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The Introduction of a New Biomedical Technology: A System Dynamics Approach to the Business Plan

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A dissertation submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg in fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2015

DECLARATION

I declare that this dissertation is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

.....
(Signature of Candidate)

.....day of.....year.....

ABSTRACT

Technologically orientated companies may have directors and board members who have engineering training but limited financial training. Clearly, it is essential for the functioning of such a company, that these individuals have a clear grasp of the financial processes. Engineers generally have a thought process that is guided by a systems approach to problem solving. This project explores the possibility of using system dynamics methodology to present the financial statements in parallel with the traditional spreadsheet approach typically used by people with financial training. The study is performed by examining the business case for a South African biomedical start-up company which is in the process of developing a device to locate a healthy vein for venepuncture. Extensive data obtained from market research, as well as a business plan in spreadsheet format is available and has been utilised in this project.

A system dynamics model of the business plan is developed. First it is shown that the system dynamics model is accurate and produces output that corresponds with the financial statements on the spreadsheet – a minimum requirement. Following this, simulations are run in which sales projections are varied with the goal of finding the minimum viable number of sales that need to be made in order to keep cash flows positive. The effects of optimising stock production are analysed and a sensitivity simulation is performed in which 49 variations of different local and international sales projections are calculated and their results analysed.

It is argued, based on the findings, that a system dynamics model of the financial statements is valuable not only because of the ability to do multiple simulations and sensitivity analysis, but also because it provides a visual perspective of the financial statements in a format that is familiar to engineers with systems training. This enables a more intuitive understanding of the relationship between the income statement, cash flow statement and balance sheet, which is invaluable for technical, but non-financially trained managers and staff.

Finally it is shown that the system dynamics model displays the dependencies of elements in the model that are hidden from the eye in a spreadsheet. This facilitates an enhanced understanding of the model and more importantly, ensures that when the model is edited, these dependencies are kept in mind thereby ensuring that the changes made maintain the veracity of the model.

This work demonstrates that the functionality of the system dynamics environment is able to capture all the relevant features that are present in the spreadsheet model, while achieving the representational advantages discussed above. It is anticipated that this approach will facilitate mutual understanding between people trained in engineering and technology and those with a purely financial background, thus facilitating the business processes in technologically orientated companies.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Professor David Rubin, for providing me with support and guidance during my studies. I am grateful for all the comments and help he has afforded me throughout the research.

The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

Finally, I would like to thank my family for their continued support and patience throughout my studies.

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1. INTRODUCTION

Financial planning is often modelled in the form of financial statements using spreadsheets. Spreadsheet software such as Microsoft Excel or Lotus 123 are very powerful software packages which allow rapid population of data and cell linkage with the use of numerous interlinked sheets of the spreadsheet. In this sense such tools are very useful. However these programs present the model in a way that may make it difficult for non-financially trained professionals to understand.

System Dynamic (SD) modelling provides a means of solving this problem. SD models are presented graphically and the relationship between the different elements of the model is apparent at face value. The different elements of the model are presented as stocks and flows and this provides an intuitive way for engineers to understand how the model works. The data is abstracted so that the big picture can be observed. The entire SD model can be seen on one page.

In contrast, within a spreadsheet, the fine details are presented to the user. However, the relationships between the details are hidden from the user. By way of example, were one to be looking at a financial model in spreadsheet form, one would see the exact *Gross Profit* amount per month. What the user will not see is that the *Gross Profit* is actually calculated by taking the *Sales Revenue* and subtracting from it, the *Cost of Sales*. In contrast to this, were one to look at a SD financial model, one would be able to see immediately the relationship between *Sales, Cost of Sales* and *Gross Profit,* but one would not be able to see the detail of how much the gross profit was on a monthly basis. In both models, one is able to access the hidden information. In the spreadsheet, were one to click on the cell *Gross Profit*, one would see the formula for that cell indicating that *Gross Profit* is equal to the *Cost of Sales* subtracted from *Sales Revenue*. Similarly, were one to click on the *Gross Profit* box in the SD model, one would be able to generate a graph or a list of precise *Gross Profit* amounts per month.

To further explain this distinction, the metaphor of "unable to see the forest for the trees" is borrowed: the spreadsheet model presents the micro view (the tree view) where the fine details are obvious but the bigger picture is difficult to see. On the other hand, the SD model presents the macro view (the view of the forest), where the bigger picture is evident because the finer details are masked.

In an SD model, the user can select variables of interest and test their sensitivity over a range of chosen inputs quickly and efficiently. The SD model simulates each scenario and represents the output graphically, allowing for fast intuitive analysis of multiple scenarios. There are many system dynamics software packages. To mention a few: PowerSim Studio, Vensim, Simantics System Dynamics and Dynamo.

The drawback of SD modelling is that while it is easy and intuitive to set up the structure of the model, it is difficult and tedious to populate the initial data to be fed into the model.

From the aforementioned paragraphs it can be understood that when spreadsheet modelling and SD modelling are combined, the disadvantage of spreadsheet modelling –namely lack of intuitive understanding - can be compensated for by SD modelling. Furthermore, it can be seen that the disadvantage of SD modelling – namely population of data - can be

compensated for by the advantage of spreadsheet modelling especially since it is the role of financially trained professionals to populate the data. The data can be populated by the financially trained staff and then exported to the SD model for the engineers.

Stated differently, spreadsheet modelling is most useful in populating the data for a financial model whereas SD modelling provides an intuitive medium for presenting the model and for simulating different case scenarios.

From this introduction, it can be seen that SD modelling has the potential to compensate for some of the drawbacks of spreadsheet modelling. Yet it is not suggested that an SD model should replace the spreadsheet model, as its drawbacks are addressed by the spreadsheet model. Instead what is alluded to is that perhaps a synergy of the two models could make for an enhanced view and understanding of a system's financial model. Therefore, the research question of this thesis is: can the combination of spreadsheet and SD modelling be implemented to give meaningful and powerful results to the financial model and if so what are some of the results and advantages?

In order to answer this question, a case study of a biomedical start-up shall be used. A South African biomedical start-up company is in the process of developing a device to locate healthy veins for venepuncture. In the process of developing the business plan for the device, intense market research was carried out to identify market segments which would require such a medical device. Furthermore sizing of each of these segments was carried out. The outcomes of the research coupled together with the start-up business's strategy was used to develop a financial model to assist in understanding what is required in order to create a sustainable business. The model was developed in spreadsheet form using Microsoft Excel. The income statement, cash flow statement and balance sheet form the core of the financial model, while there are other supplementary sheets which the core draws from for more detailed information. The model is simulated over an 8 year period on a month by month basis.

This spreadsheet model is converted into a SD model in order to answer the research question. Different scenarios are tested in order to gain an understanding of how the SD model adds value to the spreadsheet model.

2. REVIEW OF SYSTEM DYNAMICS AND ITS USE IN BUSINESS MODELS

Radzicki and Taylor (1997) describe the history of system dynamics as follows: Jay Forrester, the founder of system dynamics developed his theory of system dynamics in the mid 1950's while working with General Electric to develop a digital computer. His experience working as a manager and working with other managers made him wonder what was causing the difficulties he experienced in corporate management. In 1956, Forrester became a professor in MIT's (Massachusetts Institute of Technology's) School of Management. His primary objective was to find a way of using his background and experience in science and engineering to develop a methodology that could explain and predict the fundamental issues that determine the success and failure of corporations.

Radzicki and Taylor describe how Forrester drafted hand simulations of the stock-flow-feedback structure of the GE manufacturing facilities which included the existing corporate decision-making structure on employment decisions. Based on these simulations, Forester showed that GE's employment instability was not due to external forces such as the 'business cycle' as originally thought, but rather due to the internal structure of the firm.

Forrester and a team of graduates realised that this type of modelling would be much more powerful if it were able to be simulated on a computer and hence in the late 1950's they embarked on the development of the first SD computer modelling software.

Radzicki and Taylor further explain that in 1958, Richard Bennett designed SIMPLE (Simulation of Industrial Management Problems with Lots of Equations) which was the first SD computer modelling language. In 1959, Phyllis Fox and Alexander Pugh produced an improved version and called it DYNAMO (DYNAmic Modes). This became the industry standard for the next 30 years.

In a speech delivered by Forrester (1989) at the international meeting of System Dynamics Society entitled "The Beginning of System Dynamics", he describes some of the early applications of System Dynamics and how these applications were developed.

After discussing the example of GE's employment volatility, Forrester described how he was employed to sit on the board of a High-Tech company. As a result he felt compelled to look at the high-tech industry from a SD perspective. The nuance of this modelling – the modelling of corporate growth - was that the variables in the model were not only of the physical type such as inventories but rather of a more subtle type such as top-management influence structures, leadership qualities, character of the founders, how goals of the organization are created, as well as how past traditions of the organization determined its decision making and its future. The model also dealt with the relationships between capacity, price, quality, and delivery delay. The modelling inspired several insights into why high-tech companies often expand significantly and then deteriorate or fail completely.

Forrester continues to describe that the next area to which SD was expanded was urban dynamics. This happened when John F. Collins who had been the Mayor of Boston for the previous 8 years was offered a one year appointment as a visiting Professor of Urban Affairs at MIT. Due to Collins' disability from polio, he required elevator access to his office, and he

was thus given an office in Forrester's building. As neighbours, Forrester heard about Collins experience in coping with Boston's urban problems. Forrester couldn't help but feel that there were holes in the theory that explained the urban issues that Boston faced. He suggested to Collins that they team up using Collins hands-on experience in urban matters and Forrester's background in modelling to develop insights into cities.

The outcome of the modelling showed that the policies being followed by the United States government were at best impartial but often damaging both to the city as an institution and to its low income, unemployed residents. Surprisingly, the model showed that the most harmful policy was to build low cost housing. This result was very unappealing and at first was met with great disdain, however Forrester managed to explain the principles and outcomes clearly enough for some urban planners in New York to be convinced that the model was predicting accurate results. In fact, one urban planner's conclusion was: "they don't just have a solution to the urban problem up there at MIT, they have the only solution."

Forrester explains that the urban dynamics model was a catalyst to create the National model and eventually the World model. The purpose of the national model was to better understand the behaviour of national economies and thereby identify alternative policies for refining such behaviour.

The SD National model was formed by modelling the microstructure of the economy including corporations, an aggregate household, price setting, money flows, debt, government and monetary controls. The first outcome of the national model was to show that macroeconomics (the overall behaviour of the economy) is the result of microeconomics (the economics of households and companies). While this conclusion would appear correct and obvious, academic economic teaching has failed to explain their connectedness; instead it teaches the two sets of theory separately offering very few linkages between them.

The National Model, explains Forrester, also demonstrated the different dynamic modes observed in the industrial economy such as growth, ordinary short term business cycles, stagflation (persistent high inflation combined with high unemployment and stagnant demand in a country's economy) and the economic long wave. Business cycles refer to the regular variations in economic activity and have peaks between 3 and 10 years apart. Such cycles are driven primarily from over production of product which is followed by labour layoffs and cutbacks. In this time, inventories are brought back to equilibrium. In contrast to this, an economic long wave's peaks are 45 -70 years apart and have a much larger amplitude. They are caused by over-building of capital plant during expansion periods lasting several decades. This is then followed by a depression lasting 10 to 15 years in which capital producing sectors collapse and the surplus of hotels, office buildings and factories are worn out and depreciated on the account books. The economic long wave causes large fluctuations in debts, prices, money supply and real interest rates. These variations also magnify the economic long wave.

Forrester emphasizes that a second insight from the model is that the Great Depression of the 1930's was not due to a harsh business cycle recession, as most American economists have explained, but rather was caused by an economic long wave depression. The reason that the concept of economic long wave theory has been dismissed is because there is no theory to explain such behaviour. However the National system dynamics model generates such

long wave behaviour and therefore Forrester's model provides the missing theory for economic long wave's veracity.

Forrester's world model as explained by Proncheva and Makhov (2012) was designed to model macroeconomic behaviour that could stimulate universal crises and test scenarios that would prevent such crises from occurring. The first version of the model was created in 1970 and entitled "World-1". A year later, a corrected version "World-2" was brought out and was accepted as the classical Forrester model. Forrester identified five fundamental macro-economic variables that in his view could provoke a world crisis. They are: overpopulation of the planet, lack of basic resources, critical levels of pollution, food shortages and the upsurge of industrialization.

Proncheva and Makhov further explain that the world model proposes that population growth will increase until 2020, after which it would begin to decline. Moreover, it suggests that by 2100, non-renewable natural resources will have been depleted to less than 30% of their original stores. The highest pollution peak (5.8 times the standard level) will occur at 2050. Pollution then starts declining as a result of the general decline in population and industrialisation. As a result of resource depletion, the level of material living reaches its maximum in the early 2000's. This results in an increasing death rate and reduces investments. Forrester tried to change the original settings so as to avoid the crisis, but no matter the change, the model predicts that the crisis will still occur.

Over time, Forrester's models have been critiqued and improved. Moreover the system dynamics community has realised the far-reaching applications of system dynamics and its ability to afford insight into medical and biological systems, nuclear and other physical systems, business strategy, and financial dynamics, amongst many others. Forrester and many others have developed and continue to develop models in these areas, affording greater insight in to the world.

This chapter continues with a description of the main principles of financial system dynamics as well as their value proposition as found in the literature. In addition to this, several modern examples of financial system dynamics are reviewed.

Forrester (2009) explains that all systems can be described by stocks and flows. The stock is an accumulation, whereas the flow is what accumulates in the stock. Forrester thus makes it clear that the magnitude of the stock is changed only by flows.

Forrester (2009) goes on to elucidate that financial reports comprise two different sections: a balance sheet and a profit and loss statement. He then points out that the numerical entries in the balance sheet are equivalent to stocks or accumulations over time; the profit and loss statement on the other hand, shows the system's flows which cause the numerical changes in the accumulations indicated on the balance sheet. Thus in SD nomenclature, the balance sheet represents the levels and the profit-and-loss statement represents the rates.

In a similar vein, Craig (1980) also states that accounting balances are the levels of system dynamics while the transactions represent the flows.

Although Forrester (2009) has pointed out that a financial report can be modelled in terms of system dynamics, the question to be asked is what value can this add? Forrester (1961) warns against using financial information in a system dynamics model as it is not integral to

decision-making function, and serves only as a mechanism for reporting the systems behaviour. However Forrester (1961) does recognise the value of financial information as he states:

"As models become more subtle and begin to deal with the very important aspects of top-management decision making, the accounting system becomes an essential part of internal information loops affecting attitudes and decisions."

In contrast, de Geus (1997) emphasizes the need for a comprehensive financial strategy. Yamaguchi (2003) mentions that one of the reasons given for the major economic scandals in the United States is due to the fact that the formal structure and jargon of financial statements places it out of reach of the staff that are not formally specialised in accountancy. Thus managers and employees are not able to identify abnormal behaviours of financial practices in time to stop the major crashes. Thus he suggests that a system dynamics model could be a more friendly and intuitive way of presenting the financial statements such that non financially trained staff can also understand the finances of the business they are involved in.

Yamaguchi goes on to clarify that he is not suggesting the replacement of the financial statements but rather the incorporation of system dynamic modelling such that both views are available. As to the necessity of the financial statements, he points out that since these are used every day in the *"real world of business"* it only makes sense that any new modelling method should be based on what happens in the real world. Melse (2006) concurs by emphasizing the usefulness of the current financial accounting system as it is globally accepted.

Melse (2006) extends Yamaguchi's approach by suggesting that the value of system dynamics modelling for the financial accounting system is to:

> *"Empower the controller and his or her colleagues in other financial and managerial disciplines to extend the use of financial accounting system for management control purposes".*

In other words Melse is suggesting that system dynamics modelling be used as a tool which provides two benefits. The first benefit is that the SD model enables the financial accounts to be interpreted such that they provide management with insight into how to better manage the business. The second benefit alluded to is that this insight is provided in a format that non-accountants will be able to understand and interpret.

Notedly, Melse (2006) also points out the limitations of the financial accounting system in that it only contains *ex post* information; the accounting system has minimal value in predicting the future of the company.

Furthermore Melse (2006) suggests a second limitation in that it only caters for and stores financial information. He mentions that there are many tools that provide solutions to these limitations but on inspection *"what is missing is a predictable model that is based on the foundational principles of the financial accounting system but ties into the requirements of management control"*. This he suggests is the most powerful value-add of system dynamics modelling for financial accounting.

Whereas Forrester describes the financial statements in terms of system dynamics in broad terms, Yamaguchi (2003) and Melse (2006) formalise this description and elaborate on the fundamentals of accounting and system dynamics in order to concretise the relationship between the financial statements and system dynamics.

Yamaguchi defines five principles that are necessary to formalise this relationship. He calls them Principles of Accounting System Dynamics (PSAD). The first three are principles in system dynamics and the remaining two are principles in the accounting system. They are as follows (Yamaguchi 2003):

Principle 1 – System as a Collection of Stocks – A system comprises a group of state variables called stocks or levels. These levels describe the state of a system at a moment in time.

Principle 2 – Stock-flow Relation – The level of a stock can only be altered by flows (rates) flowing in to (inflow) or out of (outflow) the level during a given period. This relationship is depicted in the Figure 1 below.



Figure 1: Stock-flow relationship (adapted from Yamaguchi (2003))

In Figure 1, the symbol above the words 'Inflow' and 'Outflow' represents a "valve" (from a bird's eye view). A "valve" is a symbol of the rate of flows. The box around 'Stock' symbolises the storage of the stock.

Principle 3 – Information Feedback – The inflow and outflow rates can be determined by parameters from outside of the system, or directly via feedback from the stocks.

Yamaguchi points out that on the whole, the information required for SD modelling of the financial statements is obtained from outside the system. However it is the data that is fed-back from within the system that makes the model truly dynamic.

Principle 4 – Stock-flow Relation of Financial Statements – The income statement and cash flow statement are represented by the flows whilst the balance sheet is represented by the stocks.

Principle 5 – Double Entry Rule of Bookkeeping – Every inflow/outflow (transaction) of the stocks in the balance sheet has an effect on at least two stocks. This occurs simultaneously ensuring that the fundamental equation of accounting: *Assets are equal to the sum of liabilities and equity* is satisfied. Thus each transaction is booked twice, a change to assets must simultaneously cause a change to liabilities and/or equity. A change to equity must either be balanced by a change in liabilities or a change in assets. Furthermore a change in liabilities must be balanced by a change in equity or in assets. In accounting terms Yamaguchi (2003) points out that this can be described as:

"Inflows of assets and outflows of liabilities and shareholders' equity are booked on the debit side, while outflows of assets and inflows of liabilities and shareholders' equity are booked on the credit side."

The principles of the fundamental accounting equation (mentioned in Principle 5 above) have been discussed by many authors for example Kieso et.al (1995) and Porter et.al (1998). However Blommaert (1994) points out that this equation describes the two foundational elements of the accounting system namely: The Source of Capital (Claims) and The Use of Capital (Assets). He states that *assets* are equal to *claims* in [E 1] and separates *claims* in to two basic elements namely *equity* and *liabilities* to form [E 2].

[E 1]	$Assets = Claims$	Accounting Equation
[E 2]	$Assets = Equity + Liabilities$	Claim Elements

Yamaguchi's analysis focuses on the principles of Accounting and Systems Dynamics needed in the pragmatic sense in order to convert the financial model in to a system dynamics one. In contrast to this Melse uses the accounting equation as a foundation to derive the necessary theory required to conceptualise the conversion of a static financial model in to a dynamic model. He achieves this by analysing the three foundational principles that Mattessich (1995) formulated. Melse describes these principles as a framework *"that drives the synthesis, the structure and the logic of the financial accounting system"*. Based on Mattesich's principles, Melse shows the inherent dynamic nature of the accounting system and thus proves that the accounting system can be turned into a system dynamics model. A summary of Melse's work is provided below.

The three principles are (Melse 2006):

The Input-Output principle –*"an amount - in the case of the financial accounting model value – is 'transferred' from one 'position' to another"*. The 'position' referred to in this principle corresponds to a stock in system dynamics modelling which is able to store its value from one time-step in a simulation to the next.

The symmetry principle – *"Every transaction that results in a change of assets is also accounted with a change of a claim account or vice versa"* Melse proves that the symmetry principle is also upheld if a change in liabilities doesn't cause a change in assets, provided that it causes a change in equity. The same holds true for a change in equity which only causes a change in liabilities. This Melse calls "an intra-dimensional transaction".

The change principle – In Mattesich's words (Mattesich, 1995): *"If there is an ownership claim on an asset and if its' relevant attribute does change, then this change is also reflected in the corresponding ownership claim"*. Melse points out that the same applies for intra-dimensional transactions.

Before concluding Melse (2006) states that:

> *"The input-output principle necessarily determines the structure of the accounting model, whereas the symmetry principle and the change principle drive its logic"*. He concludes *"these foundational principles inescapably determine the design of a dynamic accounting model"*.

Bianchi et al. (1999) proposes that the standard accounting packages do not provide the necessary strategic feedback for SME's (Small Medium Enterprises) for the following three reasons: the first is that a person needs to be appointed and in charge of reporting analysis, interpreting the results from the accounting packages and feeding this in to the company's control process. However in SME's often there is no budget to employ such a person. The second reason is that the information that these industrial accounting packages provide is

meant to be used by managers *"to support performance evaluation and budgeting procedures"*. However Brusa (1986) points out that many SME's have not managed to implement such processes to make use of the information. The final reason Bianchi suggests is that entrepreneurs of the SME are generally incapable of doing the analysis themselves because they have never learnt how to do so and struggle to make time *"for detailed analysis, diagnosis and formulation of corrective action"*.

Bianchi (2002) therefore suggests that the incorporation of generic SD modelling which uses the financial spreadsheets as a base and includes feedback loops for strategic analyses and planning could provide an effective solution for SME's. He argues that generic SD models can be used, as SME's are generally less complex than large firms and thus resources can be saved in having to get personalised models developed at the early stages. As the SME grows and can afford a more personalised model, this becomes more feasible and is encouraged. With respect to the human resources needed, Bianchi suggests that the systems approach encourages entrepreneurs to apply themselves in the process and with the help of professional accountants and SD consultants, generic models can be modified efficiently for a specific SME.

On the point of management involving themselves with the modelling process, Richardson et al. (1989), Morecroft et al. (1991), Coyle and Exelby (1991) and Lyneis (1999) all stress the importance of this to ensure the model actually reflects the real issues that are occurring in the business. This also means that later on the entrepreneurs will be able to apply themselves to the model and use it for different scenarios with less external consulting services required.

Finally Bianchi (2002) suggests that research oriented institutions such as science parks and universities out of which many start-ups are born could also provide *"high-quality modelling support at a reasonable cost, particularly when the project is financed by public bodies"*.

Bianchi supports his assertions for the need of strategic planning and feedback loops built in to the financial model by way of example of a small pharmaceutical distribution company whose sales increased but cash flows dropped and were unable to understand the root cause of their problems. By building an SD model that incorporated their financials, he shows that the root of their problem was the alteration of payment terms with their customers. Thus the model supports his notion of the value that SD modelling provides for interpreting and predicting future results based on current decisions.

Lyneis (2000) claims that:

> *"The use of forecasts in decision making is inevitable …. Assumptions about future demand and performance are essential for many business decisions, for example: how much to produce; how much capacity and other resources to acquire; what products to develop; and how much financing will be needed by the business"*.

However despite this he notes that the SD community is reluctant to use SD modelling for forecasting. Forrester (1961) suggests that this is because forecasts are likely to be wrong. He goes on to show that this is possible even when the model is accurate and proposes that the reason this is so, is due to unknown random elements that affect the system. In addition to this, Lyneis (2000) suggests that that often forecasts of economic growth are wrong because of *"inadequate and over simplistic modelling"*. A second reason suggested by Lyneis (1980) is that the assumptions made in order to extrapolate trends can often be wrong and can lead to *"a*

system's instability". Moreover miss-estimations of demand lead to undesired consequences such as when demand is underestimated and thus there is insufficient supply to meet demand, or alternatively when demand is over-estimated which leads to cash flow difficulties and oversupply. Sterman (2000) suggests a third reason being that forecast modelling at best enables one *"to anticipate and react to problems in the environment"* however what is desired is *"to eliminate problems in the environment by changing the underlying structure of the system"*. He thus advocates for a focus on policy design to achieve this.

In spite of this Lyneis (2000) comments *"It seems to me that blind faith in either extreme (forecasts are or can be accurate; use of forecasts should be avoided) can lead to suboptimal performance, if not disaster"*. Reliance on the absolute accuracy of forecasts leads to unnecessary waste of expenditure while no forecasting leads to the risk of *"reacting rather than anticipating, and/or designing policies for too wide a range of potential conditions (such that overall performance is sub-optimal)"*. He therefore states that forecasting should be used to *"predict the approximate magnitude of important variables"*.

Lyneis (2000) uses a model of the commercial jet aircraft industry by way of example to advocate the use of system dynamics for forecasting. He shows that SD models are able to provide *"more reliable forecasts of short-to-mid-term trends than statistical models"* and therefore leads to more informed decisions. He further establishes that SD modelling gives insight into the causes of industry behaviour. This assists in early detection of industry structure changes and enables the determination of factors that are significantly sensitive to forecast behaviour. Finally, he demonstrates that SD models facilitate the choice of reasonable scenarios as input for policies and decisions.

Nair and Rodrigues (2013) model the financial system of an electronic system manufacturer which intends to ramp up its production over the next five years. They compare the effects of increasing production by 10%, 20% 30% and 40% while modelling the costs required in order to scale-up production. They simulate the net cash flow, gross income, net income, pending bills, receivable bills, debt, and book value. The results of their simulation show that when production is increased by 40%, net cash flow increases by 35%, gross income by 40%, and net income by 60%. Moreover debt gets reduced to about 27% and book value gets reduced to 64% by the end of the fifth year of operation. Nair and Rodrigues conclude that system dynamics modelling provides financial experts with a tool for simulating expansion plans of an organisation. It further forecasts the likely financial requirements for the modelled expansion.

Khaledi (2014) presents a generic system dynamics model for a firm. The model simulates a typical firm's internal system. Built in to the model are various financial and non-financial managerial policies which are representative of classic policies in the firm. The model measures and forecasts the impacts of these policies on its long term financial performance. Khaledi sets the "*present value of the total payoffs to the shareholders* and *the final equity remained for the shareholders"* as the two outcome variables of interest from the model. The model is illustrated by using the financial statements of a hypothetical corporation which manufactures one product and has the organizational structure of a medium size firm.

Bivona and Montemaggiorea (2010) concern themselves with an Italian city bus company's short sighted decisions which seem to save the company's cash flow problems but in the long run end up debilitating the company further. After meeting with the bus company's management, and obtaining an understanding on how the company operates, what issues it

faces and the decisions it makes, they develop a system dynamics model in search of a solution.

In an attempt to manage its cash flow problems, the bus company reduced its maintenance cost by not employing new maintenance staff when some of the staff reached retirement age and retired. In the first three years, this relieved their cash flow problems but from the fourth year on, the company's financial situation regressed.

Bivona and Montemaggiorea suggest that the reason for this was that with fewer maintenance staff, fewer buses were available to transport passengers. Moreover the condition of the buses in commission was of reduced quality and this reduced customer satisfaction. This further reduced the number of customers that purchased seats on the buses and thereby further reduced revenue to the company. They designed the model with these inputs and ran a simulation. The simulation results mimicked the reality on the ground verifying the effectiveness of the model.

Bivona and Montemaggiorea explain that the managers proposed a different solution which seemed counter intuitive but when they simulated their new suggestion over a five year period the results were much better with sustainably improved cash flows and profits. The suggestion was to reduce the average age of the bus fleet by dismissing old busses and buying new ones. This suggestion arose from an understanding that the major cause of bus breakdowns, reduced bus availability and poor service levels was the ageing of their buses. In order to make this plan financially viable, they dismissed 16 old buses and bought 8 new ones. However to make up for the loss of 8 buses to their fleet, they reduced the number of buses they took off the road for planned preventive maintenance to a third. This was a tenable solution as the newer buses required less maintenance. Through this they hypothesised that they would be able to improve bus frequency and service levels.

Bivona and Montemaggiorea report that the simulation of this scenario showed a sustainable trend of growth and improved financial results. This is because the sourcing of new buses decreases the failure rate. This boosts bus availability and improves customer satisfaction and hence increases the number of passengers and company revenues. Moreover the strategy of investing in new buses and improving preventative maintenance strategies reduces the number of bus breakdowns thereby decreasing the average cost to company per kilometre.

Thus it can be seen that modelling problems using system dynamics provides two benefits. The first is that one is forced to see a big picture view of what is occurring on the ground. Secondly the modelling enables the ability to think of new suggestions and quickly simulate their effects into future years.

3. BACKGROUND

Medical literature reports that 28% of adults (Brown, 1984) and 44% of paediatrics (Frey, 1998) will be punctured more than once before a needle is successfully inserted into their vein. This is due to the difficulty in finding appropriate veins for needle insertion. This problem is most pronounced in children, elderly, obese and emaciated patients; which leads them to enduring numerous punctures before a vein is found. Excess spilt blood increases the spread of diseases such as AIDS and Hepatitis. Moreover every prick is painful and increases the risk of hematomas and other complications. This also results in extra costs to the medical practitioners and service providers (Kahlberg et al., 2013).

An entrepreneurial team consisting of two engineers and an actuary have created a start-up company to develop a device to address this problem. The device is intended to locate a healthy vein and safely guide a needle into the vein in order to ensure first time needle insertion in all cases. The product will be brought to market in 2 stages. Version 1 of the device will have a manual insertion mechanism such that the user will guide the needle to the centre of the patient's vein using a manual guide. Version 2 will be developed so that at a press of the 'Insert' button, the needle will be automatically inserted to the centre of the patient's vein.

The three major responsibilities of the team are: device development, market and business analyses as well as financial planning and analyses. Each team member assumes one responsibility.

The author acknowledges the company's willingness to allow the financial model to be used in this study for the purpose of illustrating the value of system dynamic modelling of the financial statements. At the request of the company the market data presented in this paper is modified from the data used in the company's business plan so as to preserve the confidentiality of the company's market analysis. This is done in such a way that it does not detract from the modelling nor does it create absurdities in the results.

This section describes the company's financial model; first describing the financial model (Section 3.1), then listing the key assumptions of the model (Section 3.2) and finally showing a set of summary spreadsheets of the model (Section 3.3).

3.1. Description of the financial model

3.1.1. Income statement

The income statement lists the different expenses and revenues that are contained within the business. Expenses include salaries, development costs, legal and audit costs, and other expenses (Rent, Bad debts, Warranty, Stationary and Consumables, IT software and licencing/Data/Telephone, IT Hardware, Furniture, Promotional Expenses, Entertainment, Travel, Interest paid, Insurance and Training).

Revenues include local and international sales less the cost of sales. The cost of sales includes the manufacture costs as well as Sales and Distribution costs. Local and international sales are calculated in a subsidiary sheet called 'Sales Projection'.

- **Local Sales**

The 'Sales Projection' sheet splits the market into each of its segments, namely ICU, Neonatal ICU, Emergency Rooms, Operating Rooms, Emergency Medical Services, Blood Transfusion Services, Medical Practitioners, Pathology Services and Oncology Practices. It further splits each of these segments into private and public sector units.

The number of devices to be sold in each segment is determined by knowing the size of each market, the number of devices the market will require, as well as the likely uptake of the device based on need and affordability of each market.

All this data has been compiled from interactions with the Department of Health, Hospital Association South Africa (HASA), South African Private Ambulance and Emergency Services Association (SAPAESA), Health Professions Council South Africa (HPCSA), South African National Blood Services (SANBS), National Health Laboratory Services (NHLS), Lancet Laboratories and South African Oncology Consortium (SAOC).

The market entry strategy is to focus solely on the local market for the first 15 months of sales. There are several reasons for this. The first is that the company's mandate is to offer excellent service and therefore wishes to start small so as to be able to provide hands-on pre-sales service, training, after sales service and support. Being inundated by selling in multiple countries at the outset would make this difficult. Moreover, it facilitates the ability of the company to experience its teething problems in a controlled environment and learn from them so as to be ready for the international market.

The choice of the local market is because the company has done extensive market research in the local market and has built close ties with local industry. An illustration of this is that it has received letters of intent from two of the three major Pathology Laboratories in South Africa. Furthermore, it is most cost effective to start locally as there are no extra costs like overseas trips, setting up an overseas office etc. In addition to this, different countries have different regulatory requirements and the applications for certification all take time and money to be processed and approved, thus the goal is to start selling as soon as local regulatory compliance is achieved and work on the regulatory compliance for other countries during the 18 month period as revenues are generated.

The size of the local market based on the company's market research is estimated to be 50 000 devices. For the purpose of this simulation it is assumed that the company will sell 7400 devices in the local market over 18 months starting in month 32 and finishing in month 49. This assumes a market penetration of 14.8%. Manual devices will be sold in the local market at R8250 per device. Automated devices only get introduced in Month 60.

- **International Sales**

The company's market research suggests that the size of the international market is 15.5 million devices. The international market will be accessed in stages and during the modelling period, the company intends to make sales of 117 000 devices comprising 50 500 manual devices and 66 500 automatic devices. This assumes an international market penetration of 0.75%. International sales start from month 47. Manual devices are sold at R9 900 and automated devices are introduced to the market in month 60 and sold at R15 750. From month 60, both devices are sold in concurrently in the market.

3.1.2. Cash flow Statement

The cash flow statement records the cash flowing into the business (share capital, debt and revenue) and cash flowing out (expenses and tax) and thereby provides the opening and closing cash balance (Ittelson, 1998).

3.1.3. Balance sheet

The balance sheet portrays the assets (cash and fixed assets less accumulated depreciation), liabilities (current and long term) and equity of the company (share capital and accumulated profit) (Ittelson, 1998).

3.2.Key assumptions of the model

1. Sales and Cost of Sales:
    a. Units are produced in 6 month batches and are paid for in the month produced. Whilst implicitly this means that there are no creditors, the company would seek to negotiate favourable settlement terms with the manufacturer.
    b. The cost of storage for the devices is built in to the distribution cost.
    c. Sales will commence in month 32.
    d. While Sales terms are 30 days, this has not been allowed for in the model which has an impact on cash flows. To assess the impact of this, a new tab in the financial model called "deferred settlement" was created.
        i. This monitors the impact of excluding the cash in respect of the last 1 month, 2 month and 3 months of sales: i.e. same as paying 30/60/90 days late.
        ii. Figure 2 (on next page) shows that the impact of deferring settlement.
        iii. Possible interventions to minimize this risk:
            1. Arrange terms with suppliers and ensure debt collection is efficient.
            2. If the need arises, raise more debt at the time.
2. Rent – Starts off with a small office and ramps up in conjunction with increased employment of staff.
3. Day to day operational expenses are incurred and paid in the same month.
4. Development Costs and Patent Costs are expensed in the month incurred. In practice these costs will be depreciated in accordance with the appropriate accounting standards and taxation rules. At this stage they are expensed because the company will only view them as an asset once granted and are able to provide value. This is a conservative model.
5. Inflation is set at 6% per annum.
6. The exchange rates are set at:
    a. 19 R/GBP
    b. 11 R/USD
7. The company will be taxed at an effective rate of 28%.
8. Bad debts of 2% of sales have been allowed for.
9. Warranty expense of 0.5% of sales has been allowed for.
10. Interest Rate on debt is set at 20% per annum.

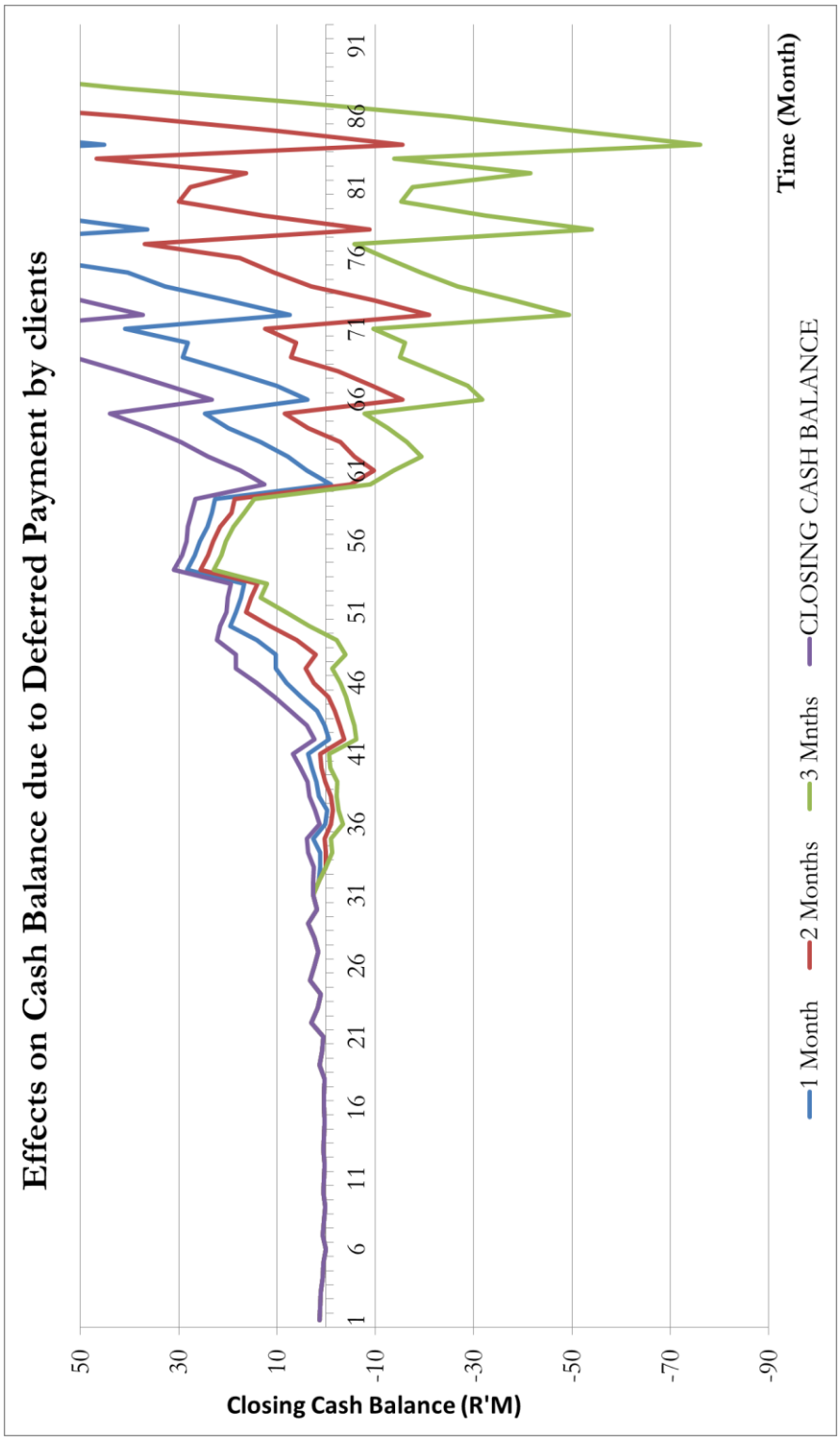


Figure 2: Effects of deferred settlement on cash flows

Figure 2 presents the results of the cash balance when no settlement terms are given (purple) as well as the results for the cash balance when deferred settlements of 1 month (blue), 2 month (red) and 3 months (green) are allowed. The effect of deferring settlement by 1 month is not detrimental as the cash balance drops below zero minimally and only in months 42 and 59. However, the effect of deferring settlement by 2 or 3 months becomes more significant and concerning.

3.3.Summary spreadsheets and graph of the financial model

The following section shows 8-year summary spreadsheets on a year by year basis of the income statement (Table 1), the balance sheet (Table 2) and the cash flow statement (Table 3, see next page). The cash flows for the first 4 years are also presented graphically in Figure 3 below on the next page.

Table 1: Yearly summary of income statement

INCOME STATEMENT	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-18	Dec-19	Dec-20	
	Year 1 2013 (R'm)	Year 2 2014 (R'm)	Year 3 2015 (R'm)	Year 4 2016 (R'm)	Year 5 2017 (R'm)	Year 6 2018 (R'm)	Year7 2019 (R'm)	Year 8 2020 (R'm)	TOTAL (R'm)
REVENUE									
Sales	0.0	0.0	1.2	29.8	53.2	170.8	449.5	903.9	1 608.4
Less: Cost of Sales	0.0	0.0	-1.7	-16.1	-23.2	-107.4	-269.4	-441.0	-858.9
Manufacture Cost	0.0	0.0	-1.5	-10.2	-9.0	-47.6	-112.1	-124.6	-305.0
Sales & Distribution Costs	0.0	0.0	-0.2	-6.0	-14.1	-59.8	-157.3	-316.3	-553.8
GROSS PROFIT	0.0	0.0	-0.5	13.7	30.0	63.4	180.1	462.9	749.6
EXPENSES									
Total Expenses	-3.6	-3.9	-7.6	-10.9	-27.5	-50.0	-81.7	-121.8	-307.1
EARNINGS BEFORE TAX	-3.6	-3.9	-8.1	2.8	2.6	13.3	98.4	341.1	442.5
Less: Tax Payable	0.0	0.0	0.0	0.0	0.0	0.0	-7.0	-116.9	-123.9
EARNINGS POST TAX	-3.6	-3.9	-8.1	2.8	2.6	13.3	91.4	224.2	318.6

Table 2: Yearly summary of the balance sheet

BALANCE SHEET	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-18	Dec-19	Dec-20
	Year 1 2013 (R'm)	Year 2 2014 (R'm)	Year 3 2015 (R'm)	Year 4 2016 (R'm)	Year 5 2017 (R'm)	Year 6 2018 (R'm)	Year7 2019 (R'm)	Year 8 2020 (R'm)
ASSETS	**0.7**	**1.3**	**2.6**	**3.9**	**29.3**	**32.1**	**103.2**	**369.8**
Current Assets								
Cash	0.7	1.3	2.6	3.9	29.3	32.1	103.2	369.8
Fixed Assets								
Assets (at cost)	2.0	3.5	7.2	9.9	10.8	10.8	10.8	10.8
Less: Accumulated Depreciation	-2.0	-3.5	-7.2	-9.9	-10.8	-10.8	-10.8	-10.8
Total Fixed Assets	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LIABILITIES	**0.0**	**0.0**	**0.0**	**0.0**	**18.5**	**18.5**	**18.5**	**0.0**
Current Liabilities	0.0	0.0	0.0	0.0	18.5	18.5	18.5	0.0
Long Term Liabilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EQUITY	**0.7**	**1.3**	**2.6**	**3.9**	**10.8**	**13.6**	**84.7**	**369.8**
Share Capital	4.0	8.2	18.2	20.1	20.1	20.1	20.1	20.1
Accumulated Profit	-3.3	-6.9	-15.6	-16.2	-9.3	-6.5	64.6	349.7
TOTAL LIABILITIES + EQUITY	**0.7**	**1.3**	**2.6**	**3.9**	**29.3**	**32.1**	**103.2**	**369.8**

Note: Stock of units held for sale is not modelled on the balance sheet. This is conservative.

Table 3: Yearly summary of projected cash flows

CASHFLOW STATEMENT	Dec-13	Dec-14	Dec-15	Dec-16	Dec-17	Dec-18	Dec-19	Dec-20	
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year7	Year 8	
	2013 (R'm)	2014 (R'm)	2015 (R'm)	2016 (R'm)	2017 (R'm)	2018 (R'm)	2019 (R'm)	2020 (R'm)	TOTAL (R'm)
OPENING CASH BALANCE	**0.0**	**0.4**	**0.7**	**2.6**	**7.3**	**28.3**	**41.7**	**133.0**	**0.0**
CASHFLOW IN	**4.0**	**4.2**	**9.5**	**15.6**	**48.5**	**63.4**	**180.1**	**444.4**	**769.7**
Share Capital	4.0	4.2	10.0	1.9	0.0	0.0	0.0	0.0	20.1
Debt	0.0	0.0	0.0	0.0	18.5	0.0	0.0	-18.5	0.0
Revenue	0.0	0.0	-0.5	13.7	30.0	63.4	180.1	462.9	749.6
CASHFLOW OUT	**-3.6**	**-3.9**	**-7.6**	**-10.9**	**-27.5**	**-50.0**	**-88.7**	**-238.7**	**-431.0**
Expenses	-3.6	-3.9	-7.6	-10.9	-27.5	-50.0	-81.7	-121.8	-307.1
Tax	0.0	0.0	0.0	0.0	0.0	0.0	-7.0	-116.9	-123.9
NET CASHFLOW	**0.4**	**0.3**	**1.9**	**4.7**	**21.1**	**13.3**	**91.4**	**205.7**	**338.7**
CLOSING CASH BALANCE	**0.4**	**0.7**	**2.6**	**7.3**	**28.3**	**41.7**	**133.0**	**338.7**	**338.7**

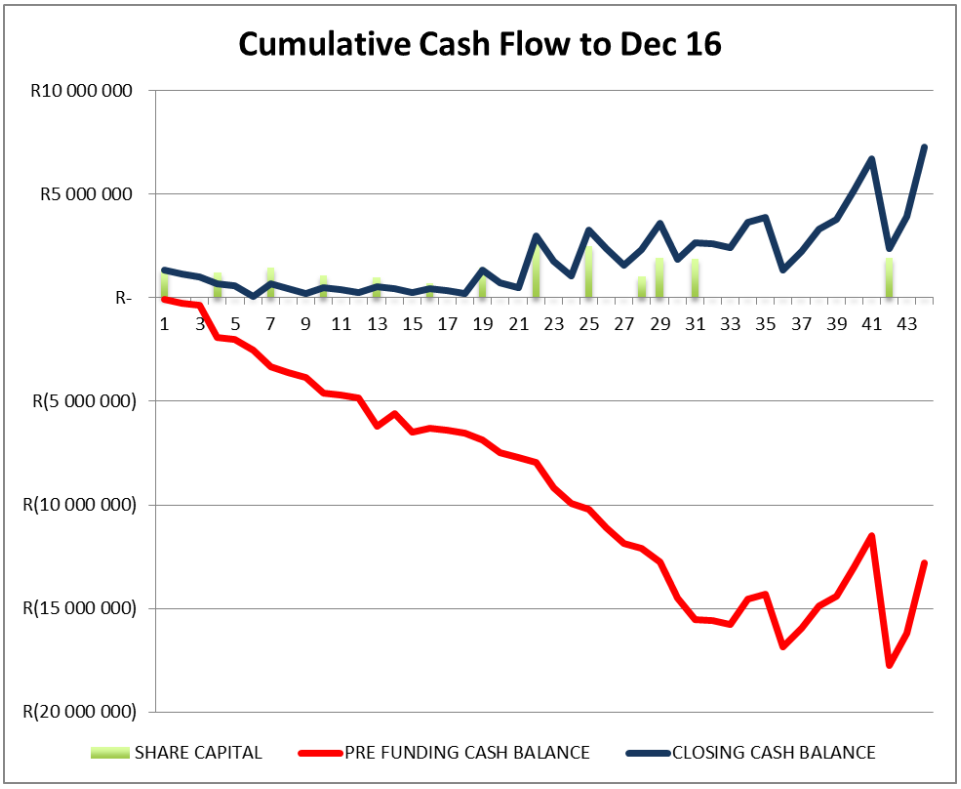


Figure 3: Cash flow charts

Figure 3 above shows the monthly cash balance for the first 44 months of the model. The green bars in the chart show the capital injected into the company by the equity partners. The red graph presents the cash balance, were no funding to be acquired. The blue graph shows the cash balance when sufficient funding is acquired from the equity partners to ensure that the cash balance never drops below zero.

4. DEVELOPMENT OF THE SYSTEM DYNAMICS MODEL

There are many different software packages that perform system dynamics (as mentioned in Section 1 above). Vensim (by Ventana Systems) was chosen for this project as it is the program in which the author learned system dynamics and it is the software that was made available by the University for this Research.

One of the useful tools in Vensim is the ability to import data from a spreadsheet. Hence in the process of converting the spreadsheet model into a SD model (described fully below), the SD model was set up to import the raw data from the spreadsheet into the SD model. The SD model then computes the raw data to formulate results.

For example, the cost of a device, the numbers of devices sold on a monthly basis as well as the expenses are all imported from the spreadsheet into the SD model. The SD model then uses this raw data to compute the gross profit, net profit, tax etc. In other words, the basic data in the system which is predefined and not calculated (such as the cost of a device, salaries and expenses) are all drawn in from the spreadsheet but all values that require calculation are calculated by the SD model (as opposed to in the spreadsheet model where they are calculated within the spreadsheet).

The logic for importing the raw data is twofold. Firstly it is an efficient use of time not to have to populate all the same raw data in the SD model, given that all the raw data has already been generated and inserted into the spreadsheet. Secondly, it means that when one chooses to make a change to any of the raw data, the change can be made in one place (the spreadsheet) and this will automatically be reflected in the SD model. Thus each time the SD model is simulated, it reads in the raw data from the spreadsheet. This means that both models stay up to date and can be used interchangeably.

In this section, the development of the financial SD model is explained. First the macro view of the entire financial model is displayed. Following this, the model is segmented into its parts and each part is explained in detail.

A macro view of the financial SD model is shown Figure 4 (next page). Each part of the model is assigned a different colour so that it can be easily identified. The income statement is presented in blue, the cash flow statement is depicted in orange and the balance sheet is shown in teal.

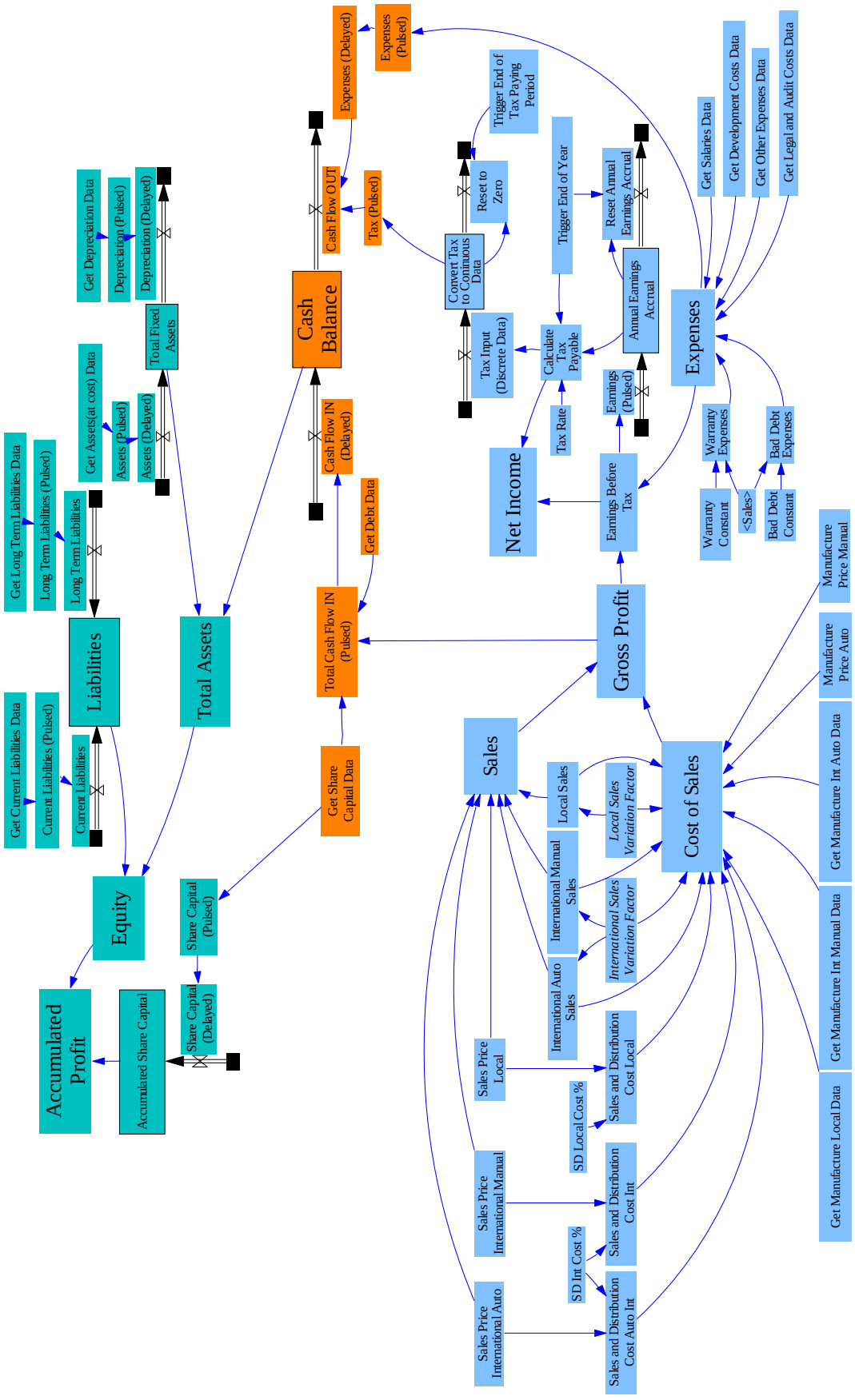


Figure 4: System dynamics model of the financial statements

4.1. Income statement

The income statement consists of 3 subsections. The first is the Gross Profit section, the second is the Expenses section and the third is the Tax and Net Income section. The Income subsection is shown in Figure 5 below.

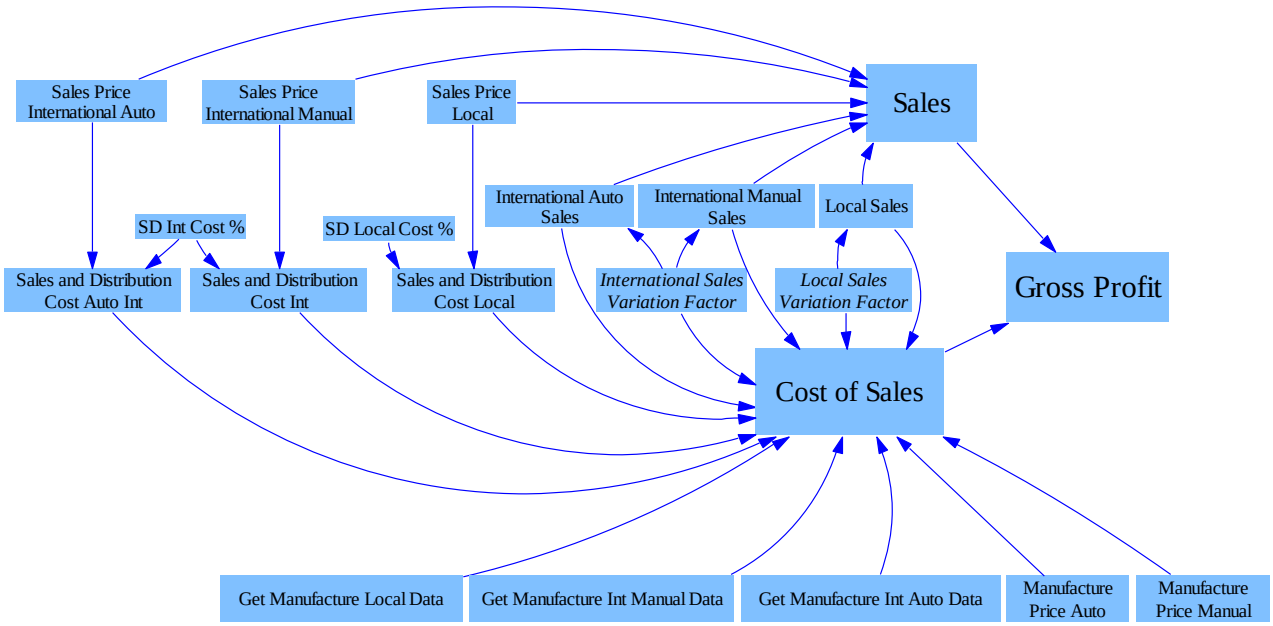


Figure 5: Income section of the income statement of the system dynamics model

'Gross Profit' is calculated by taking 'Sales' and subtracting the 'Cost of Sales' from it. 'Sales' consists of the number of sales in the local and international markets multiplied by their respective Sales Prices. 'Sales Price Local', 'Sales Price International Man (Manual)' and Sales Price International Auto (Automated) are fed in from the 'Notes' sheet from the spreadsheet. The data for 'Local Sales', 'International Man (Manual) Sales' and 'International Auto (Automated) Sales' are fed in from the 'Sales Projection' sheet.

The model is set up such that it includes a 'Local Sales Variation Factor' and an 'International Sales Variation Factor'. These are multipliers that multiply the base number of local and international device sales respectively, such that when the multipliers are equal to one, the number of devices sold is the base case number of devices to be sold. When the factors equal 0.5, half the devices are sold and when the factors equal 2, double the number of devices is sold. The factors can be manipulated and are used to test the model and assess the effects to profits and cash flows when the sales numbers change. This analysis is performed in Section 6.2.

'Cost of Sales' consists of the 'Sales and Distribution' costs as well as the 'Manufacture' costs. 'SD (Sales and Distribution) Local Cost %' and 'SD Int (International) Cost %' are percentage numbers which are used to multiply the Sales Price in order to determine the 'Sales and Distribution Cost' locally and internationally.

The manufacture cost is calculated by multiplying the 'Manufacture Data' by the manufacture price. The 'Manufacture Data' consists of the number of devices to be manufactured every 6 months to provide stock for sales. This data is fed into SD model from the spreadsheet.

The second sub-section of the income statement is the Expenses. This subsection of the model is shown in Figure 6 below.

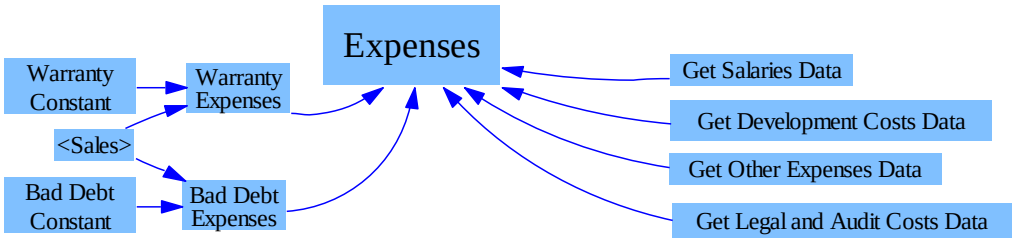


Figure 6: Expenses section of income statement of the system dynamics model

'Expenses' are a summation of 'Salaries', 'Development Costs', 'Other Expenses', 'Legal and Audit Costs', 'Warranty Expenses' and 'Bad Debt Expenses'. Each set of data for specific expenses is drawn from the spreadsheet using a 'Get Data' variable such as 'Get Salaries Data'. The Warranty and Bad Debt constants are percentages which are multiplied by 'Sales' to calculate the 'Warranty' and 'Bad Debt' expenses.

The final sub-section of the Income Statement is the Tax and Net Income subsection (Figure 7). It utilises the outcome of the first two subsections (namely: Gross Profit and Expenses) to calculate 'Earnings Before Tax', 'Tax' and 'Net Income'.

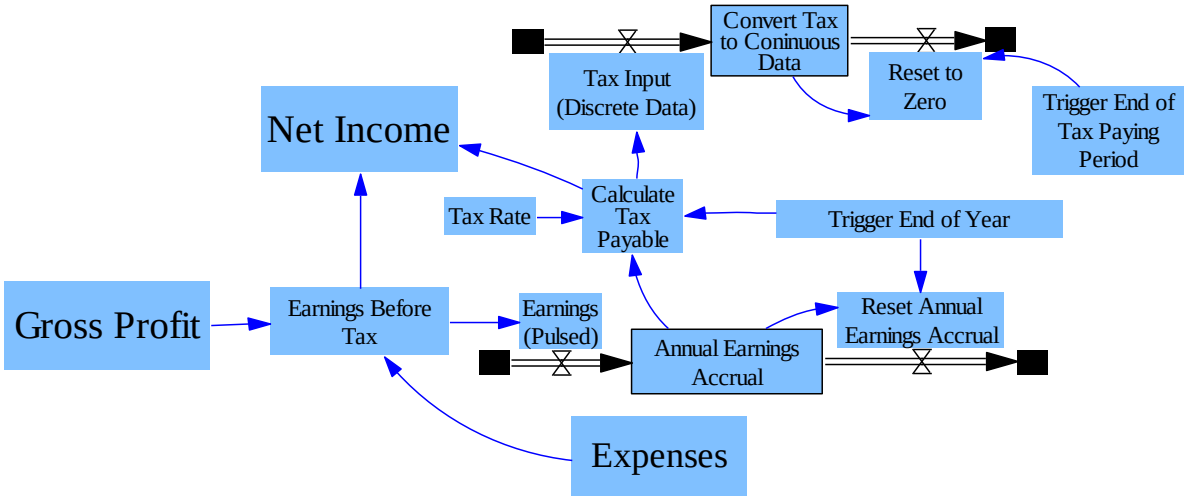


Figure 7: Tax and Net Income section of income statement of the system dynamics model

'Earnings Before Tax' is calculated by subtracting 'Expenses' from 'Gross Profit'. 'Calculate Tax Payable' is used to calculate the yearly amount of tax to be paid. This is achieved by accruing the monthly 'Earnings' and at the end of each year. 'Trigger the end of year' triggers the end of each year and the model checks to see if 'Accrued Earnings' is positive. If 'Accrued Earnings' is positive then it is multiplied by the 'Tax Rate', fed in to 'Tax Input (Discrete Data)' and the 'Accrued Earnings' level is then reset to zero for the next year. If however 'Accrued Earnings' are not positive, then no tax is calculated and 'Earnings' continue to accrue until the end of the next year when the same procedure is repeated.

The 'Tax Input (Discrete Data)' contains the amount of tax to be paid. However owing to the way this data is calculated in Vensim, the data is recorded for only one time-step within the model per year. (For a definition of what time-step is, see Section 5.2 below). This creates complexity in that all other data is recorded over 10 time-steps. If the Tax Data is not converted to 10 time-steps as well, it is possible that the data will not be processed correctly (See Appendix B, Section B 2). Thus it is necessary to convert the Tax as calculated in 'Calculate Tax Payable' to be applied over 10 time-steps. This is achieved by the 'Convert Tax to Continuous Data' level.

4.2.Cash flow statement

The cash flow statement centres around the 'Cash Balance'. The 'Cash Balance' is calculated by integrating the difference between 'Cash Flow IN' and 'Cash Flow OUT'. Figure 8 shows the cash flow statement excerpt from the model.

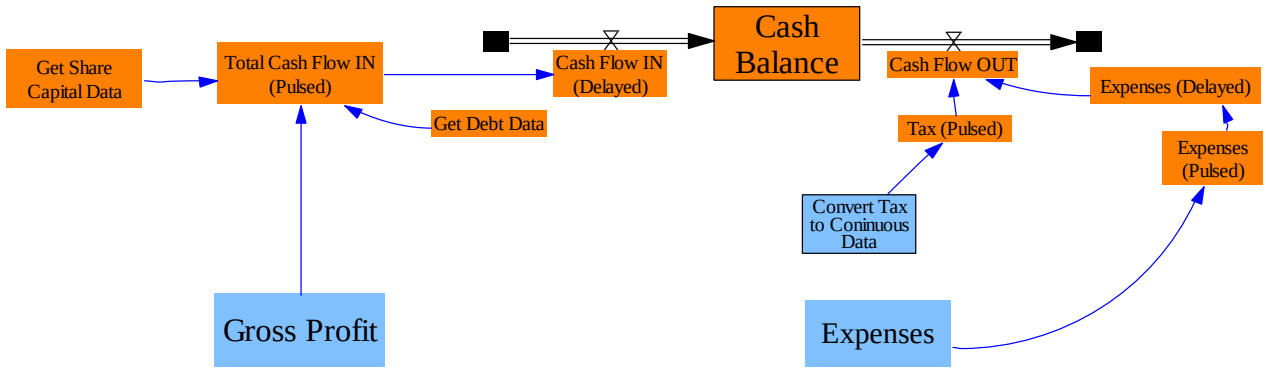


Figure 8: Cash flow section of the system dynamics model

'Get Debt Data' and 'Get Share Capital Data' fetch the debt financing and share capital financing data respectively from the spreadsheet. They are added to 'Gross Profit' to produce the 'Total Cash Flow IN'. The 'Cash Flow OUT' is produced by the summation of 'Expenses' and 'Tax Payable'.

Before the data is accumulated in any level it is necessary to pulse the data. The reason for this is explained in Appendix B, Section B 1.

The reason why a delay is applied to 'Cash Flow IN' and 'Expenses' but not to 'Tax' is because as can be seen in Figure 7 above, 'Tax' was calculated by going through 2 levels ('Annual Earnings Accrual' and 'Convert Tax to Continuous Data'). Each time data is processed through a level it takes a time-step to do the processing. Thus 'Tax' which goes through two levels is delayed by 2 time-steps with respect to all the other data in the model. Thus before the cash flows are calculated, it is necessary to apply a delay to all inputs except for 'Tax' so that all data is in sync when it is computed.

4.3.Balance sheet

The Balance sheet excerpt of the system dynamics model is shown below (next page) in Figure 9.

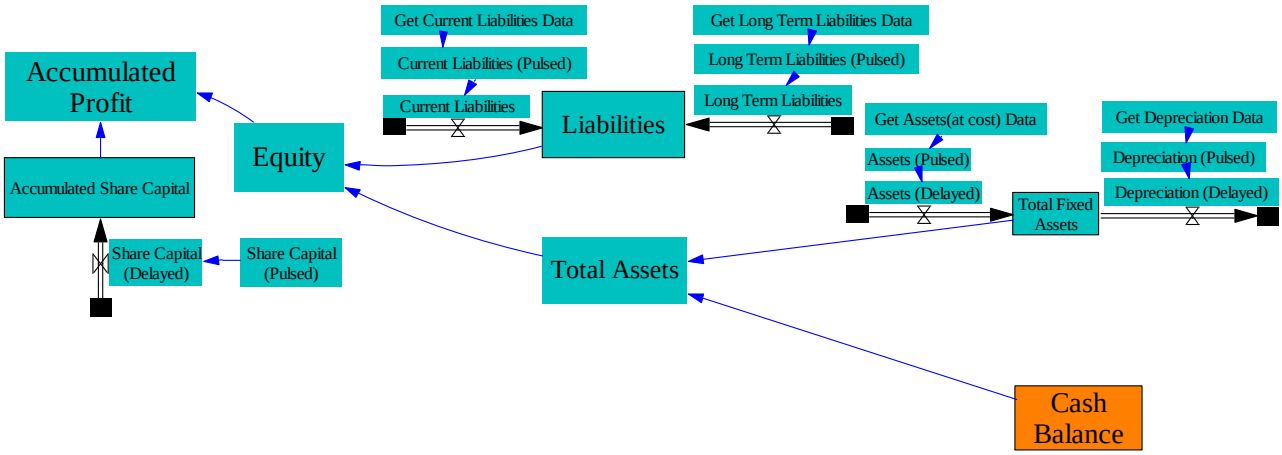


Figure 9: Balance sheet section of the system dynamics model

'Equity' is calculated by subtracting 'Liabilities' from 'Total Assets'. 'Total Assets' is the summation of the 'Cash Balance' (from the cash flow statement) and 'Total Fixed Assets'. The 'Total Fixed Assets' level is the integration of the difference between the rate of 'Assets (at cost)' and the rate of 'Depreciation' which are both drawn from the spreadsheet using "Get Data" variables and then pulsed and delayed.

Note that the 'Liability', 'Asset' and 'Deprecation' data is pulsed as explained in Appendix B, Section B 1. In addition to being pulsed, this data must also be delayed in order for it to synchronise with the 'Cash Balance' from the cash flow section of the model as is explained in Section 4.2 above.

The 'Liabilities' level is the integration of the sum of the rate 'Current Liabilities' and the rate 'Long Term Liabilities' which are also both drawn from the spreadsheet using "Get Data" variables.

'Accumulated Share Capital' is the level produced by the accumulation of 'Share Capital (month)'.

'Accumulated Profit' is calculated by subtracting 'Accumulated Share Profit' from 'Equity'.

5. SIMULATION

5.1. Unit of time chosen

The model is simulated over 92 months starting in May 2013 when the company receives its first tranche of funding and ends in December 2020. Since the model is simulating over 92 months (a large period of time), it is important to choose the right unit of time in which the model computes. This is essential so that the results are meaningful, neither lacking detail nor swamping the user with unnecessary information. For example, were the model to be simulated on a yearly basis, one would not be able to appreciate the monthly changes that occur in the business. Hence one would not be able to use the information to understand how the business is performing month-on-month; nor would one be able to compare monthly changes. However at the other extreme, were the model to be computed every hour and therefore show changes to the financials on an hourly basis, it would make the simulations much too large and sluggish. Moreover it is irrelevant exactly in which hour or even in exactly which day the transaction takes place and the information overload would make it more difficult to see the bigger picture. What is important is the net transactions for the month. This is the reason why detailed financial statements are generally presented on a month by month basis. It is also the reason that companies' financial spreadsheets are generally modelled on a monthly basis.

Therefore when setting up the SD model, the unit of time selected is: *Months*. This means that data being read in from the spreadsheet is recorded on a monthly basis.

5.2.Choice of time-Step

The time-step can be defined as the number of times the model will make a calculation per unit of time. Thus in the current SD model where the unit of time is set to *Month,* if the time-step is set to 1 (the default setting), then the model will compute once a month. If the time-step is set to 1/30, then the model will compute 30 times a month, i.e. once a day.

There are two complications which arise if the time-step is left to be set at 1. The first is that data is not captured into the SD model correctly. The second is that the data is not calculated correctly in the SD model. Appendix B elaborates on these errors and clarifies what causes them. This leads to an understanding of the function of the time-step and guides the right design choice for the time-step of the model.

As concluded in Appendix B, the time-step used for the model is 1/32768 which is comparable to a computation every 79 seconds.

5.3.Definition of the base case

The model is designed to test how changes in the quantities of device sales affect the cash flows and the success of the business. The base case refers to the initial projected number of device sales both locally and internationally. These projected device sales are considered healthy sales-targets based on the company's market analysis. As explained in Section 4.1 above, the sales factors are both equal to one for the base case. A summary of the simulation

setup data for the base case is provided in Table 4 below.

Table 4: Simulation setup data for the base case

	Base Case
International Sales factor	1.0
Local Sales Factor	1.0
Number of International sales in 8 years	117 010
Number of Local sales in 8 years	7 378

5.4.Choice of simulations

Many simulations can be done but for the purpose of this paper several key simulations are chosen. The first simulation is a validation test aimed at validating the SD model. The second group of tests observes the effects of varying the sales factor. The third simulation records the effects on the model when the production of stock is optimised and the fourth is a sensitivity analysis. Each of these simulations is described briefly below and then is described more fully when the test results are presented in Section 6 below.

5.4.1. Validation test

The validation test checks that the results of the SD model correlate with the results of the spreadsheet model. This is a minimum requirement before considering SD as a suitable modelling tool. For the purpose of this test, the base case is simulated, whereby all sales factors are equal to one. A successful outcome is when the same results that are recorded when the spreadsheet model is run, are attained when the SD model is run.

This test is imperative, as if the models do not correlate, then it would mean that the SD model is not a valid way of representing the spreadsheet model. If however they do correlate, it means that the SD model can be used in lieu of the spreadsheet, while having the potential to enhance understanding of the financial model for engineers and technically trained people as will be illustrated.

5.4.2. The effects of varying the sales factors

In this set of tests, the sales factors are varied to find the minimum and maximum sales that can be made without the company becoming insolvent. This is done by an iterative process whereby the sales factors are manipulated, the model is simulated and a check is performed to see if the cash balance ever drops below zero. When the values of the sales factors are found at which the cash balances just drop below zero, the sales factors are tweaked so that the cash balance remains positive. At this point, the minimum/maximum sales factor has been found.

These tests are designed to understand the flexibility of the financial model. They give insight in to what happens when the quantity of devices sold is different to the sales projections. The difference between local and international sales is that whereas local sales represent breaking into the first market, international sales relate to the maturing of the

device into the broader market as well as the expansion of sales. Splitting sales into these two sections allows for the analysis of a scenario in which both markets provide less opportunity than expected as well as the scenarios where one or the other markets differs from its expected targets. The outcomes of these tests provide insight into how far off actual sales can be from the projected sales, while keeping a positive cash flow.

5.4.3. The effect of optimising stock production

This test looks at the effects of changing how often stock is produced and paid for once sales increase significantly enough and how this effects cash flow. In the early stages of sales, the amount of stock needed per month is less than the minimum quantity that the manufacturer is prepared to produce per order. Therefore stock is produced in 6 month batches. The company keeps this arrangement of paying for 6 months of stock even once demand increases. However with increased demand, the amount of stock that has to be paid for upfront every 6 months puts pressure on cash flows.

The goal of this test is to see how effective the use of an optimised stock production strategy is on maintaining positive cash flows even with reduced sales.

5.4.4. Sensitivity simulation analysis

The sensitivity analysis test is similar to the second test run (the effects of varying the sales factors). However, whereas in the aforementioned test the maximum and minimum sale points were searched for, here an entire selected range of different sales factors are simulated to determine the extent to which the change in sales factors affects cash flow.

The local and international sales factors are varied between 0.50 and 2.0. This means that the simulations are computed for a range of scenarios between 50% of sales and 200% of sales. To do this manually would be tedious. Instead a sensitivity simulation analysis is set up using the system dynamics model and within minutes all the simulations are performed and the results recorded.

For the purpose of this simulation, the simulation is set up such that each sales factor varies between 0.50 and 2.0 in increments of 0.25. An increment of 0.25 provides seven increments between 0.50 and 2.0 as can be seen in Table 5 (next page).

The sensitivity simulation analysis automatically runs the simulation for every possible permutation of these seven increments. This is 7x7 permutations for the two sales factors with 7 increments. Thus the sensitivity analysis automatically simulates 49 (7^2) unique scenarios.

The results for all 49 scenarios are plotted on one graph. For example, if one were to look at the cash balance, the results for all 49 scenarios will be plotted on the same graph. This provides a big picture view of how all 49 scenarios compare to one another and gives the user insight into how many of these permutations have a stable cash flow versus how many of these scenarios lack cash flow stability.

Table 5: Increments for local and international sales factors for use in the sensitivity simulation analysis

Number of Increments	Local Sales Factor	International Sales Factor
1	0.50	0.50
2	0.75	0.75
3	1.00	1.00
4	1.25	1.25
5	1.50	1.50
6	1.75	1.75
7	2.00	2.00

6. RESULTS

This section presents the results of the validation test, the effects of varying the sales factors, the effects of optimised stock production and the sensitivity analyses.

6.1. Validation test

In order to validate that the SD model is functioning correctly and precisely, the cash balance data calculated by the SD model is compared to that of spreadsheet model. The reason the cash balance data is chosen is because it is an example of data that is not pulled in from the spreadsheet. Rather it is data calculated by the SD model using the raw data that was extracted from the spreadsheet. The reason for not pulling data in directly from the spreadsheet is that this would constitute a self-fulfilling prophecy. This is explained more comprehensively in the beginning of Section 4.

The comparison of the cash balance over the 92 months as calculated in the SD model versus that calculated in the spreadsheet model is tabulated in Appendix A. Table 6 below is a snippet taken from Appendix A and compares the cash balances of the two models for the first 8 months. For each month, the percentage error between the two models is also calculated and shown in the last column of Table 6.

Table 6: Comparison between cash balances as reported by the SD Model and the Spreadsheet Model – First 8 months

Year	Month	Cash Balance SD Model	Cash Balance Spreadsheet Model	% Error
1	1	1 323 794	1 324 000	0.02
	2	1 147 801	1 148 000	0.02
	3	1 024 771	1 025 000	0.02
	4	683 805	684 000	0.03
	5	587 746	588 000	0.04
	6	66 906	67 000	0.14
	7	700 281	700 500	0.03
	8	428 785	429 000	0.05

From Table 6 it can be seen that the largest error in all of the 8 months recorded is 0.14% (this occurs in Month 6). In fact the percentage error recorded in Month 6 is the largest error in all 92 months (See Appendix A) and the average error over the 92 months is 0.02%.

Thus it is clear that the SD model concurs with the spreadsheet model.

The output graphs as produced by the SD model for the cash balance (Figure 10), accumulated profit (Figure 11), gross profit (Figure 12), net income (Figure 13), and equity (Figure 14) are provided below.

From Figure 10 it can be seen that the cash balance never drops below zero. From months 1-20, the cash balance is very low as the device is being developed and there is no income

being generated. From month 20, higher investment amounts are raised in order to pay the final development costs and regulatory costs. From month 32 sales start and the graph rises steadily as local sales increase. From month 48 international sales start and the cash balance increases steadily. Every six months the cash balance drops as stock for the next six months is paid for. The decreases in the cash balance due to stock production are more apparent from month 60 because sales volumes increase and higher quantities of stock must be manufactured and paid for.

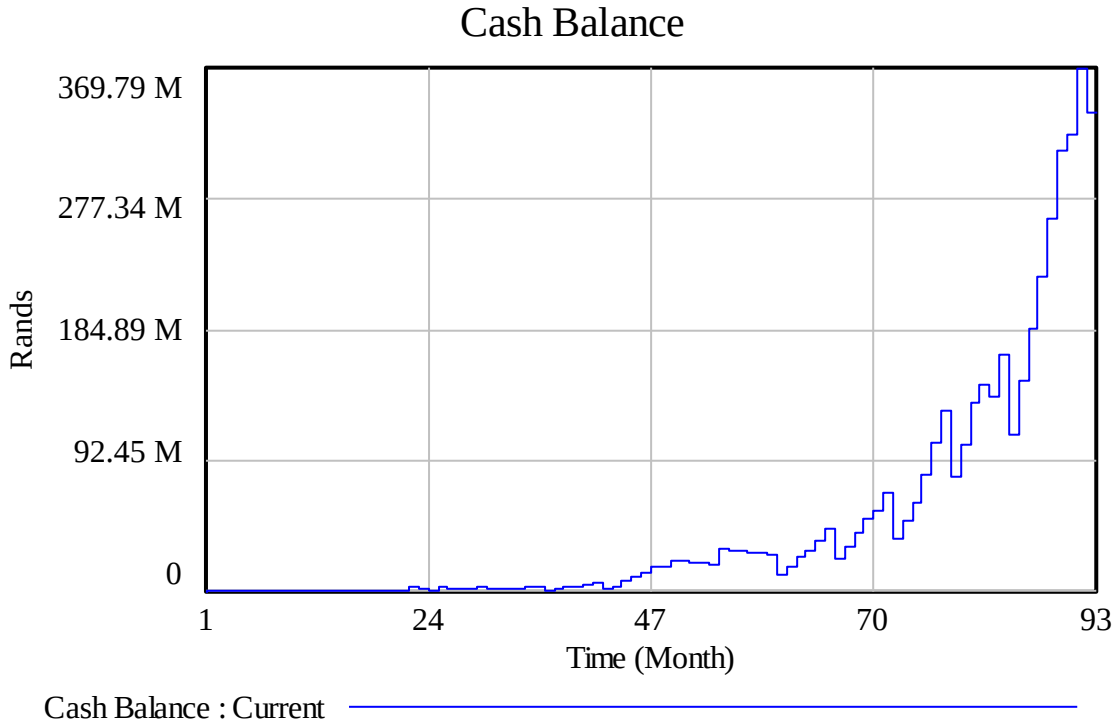


Figure 10: Cash balance projections when local and international sales factors are both 1.

Figure 11 shows that the company breaks even for the first time in month 50 (2 months after international sales start). However due to the expenses of paying for stock upfront, the company only breaks even sustainably in month 68.

Figure 12 shows the gross profit on a monthly basis. In month 28, the first batch of stock is paid for in preparation for sales in Month 32. By definition, this is the first month that a gross profit is recorded. All the negative bars indicate months in which the expenses were greater than the income. This occurs every 6 months when stock is paid for. As more devices are needed and therefore manufactured, the negative peeks increase in magnitude as more stock has to be paid for.

Figure 13 is similar to Figure 12 except that it includes all expenses (not only those belonging to the cost of sales) and hence the expenses before month 28 are reflected. Moreover the expenses from Month 32 onward are larger in magnitude as the graph is a reflection of all expenses. It can be seen that the expenses during the development phase (Months 1 to 28) are small in comparison to manufacturing hundreds and then thousands of devices.

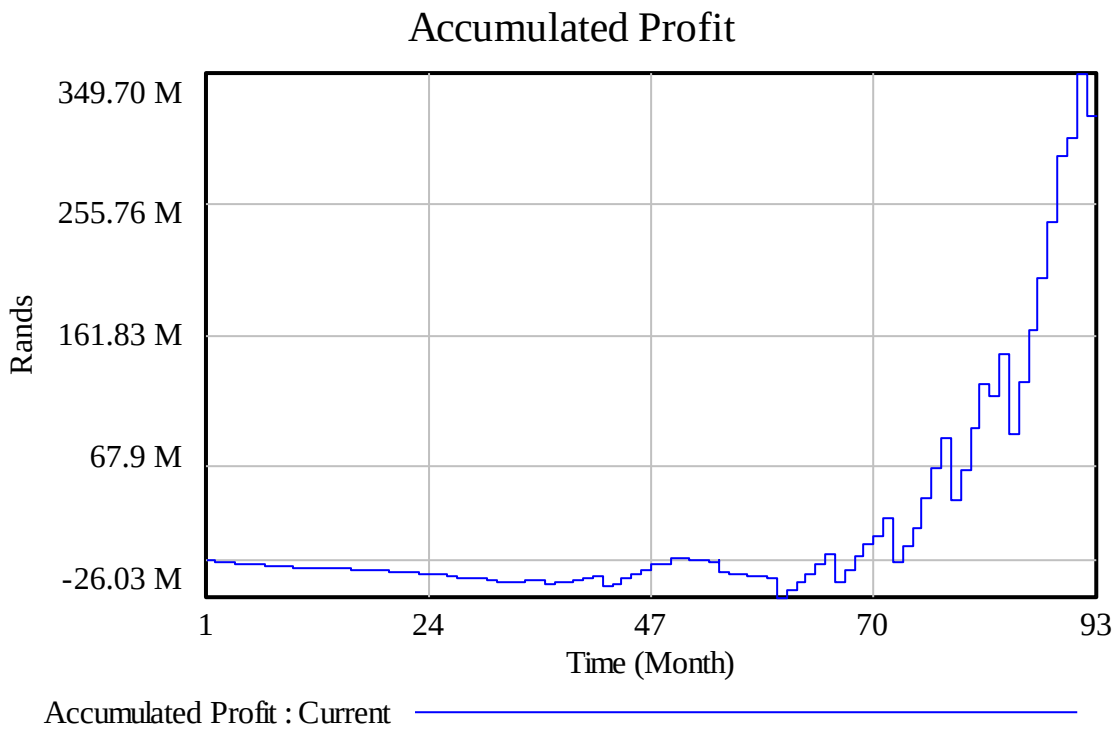


Figure 11: Accumulated profit projections when local and international sales factors are both 1

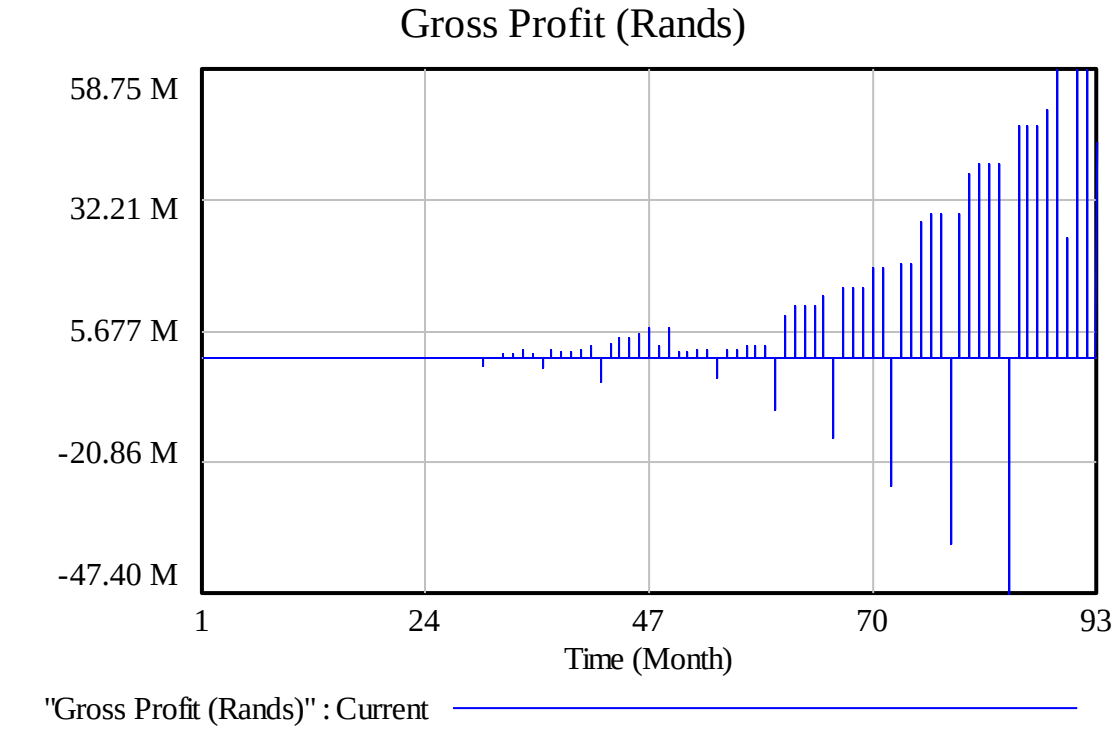


Figure 12: Gross profit projections when local and international sales factors are both 1

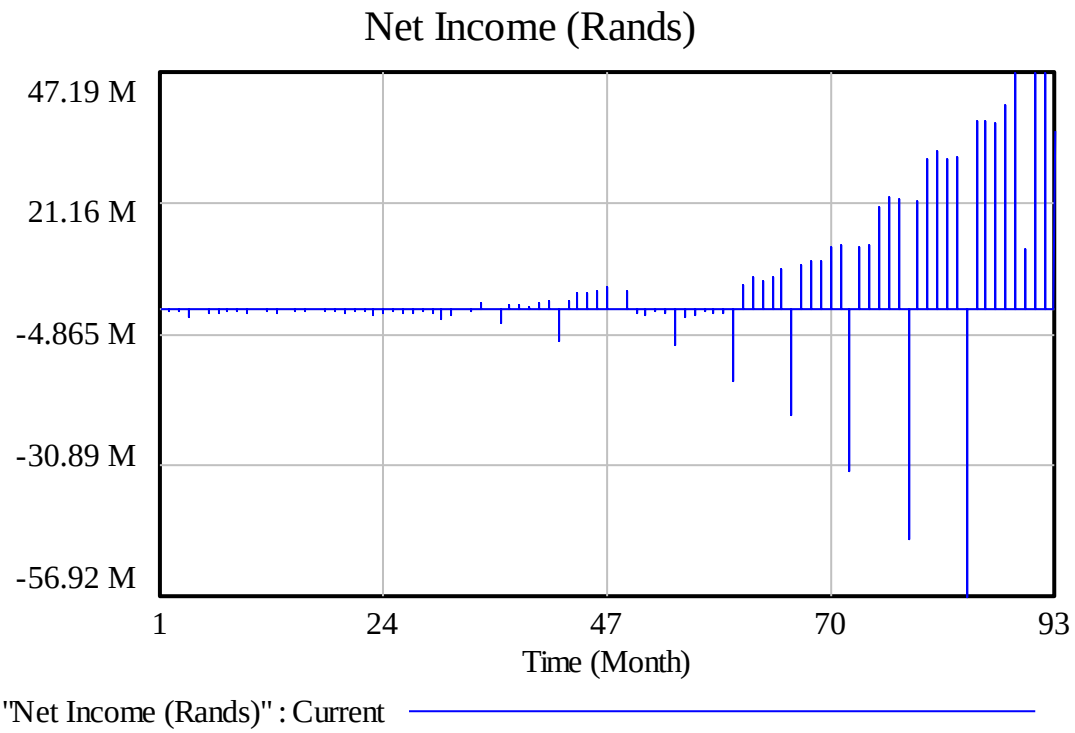


Figure 13: Net income projections when local and international sales factors are both 1

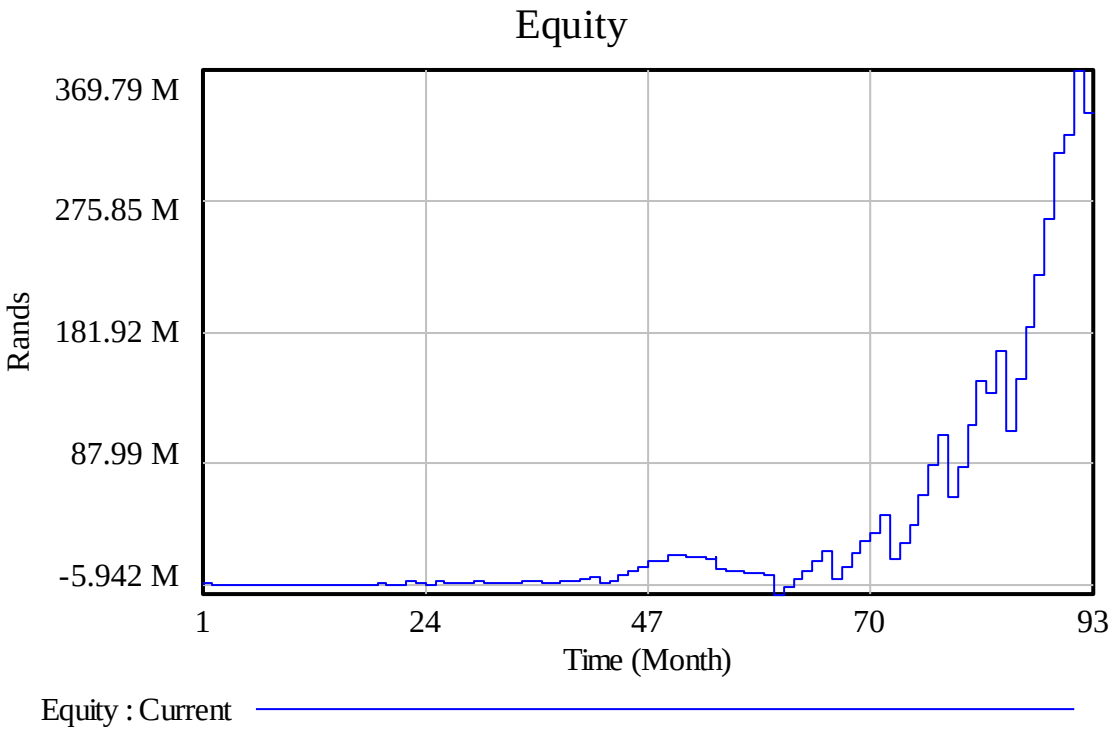


Figure 14: Equity projections when local and international sales factors are both 1

Figure 14 shows the equity projections for the company. From month 40, equity starts to rise but due to large expenses at the beginning of international sales, it drops and begins to recover from month 60.

6.2.Varying the sales factor

This set of simulations records the results for the minimum viable amount of devices that need to be sold in order to keep the company cash solvent at every point. Several scenarios are tested. The first is the minimum amount of local and international sales needed to keep the company solvent. The second is the minimum amount of local sales, if international sales stay regular. Finally the third is the minimum amount of international sales required, if local sales remain regular.

The assumption used in these tests is that fixed costs remain the same irrespective of the number of devices actually sold. The rationale behind this assumption is that the fixed costs such as rent, human resources, development and patent costs etc. have to be paid irrespective of the number of units being sold.

6.2.1. Minimum local and international devices

A test is run to find the minimum number of local and international devices that can be sold while keeping the company cash solvent. Although strictly speaking, provided that the cash balance never goes below zero, the company remains cash solvent, these simulations have been computed to ensure that there is always a little more cash than zero. This is because it is prudent to have a small buffer available in the event of minor extra sundry costs. For the purpose of these simulations it was decided that the buffer should be a minimum of R65 000. It so happens that for most of the simulations presented in this paper, due to the specific expenses, it is difficult to reach a cash balance of exactly R65 000 but R67 000 is reached. This is deemed cautious and therefore acceptable.

The results for this simulation are summarised in Table 7 and the output graphs as produced by the SD model for the cash balance (Figure 15), accumulated profit (Figure 16), equity (Figure 17), gross profit (Figure 18), and net income (Figure 19) are provided below.

Table 7: Simulation results for minimum viable local and international sales

	Simulated Results	Base Case
International Sales factor	0.7350	1.0000
Local Sales Factor	0.6700	1.0000
Number of International sales in 8 years	86 004	117 010
Number of Local sales in 8 years	4 943	7 378
Cash flow check (must be positive)	67 000	67 000

As can be seen from Table 7, the international and local sales can drop to 73.5% and 67% of their original values respectively and the minimum recorded cash balance will be R67 000 which is above the minimum buffer amount of R65 000.

Thus even if sales drop in both markets, there is enough funding and revenue being generated for the company to remain solvent provided that at least 4943 devices are sold locally and 86004 devices are sold internationally in the first 8 years.

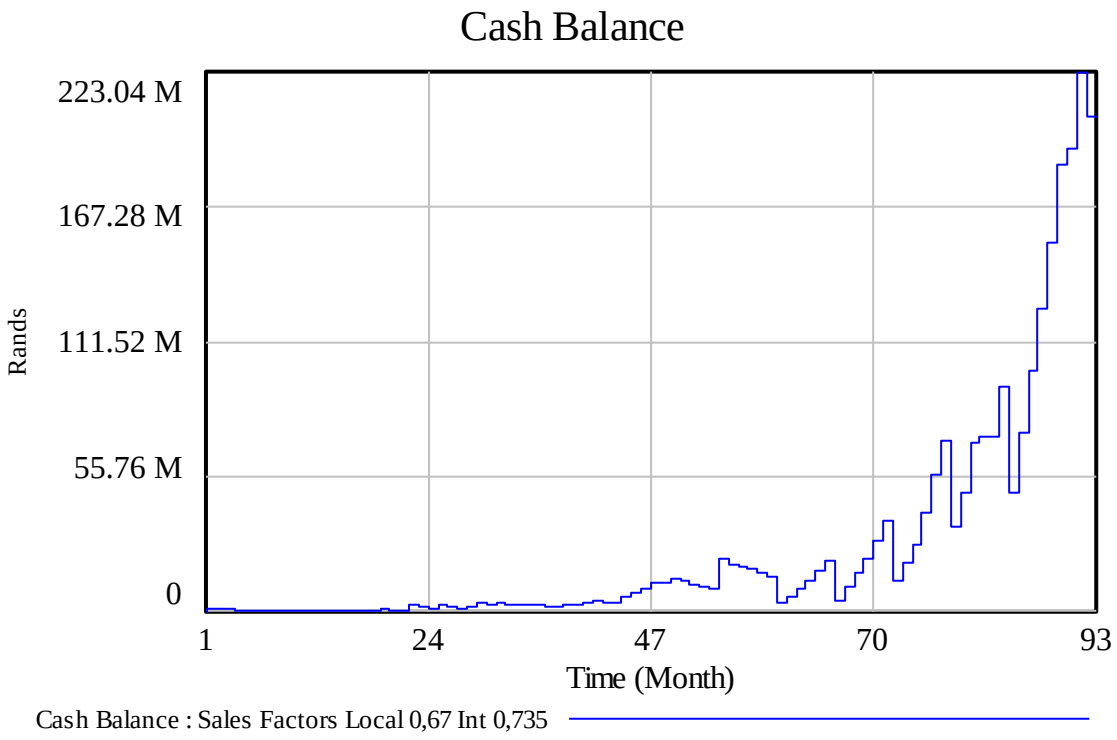


Figure 15: Cash balance projections for minimum viable local and international sales

Figure 15 shows the cash balance for the minimum viable local and international sales. The graph follows a similar profile to the base case (Figure 10) except with a reduced magnitude as fewer sales are made and therefore less income is generated.

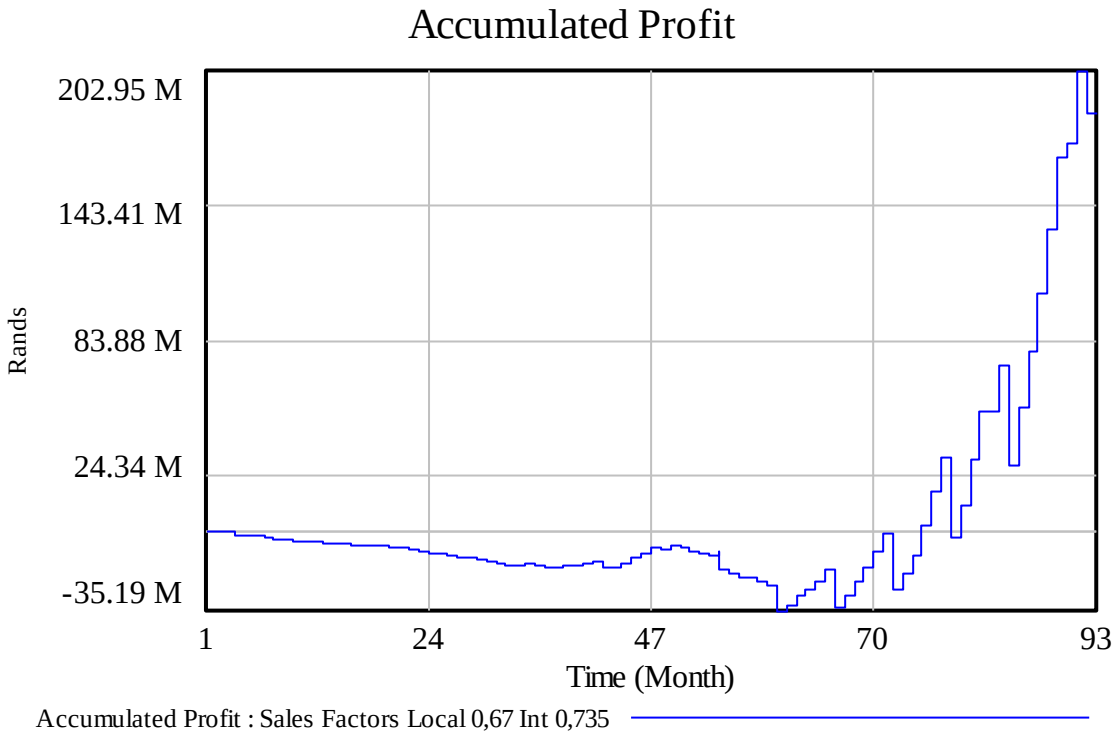


Figure 16: Accumulated profit projections for minimum viable local and international sales

Figure 16 (previous page) shows that the company breaks even for the first time in month 75 but only sustainably from month 79. This is in contrast to base case where the break even points were in months 50 and 68 respectively (see Figure 11 above).

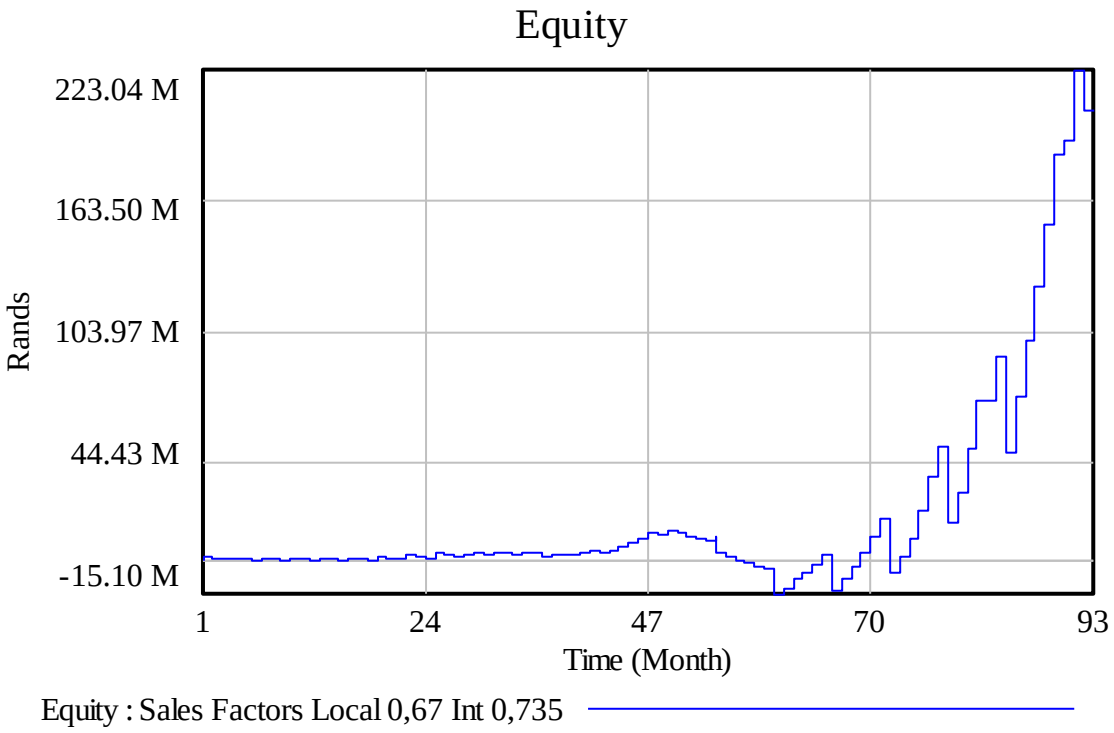


Figure 17: Equity projections for minimum viable local and international sales

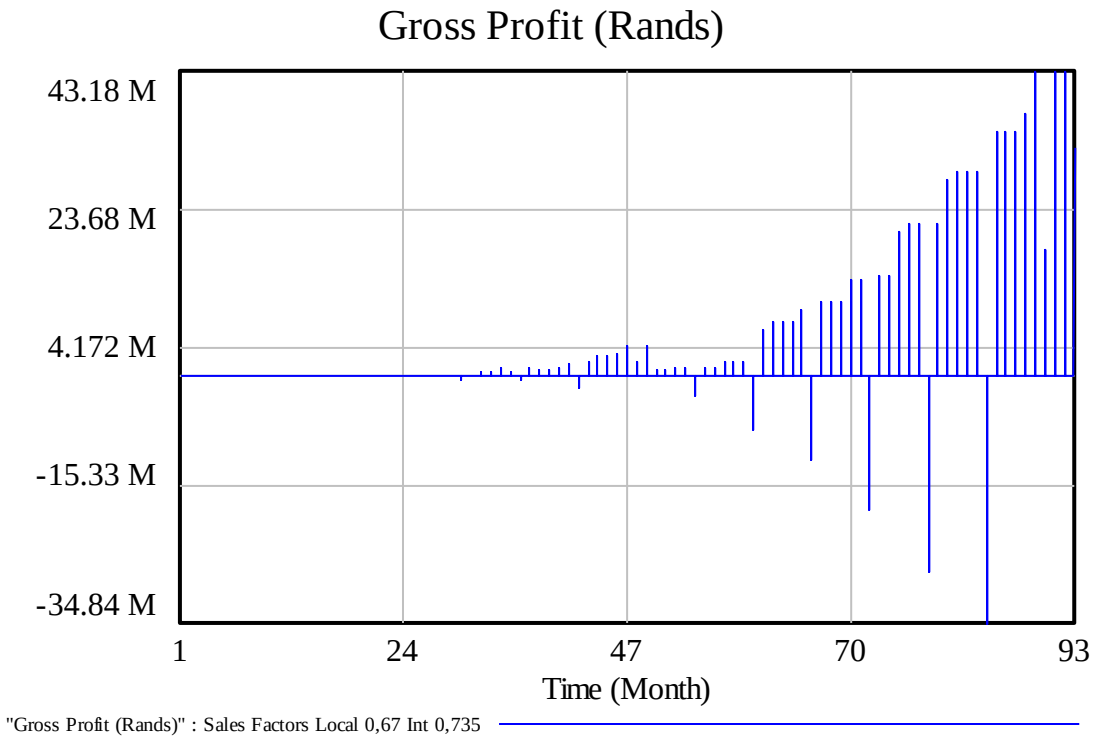


Figure 18: Gross profit projections for minimum viable local and international sales

Figure 17 (previous page) shows the equity projections for the company. From month 40, equity starts to rise but due to manufacturing expenses at the beginning of international sales, it drops in a similar fashion to the way it drops in the base case (Figure 14). The difference is that in this case, the drop is steeper due to reduced sales. Furthermore in this case, equity only makes a sustainable recovery in month 69 as opposed month 60 in the base case. It thus takes longer to recover than in the base case and never reaches the same maximum.

Figure 18 (previous page) shows the gross profit on a monthly basis. Both the positive and negative peaks are lower than in the base case (Figure 13) as fewer sales are made but also less stock is manufactured and thus the manufacturing costs are reduced.

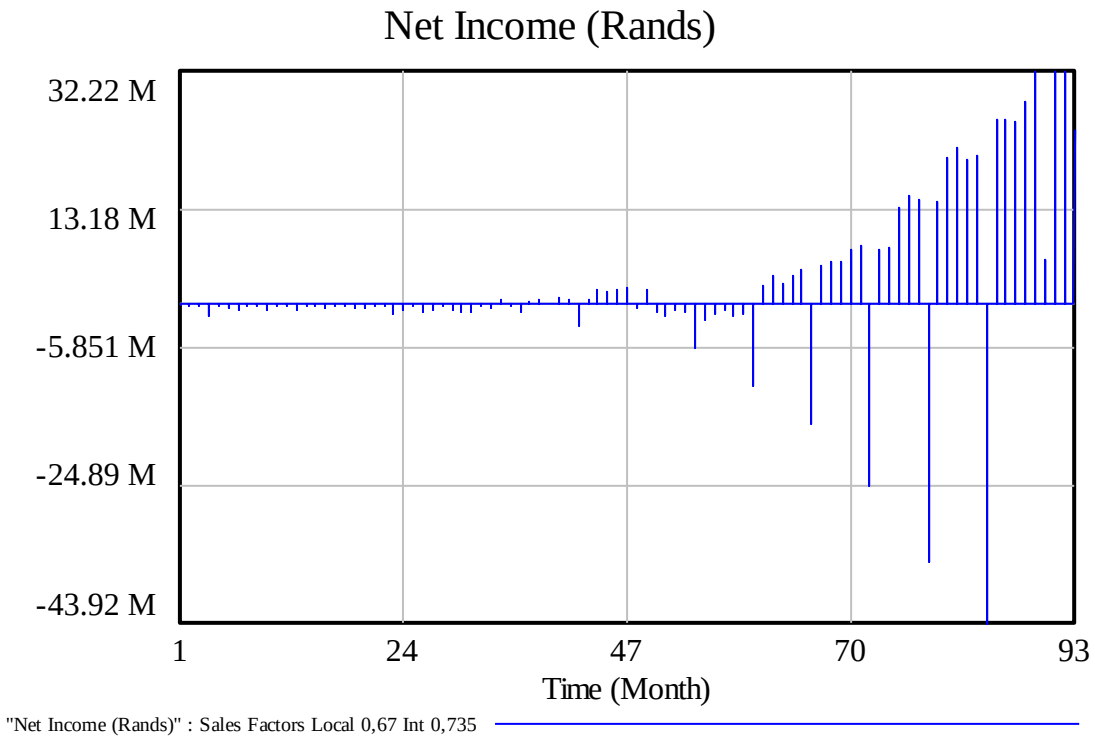


Figure 19: Net income projections for minimum viable local and international sales

Figure 19 is similar to Figure 18 except that it includes all expenses (not only those belonging to the cost of sales). Hence the expenses before month 28 (beginning of manufacture) are also reflected. The expenses before month 28 are independent of the number of sales made and therefore are the same as in the base case.

6.2.2. Minimum local sales factor (international sales factor = 1)

This test is designed to find out how small the local sales factor can be if the international sales follow their projected success. Table 8 presents the results for this simulation and compares them to the base case. The output graphs as produced by the SD model for the cash balance (Figure 20), accumulated profit (Figure 21), equity (Figure 22), gross profit (Figure 23), and net income (Figure 24) are provided below.

Table 8: Simulation results for minimum viable local sales

	Simulated Results	Base Case
International Sales factor	1.0000	1.0000
Local Sales Factor	0.6450	1.0000
Number of International sales in 8 years	117 010	117 010
Number of Local sales in 8 years	4 759	7 378
Cash flow check (must be positive)	67 000	67 000

From Table 8 it can be seen that the minimum local sales can drop to 64.5% of their original value and the minimum recorded cash balance will be R67 000 which is above the minimum buffer amount of R65 000.

Thus even if the company cannot penetrate the local market successfully and as a result the local sales drop to 64.5% of their original value, the cash flows are large enough for the company to remain solvent provided that at least 4759 devices are sold locally and that the company can maintain its projected market share in the international market.

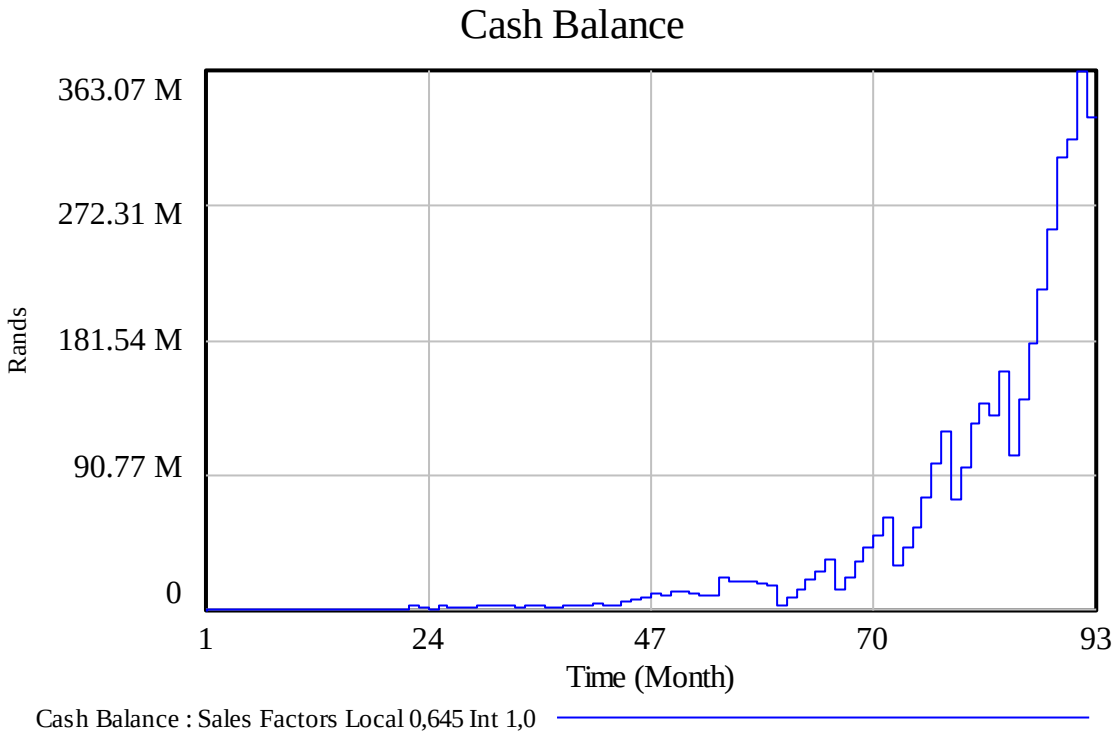


Figure 20: Cash balance projections for minimum viable local sales

Figure 20 shows the cash balance for the minimum viable local sales. From months 28 to 48 the peaks are lower than in the base case (Figure 10). This is due to the reduced sales in the local market. From month 48, the profile of the graph is the same but starting at a slightly lower base and ending with a smaller final cash balance.

Figure 21 (next page) shows that the company breaks even for the first time in month 69 but only sustainably from month 73. This is in contrast to base case where the break-even points were in months 50 and 68 respectively (see Figure 11 above).

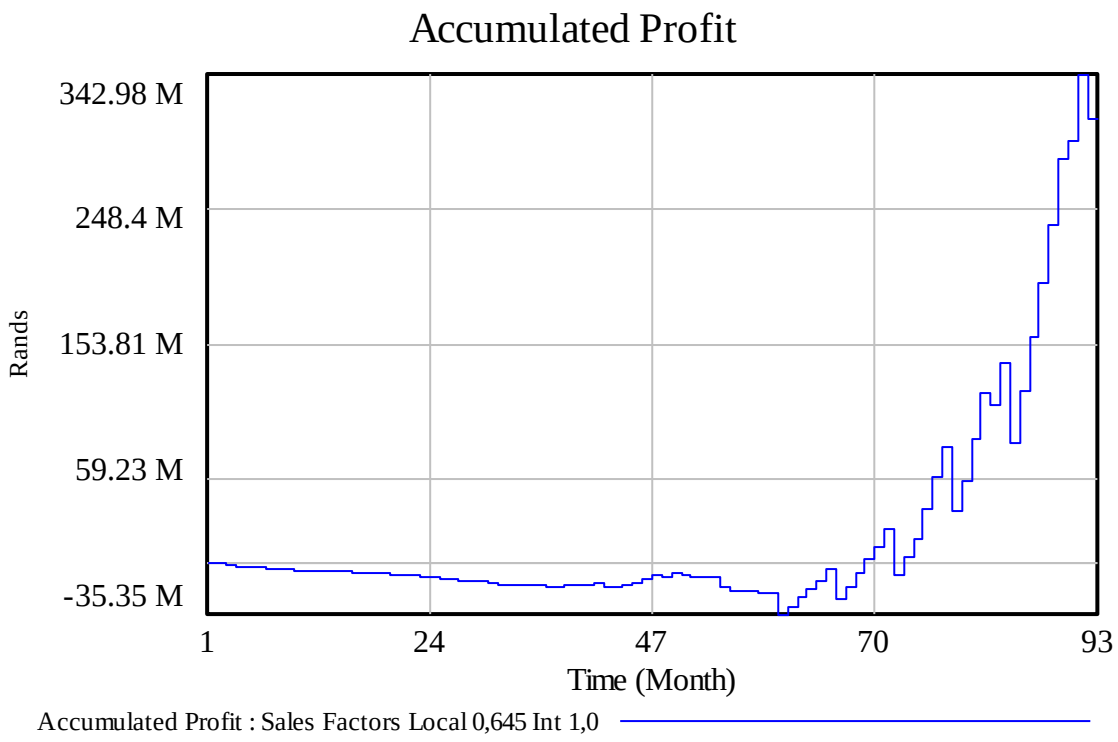


Figure 21: Accumulated profit projections for minimum viable local sales

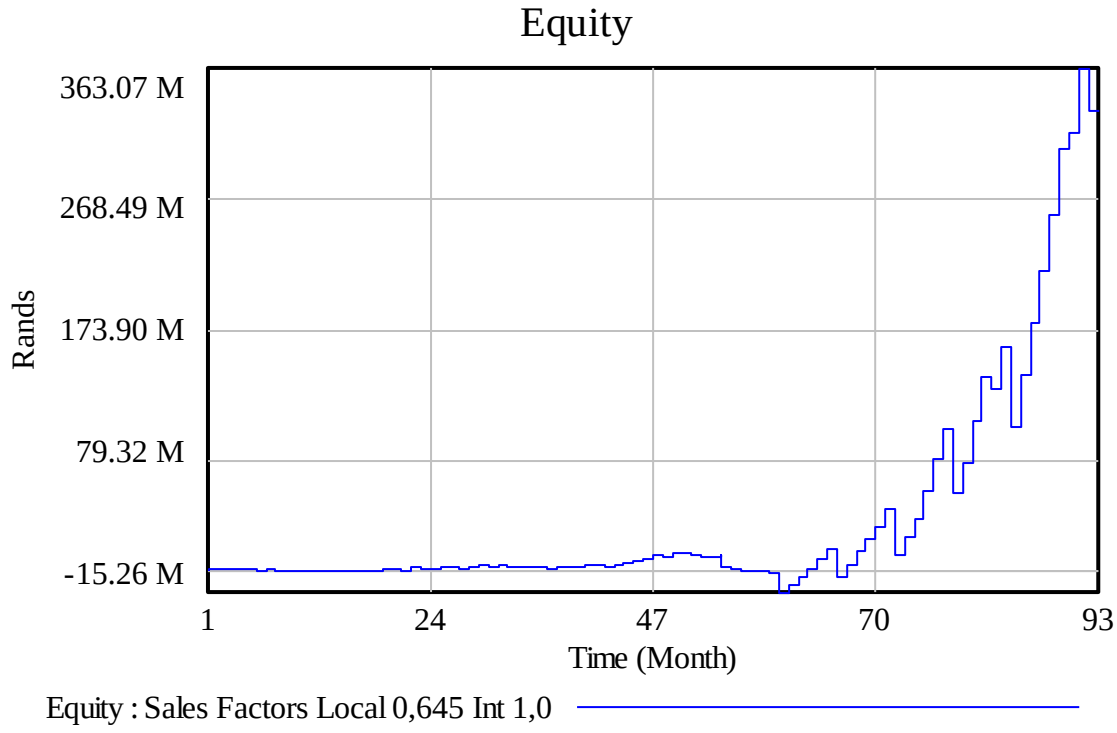


Figure 22: Equity projections for minimum viable local sales

Figure 22 shows the equity projections for the company. From month 28 to 48, the equity projections are lower than in the base case (Figure 14). This is due to the reduced sales in the local market. From month 48, the profile of the graph is the same but starting at a slightly lower base due to the reduced local sales.

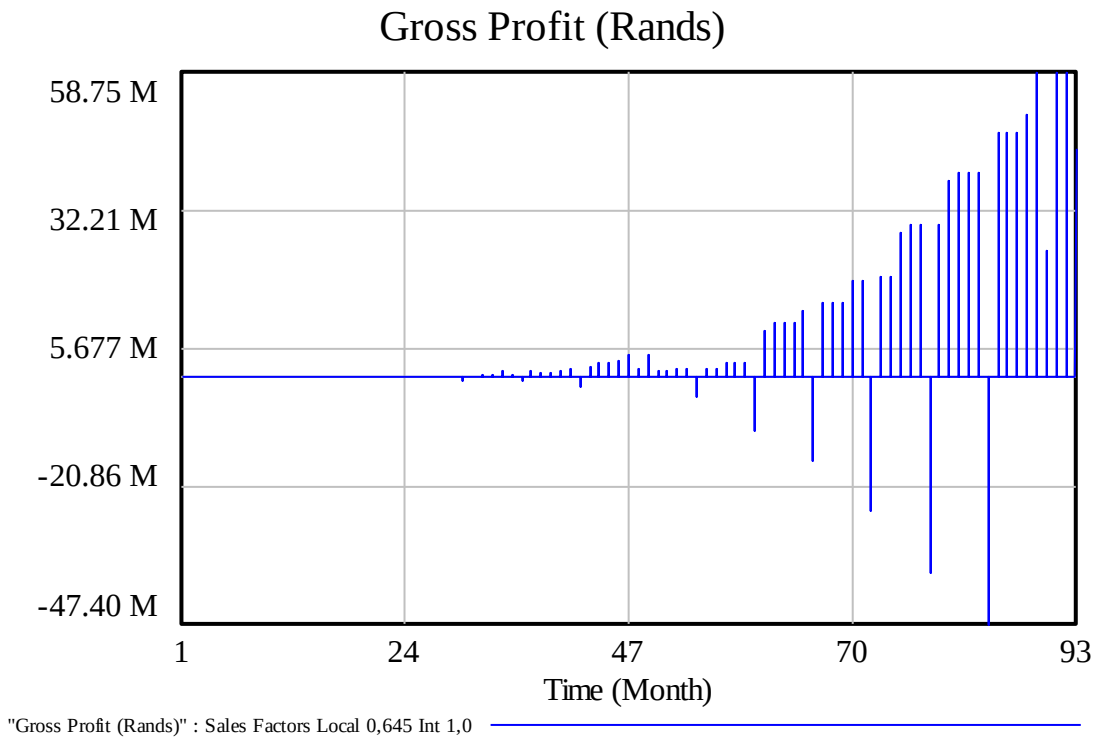


Figure 23: Gross profit projections for minimum viable local sales

Figure 23 shows the gross profit on a monthly basis. From months 28 to 48, both the positive and negative peaks are much lower than in the base case (Figure 12) as fewer sales are made but also less stock is manufactured. From month 48 onwards the positive peaks are similar to those in Figure 12 as sales in the international markets do not change between these two scenarios.

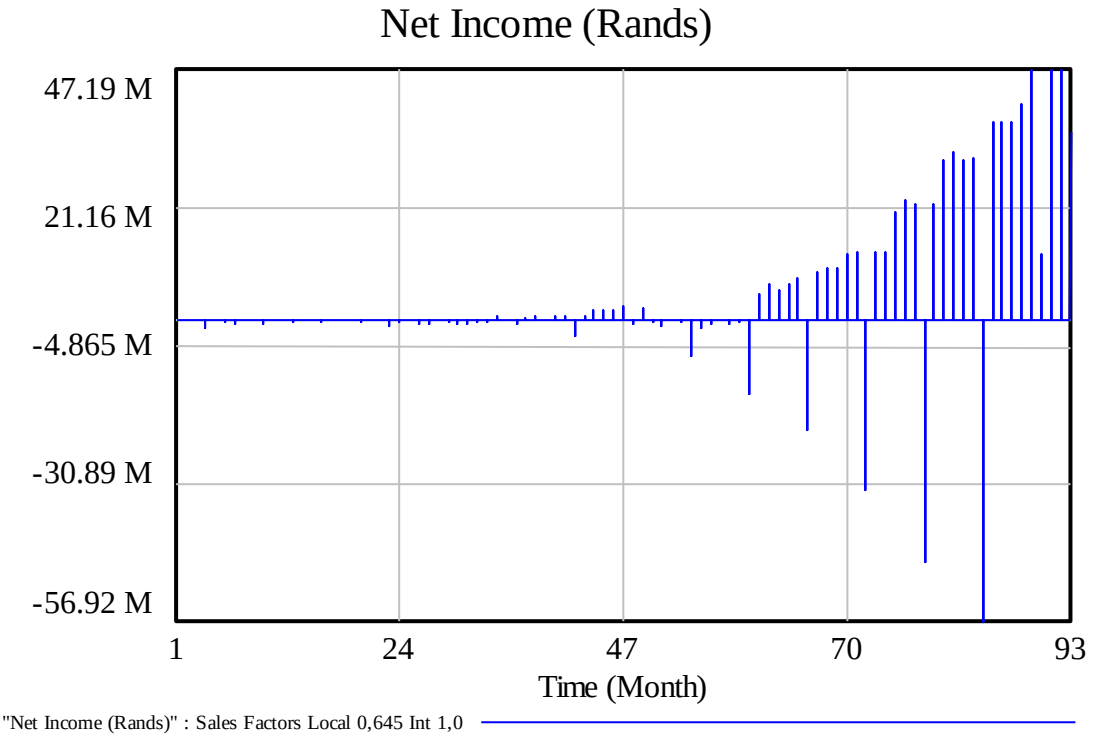


Figure 24: Net income projections for minimum viable local sales

Figure 24 (previous page) is similar to Figure 23 except that it includes all expenses (not only those belonging to the cost of sales) and hence the expenses before month 28 are reflected.

6.2.3. Minimum international sales factor (local sales factor =1)

This test is performed to find the minimum number of international device sales that are required to be made assuming that regular sales are achieved in the local market. Table 9 presents the results for this simulation and compares them to the base case.

Table 9: Simulation results for minimum viable international sales

	Simulated Results	Base Case
International Sales factor	0.5000	1.0000
Local Sales Factor	1.0000	1.0000
Number of International sales in 8 years	58 500	117 010
Number of Local sales in 8 years	7 378	7 378
Cash flow check (must be positive)	67 000	67 000

From Table 9 it can be seen that the number of international sales can drop to 50% of their original amount without the recorded cash balance dropping below R65 000.

Thus even if the company struggles to penetrate the international market and as such only manages to make sales of 50% of its projected sales strategy, the cash flows are large enough for the company to remain solvent provided that at least 58 500 devices are sold internationally and that the company can maintain its projected market share in the local market.

The output graphs as produced by the SD model for the cash balance (Figure 25), accumulated profit (Figure 26), equity (Figure 27), gross profit (Figure 28), and net income (Figure 29) are provided below.

Figure 25 (next page) shows the cash balance for the minimum viable international sales. From month 28 to 48, the graph is the same as in the base case (Figure 10) as local sales stay the same. From month 48 the peaks are lower than in the base case as sales are reduced in the international market.

Figure 26 (next page) shows that the company breaks even for the first time in month 47 but only sustainably from month 81. This is in contrast to the base case where the break-even points were in months 50 and 68 respectively (see Figure 11 above). In this case the first break-even point is earlier than in the base case. This is because fewer devices are manufactured upfront for the international market reducing the upfront cost of manufacture. At the same time, the local sales are the same as the base case, and therefore results in significant profit from sales, leading to an initial break-even point that is earlier than in the base case.

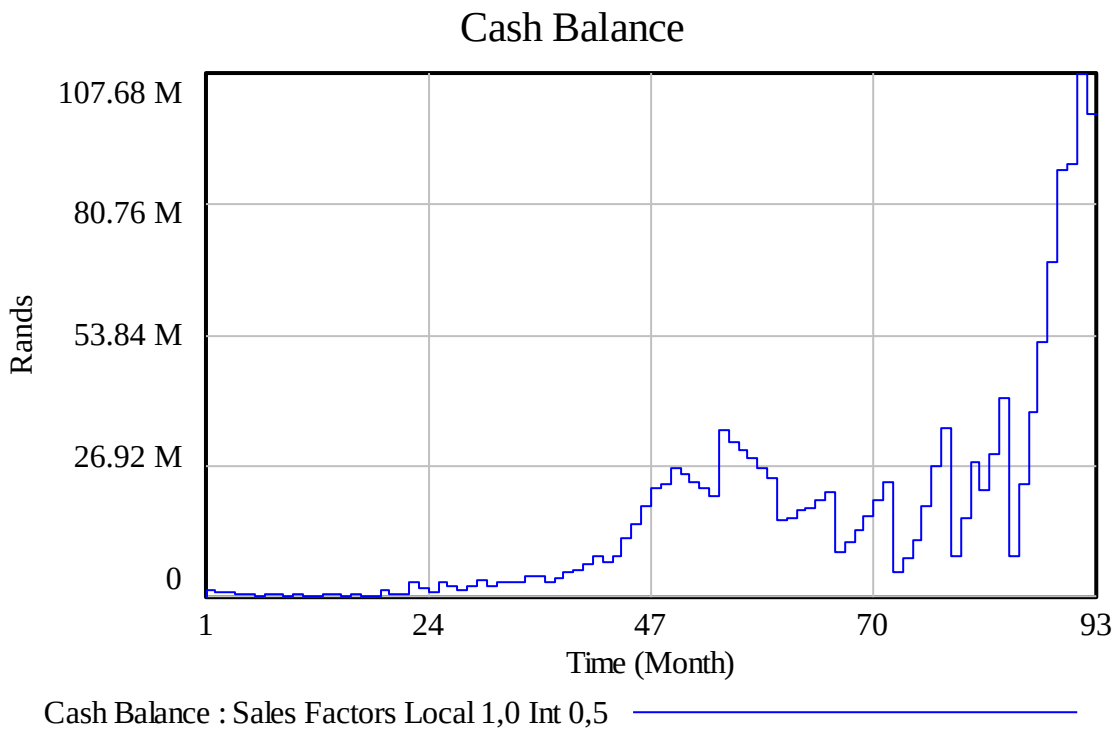


Figure 25: Cash balance projections for minimum viable international sales

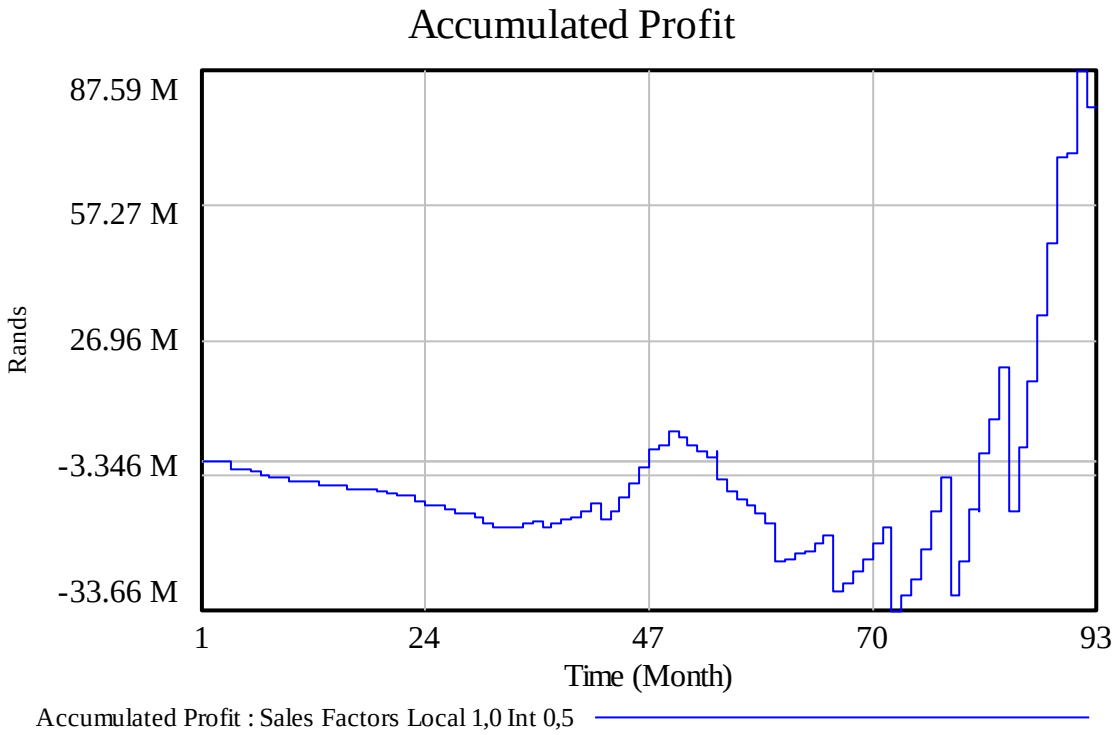


Figure 26: Accumulated profit for projections for minimum viable international sales

Figure 27 shows the equity projections for the company. From months 28 to 48, the equity projections are the same as in the base case (Figure 14). From month 48, the profile of the graph is reduced in magnitude due to the reduced international sales.

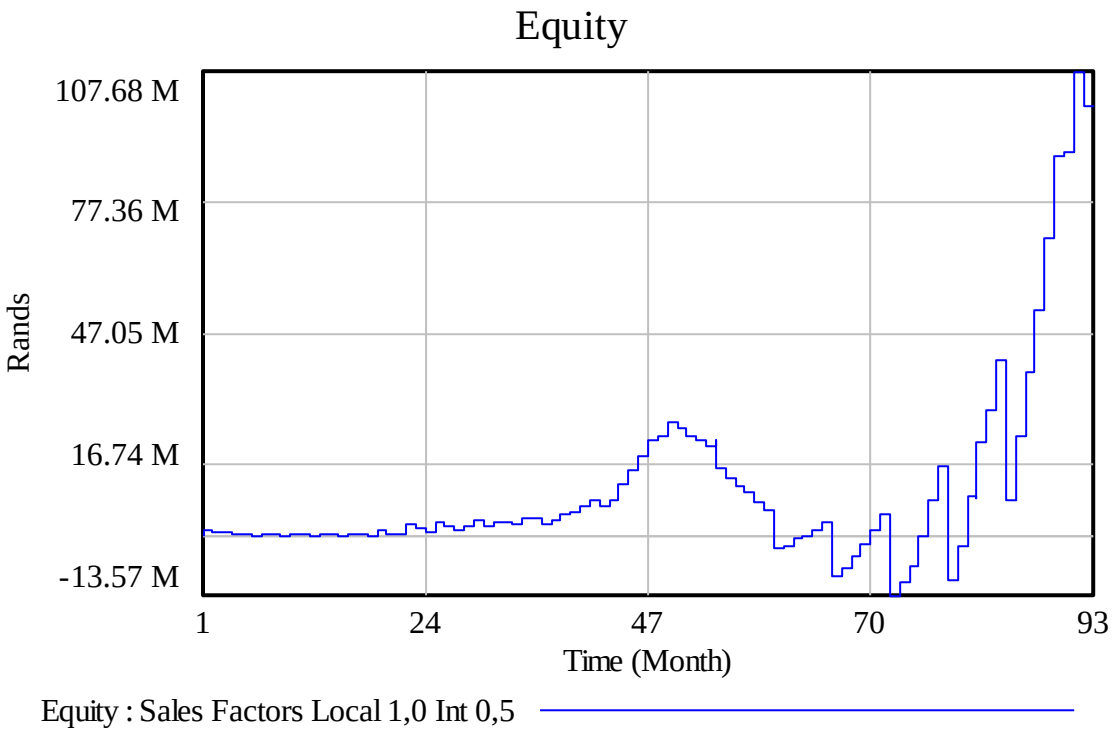


Figure 27: Equity projections for minimum viable international sales

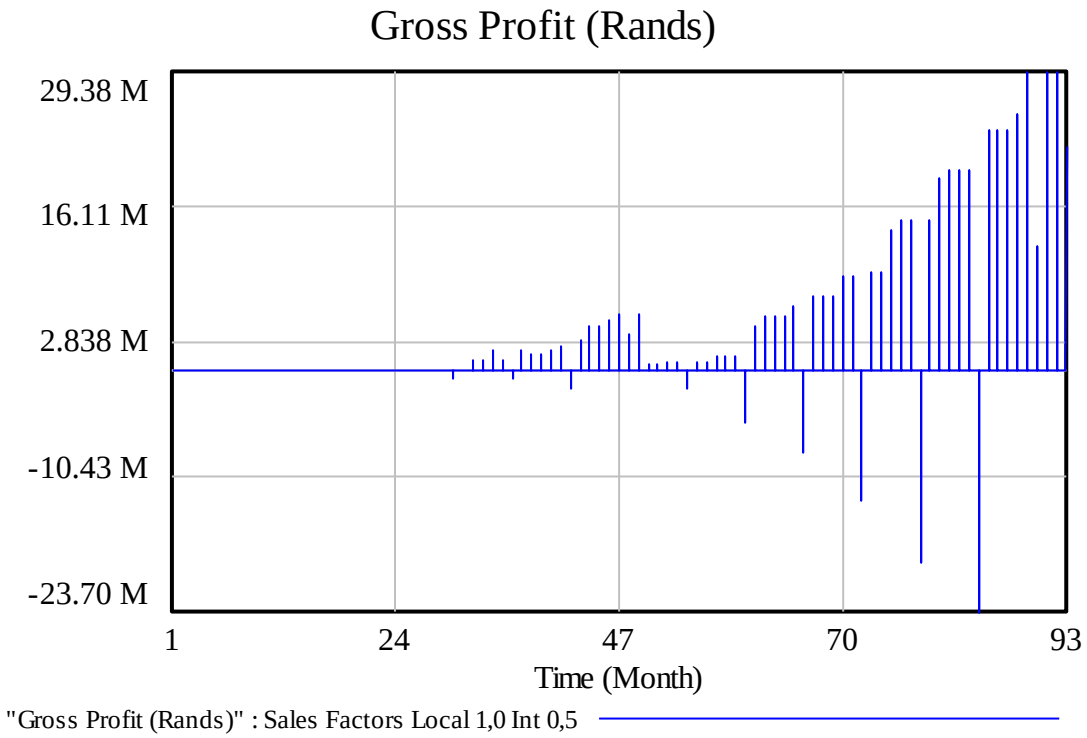


Figure 28: Gross profit projections for minimum viable international sales

Figure 28 (previous page) shows the gross profit on a monthly basis. From months 28 to 48 the peaks are the same as in the base case (Figure 12) as local sales remain the same. From month 48 onwards fewer sales are made but also less stock is manufactured and hence the magnitudes of the peaks are reduced.

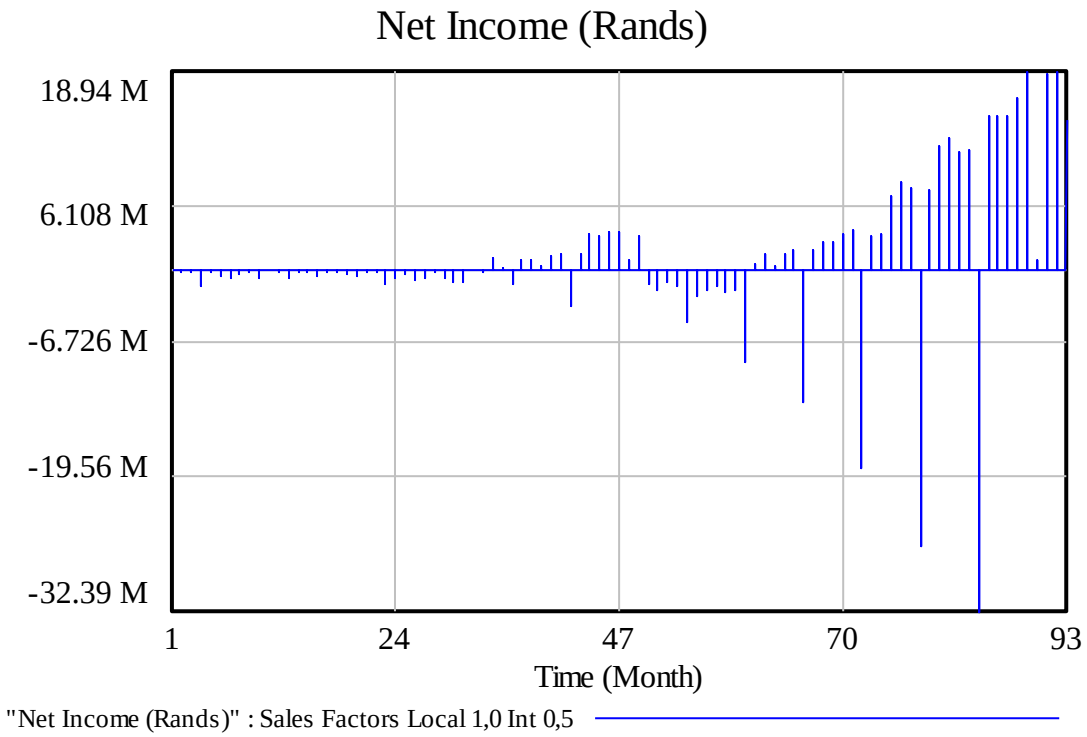


Figure 29: Net income projections for minimum viable international sales

Figure 29 is similar to Figure 28 except that it includes all expenses (not only those belonging to the cost of sales) and hence the expenses before month 28 (beginning of manufacture) are also reflected.

6.3.The effects of producing 6 months of stock upfront

The working assumption has been to produce stock upfront for 6 months. At the beginning of sales, this is a good assumption as manufacturers won't be prepared to manufacture several hundred devices per month. Based on the projected number of sales in the early stages of sales, 6 months of stock is sufficient to satisfy manufacturer's requirements. However as sales increase, and therefore the number of devices needing to be manufactured increases, it is no longer necessary for the manufacturers to produce 6 months of stock at a time for it to be financially viable for them to manufacture. Moreover the upfront cost of manufacturing for 6 months at a time becomes prohibitive to the company's cash flow which is why the loan of R18.5m is required in year 5 as can be seen in Table 2 in Section 3.3 above.

The loan amount of R18.5m was calculated by adding up all the negative cash flows that caused the cash balance to drop below zero. The total was R18.5m and hence it is compensated for by the loan of R18.5m.

In an attempt to see how substantial a difference optimising stock will make, from Month 60 stock optimisation is introduced to the model as sales have increased sufficiently to allow for it. This is done as follows: From months 60 to 80, stock is manufactured upfront for 2 months at a time (minimum of 2300 devices/2 months). From month 80, devices are manufactured monthly as a minimum of 4450 devices are required per month.

The simulations are run for three different scenarios, namely:

- To find the minimum number of local and international sales
- To find the minimum number of local sales when international sales remain regular
- To find the minimum number of international sales when local sales remain regular

Table 10 below shows the results for all 3 scenarios. The left hand column of the table provides the results for optimised stock and the right hand column summarises the results from the previous section (6 Monthly Stock). The top half of the table compares the minimum sales factors required when the loan is still taken out in year 5. The bottom half of the table presents the results of the minimum sales factors required if the loan in year 5 is not taken out at all.

Table 10: The effects of taking out a loan and optimising stock on minimum sales requirements

	Optimised Stock			6 Monthly Stock		
	International Sales Factor	Local Sales Factor	Minimum Cash Flow	International Sales Factor	Local Sales Factor	Minimum Cash Flow
Loan	0.655	0.450	61 162	0.735	0.670	67 000
	1.000	0.445	67 000	1.000	0.645	67 000
	0.405	1.000	67 000	0.500	1.000	67 000
No Loan	0.800	0.822	67 000	Cash Flow goes negative		
	0.845	0.800	39 205			
	1.000	0.728	63 906			
	0.503	1.000	67 000			

Note that in Table 10, the Minimum cash flow recorded for several scenarios is below R65 000. As explained in Section 6.2.1, the purpose of ensuring a non-zero minimum cash flow is to allow a buffer for sundry and unforeseen expenses. In this simulation, it was difficult to simulate and ensure a minimum of R65 000. It was decided to allow smaller minimum cash balances in order to get meaningful results from this simulation. This is deemed reasonable as the smallest minimum cash balance recorded is R 39 205 which still provides a significant buffer.

The results of the simulation show that the optimisation of stock management enables the company to stay cash positive at a much smaller break-even point of device sales than if devices are always manufactured for 6 months at a time. This is clearly preferable as it provides a more robust plan offering greater cash flow stability should unforeseen expenses or reductions in sales occur.

It can also be seen that if a loan is not attained but stock management is optimised, the company is still able to always remain cash positive even if device sales in both markets are reduced by between fifteen and twenty percent.

This analysis therefore shows two very important points. The first is that stock management is crucial to cash flow. The second is that although a loan is difficult to obtain and it increases expenses by having to pay it off with interest, it allows the company to maintain a positive cash flow during the start-up phase. This can prove invaluable if the market penetration proves to be more difficult than originally anticipated.

6.4.Sensitivity simulation analysis

In the previous tests, boundary points were looked at for what the minimum sales factors could be in order to keep the company's cash flows positive. In this next test, a simulation is performed to see what happens to the cash flows when each of the sales factors is varied between 0.50 and 2.0 in increments of 0.25. This means that the simulations are computed for a range of scenarios between 50% of sales and 200% of sales.

A list of all the scenarios is provided in Table 11. The final column of Table 11 shows which band each of these scenarios falls in to. The concepts of bands and the reason they are included in Table 11 will be explained shortly after the results for this simulation are presented. When one looks at all the scenarios in Table 11, it is clear how tedious and timeous it would be to manually simulate all 49 simulations without Vensim.

Table 11: List of the 49 Simulations performed during the sensitivity simulation analysis (includes the bands that the simulations fall into)

Simulation	Local Sales Factor	International Sales Factor	Bands Grey 95%-100% Blue 75%-95% Green 50%-75% Yellow 0% - 50%
1	0.50	0.50	
2	0.50	0.75	
3	0.75	0.50	
4	0.75	0.75	
5	1.00	0.50	
6	0.50	1.00	
7	0.50	1.25	
8	0.50	1.50	
9	0.75	1.00	
10	1.00	0.75	
11	1.25	0.50	
12	1.25	0.75	
13	1.50	0.50	
14	0.50	1.75	
15	0.50	2.00	

Simulation	Local Sales Factor	International Sales Factor	Bands Grey 95%-100% Blue 75%-95% Green 50%-75% Yellow 0% - 50%
16	0.75	1.25	
17	0.75	1.50	
18	0.75	1.75	
19	0.75	2.00	
20	1.00	1.00	
21	1.00	1.25	
22	1.00	1.50	
23	1.00	1.75	
24	1.25	1.00	
25	1.25	1.25	
26	1.25	1.50	
27	1.50	0.75	
28	1.50	1.00	
29	1.50	1.25	
30	1.75	0.50	
31	1.75	0.75	
32	1.75	1.00	
33	1.75	1.25	
34	2.00	0.50	
35	2.00	0.75	
36	2.00	1.00	
37	1.00	2.00	
38	1.25	1.75	
39	1.25	2.00	
40	1.50	1.50	
41	1.50	1.75	
42	1.75	1.50	
43	1.75	1.75	
44	2.00	1.25	
45	1.50	2.00	
46	1.75	2.00	
47	2.00	1.50	
48	2.00	1.75	
49	2.00	2.00	

A second challenge of performing a test with 49 simulations is: how does one present the results in a meaningful way that provides intuitive insight. Vensim achieves this by grouping the results into four different bands and plotting the bands on a single graph. Figure 30 below shows the cash balance graph for all 49 simulations. As can be seen, the results are grouped into four bands.

The first band is the 50% band (yellow). This band represents approximately 50% of the simulations which are the most moderate permutations of the varying sales factors. The far right column in Table 11 colour codes each of the 49 simulations shown in Figure 30 according to its band, thus simulations 14 to 36 fall into the 50% band. The next band is the 50% to 75% band (green). This band represents the next 25% of the simulations. These simulations are not as moderate as the yellow band but are still moderate (see simulations 6 to 13 and 37 to 44 in Table 11). The third band is 75% to 95% band (blue). This band signifies the sales factor permutations that are quite extreme (see simulations 2 to 5 and 45 to 48 in Table 11). The fourth and final band (grey) represents the most extreme sales factor permutations; such as when both sales factors are 2.0 or both sales factors are 0.5.

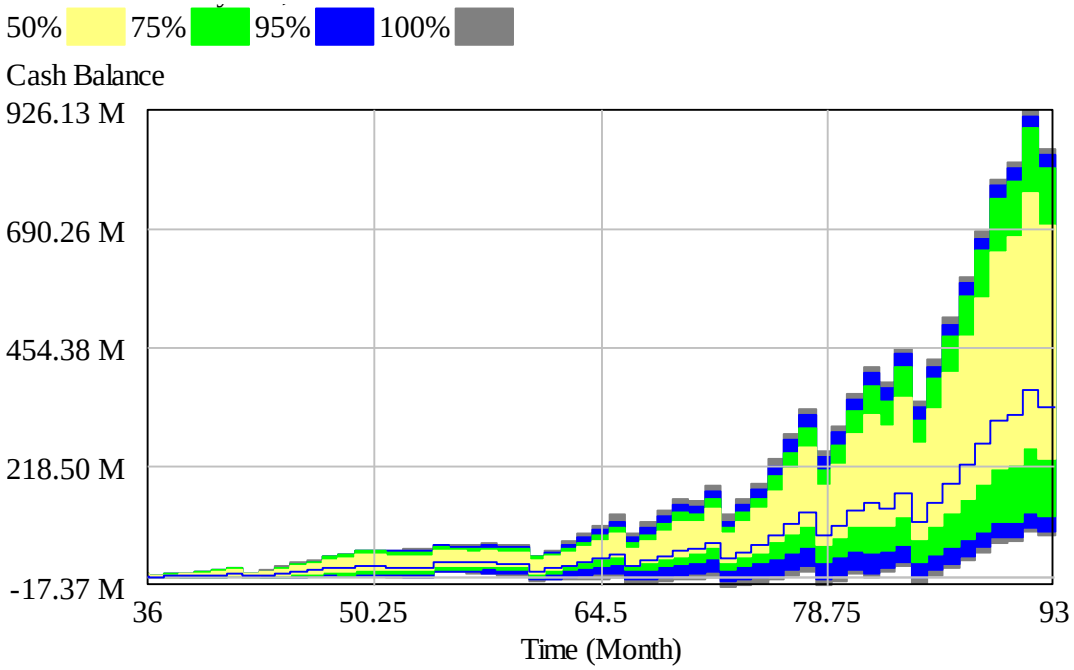


Figure 30: Sensitivity simulation analysis of variation of local and international sales factors between 0.5 and 2.0

From Figure 30, it is clear that all simulations in the 50% band (yellow) are above zero. Figure 31 (next page) magnifies the view around the y-axis zero line in order to see if the 75% band (green) ever goes sub-zero. As can be seen in Figure 31, the green band only crosses the zero line at month 42, 43 and 60.

It is important to note that month 42 and month 60 are stock producing months and the negative peaks are relatively small. Thus based on the analysis in the previous test, stock optimisation specifically around months 42 and 60 would enable the company to keep its cash balance positive throughout the modelling period for the entire green band as well.

The outcome of this simulation informs the loss or gain that is generated by decreasing or increasing sales. In the case of decreased sales, the outcome indicates how negative the cash flows could drop, and this gives an indication of how much money is required to be saved or raised should such a situation arise. This then allows management to critically analyse which costs can be brought down. For example, it might be prudent to reduce staff size; provided that it will not cripple the ability to make sales and provided that the saving will actually make a sufficient difference.

Conversely, in the case of increased sales and therefore increased cash flows, it gives an idea of whether increased stock requirements might create negative cash flows due to very high upfront stock payments. It also indicates how much extra profit the company would generate. This would provide opportunities to grow the business by for example increasing the sales force, doing further upgrades to the current device or developing further devices.

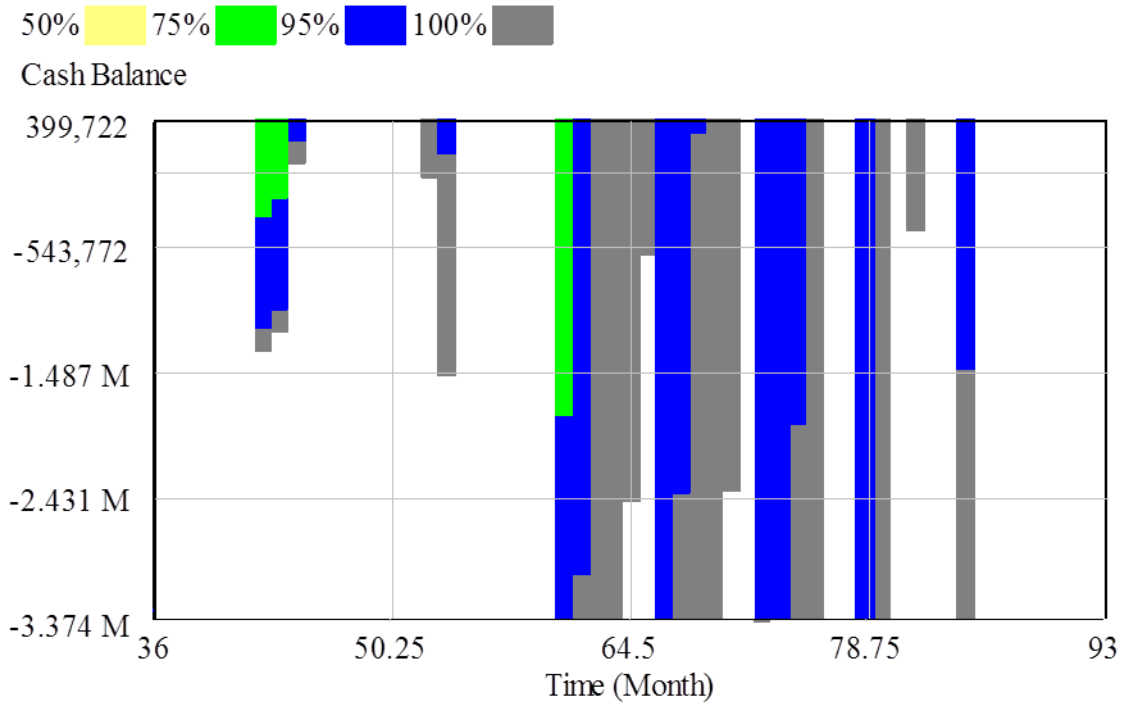


Figure 31: Magnified view of the sensitivity simulation analysis (around the y-axis zero line)

This analysis therefore shows that the financial plan is sufficiently robust to withstand significant variations to change in both the local and international sales strategy. In fact, it can tolerate nearly 75% of variation when varying the local and international sales factors between 0.5 and 2.0. This information is crucial to a start-up, as sales projections are only projections and can easily be wrong. It is thus essential that the start-up has a business plan that can handle variation both in terms of fewer sales and in terms of increased sales. Cash flows can be as concerning when there are increased sales, as when there are decreased sales. This is because when sales increase, the cost of sales increases and the company needs to be sure it can finance this.

It is also clear from this analysis that the SD model has the capability to perform multiple simulations and present the results of such simulations in useful and intuitive manner.

7. DISCUSSION AND CONLCUSIONS

Although the simulations presented above focus on the change of the sales factors, this is just by way of example. Any other variable could also have been modified and results simulated.

For example the effect of changes in the 'bad debt constant' could have been varied or alternatively the effect of changes in the 'cost of sales' could have been illustrated. Another simulation that could have been performed could have been to analyse the effect of manipulating the proportion in which Manual and Automatic devices are sold in the International market. Moreover a simulation could have been setup where all these variables could have been varied simultaneously and the results simulated. This illustrates the potential capability of SD modelling for simulation.

It is true that the simulations performed in this thesis can be done in a spreadsheet model; however the setup for these simulations is much more complex. Whereas a sensitivity analysis in Vensim could be done by clicking on one icon, in Microsoft excel, a special add-on must be installed called Solver. Furthermore, all data to be manipulated for the analysis must be on a single sheet within the spreadsheet. In the case of the financial model used in this thesis, data would have had to been moved from one sheet to another to facilitate the sensitivity analysis. This detracts from the logical structure of the spreadsheet model.

Another disadvantage of the spreadsheet model is the default manner in which the results are presented. In the spreadsheet the default presentation of results is numerical. This means that there are many numbers to sift through to get an understanding of the results. Although it is possible to convert the data in the spreadsheet model to a graph, this takes more effort and time. In contrast to this, in the SD model, the results are presented graphically. This means that at a glance, the results and the general trends can be understood. If however the numerical data is required, it can be accessed easily.

It is thus clear that there is great value in having a system dynamics model of the financial statements for simulation purposes. However there is another value proposition of the system dynamics model. This is the ability to gain visual insight in to the workings of a financial model. This is of particular value for professionals like engineers who have not been trained in finance but have been taught to think visually and follow flow diagrams; and is indeed the core objective and motivation for this study. The visual benefits of a system dynamics model provide a clearer understanding of and insight into financial modelling both in the macro sense as well as in the micro sense.

- **System dynamics modelling enhances macro understanding of the financial statements**

When looking at the separate sheets of the financial model it is hard to conceptualise the interdependencies and relationships that exist between the different sheets. This makes conceptualising the financial statements by people not trained in finance quite difficult. In reality, it is critical for managers and executives to have a real understanding of how the financial statements work such that they can make informed executive decisions with strong financial backing.

In contrast to the spreadsheet format, when looking at the systems dynamics model, firstly all elements of the model are on the same page, but more than that each variable that is linked to the next is shown by a directional arrow. Moreover all accumulations are depicted by boxes and all rates have the "valve" symbols on them to show flow rates. This means that one can immediately see how the elements of the Income Statement are rates for the accumulation of the cash balance in the cash flow statement and how the cash balance and accumulated assets and liabilities form the balance sheet.

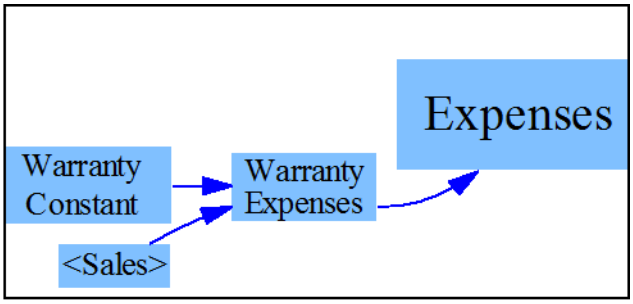
- **System dynamics modelling enhances micro understanding of the financial statements**

On the micro level, when looking at only a specific line item on the spreadsheet, one would need to view the formula to know what data is being pulled from other parts of the spreadsheet to produce the specific output. In contrast, with a system dynamics model, the dependencies are clearly shown.

As a way of clarifying the value of this, take the example of the warranty expense in the model which is discussed in this paper. Figure 32 compares the view one would obtain from the spreadsheet of the warranty expense (a) with that of the system dynamics model (b).

Year	4	4	4
Month	39	40	41
Date	Jul-16	Aug-16	Sep-16
Other Expenses	-228 684	-173 308	-91 778
Rent	-21 200	-21 200	-21 200
Bad debts	-22 095	-29 460	-36 825
Warranty	-5 524	-7 365	-9 206

(a)



(b)

Figure 32: Comparison of the 'Warranty' expense as presented in the financial spreadsheet (a) versus as presented in the system dynamics model (b)

In the financial model, the warranty expense is included as one of the 'Other Expenses' (see Section 4.1) in the Income Statement. This expense increases with time but it is not clear from the spreadsheet what it is based on. Although it is obvious that the warranty should be based on Sales, since the dependency was not clear to the eye and all the other expenses in its proximity on the spreadsheet were fixed expenses, when the spreadsheet data was first imported into SD model, the warranty data was imported directly. This meant that irrespective of the number of sales, the warranty amount remained the same and this caused major inconsistencies between the two models when the sales factors were modified. It took a substantial amount of time to identify where the problem lay, however after careful analysis, the problem was identified and corrected.

In contrast to this, in the SD model all dependencies are evident from inspection, as can be seen in Figure 32 (b) and hence this mistake would not have occurred in the first place.

Thus it can be seen how the system dynamics model provides open and clear relationships between variables which can be very difficult to realise in financial spreadsheets without going into the minutia of the formula that govern each cell.

In conclusion, this paper has shown a methodology for converting the financial statements for a biomedical start-up company developing a device for venepuncture into a system dynamics model. The model is validated against the financial statements and it is demonstrated that the largest discrepancy between the two models is 0.14%. Simulations are run to find the minimum number of local and international sales required to keep the company cash positive.

The effects of non-optimised stock production are explored and it is shown that an additional loan that was built into the financial plan is unnecessary if stock production is optimised. By way of example, a sensitivity analysis is used to understand how flexible the financial plan is if sales projections vary from the original plan. It is found that the model can uphold nearly 75% of variation when varying the local and international sales factors between 0.5 and 2.0. It is also shown that the usefulness of the system dynamics model extends beyond its simulation ability and enhances the understanding of the financial statements both in the macro and micro sense.

When all is said and done, the spreadsheet and SD models are equivalent representations of the same system. For the engineering user, the advantage of the SD model over the spreadsheet is that the SD model represents the data in a manner consistent with the engineering thought process. It is thus presented in a way that makes it highly intuitive for the engineering user. The columns of data found in the spreadsheet model are abstracted and thus hidden from view in the SD model, leaving only the fundamental skeleton of the system which can be represented on a single screen or sheet. However it makes explicit the relational aspects of the system in an unambiguous manner using the symbolic representation of the systems theorist. The user can still access any of the detailed numerical content available in the spreadsheet model.

This work has demonstrated that the functionality of the system dynamics environment is able to capture all the features that are present in the spreadsheet model while achieving the representational advantages discussed above. It is hoped that this approach will facilitate mutual understanding between people trained in engineering and technology and those with a purely financial background, thus facilitating the business processes in technologically orientated companies.

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APPENDIX A. PERCENTAGE ERROR BETWEEN THE SPREADSHEET AND THE SD MODEL

Table 12 below compares the cash balance as calculated in the spreadsheet model as well as that calculated in the SD Model. The table also shows the percentage error between the models for each month. It is found that the maximum percentage error between the two models occurs in Month 6 and is 0.14%. The average error is 0.02%.

(Note: the model starts simulating from May 2013 (first month of business), and considers the last month of each financial year as December. As a result, December 2013 is the 8th month in the model, December 2014 is the 20 month in the model, December 2015 is the 32nd month in the model etc.)

Table 12: Comparison between cash balances as reported by the SD model and the spreadsheet model

Year	Month	Cash Balance SD Model	Cash Balance Spreadsheet Model	% Error
1	1	1 323 794	1 324 000	0.02
	2	1 147 801	1 148 000	0.02
	3	1 024 771	1 025 000	0.02
	4	683 805	684 000	0.03
	5	587 746	588 000	0.04
	6	66 906	67 000	0.14
	7	700 281	700 500	0.03
	8	428 785	429 000	0.05
2	9	187 957	188 100	0.08
	10	466 409	466 600	0.04
	11	399 897	400 100	0.05
	12	241 058	241 200	0.06
	13	524 326	524 520	0.04
	14	432 331	432 540	0.05
	15	233 907	234 060	0.07
	16	441 886	442 080	0.04
	17	355 200	355 400	0.06
	18	224 292	224 320	0.01
	19	1 331 374	1 331 640	0.02
	20	728 145	728 360	0.03
3	21	490 902	490 736	0.03
	22	2 987 701	2 988 056	0.01
	23	1 745 095	1 745 376	0.02
	24	1 035 878	1 035 752	0.01
	25	3 249 768	3 250 075	0.01
	26	2 355 146	2 355 434	0.01

Year	Month	Cash Balance SD Model	Cash Balance Spreadsheet Model	% Error
3	27	1 592 372	1 592 450	0.00
	28	2 347 800	2 347 809	0.00
	29	3 597 122	3 597 550	0.01
	30	1 837 682	1 837 754	0.00
	31	2 633 027	2 633 213	0.01
	32	2 610 905	2 611 113	0.01
4	33	2 434 220	2 434 232	0.00
	34	3 644 486	3 644 638	0.00
	35	3 860 252	3 860 788	0.01
	36	1 357 619	1 357 675	0.00
	37	2 253 900	2 253 934	0.00
	38	3 307 585	3 307 699	0.00
	39	3 795 664	3 795 646	0.00
	40	5 219 921	5 219 894	0.00
	41	6 705 802	6 706 599	0.01
	42	2 355 452	2 355 414	0.00
	43	3 912 381	3 912 087	0.01
	44	7 284 193	7 283 920	0.00
5	45	10 491 582	10 491 256	0.00
	46	14 067 154	14 066 730	0.00
	47	18 333 178	18 332 067	0.01
	48	18 296 116	18 293 162	0.02
	49	22 134 408	22 130 791	0.02
	50	21 487 462	21 482 632	0.02
	51	20 254 468	20 248 215	0.03
	52	19 929 930	19 926 121	0.02
	53	19 293 162	19 290 024	0.02
	54	30 874 526	30 875 646	0.00
	55	29 285 796	29 289 220	0.01
	56	28 328 828	28 334 540	0.02
6	57	28 146 478	28 149 697	0.01
	58	27 261 394	27 261 993	0.00
	59	26 584 286	26 584 178	0.00
	60	12 557 694	12 555 991	0.01
	61	17 409 196	17 408 321	0.01
	62	23 966 414	23 969 150	0.01
	63	29 503 128	29 509 185	0.02
	64	36 067 376	36 076 706	0.03
	65	43 973 804	43 988 700	0.03
6	66	23 214 088	23 226 094	0.05
	67	32 078 888	32 094 596	0.05
	68	41 657 692	41 677 215	0.05

Year	Month	Cash Balance SD Model	Cash Balance Spreadsheet Model	% Error
7	69	51 212 316	51 235 242	0.04
	70	56 556 928	56 573 218	0.03
	71	69 257 792	69 280 257	0.03
	72	37 177 936	37 188 622	0.03
	73	49 719 860	49 725 200	0.01
	74	62 552 968	62 551 925	0.00
	75	82 825 320	82 820 262	0.01
	76	105 287 488	105 281 206	0.01
	77	127 180 216	127 182 420	0.00
	78	81 518 392	81 509 534	0.01
	79	103 195 128	103 183 784	0.01
	80	133 057 192	133 048 592	0.01
8	81	146 076 400	146 068 025	0.01
	82	137 495 120	137 495 574	0.00
	83	167 888 288	167 904 083	0.01
	84	110 983 648	110 987 104	0.00
	85	148 285 888	148 286 529	0.00
	86	185 630 688	185 628 511	0.00
	87	222 855 696	222 850 201	0.00
	88	263 537 888	263 527 245	0.00
	89	310 720 928	310 712 728	0.00
	90	322 840 064	322 824 212	0.00
	91	369 787 584	369 769 114	0.00
	92	338 721 024	338 706 071	0.00

APPENDIX B. CONSIDERATIONS THAT LEAD TO THE CHOICE OF TIME-STEP

It is essential to select the correct time-step for the SD model. In the absence of selecting the right time-step, two errors arise leading to incorrect simulation results. The first error occurs in the capturing of the data from the spreadsheet model. The second error occurs in the calculating of the data in the SD model.

The following section explains the errors caused when the time-step is set to 1 as well as clarifies what causes these errors. This sheds light on the function of the time-step and facilitates the right design choice for the time-step of the model.

B 1 Time-step as it relates to capturing the data

The unit of time selected for the model is *Months*. Therefore if one were to set the time-step to 1 and simulate the model as is, the graphs populated by the SD model would present the data incorrectly as is shown in Figure 33 below.

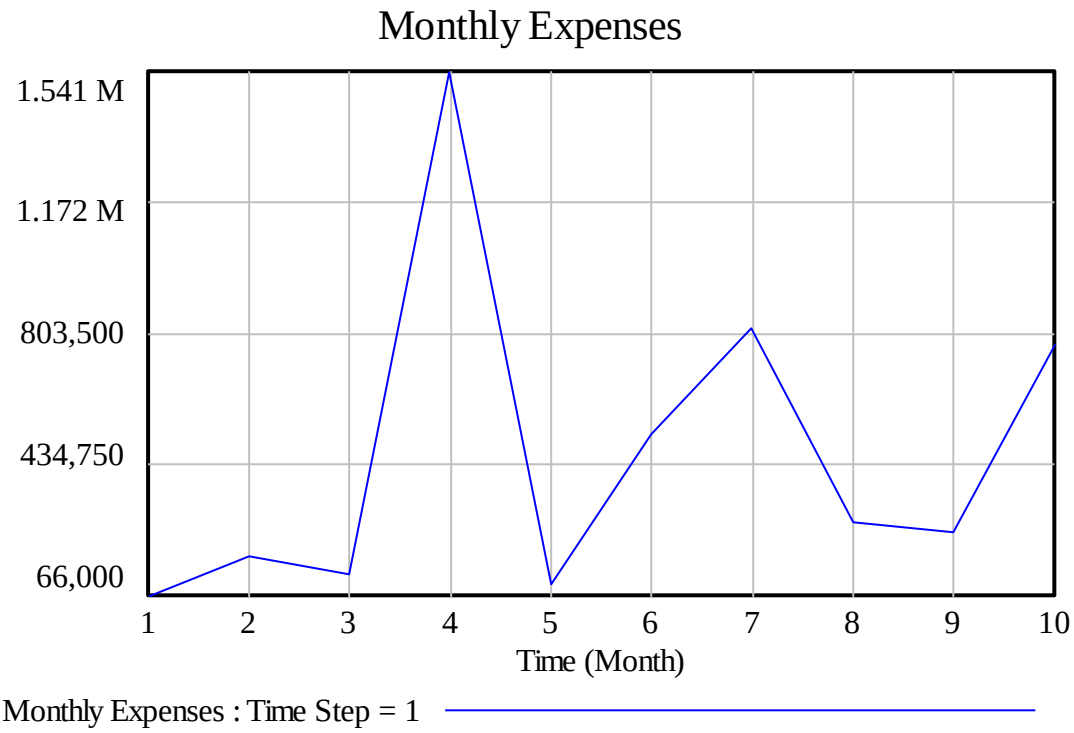


Figure 33: Monthly Expenses as shown by the SD model for the first 10 months <u>without</u> time-step correction

Figure 33 shows the Monthly Expenses over the first 10 months. As can be seen, the expenses change in a uniform manner over each month. There are two concerns with this way of showing the data. The first is that factually it is not true, expenses are not paid uniformly over the entire month, rather, on a specific day of the month an entire expense is paid and in most businesses, almost all expenses are paid for at the same time once a month. Secondly, the spreadsheet model does not present the data like this. Instead the data is

presented as one total amount that is expensed for the entire month at the end of the month. Table 13 (next page) is a snapshot of the accumulated expenses found in the spreadsheet model and illustrates this point.

Table 13: Snapshot of accumulated expenses from the spreadsheet model

Month	1	2	3	4	5	6	7	8	9	10
Date	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14
Accumulated Expenses	-66 000	-242 000	-365 000	-1 906 000	-2 002 000	-2 523 000	-3 339 500	-3 611 000	-3 851 900	-4 623 400

Figure 33 above looks as it does because when Vensim extracts the data from the spreadsheet, in this case the monthly expenses, it does not view the values as discrete points, rather it fills in the gaps from month to month. A way to picture what is happening in Vensim is as follows, picture the data points that are extracted from the spreadsheet as if they were plotted on the graph as dots in their relevant locations. Then what Vensim does is interpolation thereby producing Figure 33. In order to fix this, the data must be discretised so that the expense graph looks like Figure 34.

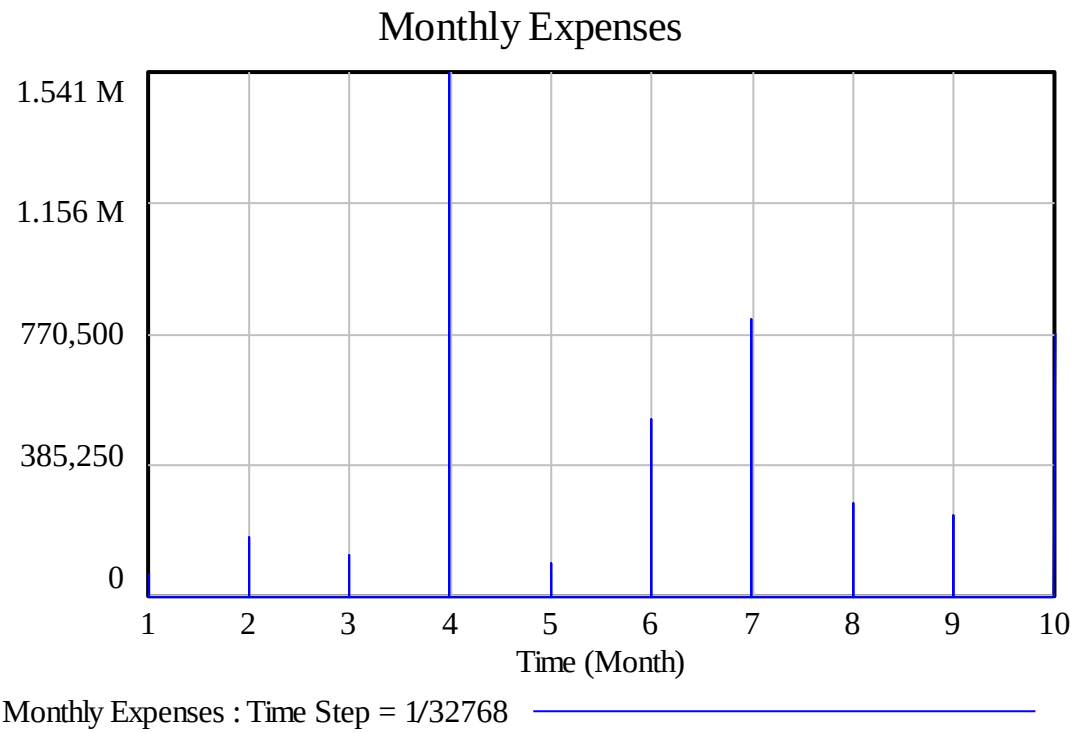


Figure 34: Monthly expenses as shown by the SD model for the first 10 months <u>with</u> time-step correction

Figure 34 above shows a graph generated by the SD model of the monthly expenses that would correctly reflect the spreadsheet model. As can be seen the expenses are reflected discreetly on a monthly basis at the end of each month.

With respect to Figure 33, the reason that Vensim "fills in the dots" is because only one computation can be done at a time. For the graph to look like it does in Figure 34, at least 2 computation times are required for each data point that is brought in from the spreadsheet. The first computational time is required for the change from the previous state (which is

usually 0 during the other 29 days of the month because no expenses are paid on these days) to the current state (the expense paid at the end of the month). The second computational time is needed to change from the new state back to 0. Therefore when there is a new state every month and there is only one computation per month (time-step = 1), there is no computational time for the data to return back to zero. Thus the computation goes from monthly entry to the next in a uniform manner. As a result you get the notion of "filling in the dots".

The way to fix this error is to introduce more computations in between every month. In other words, it is necessary to set up the model in such a way that each month is broken up into smaller realistic time bits in which a transaction takes place. This is done by manipulating the time-step. For example were a time-step of ½ chosen (2 computations per unit time), then as mentioned above, the output will drop down to zero after each data point is plotted as can be seen in Figure 35 below.

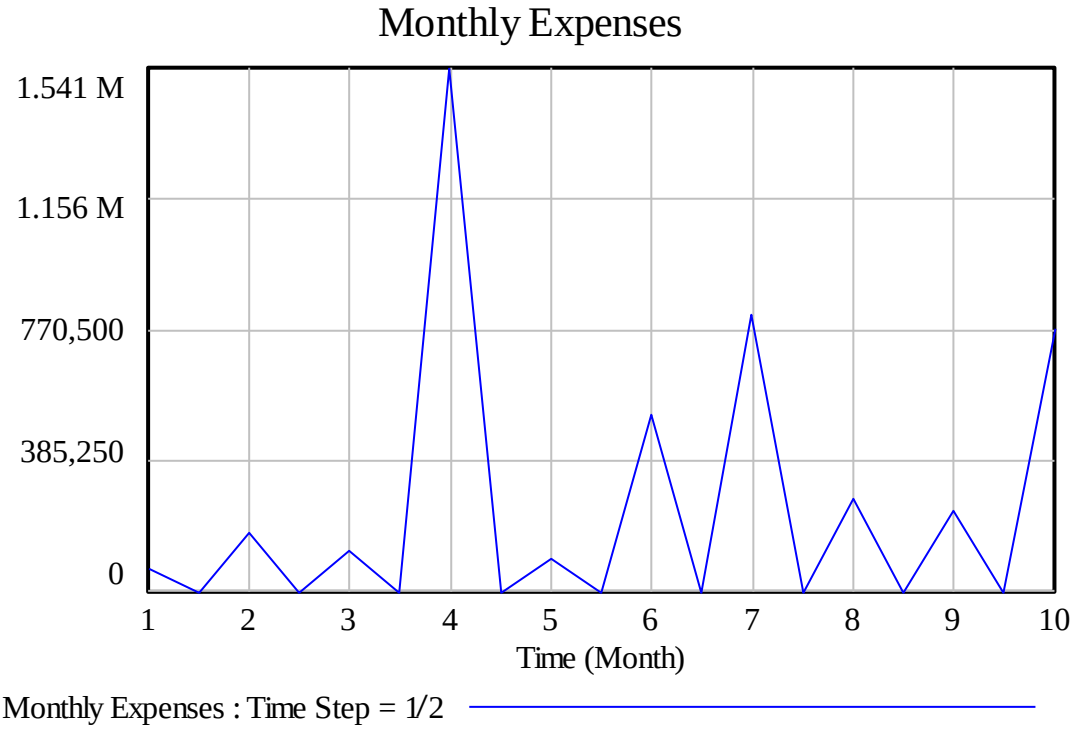


Figure 35: Monthly Expenses as shown by the SD model for the first 10 months with a time-step of 1/2

As expected, now that there are 2 computational times in each month, the same data being read in from the spreadsheet is coming down to 0 in the middle of each month. However this is not sufficient; it needs to peak for one moment in time, and then immediately go down to zero as opposed to it taking half a month to reach the correct value and another half a month to reach back to 0.

As the time-step is made smaller and smaller, this approximation becomes more and more accurate. Figure 36 below shows the effect of smaller time-steps on the accuracy of the model. As can be seen, when the time-step is varied from 1/10 to 1/100, the time between reaching peak and going back to zero is reduced and the information starts to look more realistically discrete. However, at the same time as the time-step becomes smaller and

smaller, the more computations are required per simulation. This uses up computational power and storage and therefore a balance needs to be found.

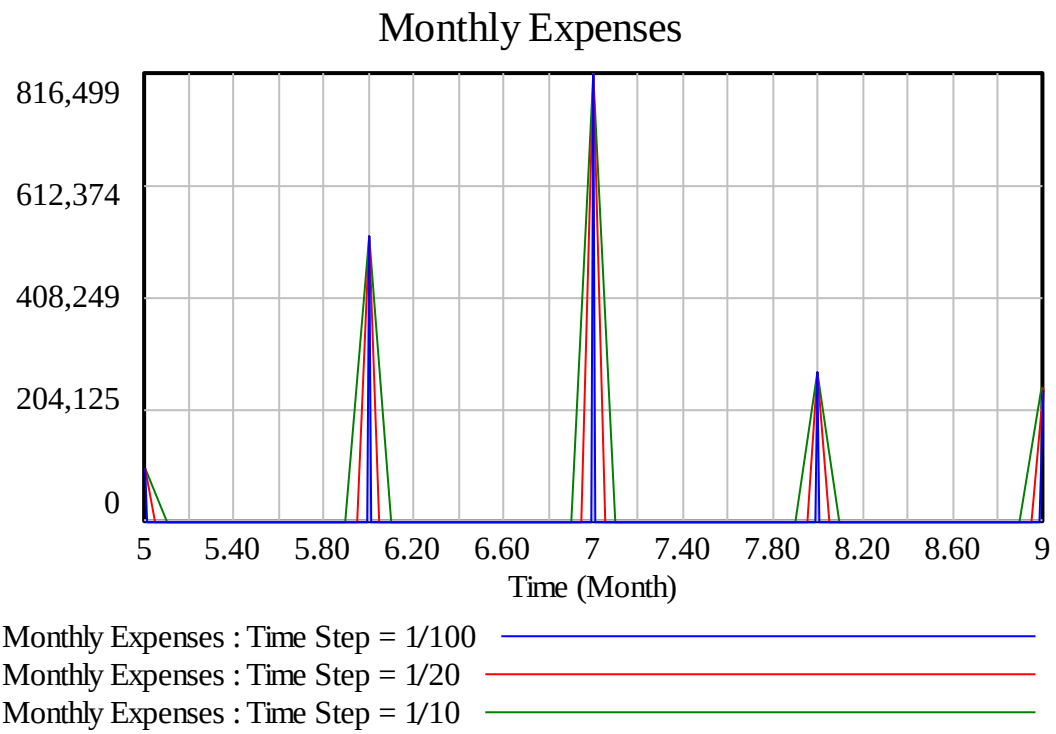


Figure 36: Comparison of the effect that smaller time-steps have on the accuracy of the model

Although any time-step can be chosen, Vensim provides a drop down menu in which each smaller time-step is half the previous times step. The first choice is a time-step of 1, the 2nd choice is a time-step of ½ which is equivalent to a computation once every 15 days. The next is ¼ which is equivalent to a computation once every 7.5 days. By this logic, the 15th choice is 1/32768 which is comparable to a computation every 79 seconds (1 minute and 19 seconds). This is calculated as follows. In a month of 30 days there are 2 592 000 seconds (30days x 24hr x 60min x 60sec). When 2 592 000 is divided by the 32768 (the number of computations that are done in one month), the result is 79 seconds or 1.32 minutes.

The reason for choosing 1.32 minutes is linked to explaining the Time-step as it relates to calculating the data. This is the subject of the next subsection and hence the rationale for a time-step corresponding to 1.32 minutes will be provided following the next subsection.

B 2 Time-step as it relates to calculating the data

In order for the SD model to be accurate, all data must be added in the correct temporal relationships, and although this may sound self-evident, delays must be introduced to ensure this as was described in Section 4.2.

Similarly, not only should all data being added be added in the correct temporal relationships, all data being added must also be added over the same duration. Most data measured in the model is measured over 10 time-steps; however tax is measured over 1 time-step, it is thus

necessary to convert the tax to be measured over 10 time-steps so that when tax is added, it is added correctly. This tax converter is built into the model and is shown in Figure 7 in Section 4.1. The reason most data is measured over 10 time-steps is to ensure that there are sufficient samples of every event such that no event is missed.

This means that the duration of an event (e.g. a transaction) takes 10 time-steps. In the case of the proposed time-step, as suggested in Section B 1 above, the duration of one time-step is 1.32 minutes, therefore the duration of a transaction would be 13.20 minutes (1.32x10). Is this acceptable?

Transactions in modern commerce are instantaneous processes in the sense that the electronic transfer of funds occurs at the press of a button. The theoretical transfer rate is thus infinite. For practical modelling, this must be dealt with in terms of real durations. The time interval for such a transaction to occur must, for computational purposes, be finite. However it must also be of a sufficiently short duration compared with other processes in the model such that its behaviour appears instantaneous for all practical purposes.

It was explained in Section B 1 above, that the smaller the time-step becomes, the more accurately the data imported from the spreadsheet model is recorded. However there is a trade-off as the smaller the time-step, the longer it takes for the model to simulate. The choice of time-step is also influenced by selecting a reasonably short duration for a transaction to occur in.

The choice of a time-step duration of 1.32 minutes achieves the balance between fast enough and of finite duration. It allows for a transaction duration within the range of 10-15 minutes and also achieves an accurate import of the data from the spreadsheet. This is proven in Section 6.1 (the Validation Test) where it is shown that the data read in from the spreadsheet is used in simulating the SD model and the maximum percentage error between the SD model and the spreadsheet model is found to be 0.14%.