1999	1439

#### 4.2.4 Calculated Manufacturing Time Compared to Magics 9.5.1

During the analysis and evaluation phase it was not possible to determine how MAGIGS 9.5.1 calculates the manufacturing time. The only possibility to calculate the manufacturing time is to use linearity as the basis to calculate the Magics 9.5.1 values. To calculate the time for more than one part, it is necessary to know the time deviation between the first and the second part. Therefore it is necessary to take the calculated time in Magics 9.5.1 for one and for two parts, then multiply the difference by the number of parts and add it to the first value to calculate the manufacturing time for more than two parts.

The manufacturing time for five parts SEV 1503 is calculated by using the following:

$$MT = (MT P2 - MT P1) \times (NP-1) + MT P1 \quad (2)$$

Where:

MT = Manufacturing time

MT P1 = Manufacturing time for one part

MT P2 = Manufacturing time for two parts

NP = Number of parts

The manufacturing time calculation for five parts SEV 1503 is (314 minutes - 297 minutes) x (5 parts - 1) + 297 minutes = 365 minutes. The results of the analysed parts are shown in Table 4.5. The deviation between the calculated time and the original time in Magics 9.5.1 is too high to use in a calculation programme. Therefore, it is only a model to calculate the manufacturing time, similar to Magics 9.5.1 does.

Table 4.5 Experimental Calculations Compared to Magics 9.5.1

Parts Name	Time Part 1	Time Part 2	Number of Parts	Calculated Time	MAGICS 9.5.1	Deviation in minutes %	
SEV 1503	297	314	5	365	367	-2	-1%
SEV 1507	68	86	6	158	161	-3	-2%
SEV 1511	83	95	4	119	121	-2	-2%
SEV 1511	83	95	6	143	147	-4	-3%
Mouse TB	27	35	10	99	106	-7	-7%
Part 01	4	4	3	4	4	0	0%
SEV1501	508	550	3	592	591	1	0%
SEV1501	508	541	9	772	842	-70	-9%

#### 4.2.5 Time Measured on Machine EOSINT P 380

For the EOSINT P 380 analysis, the same parts, number of parts and platforms are used. These results are needed to get an overview of the manufacturing time development, and to analyse the deviation from the Magics 9.5.1 software. In Table 4.6, at first glance the manufacturing time development of the analysed parts looks different from that of the Magics 9.5.1 table (Table 4.3). The start value and the development do not show linearity initially. After the start value, the manufacturing time for small volume parts increase less than for large volume parts. For large volume parts, the laser has to laser more volume and that causes an increase in manufacturing time. After many calculation tests it was proved that linearity exists between the manufacturing time and the platform height. The deviation of each part results from the volume of the part.

Table 4.6 Measured Manufacturing Time of Analysed Parts

Number of Parts	Manufacturing Time (minutes)						
	SEV 1503	SEV 1507	SEV 1511	Mouse TB	Part 01	SEV 1501	SEV 1504
1	420	104	134	59	38	717	168
2	420	105	134	59	38	721	168
3	420	105	134	59	38	726	169
4	420	105	134	60	38	733	170
5	420	109	135	62	38	742	175
6	420	112	135	64	38	759	182
7	425	115	144	66	38	807	189
8	437	119	149	68	38	851	197

#### **4.2.6 Time Deviation Magics 9.5.1 - EOSINT P 380**

Table 4.7 was generated to determine whether Magics 9.5.1 is a useable programme to calculate the manufacturing time of the EOSINT P 380 machine. The deviation of each part shows how accurate the Magics 9.5.1 software can perform the calculation. For the first part, the start value on the EOSINT P 380 machine is higher than the Magics 9.5.1 time. With more parts the deviation decreases to a break-even point and then increases again. For example, the break-even-point on part SEV 1507 is reached with three parts. Therefore the calculation in both systems gets a zero deviation, indicating that the parameters in Magics 9.5.1 and the EOSINT P 380 machine calculate the same time. For very small volume parts e.g. Part 01, the Magics 9.5.1 parameters are not able to calculate acceptable calculation times. The same with large volume parts e.g. SEV1501. With eight parts the platform space is fully utilised and Magics 9.5.1 cannot calculate an acceptable manufacturing time. In some cases e.g. SEV 1507, SEV 1511, Mouse TB 01 and SEV 1504, the parameters used in Magics 9.5.1 calculated an acceptable manufacturing time. In most cases the Magics 9.5.1 calculates a too high deviation, which is caused by incorrect parameters stored in the software programme.

Table 4.7 Time Deviation Magics 9.5.1 - EOSINT P 380

Number of Parts	Manufacturing Time (minutes)							
	1	2	3	4	5	6	7	8
Magics SEV1503	297	314	332	349	367	384	402	419
P 380 SEV1503	420	420	420	420	420	420	425	437
Deviation	123	106	88	71	53	36	23	18
Deviation (%)	29%	25%	21%	17%	13%	9%	5%	4%
Magics SEV1507	68	86	105	123	142	161	179	198
P 380 SEV1507	104	105	105	105	109	112	115	119
Deviation	36	19	0	-18	-33	-49	-64	-79
Deviation (%)	35%	18%	0%	-17%	-30%	-44%	-56%	-66%
Magics SEV1511	83	95	108	121	134	147	160	173
P 380 SEV1511	134	134	134	134	135	135	144	149
Deviation	51	39	26	13	1	-12	-16	-24
Deviation (%)	38%	29%	19%	10%	1%	-9%	-11%	-16%
Magics Mouse TB 01	27	35	44	52	61	69	78	86
P 380 Mouse TB 01	59	59	59	60	62	64	66	68
Deviation	32	24	15	8	1	-5	-12	-18
Deviation (%)	54%	41%	25%	13%	2%	-8%	-18%	-26%
Magics Part01	4	4	4	4	4	4	4	5
P 380 Part01	38	38	38	38	38	38	38	38
Deviation	34	34	34	34	34	34	34	33
Deviation (%)	89%	89%	89%	89%	89%	89%	89%	87%
Magics Part SEV1501	508	550	591	633	675	717	758	800
P 380 Part SEV1501	717	721	726	733	742	759	807	851
Deviation	209	171	135	100	67	42	49	51
Deviation (%)	29%	24%	19%	14%	9%	6%	6%	6%
Magics Part SEV1504	107	122	137	151	166	180	195	210
P 380 Part SEV1504	168	168	169	170	175	182	189	197
Deviation	61	46	32	19	9	2	-6	-13
Deviation (%)	36%	27%	19%	11%	5%	1%	-3%	-7%

### **4.3 COST ALLOCATION**

The cost allocation is needed to allocate the total cost to each part. There are some possibilities to calculate the individual part costs by dividing the total costs by the part height, area, volume and manufacturing time. The following two examples show two possibilities of allocating the total costs based either on manufacturing time or on part volume.

#### **4.3.1 Cost Allocation by Time**

In the calculation example in Table 4.8, the manufacturing time of one part is calculated, entered and added together. The result is the total manufacturing time by manufacturing part for part on a separate platform and amounts to 318 minutes. The time deviation between the manufacturing time and the calculated time for each part and platform is  $318 \text{ minutes} - 150 \text{ minutes} = 168 \text{ minutes}$ . The total costs for material and machine is R1052. These manufacturing costs are allocated proportionally to the different part's manufacturing time. The result shows the piece costs for part SEV 1503 = R364; SEV 1507 = R225; SEV 1511 = R374 and for the Mouse TB = R89.

Table 4.8 Costs Allocated by Time

<b>Calculation</b>		
Material	3,17kg	R177
Machine	150 minutes	R875
Total		R1052
<b>Parts</b>	<b>Time (minutes)</b>	<b>Costs</b>
SEV 1503	110	R364
SEV 1507	68	R225
SEV 1511	113	R374
Mouse TB	27	R89
Total	318	R1052

#### 4.3.2 Cost Allocation by Volume

In the calculation example in Table 4.9, the volume of each part is calculated, entered and added together. The result is the total manufacturing volume of 175 196 mm<sup>3</sup> for the platform. The volume can be obtained from the drawing. In Magics 9.5.1 it is possible to get the volume for merged parts and merged platforms. The total costs for material and machine are R1052. These manufacturing costs are allocated prorata to the different part volumes. The result shows the component costs for part SEV 1503 = R468; SEV 1507 = R202; SEV 1511 = R318 and for the Mouse TB = R63.

Table 4.9 Costs Allocated by Volume

<b>Calculation</b>		
Material	3,17kg	R177
Machine	150 minutes	R875
Total		R 1052
<b>Parts</b>	<b>Volume (mm<sup>3</sup>)</b>	<b>Costs</b>
SEV 1503	77 957	R468
SEV 1507	33 704	R202
SEV 1511	52 969	R318
Mouse TB	10 566	R63
Total	175 196	R1051

#### 4.3.3 Results Cost Allocation

To allocate the costs to the parts, it is necessary to have a correlation between cost and parts. By comparing the different cost allocation types, it makes sense that larger parts will cost more than smaller parts. Therefore it is necessary to find an allocation type, which is independent of the part's placement and shape and should allocate the costs fairly. This can be achieved by using the volume allocation and therefore the volume allocation is used in the new calculation concept.

# CHAPTER 5

## MANUFACTURING TIME CALCULATION, EQUATIONS, PLATFORM EVALUATION AND KEY FIGURES

This chapter describes the formula development to calculate the manufacturing time on an EOSINT P 380 machine. It describes the influence of platform volume utilisation and the total platform height. These two formula parameters are needed to generate a calculation concept described in Chapter 6.

### 5.1 MANUFACTURING TIME CALCULATION EOSINT P 380/S 700

During the test phase it was possible to calculate the parts or platform manufacturing time in minutes. The first correlation existed between the manufacturing time and the platform height. This correlation is linear, but the time deviation between each platform is too high. Each platform has a different platform volume compared to the platform height and the volume also has an effect on manufacturing time. Therefore the formula must incorporate a corrective factor, which is determined from the volume utilisation. The result is that the formula consists of two parts: The time value resulting from Height-Time (HT) Table plus a time value resulting from the volume utilisation.

### 5.1.1 Build Volume Utilisation

For the manufacturing time calculation, the correlation between platform height and the platform volume utilisation is an important parameter. The laser time depends of the part's volume and placement. The higher the parts/platform, the more layers are needed and more layers must be lasered and this increases the manufacturing time for a short time and influences the manufacturing time. Table 5.1 shows the volume utilisation development in percent by dividing the part's volume with the total platform volume.

The build volume utilisation is calculated using equation (4). The result for five parts SEV 1503 is:

$$3\% = 5 \times 77\,957 \text{ mm}^3 / 120 \text{ mm} \times 340 \text{ mm} \times 340 \text{ mm}$$

Table 5.1 Platform Volume Utilisation (Vutil) of Analysed Parts in Percent

Parts	1	2	3	4	5	6	7	8
SEV 1503	1%	1%	2%	2%	3%	3%	4%	4%
SEV 1507	1%	3%	4%	5%	7%	8%	10%	11%
SEV 1511	2%	3%	5%	6%	8%	9%	11%	12%
Mouse TB	1%	2%	3%	5%	6%	7%	8%	9%
SEV 1501	0%	0%	0%	0%	0%	0%	0%	0%
SEV 1504	1%	2%	4%	5%	6%	7%	8%	9%

### 5.1.2 Height-Time Table of Analysed Parts

The aim of numerous tests was to find a correlation between the platform height and the manufacturing time in minutes. The values in Table 5.2 are the result of the tested parts and it also includes a fixed time value to get the best values for each height. For each material, Table 5.2 must be adjusted by a formula to get the best time values. Table 5.2 only contains values to a platform height up to 620 mm.

Table 5.2 Height-Time Table of Analysed Parts

Platform Height (mm)	Manufacturing Time (minutes)
116	419
117	422
118	425
119	429
120	432
121	435
122	439
123	442

## 5.2 EQUATIONS

### 5.2.1 Equation Height-Time Calculation

The calculation for the manufacturing time, depending on the platform height is a linear function. The parameter and the fixed value must be adjusted in experiments to achieve a zero relative deviation. The parameter and the fixed value is also the result of tests, which can differ with the material and machine. The height-time calculation for a platform height of 120 mm and material Polyamide PA 2200 is calculated using equation (3):

$$432 \text{ minutes} = 3.3341 \times 120 \text{ mm} + 32 \text{ minutes}$$

The Height-Time (HT) value can be calculated using the following:

$$\mathbf{HT = a * Hplat + b} \quad \mathbf{(3)}$$

Where:

HT = Platform Height-Time calculated in minutes

a = Parameter, for Pa2200 = 3.3341

Hplat = Part or platform height

b = Fixed time value for Pa2200 = 32

### 5.2.2 Volume Utilisation Factor

The necessary adjustment to achieve acceptable results is to include the volume utilisation in the developed Equation. The volume utilisation factor is a quotient of the part's volume divided by the platform volume.

The Volume Utilisation Factor (VUF) is:

$$\mathbf{VUF = Vpart / Vplat} \quad \mathbf{(4)}$$

Where:

VUF = Volume utilisation factor

Vpart = Volume of part

Vplat = Volume of platform

### 5.2.3 Manufacturing Time

The equation includes the height value plus the height value multiplied by the volume utilisation. This equation is the result of tests to calculate the manufacturing time.

The equation for manufacturing time is given by:

$$\mathbf{MT = HT * (1+ (VF * VUF))} \quad \mathbf{(5)}$$

Where:

MT = Manufacturing time

HT = Platform Height-Time calculated in minutes

VF = Volume factor

VUF = Volume utilisation factor

### 5.3 PLATFORM EVALUATION

#### 5.3.1 Manufacturing Time Calculation of Analysed Parts

The results of the first calculated manufacturing time is shown in Table 5.3. The manufacturing time is calculated using equation (5). The deviation is between -14% and +4%, resulting in an absolute deviation of 4%. The measured time and calculated time are all in minutes.

Table 5.3 Manufacturing Time Calculation of Analysed Parts

Parts Name	Height (mm)	Volume (mm <sup>3</sup> )	Number of parts	Measured Time (minutes)	Calculated Time (minutes)	Deviation	
SEV 1503	120	77 957	2	420	433	13	3%
SEV 1503	120	77 957	5	420	436	16	4%
SEV 1503	120	77 957	8	437	438	1	0%
SEV 1507	21	33 704	4	105	104	-1	-1%
SEV 1507	21	33 704	6	112	105	-7	-7%
SEV 1507	21	33 704	8	119	105	-14	-11%
SEV 1511	31	52 969	3	134	137	3	2%
SEV 1511	31	52 969	5	135	138	3	2%
SEV 1511	31	52 969	7	144	139	-5	-3%
Mouse TB	8	10 566	3	59	60	1	1%
Mouse TB	8	10 566	6	64	60	-4	-6%
Mouse TB	8	10 566	7	66	60	-6	-8%
Part 01	2	20	4	38	39	1	3%
Part 01	2	20	5	38	39	1	3%
Part 01	2	20	6	38	39	1	3%
SEV1501	200	271 565	2	721	674	-47	-7%
SEV1501	200	271 565	5	742	681	-61	-8%
SEV1501	200	271 565	6	759	683	-76	-10%
SEV1504	40	40 862	2	168	166	-2	-1%
SEV1504	40	40 862	5	175	167	-8	-4%
SEV1504	40	40 862	8	197	169	-28	-14%

### 5.3.2 Manufacturing Time Calculation Polyamide PA 2200

The result of the manufacturing time deviation is shown in Table 5.4 and Figure 5.1. The values were accumulated and calculated from 45 analysed platforms manufactured on the EOSINT P 380 machine. With the material Polyamide PA 2200 a total volume of 46 956 253 mm<sup>3</sup> and a total height of 12 616 mm were manufactured. The total manufacturing time amounts to 45 716 minutes and the absolute deviation from the calculated manufacturing time is 1447 minutes (3.2%). The calculated platform VU for the Polyamide PA 2200 material has an average of 3.2%.

Table 5.4 45 Analysed Polyamide PA 2200 Platforms

<b>Material</b>	<b>Platform Height (mm)</b>	<b>Volume (mm<sup>3</sup>)</b>	<b>Actual Manufacturing Time (minutes)</b>	<b>Calculated Deviation (minutes)</b>		<b>VU</b>
Polyamide PA 2200	12 616	46 956 253	45 716	1447	3.2%	3%

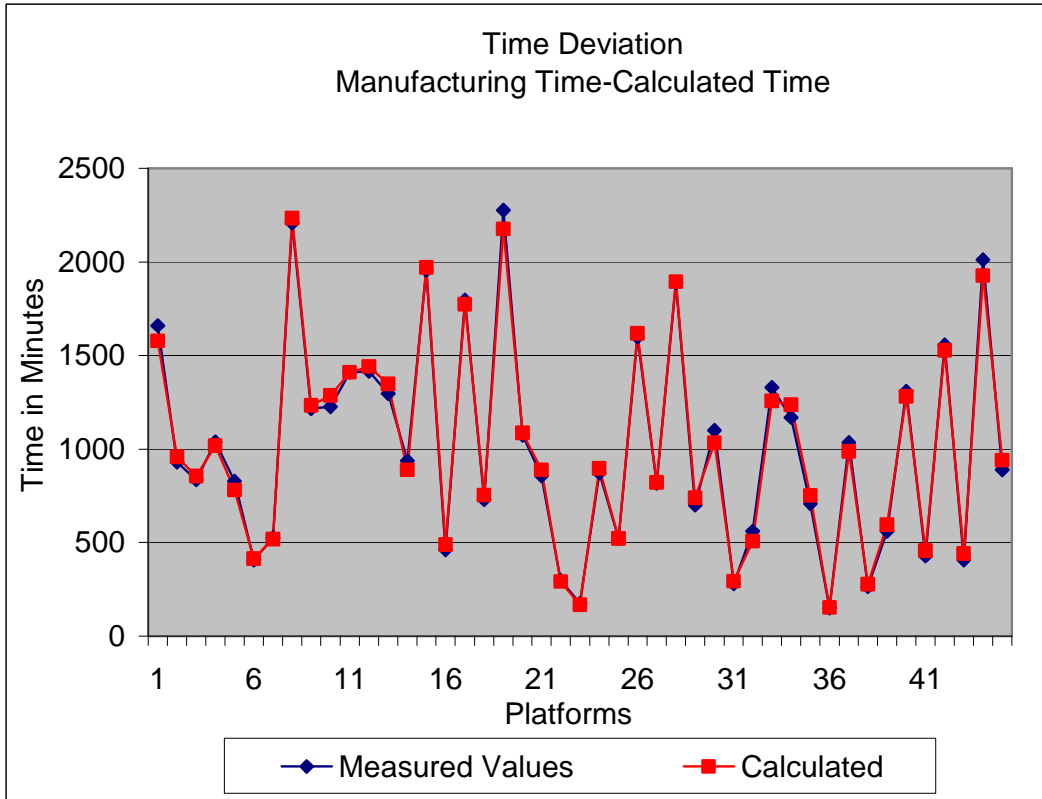


Figure 5.1 45 Analysed Polyamide PA 2200 Platforms

### 5.3.3 Manufacturing Time Calculation ALUMIDE®

The result of the manufacturing time deviation for ALUMIDE® is shown in Table 5.5 and Figure 5.2. The values were accumulated and calculated from five analysed platforms manufactured on the EOSINT P 380 machine. With the material ALUMIDE® a total volume of 10 445 852 mm<sup>3</sup> and a total height of 907 mm were manufactured. The total manufacturing time amounts to 4924 minutes and the absolute deviation from the calculated manufacturing time is 212 minutes (4.3%). The calculated platform VU for the ALUMIDE® material has an average of 10.0%.

Table 5.5 Five Analysed ALUMIDE® Platforms

Material	Platform Height (mm)	Volume (mm <sup>3</sup> )	Actual Manufacturing Time (minutes)	Calculated Deviation (minutes)		VU
ALUMIDE®	907	10 445 852	4924	212	4%	10%

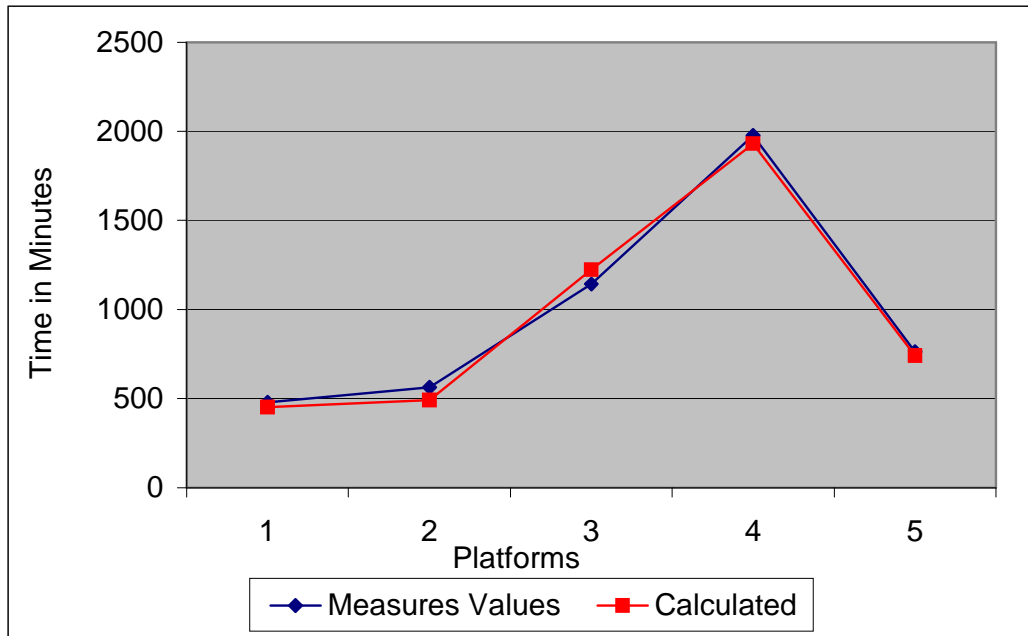


Figure 5.2 Five Analysed ALUMIDE® Platforms

### 5.3.4 Manufacturing Time Calculation PrimeCast 100

The result of the manufacturing time deviation is shown in Table 5.6 and Figure 5.3. The values are accumulated and calculated from two analysed platforms manufactured on the EOSINT P 380 machine. With the material PrimeCast 100 a total volume of 1 429 346 mm<sup>3</sup> and a total height of 235 mm were manufactured. The total manufacturing time amounts to 1033 minutes and the absolute deviation from the calculated manufacturing time is 67 minutes

(6.5%). The calculated platform VU for the PrimeCast 100 material has an average of 4.9%.

Table 5.6 Two Analysed PrimeCast 100 Platforms

Material	Platform Height (mm)	Volume (mm <sup>3</sup> )	Actual Manufacturing Time (minutes)	Calculated Deviation (minutes)		VU
PrimeCast 100	253	1 429 346	1033	67	7%	5%

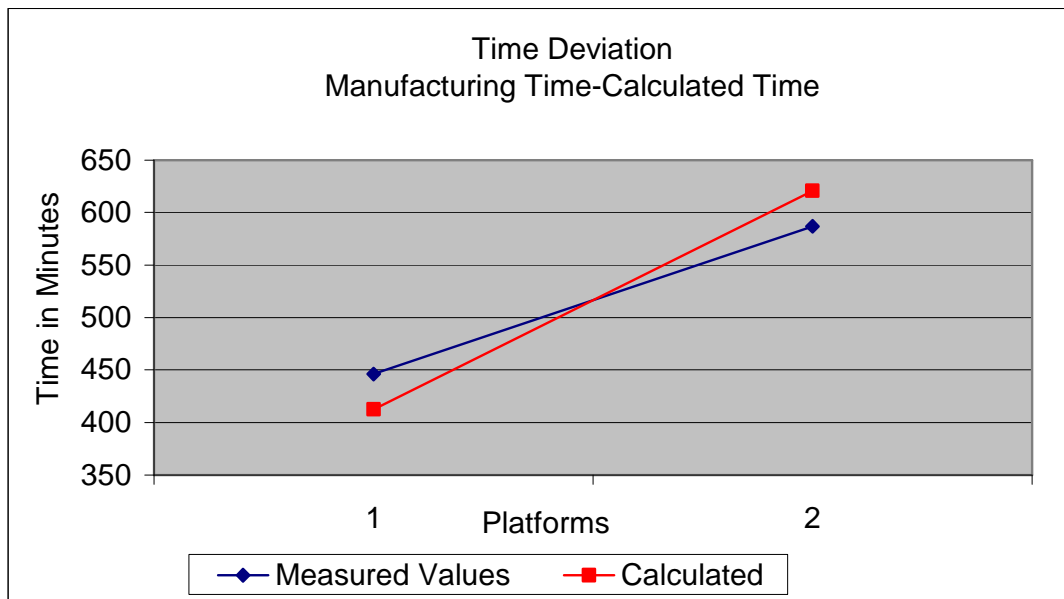


Figure 5.3 Two Analysed PrimeCast 100 Platforms

### 5.3.5 Manufacturing Time Calculation Ceramics 5.2

The result of the manufacturing time deviation is shown in Table 5.7 and Figure 5.4. The values are accumulated and calculated from 16 analysed platforms manufactured on the EOSINT S 700 machine. With the material Ceramics 5.2 a total volume of 116 143 346 mm<sup>3</sup> and a total height of 3604 mm

were manufactured. The total manufacturing time amounts to 10 656 minutes and the absolute deviation from the calculated manufacturing time is 654 minutes (6.1%). The calculated platform VU for the Ceramics 5.2 material has an average of 22.3%.

Table 5.7 16 Analysed Ceramics 5.2 Platforms

Material	Platform Height (mm)	Volume (mm <sup>3</sup> )	Actual Manufacturing Time (minutes)	Calculated Deviation (minutes)		VU
Ceramics 5.2	3604	116 143 346	10 656	654	6%	22%

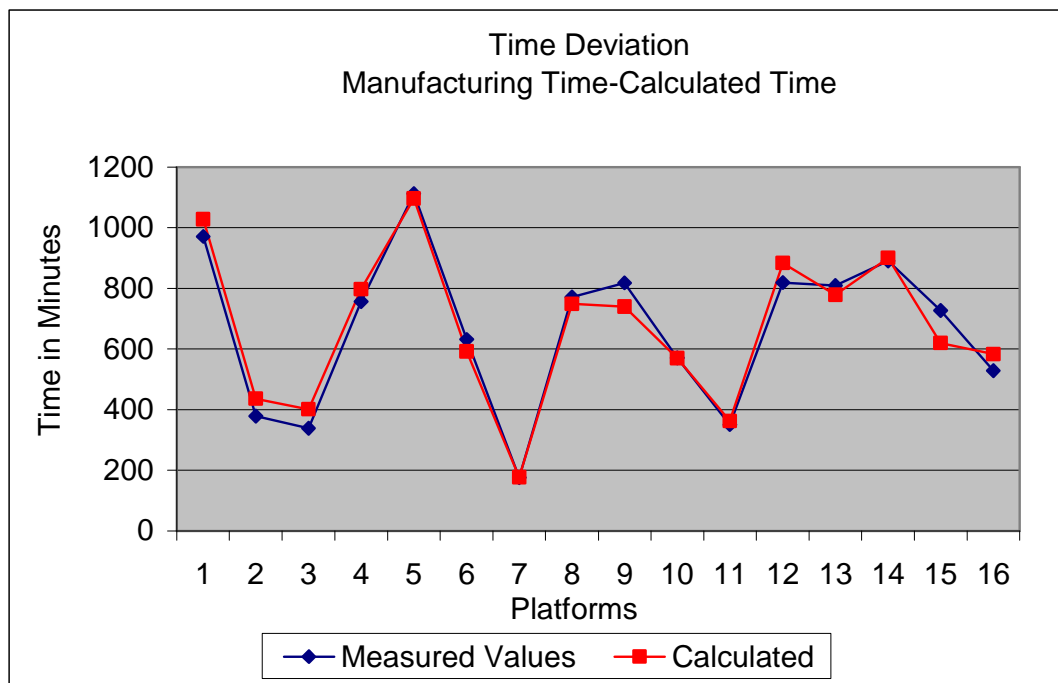


Figure 5.4 16 Analysed Ceramics 5.2 Platforms

### 5.3.6 Manufacturing Time Calculation of Average Platform Growing Time

A further possibility calculating the manufacturing time is to calculate the manufacturing time by the average platform growing time dependent on material. The “Height-Volume” method calculates the manufacturing time more accurately than the “Average” method, especially when a material with a higher volume utilisation such as ALUMIDE® or Ceramics 5.2 is used.

The average growing time is calculated by using the following equation:

$$\text{Average Growing Time} = \frac{\text{Total Platform Height}}{\text{Total Manufacturing Time}} \quad (6)$$

The average growing time for Polyamide PA 2200 is calculated using equation (6):

$$16.6 \text{ mm/h} = 12\,616 \text{ mm} / 45\,716 \text{ minutes} \times 60 \text{ minutes}$$

The platform “ge02” has a platform height of 104 mm. The calculated manufacturing time of 16.6 mm/h multiplied by 104 mm is 376 minutes. Compared to the original manufacturing time of 407 minutes the deviation is 31 minutes (8%). The calculated time in the “Height-Volume” method is 413 minutes and the deviation is 6 minutes (1%).

The average growing time for ALUMIDE® is calculated using equation (6):

$$11.1 \text{ mm/h} = 907 \text{ mm} / 4924 \text{ minutes} \times 60 \text{ minutes}$$

The platform “gf07” has a platform height of 321 mm. The calculated manufacturing time of 11.1 mm/h multiplied by 321 mm is 1735 minutes.

Compared to the original manufacturing time of 1976 minutes the deviation is 197 minutes (10%). The calculated time in the “Height-Volume” method is 1931 minutes and the deviation is 45 minutes (2%).

The average growing time for PrimeCast 100 is calculated by the equation (6):

$$14.7 \text{ mm/h} = 253 \text{ mm} / 1033 \text{ minutes} \times 60 \text{ minutes}$$

The platform “gd04” has a platform height of 153 mm. The calculated manufacturing time of 14.7 mm/h multiplied by 153 mm is 625 minutes. Compared to the original manufacturing time of 587 minutes the deviation is 38 minutes (6.5%). The calculated time in the “Height-Volume” method is 621 minutes and the deviation is 34 minutes (5.7%).

The average growing time for Ceramics 5.2 is calculated by the equation (6):

$$20.3 \text{ mm/h} = 3604 \text{ mm} / 10\ 656 \text{ minutes} \times 60 \text{ minutes}$$

The platform “gi02” has a platform height of 244 mm. The calculated manufacturing time of 20.3 mm/h multiplied by 244 mm is 721 minutes. Compared to the original manufacturing time of 571 minutes the deviation is 150 minutes (26%). The calculated time in the “Height-Volume” method is 568 minutes and the deviation is 3 minutes (1%). Table 5.8 shows the calculated average platform growing time depending on the material.

Table 5.8 Average Platform Growing Time Dependent on Material

<b>Material</b>	<b>Platform Height (mm)</b>	<b>Actual Manufacturing Time (minutes)</b>	<b>Average Platform Growing Time (mm/h)</b>
Polyamide PA 2200	12 616	45 716	16.6
ALUMIDE®	907	4924	11.1
PrimeCast 100	253	1033	14.7
Ceramics 5.2	3604	10 656	20.3

## 5.4 KEY FIGURES

Key Figures (KFs) are generated to compare and analyse platforms under determined criteria. These criteria are the prototype quantity, volume, manufacturing time and total costs of a platform. The KFs are also discussed in the case studies. Table 5.9 shows calculated KFs of different platforms.

### 5.4.1 Production Rate

To get an idea about the “platform productivity”, the KF production rate (PR) is generated. Using equation (7), it is possible to compare one platform to another by dividing the platforms’ output by manufacturing time. The result is a KF that describes the output, quantity (parts) per minute or volume (mm<sup>3</sup>) per minute. Comparing the quantity output, it must be assumed that the parts have the same volume. The KF is useful for Rapid Manufacturing (RM) to verify the cost when the parts are manufactured on a bulk platform. In Table 5.9 there are, for example, 10 platforms compared to the KF volume per minute. The KFs range between 306 mm<sup>3</sup>/minute to 1320 mm<sup>3</sup>/minute and the average value is

874 mm<sup>3</sup>/minute. As result, the KF for further platforms should have at least the average value of 874 mm<sup>3</sup>/minute. Furthermore each platform that has a bigger KF, has a better output per minute and consequently, such parts have lower manufacturing costs. To increase the production factor it is necessary to decrease the manufacturing time or increase the quantity.

Table 5.9 Platforms with the Key Figure Production Rate

<b>Platform Name</b>	<b>Volume (mm<sup>3</sup>)</b>	<b>Manufacturing Time (minutes)</b>	<b>Production Rate (mm<sup>3</sup>/minute)</b>
gf08	1 333 224	1 796	742
gf09	439 346	730	602
gg09	1 908 343	1 599	1193
gh01	465 503	816	570
gh05	1 452 315	1 100	1320
gh06	78 936	258	306
gh07	505 067	560	902
gh09	786 393	1 168	673
gi02	1 009 387	1 035	975
gi03	169 388	264	642
<b>Sum</b>	<b>8 147 902</b>	<b>9 326</b>	<b>874</b>

The Production Rate (PR) can be calculated using the following:

$$\mathbf{PR = N / MT} \quad (7)$$

Where:

PR = Production Rate

N = Output (Volume, Quantity)

MT = Manufacturing Time

#### 5.4.2 Volume Utilisation Rate (VUR)

The VUR describes the platform for volume utilisation. For example the deviation of the VUR from platform “gf08” to “gi03” differs from 0.9% to 4.5% and the average of these 10 platforms is 2.8% as shown in Table 5.10. Platforms with a low VUR are not fully packed or the parts have a large geometry and the space is filled up with loose material. Therefore, it is always useful to calculate the VUR to see how dense the platform is packed.

The VUR can be calculated using the following:

$$\mathbf{VUR = PV / TPV} \quad \mathbf{(8)}$$

Where:

VUR = Volume Utilisation Rate

PV = Production Volume or Parts Volume

TPV = Platform Volume

#### 5.4.3 Cost Key Figure (CKF)

The CKF is calculated by dividing the total costs with the platform volume. It calculates the price per mm<sup>3</sup>. This is a simple cost comparison using KFs to obtain the information about the cost reduction with reference to the part's volume. For example the analysed platforms in Table 5.10 with the material Polyamide PA 2200 have a CKF between R0.01 to R0.5 per mm<sup>3</sup>. As result, the smaller the CKF the lower the part's manufacturing costs. See Table 5.10, the average CKF per mm<sup>3</sup> is R0.015. When a part with the volume of 10 000 mm<sup>3</sup> is manufactured on each platform, the manufacturing costs range between R97 and R504, the average is R152.

The CKF can be calculated using the following:

$$\mathbf{CKF = TC / PV} \quad \mathbf{(9)}$$

CKF = Cost Key Figure

TC = Total Costs

PV = Production Volume or Parts Volume

Table 5.10 Platforms and CKF

Platform Name	Platform Height (mm)	Production Volume (mm <sup>3</sup> )	Total Costs (R)	VUR	Cost Key Figure (R/mm <sup>3</sup> )
gf08	504	1 333 224	23 495	2.3%	0.018
gf09	210	439 346	10 080	1.8%	0.023
gg09	430	1 908 343	20 587	3.8%	0.011
gh01	230	465 503	11 085	1.8%	0.024
gh05	279	1 452 315	14 050	4.5%	0.010
gh06	72	78 936	3 977	0.9%	0.050
gh07	135	505 067	7 357	3.2%	0.015
gh09	350	786 393	15 990	1.9%	0.020
gi02	272	1 009 387	13 459	3.2%	0.013
gi03	71	169 388	3 998	2.1%	0.024
Sum/Aver.	2553	8 147 902	124 078	2.8%	0.015

## **CHAPTER 6**

### **IMPLEMENTATION OF THE RESULTS INTO A SOFTWARE BASED CALCULATION**

This chapter describes the structure, procedure and advantage of a specially designed calculation programme for the EOSINT P 380 and EOSINT S 700 machines. It also explains the correlation between linked data tables to insert data easily into the main calculation sheets. All this information is available for platform-, part-, pre- and post-calculation. The pre-calculation is needed to offer the client a quotation for his prototype. The post calculation is needed to get a deviation between both calculations. After the manufacturing process a cost overview and control is immediately possible. It also includes a part cost calculation by only entering the parts volume and total platform height. The calculation programme automatically calculates all cost drivers such as material costs and machine costs. The machine running time calculation is especially important and a complex part of the calculation programme. To calculate the manufacturing costs, the labour costs are also included. Further costs like postage, VAT and profit margin are taken into account to determine the final selling price.

## 6.1 DATA TABLES

Figure 6.1 shows the data tables of the calculation programme. All tables are linked to the calculation sheets and feeds the calculation programme with data. The different tables are created for material, machine, personnel and miscellaneous costs. In these tables, the basic data are already prepared and ready for use in the calculation programme.

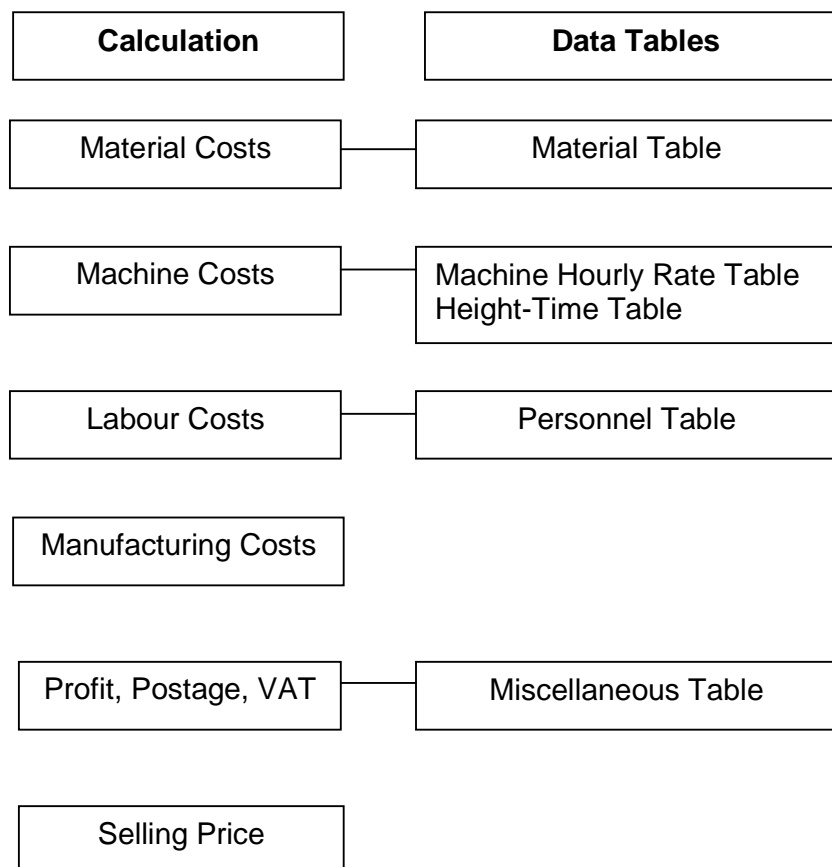


Figure 6.1 Structure of Calculation and Linked Data Tables

### 6.1.1 Material

The material data Table 6.1 includes the analysed materials. Different material data such as sintered density, waste material rate and material price is inserted into the material table. The part's volume in mm<sup>3</sup> is given by the Magics 9.5.1 software. To calculate the material consumption, it is necessary to separate the materials by their reusability.

Table 6.1 Material Data

Name	Sintered Density (kg/mm <sup>3</sup> )	Waste Material Factor (kg/mm <sup>3</sup> )	Material Price (R/kg)
PrimeCast 100	6.10E-07	0.00	552
Polyamide PA 2200	1.02979E-06	1.60	550
ALUMIDE®	7.65601E-07	0.00	590
Ceramics 5.2	0.000014	0.00	80

The material Polyamide PA 2200 is partly reusable, only the material close to the parts is not reusable. Therefore the consumption is calculated by the sintered material plus the waste material. The sintered material weight is calculated by the part's volume multiplied by sintered density and the waste material is calculated by an average value, which is 1.60. Tubes or bottles have a higher waste rate than flat or small parts, which are subjected to less material. Table 6.2 shows the Polyamide PA 2200 waste rate of analysed platforms. The material cost is calculated using the following equation:

$$\text{Material Cost} = \text{Sintered Density} \times \text{Part's Volume} \times \text{Material Waste Factor} \times \text{Material Price} \quad (10)$$

Table 6.2 Material Waste Factor Polyamide PA 2200

Platform Name	Sintered Material (kg)	Waste Material (kg)	Total Weight (kg)	Waste Material Factor
ha 01	2.04	2.77	4.81	1.36
gl 06	0.42	1.09	1.51	2.60
gk 02	0.92	1.56	2.48	1.70
Total/Average	3.38	5.42	8.80	1.60

The material cost for a Polyamide PA 2200 part with 500 000 mm<sup>3</sup> volume is calculated by using equation (10):

$$R\ 453 = 1,02979E-6\ \text{kg/mm}^3 \times 500\ 000\ \text{mm}^3 \times 1.6 \times R\ 550$$

The material ALUMIDE® is not reusable after the sintering process and must be discarded. Therefore the consumption is calculated by the platform's volume, because the sintered parts have no effect. The material cost is calculated by using the following equation:

$$\text{Material Cost} = \text{Platform Volume} \times \text{Material Density} \times \text{Material Price} \quad (11)$$

The material cost of a part with a volume of 500 000 mm<sup>3</sup> and a platform height of 100 mm is calculated by using equation (11):

$$\text{ALUMIDE®; R5222} = 7,66E-7\ \text{kg/mm}^3 \times 11560000\ \text{mm}^3 \times R590$$

The material cost for Ceramics 5.2 and PrimeCast 100 are the sintered part and the loose material is totally reusable. Therefore the cost is calculated by the part's volume multiplied by the material density and the material cost. The material cost is calculated by using the following equation:

$$\text{Material Cost} = \text{Part Volume} \times \text{Material Density} \times \text{Material Price} \quad (12)$$

The cost of a Ceramics 5.2 and PrimeCast 100 part both with a volume of 500 000 mm<sup>3</sup> is calculated by using equation (12):

$$R560 = 500\,000 \text{ mm}^3 \times 1,4\text{E-}5 \text{ kg/mm}^3 \times R80 \text{ (Ceramics 5.2)}$$

$$R168 = 500\,000 \text{ mm}^3 \times 6,10\text{E-}7 \text{ kg/mm}^3 \times R552 \text{ (PrimeCast 100)}$$

### 6.1.2 Machine Hourly Rates

The machine hourly rates (MHR) in Table 6.3 is needed to calculate the machine running costs. The rate is determined by the CRPM and it is calculated by dividing the total machine costs by the running hours per year. The MHR includes the energy costs, repair, maintenance, depreciation, housing costs and interest.

Table 6.3 Machine Hourly Rates

Machine	MHR
EOSINT P380	R 350
EOSINT S 700	R 868

### 6.1.3 Personnel Hourly Rates

The Personnel Hourly Rates (Table 6.4) includes the personnel names, the hourly rate and the % overhead rate. For each person it is possible to insert the specific hourly rate and overhead rate in percentage. At present no personnel overhead rates are added to the calculation.

Table 6.4 Personnel Hourly Rates

Name	Hourly Rate (R)
Student	100
Lecturer	100
David	100
Martin	100
Marinus	100

#### 6.1.4 Miscellaneous Data Tables

Table 6.5 contains miscellaneous data such as cost and rates for profit, postage, VAT and manufacturing waste. The profit margin can be calculated in the cost allocation sheet or determined for each platform. The postage cost depends on the type of delivery. The manufacturing waste and percentage rate is calculated from 66 platforms. It contains the costs of parts that are not manufactured correctly. These costs are allocated to the other platforms.

Table 6.5 Miscellaneous Data

Profit Rate	15%
Postage	R125
VAT	14%
Manufacturing Waste EOSINT P 380	5%
Manufacturing Waste EOSINT S 700	15%

## **6.2 MACHINE RUNNING TIME CALCULATION**

For the pre-calculation it is important to calculate the machine running time. The machine costs are the calculated machine running time multiplied by the machine hourly rate. To calculate the machine running time, two values namely the platform volume and platform height are needed. The manufacturing time is calculated by equation (5). The volume time is calculated by multiplying the volume utilisation factor by the volume factor depending on material and the platform height refers to the HT-Table for the specific platform Height-Time.

### **6.2.1 Material Dependent HT-Tables**

The HT-Table is needed to calculate the manufacturing time for the platform height. The HT-Table values are calculated for each machine and material. On the EOSINT P 380 machine there is a selection of three materials, namely the Polyamide PA 2200, PrimeCast 100 and ALUMIDE®. Each material needs its own manufacturing time, which has been calculated by numerous experiments. For the EOSINT S 700 only the Ceramics 5.2 material can be selected, because no other materials are used at present. The HT - manufacturing time has also been calculated by numerous experiments. Table 6.6 only depicts a section of the total HT-Table. The height values are calculated up to 620 mm for each machine and material.

Table 6.6 Height-Time Table Calculation Programme

<b>Platform Height</b>	<b>Polyamide PA2200</b>	<b>PrimeCast 100</b>	<b>Alumide®</b>	<b>Ceramics 5.2</b>
<b>(mm)</b>	<b>(minutes)</b>	<b>(minutes)</b>	<b>(minutes)</b>	<b>(minutes)</b>
152	539	570	527	222
153	542	573	530	223
154	545	577	534	224
155	549	580	537	226
156	552	584	540	227
157	555	588	543	228
158	559	591	547	229
159	562	595	550	231
160	565	598	553	232
161	569	602	556	233
162	572	605	560	234
163	575	609	563	236
164	579	612	566	237
165	582	616	569	238
166	585	619	573	239

### 6.3 CALCULATION SYSTEM

The calculation system is built up based on several sheets. The calculation system contains one inserted table sheet that transfers all the data to the pre- and post- calculation sheets. The data of each prototype volume, the estimated platform height, actual platform height and actual machine running time must be entered in this table. The prototype volume is for a cost allocation for each part. It is used for the pre-calculation part sheet and post-calculation part sheet. The total platform costs are allocated by the volume to get the prototype part costs. The estimated platform height is needed to calculate the machine running time for the pre-calculation sheet. The machine running time is calculated by using the HT-Table, the machine hourly rate sheet and the total platform volume. The material

costs are calculated from the part's volume, the waste material rate and the material cost per unit of the material sheet. For the post-calculation, the actual material consumption, actual platform height and the actual machine running time are needed. The real platform material costs are calculated using the actual material and the material price in the material table. The real machine costs are calculated using the actual machine running time from the MHR sheet in the post-calculation sheet. The deviation on the platform is shown in the platform deviation sheet and the deviation on each part is shown in the platform deviation part sheet. This comparison calculates the deviation between the pre- and post-calculation. All the other data tables transfer their information to the platform pre- and post-calculation sheets. Figure 6.2 shows the schematic diagram of the calculation system.

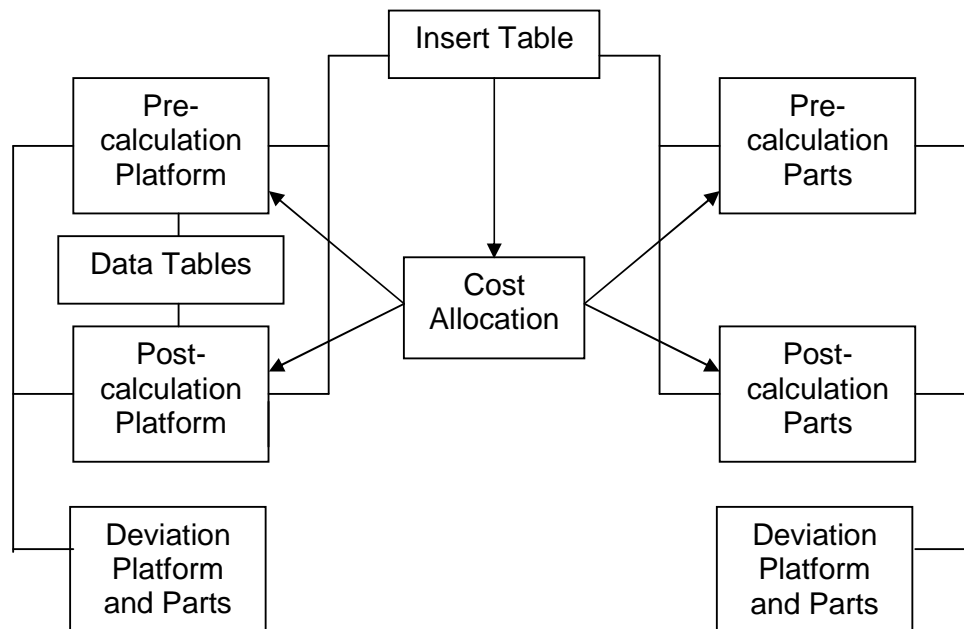


Figure 6.2 Schematic Diagram of the Calculation System

### 6.3.1 Insert Table

Table 6.7 contains all important prototype and platform information. These are the client/prototype names, number of prototypes, estimated platform height, actual platform height and actual running time. The numbers of parts are multiplied by the individual part volume to obtain the total volume of these prototypes. It also contains the platform date, name and the machine used.

Table 6.7 Insert Table

<b>Date:</b>		<b>02.07.05</b>	
<b>Platform Name:</b>		<b>Test</b>	
<b>Machine:</b>		<b>EOSINT P 380</b>	
<b>Material:</b>		<b>Polyamide PA 2200</b>	
<b>Pre-Calculation Platform Height (mm)</b>	<b>Actual Platform Height (mm)</b>	<b>EOSINT P380 Actual Running Time (hours.minutes)</b>	
241	241	14.16	
<b>Name</b>	<b>Parts to Manufacture</b>	<b>Parts Volume (mm<sup>3</sup>)</b>	<b>Total Volume (mm<sup>3</sup>)</b>
Test Part 1	3	25 000	75 000
Test Part 2	1	125 000	125 000
Test Part 3	2	30 000	60 000
Test Part 4	4	10 000	40 000
Test Part 5	3	50 000	150 000
Test Part 6	4	33 000	132 000
Test Part 7	1	100 000	100 000
Test Part 8	1	318 000	318 000

### 6.3.2 Pre-Calculation

The most important information for the pre-calculation is the prototype volume and the estimated platform height. The data are automatically transferred from the Insert Table sheet into the Pre-Calculation sheet. This results in an estimated platform cost. The pre-calculation table (Table 6.8) shows the accrued costs and

whether it is worthwhile to manufacture the parts on this platform. It is furthermore a simulation tool to see the cost development by placing the parts in another direction to reduce the platform height. The platform information is the platform name, how many parts to manufacture, the total platform volume and the estimated platform height. This information shows the basis-platform data, which is needed for the manufacturing time calculation. The first calculation is the manufacturing time of the estimated platform height, selected machine and material. For a better understanding, the calculated manufacturing time is calculated in minutes and translated into hours and minutes. In this case 19 parts, with a total volume of  $1\,000\,000\text{ mm}^3$  and a 241 mm platform height has a manufacturing time of 883 minutes = 14 hours and 43 minutes. As soon as the material is selected in a drop-down list, the specific material values are transferred from the material sheet. The material consumption is calculated from the sintered density and the material waste factor. The material waste factor is calculated using the waste material factor from the material data table (Table 6.1). The total material costs are calculated using the material price multiplied by the total material consumption and amount to R1472. The machine type is selected from a drop-down list. The MHR is transferred from Table 6.3 to Table 6.8. The machine cost is calculated by the estimated machine running time multiplied by the MHR. In this case the MHR for the EOSINT P 380 is R350 and the estimated running time 883 minutes resulting in a total machine cost of R5151. The labour costs are calculated by selecting the person's name in the drop-down list. The labour hourly rate and overhead costs are transferred from the personnel table (Table 6.4). The labour costs are calculated from the hourly rate and working time in hours. In this specific case the labour costs are R500.

The manufacturing cost is calculated by adding the total material, machine, labour cost and waste material, and for this example it amounts to R7479. The manufacturing costs also include the waste material, because not every platform produces perfect prototypes. These prototypes must be manufactured again and causes additional manufacturing costs, which are paid by the CRPM and not by the client. Therefore, these waste parts' costs must be allocated to other platforms. The waste rate in this example is 5% and amounts to R356. The total platform costs are calculated by adding the profit margin and the postage to the manufacturing costs. The profit margin rate and the postage costs are transferred from the standard values sheet. It is also possible to add the number of clients to get the total postage cost for this platform. The selling price is calculated by adding the VAT to the total platform cost and amounts to R9948. The VAT rate is transferred from the standard values sheet.

Table 6.8 Pre-Calculation

Pre-Calculation Platform			
Name	Parts to Manufacture	Total Volume in (mm <sup>3</sup> )	Pre-Calculation Platform Height
Test	8	1 000 000	241
Pre-Calculated Manufacturing Time			
	(hours.minutes)	(minutes)	
Total	14.43	883	
Select Material	Sintered Density in kg	Material Waste Factor	Material Costs
Polyamide PA 2200 ▼	1.03		R 566
Waste Material (kg/mm <sup>3</sup> )	1.6	1.6	R 906
			R 1472 20%
Select Machine	MHR	Time (hours.minutes)	Machine Costs
EOSINT P380 ▼	R 350	14.43	R 5151
			R 5151 69%
Labour	LHR	Time (hours)	Labour Costs
Student ▼	R 100	5	R 500
- ▼	R 0	0	R 0
			R 500 7%
Manufacturing Waste Rate		5%	R 356
Manufacturing Costs			R 7479 100%
Profit Margin			R 1122
POSTAGE	Number of Clients	1	R 125
Total Costs			R 8726
VAT		14%	R 1222
Selling Price			R 9948

### 6.3.3 Pre-Calculation: Single Parts

The calculated costs from the Pre-Calculation sheet are divided by the part's volume, which are transferred from the Insert Table (Table 6.7) and costs calculated in the Pre-Calculation data sheet (Table 6.8). The result is the costs for the total prototype series and each prototype. All the different costs are shown in Table 6.9. The material, machine, labour, manufacturing, total costs and selling price for the prototypes are all depicted in the table. For example the prototypes "Test Part 5" are in total three parts. These three parts have manufacturing costs of R1122 and selling price of R1492. The selling price for one prototype is R497.

Table 6.9 Pre-Calculation: Single Parts

Name	Material Costs (R)	Machine Costs (R)	Labour Costs (R)	Manufacturing Waste Rate	Manufacturing Costs (R)
Part 1	110	386	38	27	561
Part 2	184	644	63	45	935
Part 3	88	309	30	21	449
Part 4	59	206	20	14	299
Part 5	221	773	75	53	1122
Part 6	194	680	66	47	987
Part 7	147	515	50	36	748
Part 8	468	1638	159	113	2378
Total	1472	5151	500	356	7479
Name	Profit Margin (R)	Postage (R)	Total Cost (R)	VAT (R)	Selling Price / Unit (R)
Part 1	84	9	654	92	746
Part 2	140	16	1091	153	1244
Part 3	67	8	524	73	597
Part 4	45	5	349	49	398
Part 5	168	19	1309	183	1492
Part 6	148	17	1152	161	1313
Part 7	112	13	873	122	995
Part 8	357	40	2775	389	3163
Total	1122	125	8726	1222	9948

#### **6.3.4 Post-Calculation**

The most important information for the post-calculation is the actual material consumption, the actual machine running time and the actual platform height. The data are automatically transferred from the Insert Table sheet (Table 6.7) resulting in the actual platform cost. The post-calculation in Table 6.10 shows the overview of the actual cost of this platform. The platform information is the same as for the pre-calculation. When the material is selected in the Pre-Calculation sheet (Table 6.8), the specific material values are transferred from the material data sheet (Table 6.1). The material calculation is the same as for the pre-calculation, but with the actual material consumption. When the machine is selected in the Pre-Calculation sheet (Table 6.8), the specific MHR is transferred from the machine data sheet (Table 6.1). The machine calculation is the same as for the pre-calculation; only the machine cost is calculated by the actual machine running time. The labour costs, the manufacturing costs, total platform costs and selling price are the same calculation scheme as used in the pre-calculation.

Table 6.10 Post-Calculation

Post-Calculation Platform			
Name	Parts to Manufacture	Total Volume (mm <sup>3</sup> )	Pre-Calculation Platform Height
Test	8	1 000 000	241
Post-Calculated Manufacturing Time			
	(hours.minutes)	(minutes)	
Total	14.16	856	
Select Material	Sintered Weight (kg)	Material Waste Factor	Material Costs
Polyamide PA 2200	1.03		R 566
Waste Material (kg/mm <sup>3</sup> )	1.7	1.69	R 958
			R 1524 21%
Select Machine	MHR	Time (hours.minutes)	Machine Costs
EOSINTP 380	R 350	14.16	R 4993
			R 4993 68%
Labour Student	LHR R 100	Time (hours) 5	Labour Costs R 500
			R 500 7%
Manufacturing Waste Rate		5%	R 351
Manufacturing Costs			R 7368 100%
Profit Margin			R 1105
POSTAGE Clients		1	R 125
Total Costs			R 8598
VAT		14%	R 1204
Selling Price			R 9802

### 6.3.5 Post-Calculation: Single Parts

The actual cost from the Post-Calculation sheet (Table 6.10) is now divided by the part volume, which is transferred from the Insert Table (Table 6.7), resulting in the costs for the total prototype series and each prototype. All the different costs are shown in Table 6.11. It is easy to see the material, machine, labour, manufacturing, total costs and selling price for the prototypes. For example, “Test Part 5” consists of three parts. These three parts have manufacturing costs of R1105 and selling price of R1470. The selling price for one prototype is R490.

Table 6.11 Post-Calculation: Single Parts

Name	Material Costs (R)	Machine Costs (R)	Labour Costs (R)	Manufacturing Waste Rate	Manufacturing Costs (R)
Part 1	114	374	38	26	553
Part 2	191	624	63	44	921
Part 3	91	300	30	21	442
Part 4	61	200	20	14	295
Part 5	229	749	75	53	1105
Part 6	201	659	66	46	973
Part 7	152	499	50	35	737
Part 8	485	1588	159	112	2343
Total	1524	4993	500	351	7368
Name	Profit Margin (R)	Postage (R)	Total Cost (R)	VAT (R)	Selling Price / Unit (R)
Part 1	83	9	645	90	735
Part 2	138	16	1075	151	1225
Part 3	66	8	516	72	588
Part 4	44	5	344	48	392
Part 5	166	19	1290	181	1470
Part 6	146	17	1135	159	1294
Part 7	111	13	860	120	980
Part 8	351	40	2734	383	3117
Total	1105	125	8598	1204	9802

### 6.3.6 Deviation

In Table 6.12, the deviation is shown between the pre- and post-calculation. In this case, the estimated platform height and the actual platform height have the same value. The material costs differs which results in a different material waste factor and amounts to R52. The actual machine running time differs from the calculated time with 27 minutes. The total platform cost deviation is R128 and selling price deviation is R146.

Table 6.12 Deviation Pre- and Post-Calculation

Deviation Calculation Platform				
Name	Pre-Calculation Platform Height (mm)	Actual Platform Height (mm)	Dev.	%
Test	241	241	0	0%
Running Time (minutes)				
Total	883	856	27	3%
Material Costs				
Material Costs	R 1472	R 1524	R -52	-3%
Machine Costs				
EOSINT P380	R 5151	R 4993	R 158	3%
Labour Costs				
Total Labour Time (hours)	5	1	4	
Total Labour Costs	R 500	R 500	R 0	0%
Manufacturing Costs	R 7479	R 7368	R 111	2%
Total Costs	R 8726	R 8598	R 128	1%
Selling Price	R 9948	R 9802	R 146	1%

### 6.3.7 Deviation: Single Parts

In Table 6.13, the deviation is shown between the pre- and post-calculation per part. The platform costs deviation is allocated to the prototypes. In this case for "Test Part 5" the total cost deviation is R19 and selling price deviation R22.

Table 6.13 Deviation Pre- and Post-Calculation: Single Parts

<b>Name</b>	<b>Material Cost (R)</b>	<b>Machine Costs (R)</b>	<b>Labour Costs (R)</b>	<b>Manufacturing Costs (R)</b>	<b>Total Costs (R)</b>	<b>Selling Price (R)</b>	<b>Selling Price / Unit (R)</b>
Part 1	-4	12	0	8	10	11	4
Part 2	-6	20	0	14	16	18	18
Part 3	-3	9	0	7	8	9	4
Part 4	-2	6	0	4	5	6	1
Part 5	-8	24	0	17	19	22	7
Part 6	-7	21	0	15	17	19	5
Part 7	-5	16	0	11	13	15	15
Part 8	-16	50	0	35	41	46	46
<b>Total</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>111</b>	<b>128</b>	<b>146</b>	

# CHAPTER 7

## CASE STUDIES

Several platforms were selected for the case studies. These platforms highlight special cases where the platform height and volume affect the material and machine costs. Examples are also included, which give an overview of RM. Some platforms are split up in several prototype layers to work out a cost comparison. KFs are used to compare different platforms with one other. These results give a guideline to building platforms under KF conditions. Therefore it is possible to build several platforms with the same prototypes and to select the cheapest manufacturing method.

### 7.1 REDUCING COSTS BY NESTING PARTS

The reduction of the manufacturing costs is shown in calculating a nested platform compared to each part, separately. The results highlight the way the machine manufactures and offers a means of calculating the costs. This is greatly dependent on how the parts are nested together on a platform and how the single parts are placed.

#### 7.1.1 Nested Platform Calculation “Analysed Parts”

In this example, seven analysed parts were nested together and calculated in Table 7.1. The platform had a total volume of 1 044 195 mm<sup>3</sup>, a total height of 165 mm, a manufacturing time of 633 minutes and the total cost was R5724. To compare the results of a nested platform to the single part manufacturing, the

single parts were calculated separately. Table 7.2 shows the deviation between the nested platform and single parts. The manufacturing time increased by 70% from 633 minutes to 1075 minutes. A reason for this is that the nested platform is better packed and parts are placed differently to the single part placing. The KF VUR indicates this fact by 24% decrease (Table 7.2). The total costs increased by 76% i.e. from R5724 to R10 089, because the single parts need in total more height and therefore more material and manufacturing time.

Table 7.1 Calculation Nested Platform

<b>Platform: Analysed Parts</b>						
EOSINT P380		▼	Polyamide PA 2200		▼	
<b>Name</b>	<b>Parts to Manufacture</b>	<b>Parts Volume (mm<sup>3</sup>)</b>	<b>Calculation Platform Height (mm)</b>	<b>VUR</b>	<b>CKF (R/mm<sup>3</sup>)</b>	<b>Total Costs (R)</b>
SEV 1503	4	77 957	165	5%	0.0055	5724
SEV 1507	2	33 704				
SEV 1511	2	52 969				
Mouse TB	4	10 566				
Part 01	1	20				
SEV1501	1	271 565				
SEV1504	6	40 862				

Table 7.2 Comparison of Single Parts to Nested Platform “Analysed Parts”

Parts Name	Volume (mm <sup>3</sup> )	Height (mm)	Time (minutes)	Total Costs (R)	VUR	CKF (R/mm <sup>3</sup> )
Nested Platform	1 044 195	165	633	5724	5%	0,0055
Single Parts						
SEV 1503	311 828	34	164	1575	8%	0,0061
SEV 1507	67 408	23	113	918	3%	0,0186
SEV 1511	105 938	30	138	1126	3%	0,0138
Mouse TB	42 264	8	63	589	5%	0,0219
Part 01	20	2	39	387	0%	36,085
SEV1501	271 565	100	379	2770	2%	0,0114
SEV1504	245 172	40	179	2725	5%	0,0125
Sum/Average	1 044 195	237	1075	10 089	4%	0,0097
Deviation	0%	44%	70%	76%	-24%	76%

### 7.1.2 Nested Platform Calculation “gh05”

Table 7.3 shows the platform “gh05”, which had a manufacturing time of 1100 minutes, a volume of 1 452 315 mm<sup>3</sup>, a height of 279 mm and total cost of R8556. To compare the results of a nested platform to single part manufacturing, the single parts were calculated separately. Table 7.3 shows the deviation between the nested platform and single parts. The manufacturing time increased by 138% from 1100 minutes to 2621 minutes. A reason for this is that the nested platform is better packed and parts are placed differently to the single part placing. The KF VUR indicates this fact by a 45% decrease (Table 7.3). The total costs increased by 104% i.e. from R8556 to R17426, because the single parts need in total more height and therefore more material and manufacturing time.

Table 7.3 Comparison of Single Parts to Nested Platform Calculation “gh05”

Name	Volume (mm <sup>3</sup> )	Height (mm)	Time (minutes)	Total Costs (R)	VUR	CKF (R/mm <sup>3</sup> )
Platform gh05	1452 315	279	1100	8 556	5%	0.0059
Single Parts						
sim	3 250	7	56	330	0%	0.1014
compound	657	19	95	557	0%	0.8484
snap_plate	50 116	20	102	669	2%	0.0134
button	1 582	9	62	365	0%	0.2307
vent_plate	46 864	19	99	644	2%	0.0137
lens	2 956	8	59	348	0%	0.1178
controller_base	1 111	13	75	442	0%	0.3975
lid	127 982	22	114	852	5%	0.0067
cover	289 216	53	224	1 734	5%	0.0060
boss	7 776	14	79	474	0%	0.0609
frame	143 439	60	240	1 609	2%	0.0112
controller_base	302 346	52	222	1 739	5%	0.0058
housing_base	127 145	24	120	888	5%	0.0070
housing-slide	45 700	19	98	642	2%	0.0140
xyz 101	88 038	35	154	1 027	2%	0.0117
xyz 102	123 875	37	162	1 130	3%	0.0091
Dutton sleeve	19 391	34	146	883	0%	0.0455
Dutton outlet	30 429	38	160	981	1%	0.0322
Dutton shaped	33 362	49	197	1 199	1%	0.0360
Dutton spoon	3 015	10	65	385	0%	0.1278
Dutton cap	4 065	17	89	527	0%	0.1296
Sum/Average	1452 315	559	2621	17 426	2%	0.0120
Deviation	0%	100%	138%	104%	-45%	104%

### 7.1.3 Nested Platform Calculation “gh06”

Platform “gh06 has a manufacturing time of 258 minutes, a volume of 78 936 mm<sup>3</sup>, a height of 72 mm and the total cost is R1621. To compare the results of a nested platform to the single part manufacturing, the single parts are again calculated separately. Table 7.4 shows the deviation between the nested platform and single parts. The manufacturing time increased by 67% from

258 minutes to 432 minutes. A reason for this is that the nested platform is better packed and parts are placed differently to the single part placing. The KF VUR indicates this fact by a 19% decrease (Table 7.4). The total costs increased by 46% i.e. from R1621 to R2365, because the single parts need in total more height and therefore more material and manufacturing time.

Table 7.4 Comparison of Single Parts to Nested Platform Calculation “gh06”

Name	Volume (mm <sup>3</sup> )	Height (mm)	Time (minutes)	Total Costs (R)	VUR	CKF (R/mm <sup>3</sup> )
Platform gh06	78 936	72	258	1621	1%	0,0205
Single Parts						
19 former ver 3	58 670	3	44	268	3%	0,0046
98 former ver 3	9 778	3	44	270	3%	0,0277
24_of_bobbin25	1 582	11	69	404	0%	0,2552
CellStun cover2	8 906	72	275	1691	1%	0,1899
Sum/Average	78 936	89	432	2365	1%	0,0300
Deviation	0%	24%	67%	46%	-19%	46%

#### 7.1.4 Nested Platform Calculation “gi03”

Table 7.5 shows the Platform “gi03”, which has a manufacturing time of 264 minutes, a volume of 165 632 mm<sup>3</sup>, a height of 71 mm and the total cost is R1784. To compare the results of a nested platform to the single part manufacturing, the single parts are calculated separately. Table 7.5 shows the deviation between the nested platform and single parts. The manufacturing time increased by 56% from 264 minutes to 413 minutes. An explanation for this is that the nested platform is better packed and parts are placed differently to the single part placing. The KF VUR indicates this fact by 13% decrease (Table 7.5).

The total costs increased by 49% i.e. from R1784 to R2654, because the single parts need in total more height and therefore more material and manufacturing time.

Table 7.5 Comparison of Single Parts to Nested Platform Calculation “gi03”

Name	Volume (mm <sup>3</sup> )	Height (mm)	Time (minutes)	Total Costs (R)	VUR	CKF (R/mm <sup>3</sup> )
Platform gi03	165 632	71	264	1784	2%	0,0108
Single Parts						
Housing_Front	72 040	12	78	561	5%	0,0078
Housing_Back	86 032	29	134	908	3%	0,0106
Exst3566_pin	2 154	26	119	696	0%	0,3233
Screw_plate	5 406	15	82	489	0%	0,0904
Sum/Average	165 632	82	413	2654	2%	0,0160
Deviation	0%	15%	56%	49%	-13%	49%

## 7.2 BLOCK CALCULATION

The maximum platform height for an EOSINT P 380 machine is 620 mm. The calculated average platform height for each platform is 296 mm. Therefore, every platform has in average more than 300 mm left for manufacturing further parts. The volume could be used for manufacturing a number of the same parts, which can be used for RM (RM means that product ranges from one-off to an unlimited quantity can be manufactured directly from CAD over a period of time, without spending time or money on tooling development). These processes have the effect of both improving products and reducing their development time. It manufactures series parts in large quantities. This form of manufacturing can be incredibly cost-effective and the process is far more flexible than conventional manufacturing. A further reason to include the RM process into the day-to-day RP

process is for better machine utilisation. It can reduce the machine hourly rate to produce cheaper parts. For example, on a total of 1600 running hours, the machine costs are R560 000 per year, resulting in an hourly rate of R350. Using machine costs of R560 000 and 2500 running hours as basis can decrease the hourly rate to R224. For a 500 mm platform, which runs approximately 30 hours, the machine costs are then reduced from R10 500 to R6720, utilising a cheaper MHR. The following examples give an idea of how this potential can be used.

### **7.2.1 Platform Calculation “ge06”**

Table 7.6 shows 300 parts that must be manufactured in a period of four weeks. It is possible to place 50 parts in the platform area of 340 mm x 340 mm at the same height of 100 mm. In this case, the 300 parts have a total height of 600 mm. To calculate the 600 mm platform, it is divided into “blocks” of 50 parts, which have the same height of 100 mm by using the “ge06” platform figures (Table 7.6). This platform has a total height of 618 mm, volume 3 061 430 mm<sup>3</sup> and an actual manufacturing time of 2209 minutes. The costs are calculated using the calculated manufacturing time, which is 2176 minutes. It also includes loose material of 12 mm on the bottom and 6 mm on top. The total platform is now divided and calculated as “blocks”. The “block” ge06\_400 contains 200 parts and has material and machine costs of R16 852. Compared to the original platform the costs increased by 2%. In the case of the ge01\_100, the cost increased by 16% compared with the original platform. This is caused by bottom and top material layers. The material layers have a height of 18 mm and for six “blocks” these are the costs for 108 mm material layers. To produce these “six blocks” – a total of 300 parts – the following calculation was used. Each “block” is

calculated separately and the costs added together. For example “three blocks” of 300 mm, 200 mm and 100 mm height are produced. This option costs R26 389 and is 6% more than the original platform. The different options of manufacturing are shown below. The increased costs are shown as percentages. Another way to include these 300 parts into the day to day RM process is to divide the platform into “blocks”, but without including the bottom and top exposure. Here the exposure costs are allocated to the ordinary prototypes and the RM parts are only added to the platform. The result shows that it is not important how the 300 parts are split up into different “blocks”. The RM costs are now nearly linear and the deviation is between -1% and 2%. This is one possibility to integrate the RM process into the manufacturing process. Figure 7.1 shows how the platform is divided into “blocks”.

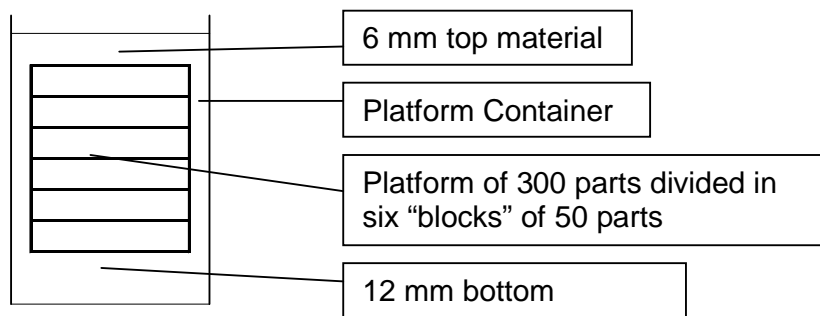


Figure 7.1 Platform Divided into “Blocks”

Table 7.6 Platform Calculation for Rapid Manufacturing

	Name	Blocks Height (mm)	Total Costs (R)	Deviation
	ge06_600	618	24 692	0%
inclusive 18 mm bottom and top material	100+500	118+518	25 650	4%
	200+400	218+418	25 650	4%
	300+300	318+318	25 645	4%
	3x200	3x218	26 395	6%
	6x100	6x118	28 610	14%
	400+2x100	418+2x118	26 389	6%
	300+3x100	318+3x118	27 127	9%
	300+200+100	318+218+118	26 389	6%
	exclusive 18 mm bottom and top material	100+500	100+500	24 418
200+400		200+400	24 412	-1%
300+300		300+300	24 424	-1%
3x200		3x200	24 599	0%
6x100		6x100	25 159	2%
400+2x100		400+2x100	24 599	0%
300+3x100		300+3x100	24 791	0%
300+200+100		300+200+100	24 605	0%

### 7.2.2 Cost Development Part “SEV 1501”

Table 7.7 shows the calculated cost development in total and for each SEV 1501 part shown in Figure 7.2 and Table 7.8 by placing the parts in “blocks”. Each “block” contains up to eight parts, because of the platform area. For example 20 parts cost R25 159 in total and each piece costs R1258. Compared with the costs for one part, which amounts to R8042, the cost reduction is over 539%. To manufacture the cheapest parts, the “block” must be utilised to the maximum. In this case, the cost is minimised for 24 parts manufactured in three “blocks”.

Table 7.7 Cost Development Part “SEV 1501”

	Number of Parts	Platform Costs (R)	Part Costs (R)
<b>Block 1</b>	1	8042	8042
	2	8118	4059
	3	8194	2731
	4	8270	2068
	5	8346	1669
	6	8421	1404
	7	8497	1214
	8	8573	1072
<b>Block 2</b>	9	16 493	1833
	10	16 569	1657
	11	16 645	1513
	12	16 715	1393
	13	16 790	1292
	14	16 866	1205
	15	16 942	1129
	16	17 012	1063
<b>Block 3</b>	17	24 938	1467
	18	25 008	1389
	19	25 083	1320
	20	25 159	1258
	21	25 229	1201
	22	25 305	1150
	23	25 375	1103
	24	25 451	1060

Table 7.8 Data Part “SEV 1501”

Volume:	271 565 mm <sup>3</sup>
Area:	111 023 mm <sup>2</sup>
B x D x H:	32 mm x 33 mm x 100 mm

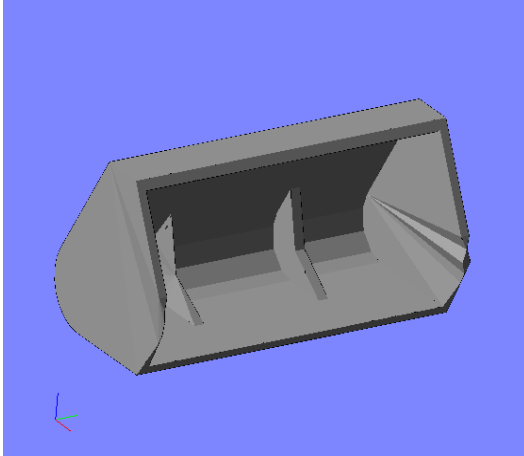


Figure 7.2 Part “SEV 1501”

The platform cost development for part SEV 1501 is shown in the Figure 7.3. The “block steps” show that the costs increase dramatically when the first part is manufactured in a new block. In this case one block can contain up to eight parts. The next part must be placed in the second block, which can accommodate up to 16 parts and the next part (17<sup>th</sup> part) must be placed in the third block that can accommodate up to 24 parts. That causes less platform volume utilisation and the new platform height. To reduce the cost to the minimum, the platform volume must be fully utilised and the platform height minimised.

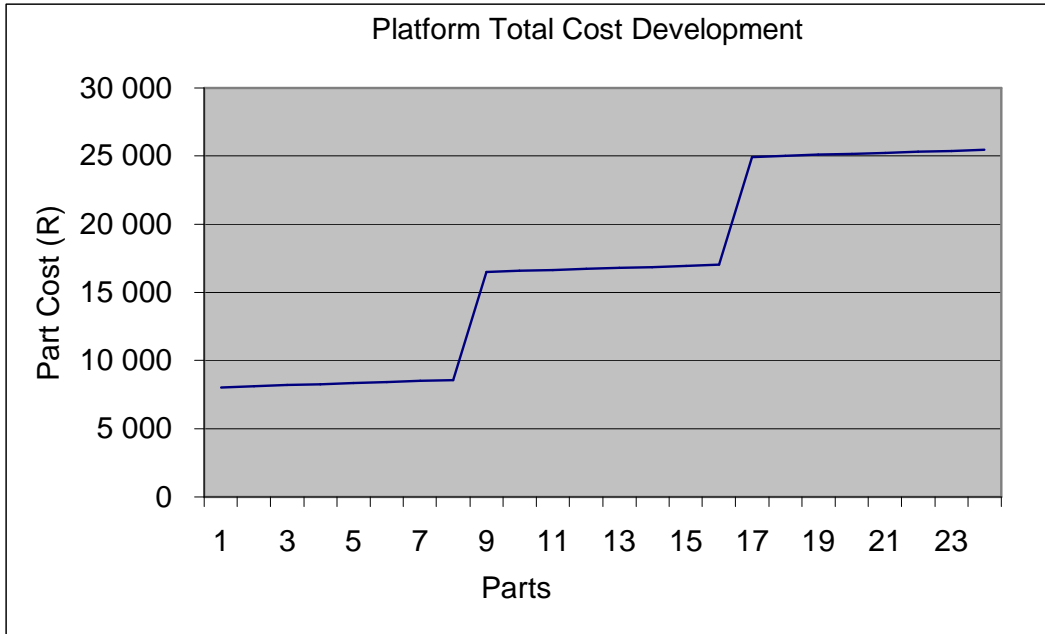


Figure 7.3 Platform Cost Development Part “SEV 1501”

The part costs development for part “SEV 1501” is shown in Figure 7.4 and decrease dramatically for the first four parts. After the ninth part, the costs become more linear.

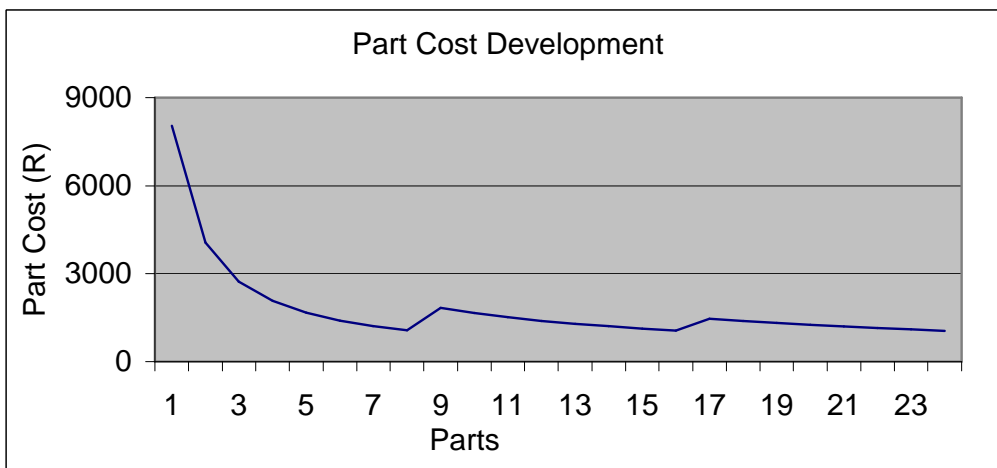


Figure 7.4 Part Cost Development Part “SEV 1501”

### 7.2.3 Cost Development Platform “gi09” and Part 02

In this case study, the “gi09” platform costs are taken as basic costs and the manufactured part “part 02” is shown in Figure 7.5. To determine the cost development, the data in Table 7.9 are taken, which theoretically fits up to 50 parts in one “block”. Table 7.10 shows the platform costs that increased by one part to 50 parts from R5456 to R6386 and the part costs decreased from R5456 to R128 as shown in Figure 7.7. Figure 7.6 shows the total platform cost development for “part 02”. The platform costs continue to decrease, because the platform has the same height and only the costs for the part’s volume are accrued. Compared to the manufacturing costs of one part with one out of the 50 part block, a part can be manufactured at a much lower cost.

Table 7.9 Data Part 02

Volume:	915 mm <sup>3</sup>
Area:	37046 mm <sup>2</sup>
B x D x H:	6 mm x 6 mm x 106 mm

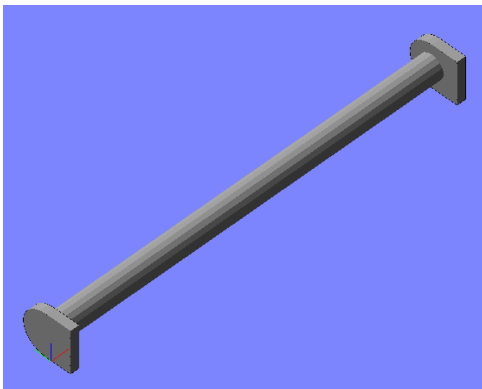


Figure 7.5 Part 02

Table 7.10 Cost Development Platform “gi09” and Part 02

Parts	Total Cost (R)	Part Cost (R)	Parts	Total Cost (R)	Part Cost (R)
1	5456	5456	26	5900	227
2	5468	2734	27	5920	219
3	5487	1829	28	5939	212
4	5499	1375	29	5959	205
5	5517	1103	30	5978	199
6	5530	922	31	5998	193
7	5548	793	32	6018	188
8	5560	695	33	6038	183
9	5579	620	34	6058	178
10	5597	560	35	6078	174
11	5616	511	36	6098	169
12	5634	470	37	6118	165
13	5653	435	38	6138	162
14	5671	405	39	6158	158
15	5690	379	40	6179	154
16	5709	357	41	6199	151
17	5728	337	42	6219	148
18	5747	319	43	6240	145
19	5766	303	44	6261	142
20	5785	289	45	6281	140
21	5804	276	46	6302	137
22	5823	265	47	6323	135
23	5842	254	48	6344	132
24	5861	244	49	6365	130
25	5881	235	50	6386	128

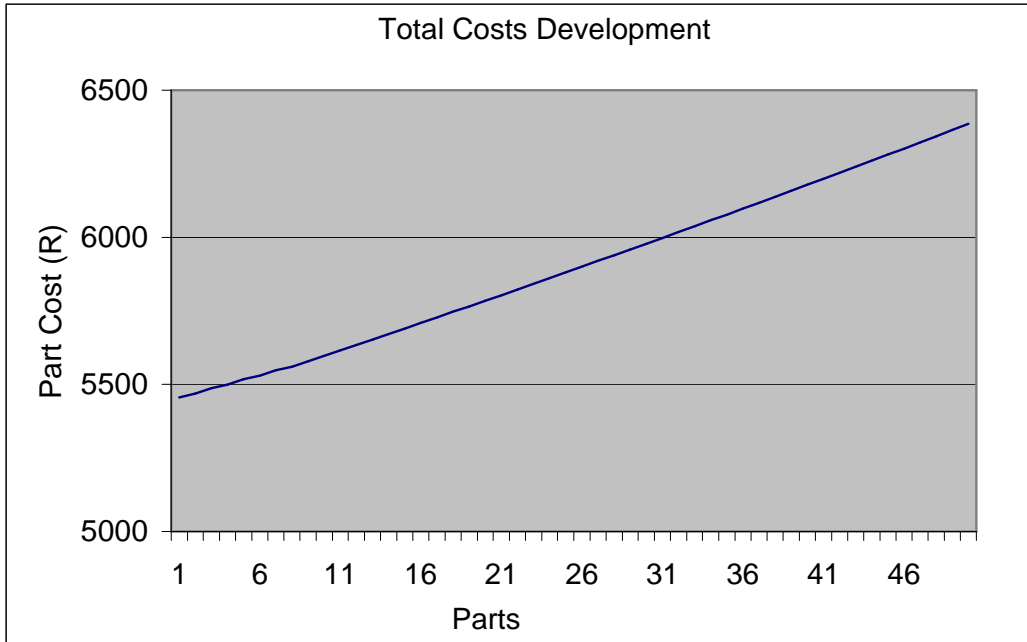


Figure 7.6 Platform Cost Development Platform “gi09”

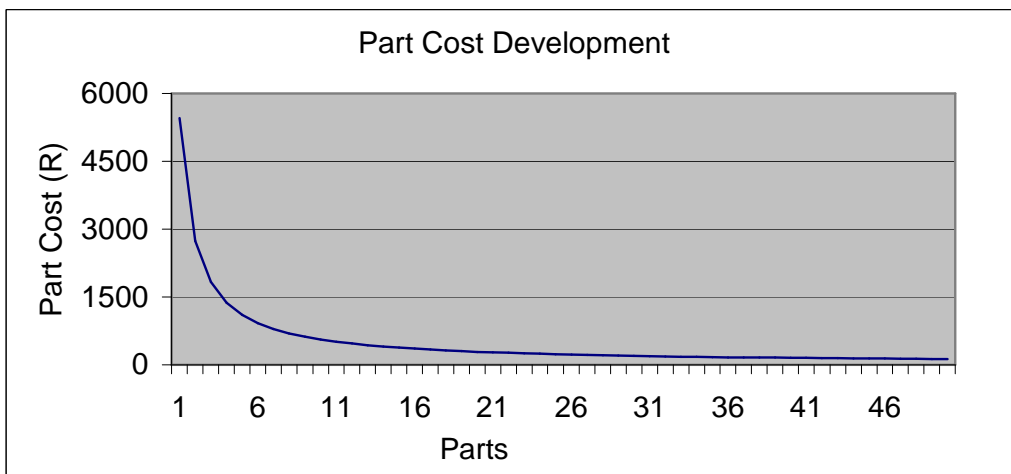


Figure 7.7 Part Cost Development Part 02

### 7.3 REDUCTION OF COSTS BY REDUCING THE PLATFORM HEIGHT

A possibility to reduce manufacturing costs is to build a platform as flat as possible. The analysed Platforms “gk02” and “gl06”, are shown in Table 7.11 and Table 7.12. The original height for platform “gk02” is 167 mm and for “gl06” is 128 mm. The example shows what happens when the original platform height can be theoretically reduced by 10% of placing the parts differently. This can be achieved by better placing and packing of the parts within a build. For the calculation the platform height for platform “gk02” is 150 mm and for “gl06” 115 mm. The part’s volume and the material waste factor are taken from the original platform results. The 10% lower platform height calculates a manufacturing time for the platform “gk02” of 580 minutes (-9%) and for “gl06” of 438 minutes (-9%). The shorter machine running time reduces machine costs for platform “gk02” from R5407 to R5074 and for “gl06” from 3836 to R3606. As a result of a platform height reduction of 10%, the manufacturing costs have been reduced by 6.2% for platform “gk02” and 6.1% for “gl06”. The material used for both platforms and for the calculation is Polyamide PA 2200.

Table 7.11 Information of Platform “gk02” and “gl06”

<b>Platform Name</b>	<b>Platform Height (mm)</b>	<b>Volume (mm<sup>3</sup>)</b>	<b>Time (minutes)</b>	<b>Material Waste Factor</b>
gk02	150	987 108	580	1.70
gl06	115	451 603	438	2.57

Table 7.12 Cost Overview of Platform “gk02” and “gl06”

Platform Name	Platform Height (mm)	Total Costs (R)	Platform Height (mm)	Total Costs (R)	Deviation
gk02	167	5407	150	5074	6,2%
gl06	115	3836	115	3603	6,1%

### 7.3.1 Platform Calculation “gi07” and “gi07\*”

Table 7.13 shows the Platform “gi07” and Platform “gi07\*”. The difference between platform “gi07” and “gi07\*” is the placing of one part turned by 90°. The part that is turned by 90° reduces the platform height from height 127 mm to 77 mm. The manufacturing time is reduced from 459 minutes to 292 minutes and the total costs from R2743 to R1768.

Table 7.13 Comparison of Platform Calculation “gi07” and “gi07\*”

Platform Name	Height (mm)	Volume (mm <sup>3</sup> )	Time (minutes)	Total Costs (R)
gi07	127	44 305	459	2743
gi07*	77	45 305	292	1768
Deviation	50	0	167	974
(%)	-61%		-64%	-64%

#### 7.4 REDUCTION OF COSTS BY VOLUME UTILISATION

Another possibility to reduce manufacturing costs is to place as many as possible parts in a certain platform volume for a build. That increases the volume of a platform and decreases the part costs. The example in Table 7.14 and Table 7.15 show the cost reduction by increasing the platform volume utilisation. The platform height for all materials is 500 mm, only the volume utilisation differs for each material.

The Polyamide PA 2200 platform costs are calculated with a waste factor of 1.6. The total platform cost increased by R3133 (20%) from R15 838 to R18 971. For example a part of 200 000 mm<sup>3</sup> volume manufactured in the platform with 3% to 5% volume utilisation, the cost decreased from R1914 to R1309 (32%). The ALUMIDE ® platform costs are calculated with used material of 44.6 kg. The total platform cost increased by R6066 (16%) from R37 645 to R43 711. For example a part of 200 000 mm<sup>3</sup> volume manufactured in the platform with 5% to 10% volume utilisation, the cost decreased from R4857 to R3015 (38%). The PrimeCast 100 platform costs are calculated with used material of 1.07 kg. The total platform cost increased by R2194 (16%) from R11 614 to R13 808. For example a part of 200 000 mm<sup>3</sup> volume manufactured in the platform with 3% to 5% volume utilisation, the cost decreased from R1487 to R952 (36%). The Ceramics 5.2 platform costs are calculated with used material of 2.8 kg. The total platform cost increased by R415 (3%) from R15 222 to R15 637. For example a part of 200 000 mm<sup>3</sup> volume manufactured in the platform with 5% to 10% volume utilisation, the cost decreased from R826 to R464 (44%).

Table 7.14 Part and Platform Costs by Different Volume Utilisation

Material	VUR	Part Cost (R)	Total Cost (R)	VUR	Part Cost (R)	Total Cost (R)
Polyamide PA 2200	3%	1914	15 838	5%	1309	18 971
Alumide®	3%	4857	37 645	5%	3015	43 711
PrimeCast 100	3%	1487	11 614	5%	952	13 808
Ceramic 5.2 Sand	3%	826	15 222	5%	464	15 637

Table 7.15 Part and Platform Cost Deviation of 3% and 5% VUR

Material	Part Cost Deviation (R)		Total Cost Deviation (R)	
	Value	%	Value	%
Polyamide PA 2200	605	32%	3 133	20%
Alumide®	1 842	38%	6 066	16%
PrimeCast 100	535	13%	2 194	6%
Ceramic 5.2 Sand	362	44%	415	3%

The volume utilisation analysis is made with the platforms “gk02” and “gl06”. The results are shown in Table 7.16. The VUR for platform “gk02” is 5.1% and for “gl06” is 3.4%. The VUR deviation results that too few parts (volume) are contained in platform “gl06”. To manufacture the same part on each platform will result in different part costs. For example a part of 200 000 mm<sup>3</sup> volume, manufactured in the “gk02” platform would cost R1096 and in the “gl06” platform would cost R1699 (55%).

Table 7.16 Platform Data “gk02” and “gl06”

Platform Name	Platform Height (mm)	Volume (mm <sup>3</sup> )	Time (minutes)	Total Cost (R)	VUR	CKF (R/mm <sup>3</sup> )
gk02	167	987 108	637	5407	5,1%	0,005
gl06	128	451 603	478	3836	3,4%	0,008

## 7.5 MATERIAL WASTE FACTOR CALCULATION FOR POLYAMIDE PA 2200

The waste factor calculation for Polyamide PA 2200 platforms is needed for the material consumption calculation. Polyamide PA 2200 is calculated from the sintered material weight multiplied by the material waste factor. The part weight is calculated by the sintered material density multiplied by the part volume. The waste material is determined by taking the part out of the build and weighing the powder after cleaning the parts. With the part weight and the waste powder weight, the waste factor can be calculated. For example a platform with 1.2 kg parts has 1.8 kg waste powder; the waste factor is 1.50. The three analysed platforms are shown in Table 7.17 and have a total weight of 3.38 kg, a total waste material of 8.8 kg and the average waste factor amounts to 1.60.

Table 7.17 Polyamide PA 2200 Material Waste Factor Calculation

Platform Name	Sintered Material (kg)	Waste Material (kg)	Total Weight (kg)	Material Waste factor
gk02	2.04	2.77	4.81	1.36
gl06	0.42	1.09	1.51	2.60
ha01	0.92	1.56	2.48	1.70
Total	3.38	5.42	8.8	1.60

### 7.5.1 Material Waste Factor Calculation for Platform “gk02”

Figure 7.8 shows the platform “gk02”, which has a part’s volume of 987 108 mm<sup>3</sup>, a platform height of 167 mm and a VUR of 5%. The part’s geometry causes that a lot of material is in and around the parts and the waste factor amounts to 1.36.

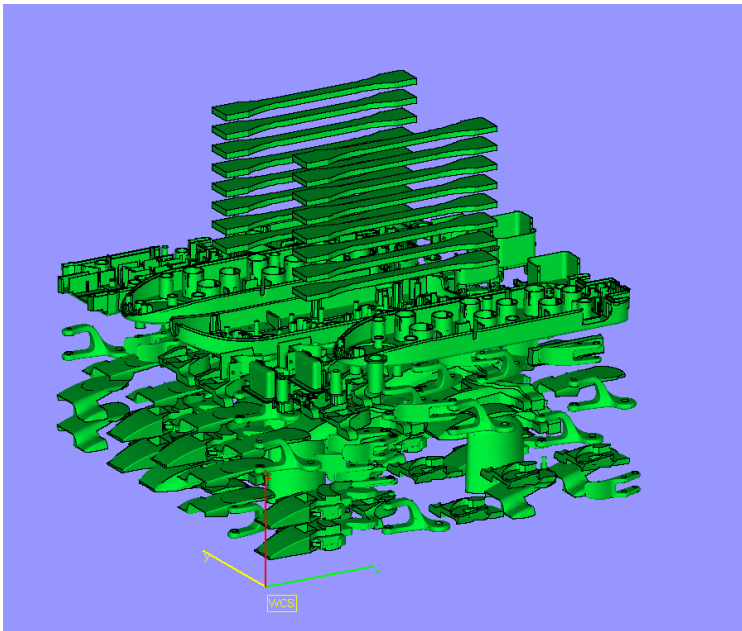


Figure 7.8 Platform “gk02” with a Waste Factor of 1.36

### 7.5.2 Material Waste Factor Calculation for Platform “gl06”

Figure 7.9 shows the platform “gl06”, which has a part’s volume of 451 603 mm<sup>3</sup>, a platform height of 128 mm and a VUR of 3%. The part’s geometry causes once more that a lot of material is in and around the parts, especially in the cups. These parts are responsible for the high waste factor of 2.60.

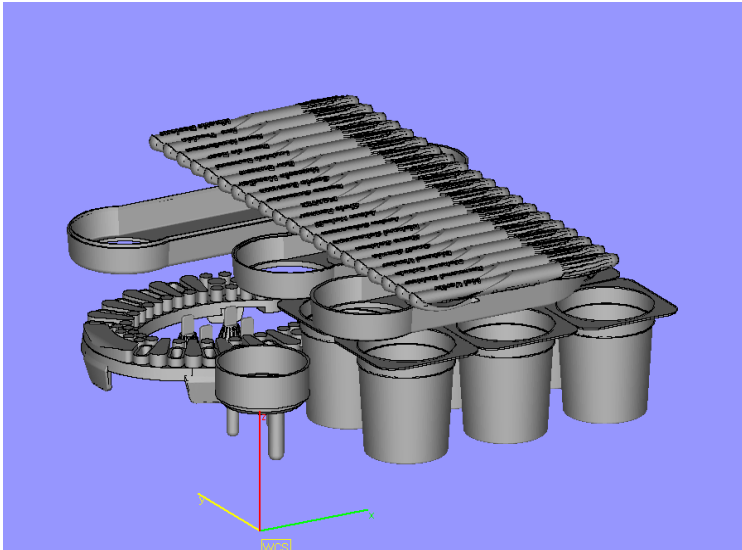


Figure 7.9 Platform “gl06” with a Waste Factor of 2.60

### 7.5.3 Material Waste Factor Calculation for Platform “ha01”

Figure 7.10 shows the platform “ha01”, which has a part volume of  $1\,977\,669\text{ mm}^3$ , a platform height of 368 mm and a VUR of 5%. The part’s geometry causes that less material is in and around the parts and the waste rate amounts to 1.70. The three cups cause more waste material, but in correlation with the high platform volume and many parts with less waste powder, the waste factor is close to the average of 1.6.

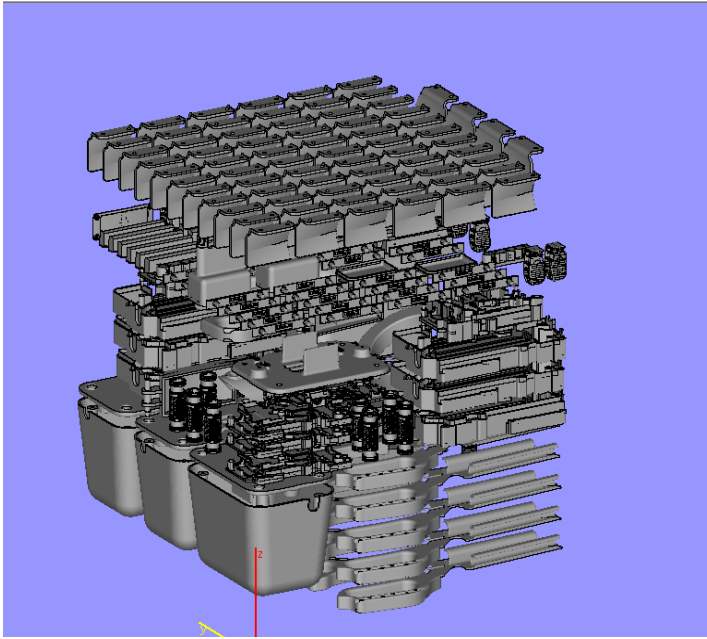


Figure 7.10 Platform “ha01” with a Waste Factor of 1.70

#### **7.5.4 Conclusion of Material Waste Factor Calculation**

The platform material consumption depends on the volume and shape of the sintered parts. The waste material is a high cost factor of the material costs. Some parts e.g. cups have a certain shape, which wastes more material. To reduce platform costs, it makes sense to nest different shapes of parts together on a platform.

#### **7.6 MACHINE WASTE RATE CALCULATION**

The platform waste rate allocates waste parts and failed platform costs to manufactured platforms. Failed platforms can happen when the recoater picks up a part during the manufacturing process. Furthermore the Ceramics 5.2 parts are fragile after the manufacturing process. During the cleaning process a part can break and has to be manufactured again. Therefore the platform waste rate is much higher for the EOSINT S 700 than for the EOSINT P 380 machine.

### 7.6.1 Waste Rate Calculation for EOSINT P 380

For the machine waste rate calculation, the results of 55 analysed platforms are used and shown in Table 7.18. The waste parts produced a waste time of 2858 minutes and a waste volume of 3 203 877 mm<sup>3</sup>. The manufacturing time and manufactured volume are used to calculate the material and machine costs. The 55 platforms are divided into the manufactured materials and their waste costs. The material costs are calculated by multiplying the material costs with the material consumption. The machine costs are calculated with the MHR multiplied by the total and waste time. The EOSINT P 380 waste rate of 5% is depicted in Table 7.19.

Table 7.18 EOSINT P 380 Waste Time and Volume Calculation

Number of Platforms	Waste Time (minutes)	Total Time (minutes)	Deviation	Waste Volume (mm <sup>3</sup> )	Volume (mm <sup>3</sup> )	Deviation
55	2858	50 063	6%	3 203 877	66 549 905	5%

Table 7.19 EOSINT P 380 Waste Cost and Rate Calculation

	Total Costs (R)	Waste Costs (R)	Waste Rate %
Material Cost	124 241	2903	2%
Machine Cost	292 033	16 671	6%
Total	416 274	19 575	5%

### 7.6.2 WASTE RATE CALCULATION FOR EOSINT S 700

For the machine waste rate calculation, the results of 16 analysed platforms are used and shown in Table 7.20. The waste parts produced a waste time of 1694 minutes and a waste volume of 116 143 346 mm<sup>3</sup>. The manufacturing time and manufactured volume are used to calculate the material and machine costs. The material costs are calculated with the material costs multiplied by the material consumption. The machine costs are calculated with the MHR multiplied by the total and waste time. The EOSINT S 700 waste rate of 15% is depicted in Table 7.21.

Table 7.20 EOSINT S 700 Waste Time and Volume Calculation

Waste Time (minutes)	Total Time (minutes)	Deviation	Waste Volume (mm <sup>3</sup> )	Volume (mm <sup>3</sup> )	Deviation
1694	10 656	16%	15 087 579	116 143 346	13%

Table 7.21 EOSINT S 700 Waste Cost and Rate Calculation

	Total Costs (R)	Waste Costs (R)	Waste Rate
Material Cost	130 081	16 898	13%
Machine Cost	154 157	24 507	16%
Total	284 237	41 405	15%

## CHAPTER 8

### SUMMARY AND CONCLUSIONS

The calculation programme makes it possible to calculate prototype and platform costs. The necessary data are available from the part's .STL file that is imported, multiplied and built up to a platform in Magics 9.5.1. The basic information includes the platform height, part and platform volume. This information is sufficient to calculate the material consumption, machine running time, part and platform costs. The selection between machine and material types saves time and avoids calculation mistakes. The advantage is to use the calculation programme as a cost simulation tool, especially when unsatisfactory KFs are calculated. The parts must be placed in a new platform to reduce the platform height. The machine running time calculation can be used for production planning, because the start and finish time can be planned. The post-calculation and the deviation between pre- and post-calculation can be done by entering the actual machine running time and the actual platform height in the software programme. This ensures cost control and gives an overview of how accurate the calculation software works.

The results from the analysed platforms show that the calculation concept has a manufacturing time deviation for Polyamide PA 2200 of 3.2%, for ALUMIDE® of 4.3%, for PrimeCast 100 of 6.5% and Ceramics 5.2 of 6.1%. These deviations are more accurate than the calculated time in Magics 9.5.1 and the single part method. For minimisation of manufacturing costs, the KF plays an important role.

The results have shown that for the different materials in use, the KF for the VUR must be higher than the average values given below:

- Polyamide PA 2200: higher than 3.2%;
- ALUMIDE®: higher than 10.0%;
- PrimeCast 100: higher than 4.9%; and
- Ceramics 5.2: higher than 22%.

Also, the KF for the production rate must be higher than the average PR-value for the various materials, as listed below:

- Polyamide PA 2200: higher than 1092 mm<sup>3</sup>/minute;
- ALUMIDE®: higher than 1384 mm<sup>3</sup>/minute;
- PrimeCast 100: higher than 2286 mm<sup>3</sup>/minute; and
- Ceramics 5.2: higher than 10 899 mm<sup>3</sup>/minute.

Furthermore, the KF for the KCF must be smaller than the average PR value for the materials as listed below:

- Polyamide PA 2200: smaller than 0.01 R/mm<sup>3</sup>;
- ALUMIDE®: smaller than 0.013 R/mm<sup>3</sup>;
- PrimeCast 100: smaller than 0.018 R/mm<sup>3</sup>; and
- Ceramics 5.2: smaller than 0.002 R/mm<sup>3</sup>.

An evaluation of the KF after grouping the parts in a platform proved that the manufacturing costs were reduced to the minimum.

A further application of the calculation is the costing of series production. The series' parts are collected and placed into blocks. The advantage is that it allows

cost calculation of the block and a single part, as well as its manufacturing time. Furthermore the block's data is available for scheduling and manufacturing in the daily operational process. As an example, the eight "SEV 1501" parts in Table 7.7 are collected in a block. Using the formulae derived, the calculated manufacturing time is 474 minutes, the cost of the block is R8573 and the resultant cost for one part "SEV 1501" is R1071.63.

The calculation programme enables an accurate part and platform calculation for the EOSINT P 380 and EOSINT S 700 LS machines. The experimental results have proven the software, based on a thorough analysis and discussion of the manufacturing process and the software application. Furthermore it elaborates on the comparison of KFs and the abatement of part and platform costs. The case studies illustrate how the calculation programme can be applied as an important tool in the daily working process, to reduce manufacturing costs on LS machines.

## **DATA CONTAINED IN APPENDICES**

The appendices include the Machine Utilisation (**Appendix A**), the Cost Allocation (**Appendix B**), as well Sheet and Platform Pictures (**Appendix C**). The machine utilisation explains the actual, planned and forecast manufacturing hours and whether or not it is required to adjust the machine hourly rate. The cost allocation sheets illustrate cost types, allocation to cost centres and overhead rates calculation. The platform pictures show examples that were used in the thesis to evaluate the building of individual parts, in comparison with the building of a platform.

## APPENDIX A: MACHINE UTILISATION

The machine utilisation is used for calculating the machine hourly rate. The total machine costs are divided by the machine running hours. The calculated machine hourly rate is necessary to calculate the machine costs in the calculation programme. Tables 1 and 2 are used to obtain an overview of the machine utilisation. It includes the planned running hours, the actual running hours and the forecasted running hours for two months. The planned running hours are linearly allocated from February to November. Fewer running hours are planned in the months January and December, due to the semester holidays. The total planned running hours in this example are 1600 hours. The actual running hours for this machine are the sum of running hours for each month. The accumulated hours are also available to compare. For example in June there were 800 hours planned compared to the actual 852 hours. The advantage of this table is that it is possible to enter forecast values to obtain the target running time until December. The forecast for July is 169 hours and for August, 166 hours. The addition of planned, actual and forecast values results in efficient utilisation for the whole period of time. In this specific example, 1700 hours are calculated until December. That means that the utilisation is 100 hours (6%) more than planned and that the machine hourly rate can be adjusted with the total cost and can be divided by more than 1600 hours. This produces an effect on the machine hourly rate, which in this case increases. This tool is also usable to determine the turnover, orders and manufacturing output. It is important that the information is updated regularly to react to at an early stage when actual values are not running in line with the planned values. At first glance the table looks difficult to interpret, however it is simple and useful. It is only necessary to enter the data into the

planned, actual and forecast column for each month. The data are transferred automatically into the cells (stairs) in Table 1. The result development is shown on the bottom lines as the total forecast and as percentage deviation if there is over- or under utilisation.

Table 1 Planned-Actual Machine Utilisation (in hours)

Month	Plan (P)	Actual (A)	Forecast (F)	Accumulated	
				Plan	Actual
Jan	80	96	110	80	96
Feb	144	142	120	224	238
Mar	144	106	119	368	344
Apr	144	138	115	512	482
May	144	141	129	656	623
Jun	144	229	129	800	852
Jul	144	128	169	944	980
Aug	144	143	167	1088	1123
Sep	144	156	167	1232	1279
Oct	144	212	142	1376	1491
Nov	144	273	150	1520	1764
Dec	80	139	150	1600	1903

Table 2 Forecast Machine Utilisation (in hours)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A											
96											
F	A										
0	142										
F	F	A									
120	119	106									
P	F	F	A								
144	115	115	138								
P	P	F	F	A							
144	144	129	129	141							
P	P	P	F	F	A						
144	144	144	129	129	229						
P	P	P	P	F	F	A					
144	144	144	144	169	169	128					
P	P	P	P	P	F	F	A				
144	144	144	144	144	166	166	143				
P	P	P	P	P	P	F	F	A			
144	144	144	144	144	144	167	167	156			
P	P	P	P	P	P	P	F	F	A		
144	144	144	144	144	144	144	142	142	212		
P	P	P	P	P	P	P	P	F	F	A	
144	144	144	144	144	144	144	144	150	150	273	
P	P	P	P	P	P	P	P	P	F	F	A
80	80	80	80	80	80	80	80	80	80	80	139
Forecast 2005											
1448	1559	1531	1539	1577	1700	1681	1656	1651	1721	1844	1903
-9%	-3%	-4%	-4%	-1%	6%	5%	4%	3%	8%	15%	19%

## APPENDIX B: COST ALLOCATION SHEET

The cost allocation sheet is the most important tool to allocate internal costs. The main purpose is to determine overhead cost rates, which are needed for the calculation. For this purpose the overhead cost rates are calculated to the direct costs [16]. The percentage rate on the direct costs is calculated with the following equations:

$$\text{Overhead Rate in \%} = \frac{\text{Overhead Costs}}{\text{Direct Costs}} \quad (13)$$

For the administration, sales and distribution:

$$\text{Overhead Rate in \%} = \frac{\text{Overhead Costs}}{\text{Manufacturing Costs}} \quad (14)$$

The machine costs are calculated with the total costs (= fixed costs + variable costs) divided by the output (hours, number of parts, etc.).

$$\text{Machine Hourly Rate} = \frac{\text{Total Costs}}{\text{Output}} \quad (15)$$

For the quotation and the calculation of the prototypes, these percentage rates can be used. This will ensure that all the costs are covered and calculated. In order to allocate the costs to the cost centres it is necessary to determine main cost centres, which give their output to the market and internal cost centres, which in turn give their output to the main cost centres. Main cost centres are for example stock, manufacture and sales [16]. Table 3 shows cost centres and their rate basis.

Table 3 Cost Centres

<b>Cost Centre</b>	<b>Rate Basis</b>
Stock in industry companies	Direct material costs
Non-machine manufacturing	Loans
Machine manufacturing	Machine output
Administration	Manufacturing costs
Sales and Distribution	Manufacturing costs

The main cost centres are the result of the cost allocation in the cost allocation sheet. Main cost centres contain the main output field of the company. These should be fixed first before the company is divided into the different cost centres. Internal cost centres include work preparation, cafeteria, security, total quality management. These cost centres give all their outputs to the main cost centres and therefore must be calculated from the main cost centres to cover all costs. They have no percentage rates and exist only to support the main cost centres [16].

In the above-mentioned example all the planned costs for a certain period of time are added. It is therefore possible to determine the profit and calculate the target turnover for this period.

In tables 4-6 all the figures, cost allocation, percentage rates cost types and cost centres are examples and serve only to explain how the overhead costs are calculated.

Table 4 Cost Allocation Sheet, Cost Types and Total Costs

<b>Account Number</b>	<b>Cost Type</b>	<b>Total Cost (R)</b>
<b>Direct Costs</b>		
1184	Consumable Materials	100 000
	Loans	250 000
	Salaries	250 000
	Personnel Costs	50 000
<b>Overhead Costs</b>		
1012	Stationary	5 000
1104	Phone Costs	6 000
1154	Travel / Accommodation	7 000
1606	Repairs / Maintenance	8 000
1520	Memento / Corporate	9 000
1524	Entertainment / Functions	10 000
1526	Advertisement	11 000
3014	Computer Equipment	12 000
1610	Loose Equipment	13 000
906	Training	14 000
4352	Project Costs	16 000
1019	Postage	17 000
1425	Centres Work	18 000
1558	Marketing	19 000
1425	External Consultants	20 000
1444	Program Software	21 000
1521	Contingent Expenses	22 000
1102	Import Costs	23 000
	Sum Direct Costs	650 000
	Sum Overhead Costs	251 000
	Sum Total Costs	901 000
	Target Win	75 000
	Target Turnover	976 000

Table 5 Cost Allocation to Cost Centres

Cost Type	Main Cost Centres - Total Costs (R)				
	Design	Manu- facturing	Admin	Sales & Distribution	Stocks / Material
Consum. Materials					100 000
Loans	50 000	200 000			
Salaries	0	20 833	166 667	62 500	0
Personnel Costs	8 333	8 333	16 667	8 333	8 333
Stationary	833	833	1 667	833	833
Phone Costs	545	545	2 727	1 636	545
Travel / Accommodation	500	500	1 500	4 000	500
Repairs / Maintenance	471	4 235	1 412	941	941
Memento / Corporate	818	818	2 455	4 091	818
Entertainment / Functions	714	1 429	2 857	4 286	714
Advertisement	846	846	1 692	6 769	846
Computer Equipment	1 500	4 500	3 000	1 500	1 500
Loose Equipment	929	1 857	4 643	4 643	929
Training	1 000	8 000	2 000	2 000	1 000
Project Costs	1 333	8 000	2 667	2 667	1 333
Postage	1 417	1 417	7 083	5 667	1 417
Centres Work	1 286	11 571	1 286	1 286	2 571
Marketing	1 583	1 583	1 583	12 667	1 583
External Consultants	1 818	5 455	5 455	5 455	1 818
Program Software	4 200	8 400	4 200	2 100	2 100
Contingent Expenses	1 375	2 750	8 250	6 875	2 750
Import Costs	1 353	6 765	1 353	2 706	10 824

Table 6 Cost Centres and Percentage Rates

	<b>Main Cost Centres - Total Costs (R)</b>				
<b>Cost Type</b>	<b>Design</b>	<b>Manu- facturing</b>	<b>Admin</b>	<b>Sales &amp; Distribution</b>	<b>Stocks / Material</b>
Direct Costs	50 000	200 000			100 000
Overhead Costs	30 855	98 671	239 162	140 954	41 357
Sum Manufacturing Costs	520 884				
Sum Total Costs	80 855	298 671	239 162	140 954	141 357
Overhead Rates	62%	49%	46%	27%	41%

## APPENDIX C: PLATFORM PICTURES

Platform “gf08”: Volume = 1 333 224 mm<sup>3</sup>, Height = 504 mm, Manufacturing Time = 1796 minutes

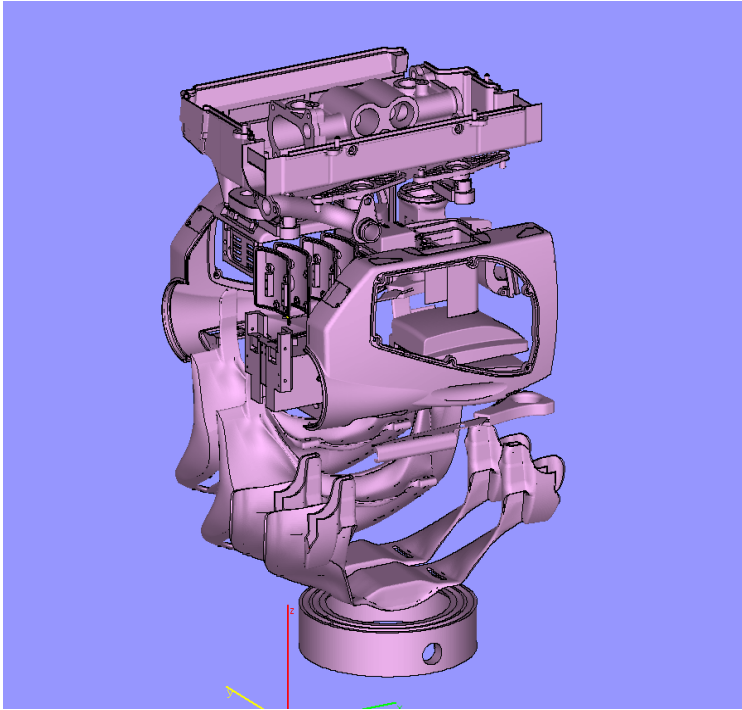


Figure 1 Platform “gf08”

Platform “gh05”: Volume = 1 452 315 mm<sup>3</sup>, Height = 279 mm, Manufacturing Time = 1100 minutes

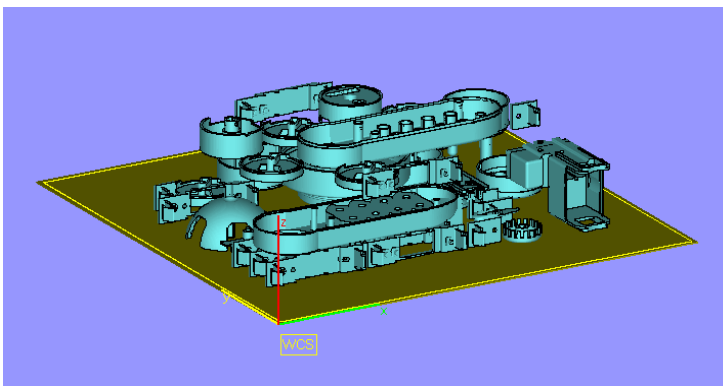


Figure 2 Platform "gh05"

Platform "gi03": Volume = 165 652 mm<sup>3</sup>, Height = 71 mm, Manufacturing

Time = 264 minutes

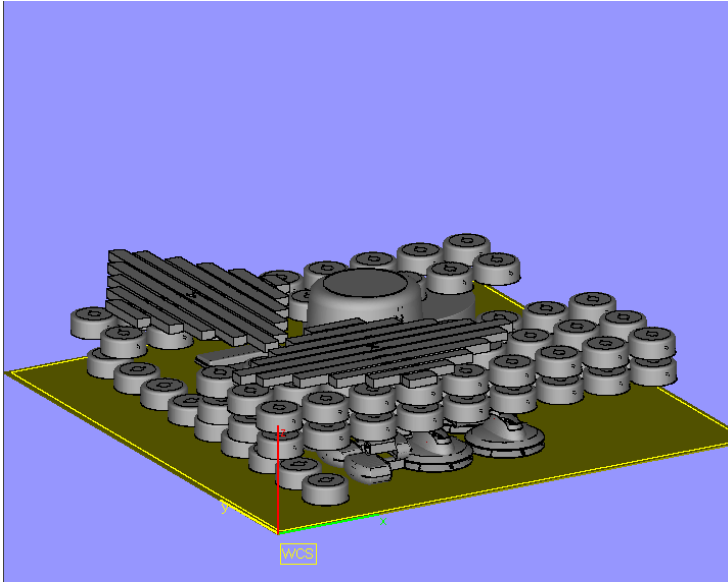


Figure 3 Platform "gi03"

Platform "gi07": Volume = 44 305 mm<sup>3</sup>, Height = 127 mm, Manufacturing

Time = 459 minutes

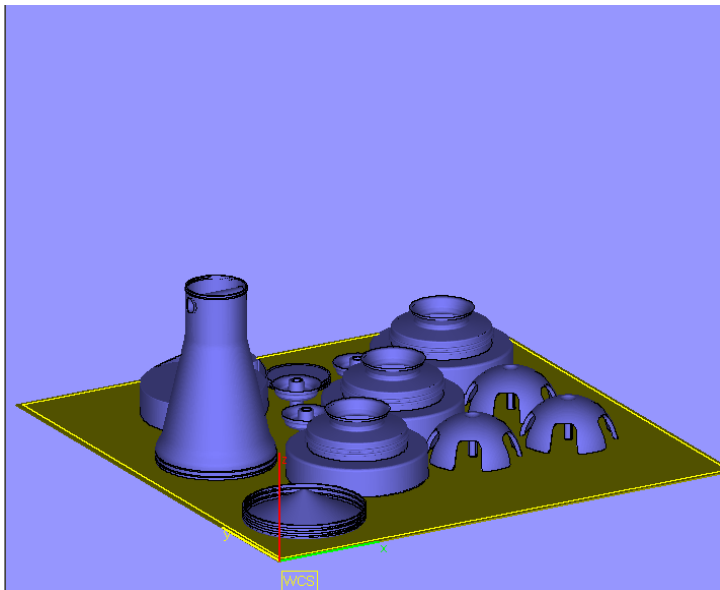


Figure 4 Platform "gi07"

Platform "gh06": Volume = 78 936 mm<sup>3</sup>, Height = 72 mm, Manufacturing  
Time = 258 minutes

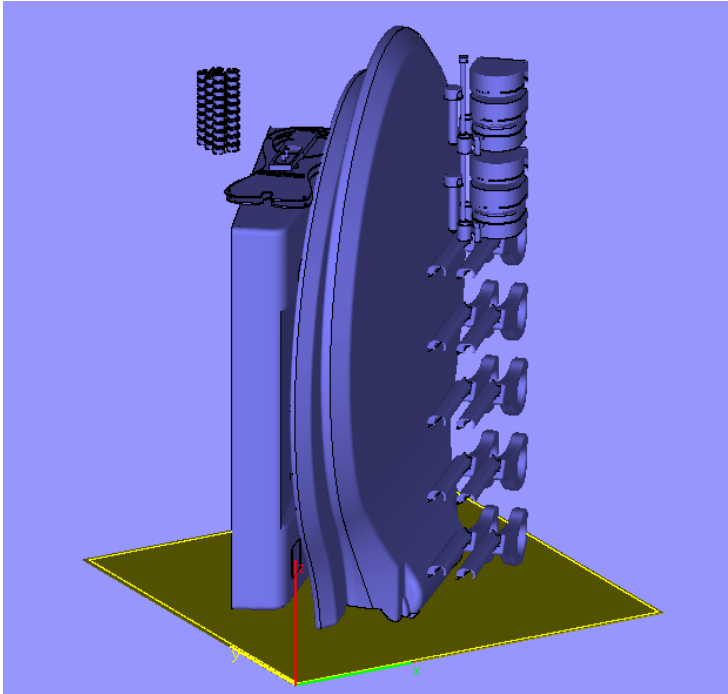


Figure 5 Platform "gh06"

Platform "ge06": Volume = 3 061 430 mm<sup>3</sup>, Height = 618 mm, Manufacturing

Time = 2209 minutes

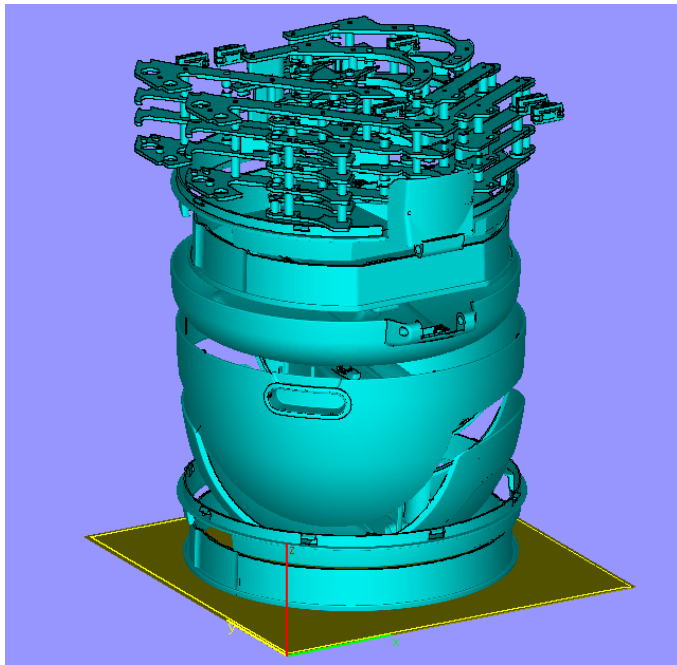


Figure 6 Platform "ge06"

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