Spreadsheets – an organization's bane or boon? An exploratory study using system dynamics modelling.

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Abstract:

This paper discusses whether Excel is not a true "living fossil" due to its continuous evolution, or whether it aligns more with the concept of constant adaptation and evolution, akin to species speciation and radiation. The other question that is investigated as to whether Excel's role might diminish as businesses adopt new technology models and platforms to remain competitive and handle digital information innovatively. The paper also touches on the complexities of software choices, distinguishing between dynamic complexity and detail complexity. Excel appears to be superior at handling detailed complexity but may fall short in addressing dynamic complexity and understanding the inter-relationship between variables in complex systems, where other tools such as system dynamics may be better suited. Despite its limitations, Excel continues to offer value in specific contexts, even as businesses consider alternatives aligned with evolving technological landscapes, however, it has limitations in addressing the in-depth critical data analysis required by businesses aligning with the fourth Industrial Revolution (4IR). This was then explored through a case study and this is illustrated through examples and then compared with tackling the same problem using system dynamics modelling.

Keywords: System dynamics, models, spreadsheets.

1. Introduction

Engagements with stakeholders in the corporate environment revealed a desire to move away from spreadsheet models. So, we asked the question – "if something isn't broken, why are we trying to fix it?" When decision makers were questioned, one of the reasons cited included executive management's need to see something different, more advanced and preferably automated in an attempt to take the organization into modern data management models and platforms. The general stance was that the organization needs alternative tools to phase out the reliance on MS Excel spreadsheets. Other observations, based on experience in the corporate environment, is that projects tend to get more attention and buy-in based on the graphical user interface. Although spreadsheets are easy to use and allow extensive data analysis, it does not create excitement.

In this paper, we attempted to answer 2 research questions:

1.1 What are the unintended consequences of using spreadsheets?

1.2 Is there value in using system dynamics modelling even without feedback loops when compared to spreadsheets?

2. Background

Charles Darwin first coined the words "living fossil" in 1859. A living fossil has been used to describe species or groups with DNA that has remained unchanged in millions of years with an enduring lineage. Examples of these include the goblin shark, duck-billed platypus, lungfish, tadpole shrimp, cockroach, *coelacanths* and the horseshoe crab. Would it then be fair of us to liken our MS Excel software to that of a "living fossil"? Like these living fossils, Excel spreadsheets have dominated businesses from small enterprises to large corporates as an all-inclusive tool to keep financial records, manage finances, perform risk analysis and data analysis, with aesthetically pleasing graphs to use in reports and presentations.

One might, however, argue that the Excel spreadsheets are not strictly "living fossils" as per Darwin's oversimplified context, but rather, more aligned to an analysis by Africa Gomez, a biologist at Hull University in the United Kingdom "they have been evolving non-stop and speciating and radiating" (Warmflash, 2023). But what do we know of this subtle evolving species known as Ms Excel? It was initially introduced in 1982 as Multiplan, a popular control program for microcomputers (Excelhelp, 2021). Although it lost popularity on the MS-DOS systems to Lotus 1-2-3; in 1987, it re-emerged by Microsoft as Excel v2.0 and by 1993 with its version 5, it included Visual Basic for Applications which created "limitless" possibilities with respect to number crunching, automating process and data presentation. The gradual evolution of Excel is premised to keep up with cloud-based computing that also provides multi-user access to large data sets that can be interrogated.

Despite the advantages of being a user friendly data analysis and management tool, Excel does not cater for in-depth critical data analysis required by the contemporary business, the type of business that is aligning with the fourth Industrial Revolution (4IR), where conducting business involves technology changes and generational or societal change (Barrenechea, 2017). So, if the new business landscape requires the use of new technology models and platforms (other than Excel) to maintain the competitive edge and to innovatively handle digital information, will Excel soon become extinct? In the United States it was estimated that 60% of companies were still using spreadsheets with 21% planning to move to more specialised software (Brooks, 2016). In 2017, Mark Garrett, Chief Financial Officer of Adobe Inc. said he was working on cutting Excel out of the business process and said, "I don't want financial planning people spending their time importing and exporting and manipulating data, I want them to focus on what the data is telling us" (Shumsky, 2017). Similar drives were cited by CFOs at other companies such as P.F. Chang China Bistro, ABM Industries Inc. and Wintrust Financial Corp.

In 2021, BPM Partners conducted a survey of finance professionals and found that more than 80% still relied on Excel after purchasing other planning and analysis tools. So if employees remain reluctant to give up on Excel then could Mark Twain's words be more befitting, "the reports of my death are greatly exaggerated." Besides financial management, a 2020 Wellington State of Project Management report showed that almost 36% of teams were also using Excel for resource management as well (Wellingstone, 2021). Further exploration into the use of Excel specifically for project management by the team behind the annual State of Agile Report found that the number of organizations using Excel for agile project management decreased from 74% in 2015 to about 32% in 2021 (Agile Business Consortium, 2021).

Peter Senge defines two types of complexity: Dynamic complexity and detail complexity. Understanding the difference may underpin the reason for a company to choose one particular software

tool over the other. Detailed complexity is satisfactorily handled by Excel since it can accommodate and compute thousands of data inputs and outputs through its linear mathematical relationships. Spreadsheets can assist in organizing data points and generating historical performance metrics for reporting purposes but does not assist decision makers in understanding the inter-relationship between variables and the conceptual architecture associated with dynamic complexity (Hennessy, 2016). With system dynamics models, a visual representation exists of the inter-relationship between variables, which allows engagement of the model by the user and the relevant stakeholders.

Many system dynamicists would view a system dynamics model without a feedback loop as nothing short of "loopy", however, many models extend into hundreds of variables and so having a visual to explain the interconnectedness of the variables in a model is greatly facilitated using system dynamics modelling software (with and without feedback loops). It is certainly noted that the value of a system dynamics model often lies in its ability to simulate and understand the dynamic behaviour of complex systems, which is achieved through the representation of feedback loops, however in this paper, we will illustrate the value that can still be derived from a system dynamics model when dealing with variables that are not synchronised in terms of times when events occur; and compare it to a spreadsheet approach for a specific case study.

3. Methodology

iSee Stella Architect was the modelling software used to address both research questions. The results are explained in Section 4.

4. Results and Discussion

4.1 Spreadsheets and complexity

Figure 1 shows a conceptual system dynamics model that was developed, which has not been calibrated against empirical data. The underlying structure and results however reflect the reality experienced in many companies.

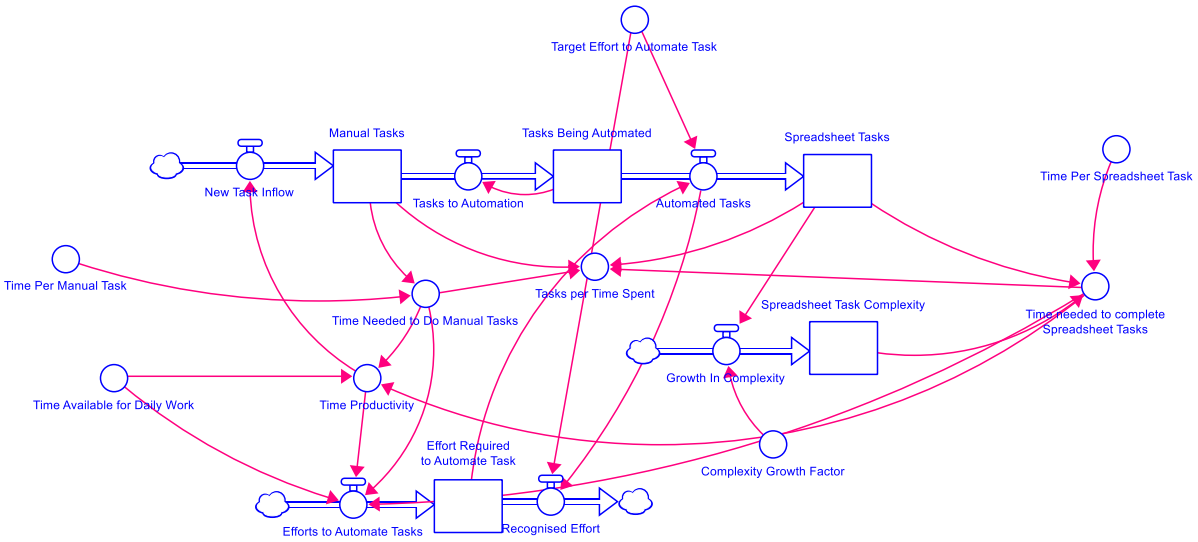


Figure 1: Spreadsheet Automation, Complexity and Productivity Model

It is assumed that each task requires a fixed time to complete. At the start of the simulation, all tasks are executed manually, as they were in the 1970's and early 1980's, or single use spreadsheets later on. As a staff member has more time on their hands, they get assigned additional tasks. Members can also use non allocated time to start automating tasks through the use of reusable spreadsheets. To automate a task to a spreadsheet requires a fixed amount of time namely the Target Effort to Automate Tasks. Time spent on automating a task to a spreadsheet accumulates and once the effort has been invested, the task becomes a Spreadsheet Task.

Spreadsheet tasks require 50% less time to complete, meaning staff have more time to automate additional tasks and get assigned more new tasks. However, once tasks have been converted to spreadsheet tasks, they grow in complexity over time, based on a simple multiplication factor. Every time you use the spreadsheet you realise more elements can be automated or additional features can be added. In addition, a series of spreadsheets can be linked, each with its own data management custodian. The result of the complexity is to make the spreadsheet consume more resources and take more time to run, manage and maintain. The productivity is measured in tasks completed per time spent.

In the base case (50% of time to complete a spreadsheet task compared to the time taken for a manual task), the results are shown in Figure 2. As the number of automated tasks increase in the form of spreadsheets, the number of manual tasks decrease.

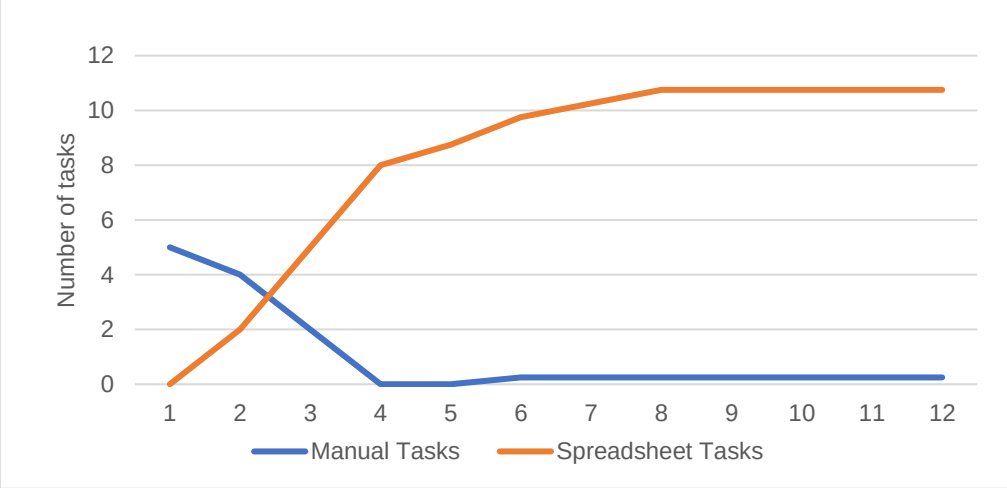


Figure 2: Number of tasks

Although the level of automation though spreadsheets reduces the number of time consuming manual tasks, the organisation is then faced with a different dilemma shown in Figure 3 i.e. an increase in the number of spreadsheet tasks resulting in an increase in the time required to complete the tasks and an increase in spreadsheet task complexity. The y-axis is intentionally unitless to illustrate the behaviour over time of the variables.

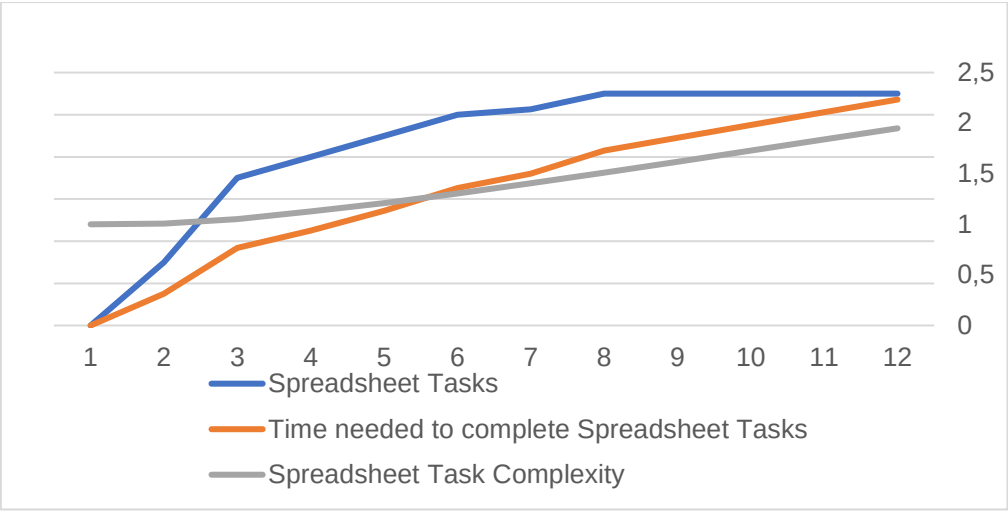


Figure 3: Number of spreadsheet tasks and time needed to complete the tasks

Figure 4 shows the tasks per time spent i.e. the productivity.

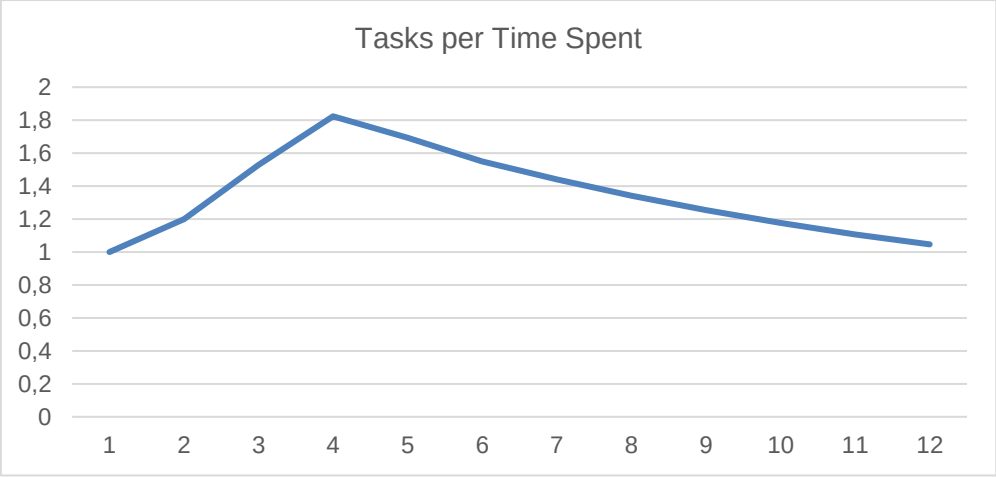


Figure 4: Productivity over time

The simulation demonstrates both when the volume of data driven work increases, then automation through the use of spreadsheets increases productivity. However, as the spreadsheet becomes more complicated, the time needed to manage the complexity has a negative impact on long term productivity. The negative impact of productivity highlights the need for more complex systems to turn automated spreadsheets into automated applications. The model does not address the gaps arising in the solutions provided as spreadsheet complexity results in expectations of higher order solutions.

4.2 Spreadsheets versus System Dynamics Models

The purpose of this section is to demonstrate how system dynamics simulations can be used to significantly enhance our understanding of systems where time horizons of variables are out of synchronisation. Take the simple case of Mr Greg's startup business (these are not actual numbers from any business but used to illustrate the argument). During the first financial year of business, Mr Greg ended with a retained profit of R100 000. Mr Greg's plan at the end of the financial year was to appoint

2 additional staff members since he had signed up a client who would pay R200 000 per month. Mr Greg was pleased since his costs were R180 000 per month and he had working capital of R 100 000, as shown in the original budget (Table 1).

Table 1: Original Cash Flow Budget

Business Cash Flow - Original Budget				
Month	**Income**	**Expenses**	**Profit**	**Cash Flow**
Feb-23	Carry Over			R100 000
Mar-23	R200 000	R180 000	R20 000	R120 000
Apr-23	R200 000	R180 000	R20 000	R140 000
May-23	R200 000	R180 000	R20 000	R160 000
Jun-23	R200 000	R180 000	R20 000	R180 000
Jul-23	R200 000	R180 000	R20 000	R200 000
Aug-23	R200 000	R180 000	R20 000	R220 000
Sep-23	R200 000	R180 000	R20 000	R240 000
Oct-23	R200 000	R180 000	R20 000	R260 000
Nov-23	R200 000	R180 000	R20 000	R280 000
Dec-23	R200 000	R180 000	R20 000	R300 000
Jan-24	R200 000	R180 000	R20 000	R320 000
Feb-24	R200 000	R180 000	R20 000	R340 000
Mar-24	R200 000	R180 000	R20 000	R360 000

The monthly cash flow projection, based on the monthly income and expenses, inspired Mr Greg to plan for the purchase of a high-end server (computer) to improve the business's overall productivity in the beginning of July as this would be affordable from a cash flow point of view as shown in Table 2.

Table 2: Revised Budget to Accommodate Server Purchase.

Business Cash Flow - Let's Buy a New Server				
Month	**Income**	**Expenses**	**Profit**	**Cash Flow**
Feb-23	Carry Over			R100 000
Mar-23	R200 000	R180 000	R20 000	R120 000
Apr-23	R200 000	R180 000	R20 000	R140 000
May-23	R200 000	R180 000	R20 000	R160 000.00
Jun-23	R200 000	R180 000	R20 000	R180 000
Jul-23	R200 000	R180 000	-R165 000	R15 000
Aug-23	R200 000	R180 000	R20 000	R35 000
Sep-23	R200 000	R180 000	R20 000	R55 000
Oct-23	R200 000	R180 000	R20 000	R75 000
Nov-23	R200 000	R180 000	R20 000	R95 000
Dec-23	R200 000	R180 000	R20 000	R115 000
Jan-24	R200 000	R180 000	R20 000	R135 000
Feb-24	R200 000	R180 000	R20 000	R155 000
Mar-24	R200 000	R180 000	R20 000	R175 000

Mr Greg then received a call from his bank to inform him that there were insufficient funds available and payments from the business could no longer be honoured. So the question is, where did Mr Greg go wrong? His spreadsheet had provided reassurance that he did not have a cash flow problem.

To help Mr Greg understand this dilemma, a system dynamics simulation (Figure 5) of the cash flow model was built to replicate the results of both cash flow spreadsheets.

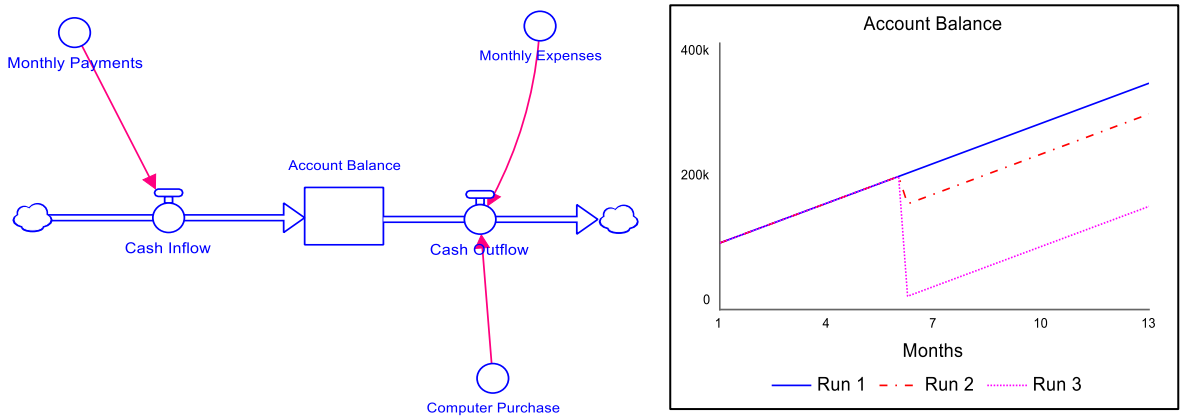


Figure 5: System dynamics simulation of cash flow at an aggregated level

Run 1 represents the original cash flow plan. In Run 2, the server (computer) is added, but as a once off purchase. Run 3 demonstrates what happens when the server purchase enters the expenses as part of a PULSE function to represent that the full server (computer) cost is paid off on the day of purchase. The results are identical to that of the spreadsheet, meaning that the logic is validated (Table 3).

Table 3: Budgets from the system dynamics model runs

	1	2	3	4	5	6	7	8	9	10	11	12	Final
Run 1: Account Balance	100k	120k	140k	160k	180k	200k	220k	240k	260k	280k	300k	320k	340k
Run 2: Account Balance	100k	120k	140k	160k	180k	200k	174k	194k	214k	234k	254k	274k	294k
Run 3: Account Balance	100k	120k	140k	160k	180k	200k	35k	55k	75k	95k	115k	135k	155k

However, if we take into account that cash flow is an instantaneous event, the model itself is not accurate. While the model showed that the budget was correctly stated for a financial year in monthly intervals, the status of the bank account was affected by instantaneous transactions that happened on specific days of the month. On further investigation, it was found that staff were paid on the 25th day of every month, and Mr Greg's customer only paid him on the 30th of the month. By changing the system dynamics model to reflect the daily behaviour, it was possible to get a more realistic understanding of the behaviour of Mr Greg's account as shown in Figure 6.

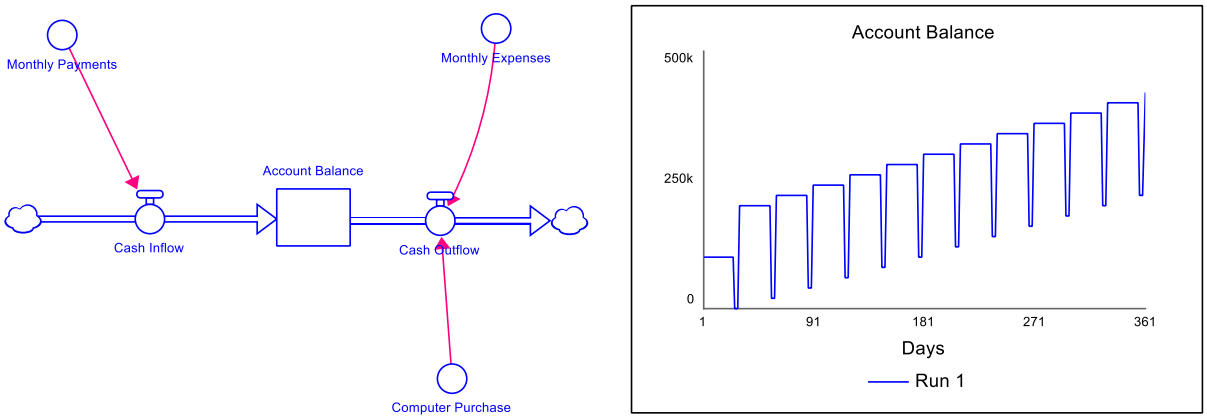


Figure 6: System dynamics simulation of cash flow with greater resolution

The model still did not reflect the system behaviour i.e. what had actually happened with the cash flow. A modification to the structure was made to allow the stock in Figure 6 to go negative, as shown in Figure 7. The initial model was built with a non-negative stock based on the general observation that no natural stock can have negative values. Stocks are either empty or have a content. Human defined stocks however can in some instances become negative. The most obvious case is bank accounts that can have a negative balance, if an overdraft is provided. (The second case, temperature only holds true when the zero point is defined above absolute zero Kelvin. Degrees Fahrenheit and Celsius have a defined zero and can be negative or positive). As a small business owner Mr Greg does not have the luxury of an understanding bank issuing him with an overdraft.

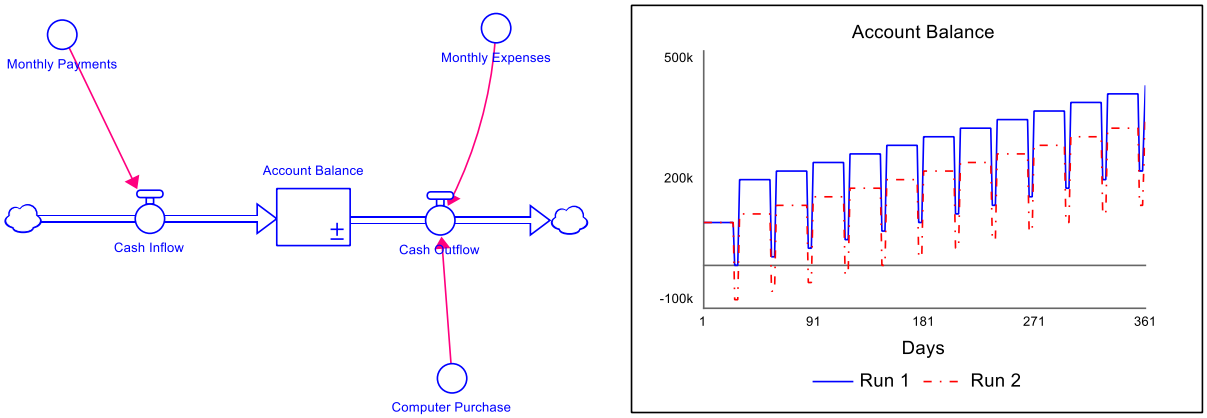


Figure 7: System dynamics simulation of cash flow with a negative stock

As soon as the salary expenses are withdrawn from the bank account, the cash flow is negative until the customer pays. Figure 8 shows the results of adding the new server purchase at the start of July.

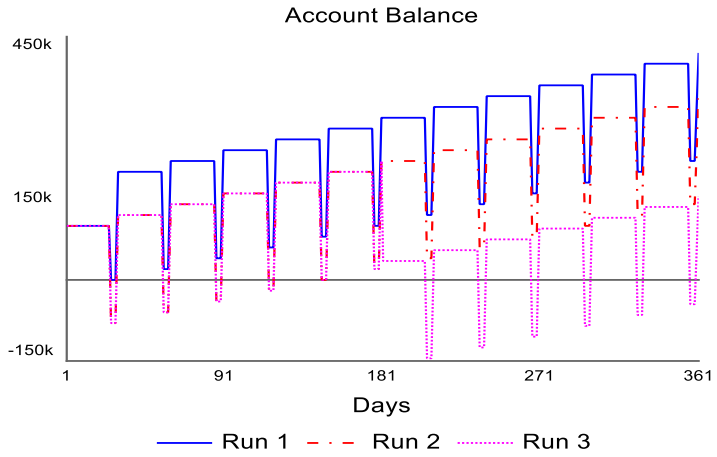


Figure 8: System dynamics runs with run 3 showing the impact of buying the server

In changing the model time resolution to daily instead of monthly, it was possible to obtain a more accurate reflection of Mr Greg's cash flow.

Graphical interfaces provide a visual representation of data, processes, and relationships. This visual feedback can help users understand complex concepts, analyze information, and make informed decisions more easily than text-only interfaces. When it comes to visualization elements, Figure 9 shows the results and graphical user interface (GUI) on Excel and Figure 10 shows the results and the interface on the iSee Stella Architect model.

Business Cash Flow - Let's Buy a New Server				
Month	Income	Expenses	Profit	Cash Flow
23-Feb	Carry Over			R100 000
23-Mar	R200 000	R180 000	R20 000	R120 000
23-Apr	R200 000	R180 000	R20 000	R140 000
23-May	R200 000	R180 000	R20 000	R160 000.00
23-Jun	R200 000	R180 000	R20 000	R180 000
23-Jul	R200 000	R180 000	-R165 000	R15 000
23-Aug	R200 000	R180 000	R20 000	R35 000
23-Sep	R200 000	R180 000	R20 000	R55 000
23-Oct	R200 000	R180 000	R20 000	R75 000
23-Nov	R200 000	R180 000	R20 000	R95 000
23-Dec	R200 000	R180 000	R20 000	R115 000
24-Jan	R200 000	R180 000	R20 000	R135 000
24-Feb	R200 000	R180 000	R20 000	R155 000
24-Mar	R200 000	R180 000	R20 000	R175 000

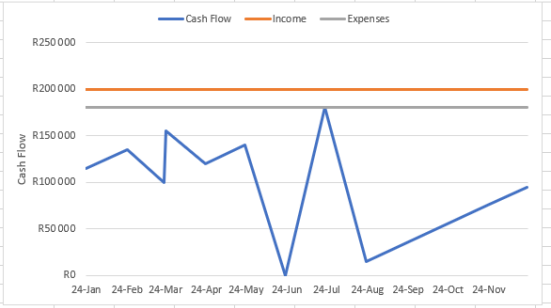
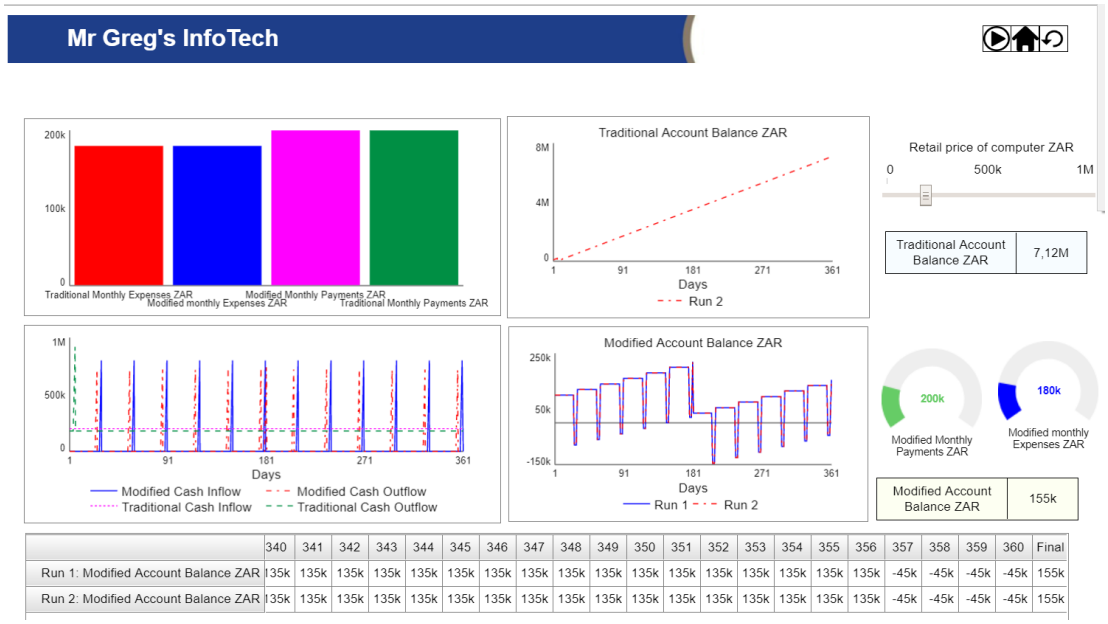


Figure 9: Excel interface



	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	Final
Run 1: Modified Account Balance ZAR	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	-45k	-45k	-45k	-45k	155k
Run 2: Modified Account Balance ZAR	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	135k	-45k	-45k	-45k	-45k	155k

Figure 10: System dynamics model interface

With the system dynamics interface, it is easier to customize the interfaces by arranging elements, changing themes, or setting preferences. This level of personalization can improve user satisfaction and efficiency and is perceived as a more exciting and modern engagement interface relative to the Excel interface as perceived by management.

5. Conclusions and recommendations

As technology evolves, new tools and platforms emerge that may offer more features, better performance, and improved security. Companies may consider exploring these options to stay at the forefront of technological advancements. Ultimately, the decision to move away from Excel depends on the specific needs and challenges faced by a company. It is recommended that the requirements of the business be assessed and evaluated as to whether Excel or alternative solutions better align with those needs so it could be a boon or a bane depending on the business environment in which it would be used.

If your system is inherently dynamic and characterized by interactions between variables that influence each other over time, incorporating feedback loops would likely enhance the model's accuracy and usefulness. In the case of Excel versus the system dynamics model with no feedback loop: the final system dynamics model with the negative stock showed why Mr Greg's business plan, supported by a typical cash flow spreadsheet resulted in the demise of his business, which the Excel spreadsheet did not. When the time horizons of events are out of synchronisation and time horizons are not identical, system dynamics provides a huge advantage over traditional methods. With a system dynamics model in hand, Mr Greg can rapidly assess a range of scenarios and rethink his strategy taking the full complexity into account.

GUIs make computing more accessible to a broader audience, including those who may not be comfortable or proficient with text-based commands. In our example, the graphical representation of information and actions could be easily understood by users with varying levels of technical expertise for both Excel and the system dynamics software, however the bells and whistles or gadgets on the iSee Stella Architect interface provided for greater interest and would engage the audience better.

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