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Stress Testing with System Dynamics for Enterprises: Proposing a New Risk Approach for the Transition to Circular Economy and Sustainable Development

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ABSTRACT

The goal of this paper is to examine the current state of research on optimal approaches to making effective models that simulate the behaviour of the enterprise as a whole, for the risk assessment purposes with an emphasis on stress testing. Stress testing can potentially aid in the development of highly uncertain policies like the shift to the circular economy, or other policies that have a high impact in the areas of sustainable development. The paper will examine this problem through the scope of system dynamics modelling, however, the goal of the paper is to examine the right heuristics where this kind of modelling can be done with different approaches. When proposing a novel concept like the shift to a more circular economy, a variety of economic and other benefits could be anticipated in the long run, but the potential for large losses in the short term should not be neglected. The paper explores novelty on two levels, in proposing the model for this use, as well as advocating for stress testing approach that has been neglected in use and research outside of the financial industry.

1. Introduction

Executives and managers of modern companies of all sizes face many difficulties of managing uncertainty in form of projects, strategies, and every day decisions. Globalization, which was hastened at the beginning of the 21st century, has brought hyper competitive markets, where mismanagement of resources by managers and executives can deliver high penalties to the enterprise. In 1965, the average tenure of companies on the Standard and Poor's listing was 33 years, by 1990, it was 20 years, and it has been estimated to shrink to 14 years by 2026 (Anthony et al., 2018). Another study (Mauboussin et al., 2017) points out that, between 1963 and 1982, life span of more than 250,000 analysed US manufacturing firms was 5 years for roughly 65 % of them, and for 20 % of them was 10 years. Companies failing at a high rate is not a new phenomenon, and certainly it is not exclusive for high tech companies and start-ups where the rate of failure is the highest (Dimov and De Clercq, 2006; Luo and Mann, 2011). It is important to observe the failure rate on a micro level inside of a company as well, where in certain industries the failure rate of projects can be close to 70 % (Daniels and La Marsh, 2007). A question emerges weather our tools for tackling complexity and uncertainty are efficient at all. There is a substantial proof of our inability to predict and forecast business events and crisis, but most of our risk management does

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precisely that (Makridakis, 1981, 1982). Also many popular books and publications have analysed the concept of predictions by expert opinion, and pointed out the low reliability of these predictions, where experts who analyse and judge potential future success and quality (that is not measured by technology) show extreme inconsistency in many areas (Camerer and Johnson, 1991; Tetlock and Gardner, 2016; Tetlock 2017; Barabási, 2018). With an increase of data gathering capabilities across many sectors, including the old bricks and motor industries, there is a demand for new modelling techniques that can facilitate the bottom line decision making process (Ellen MacArthur Foundation, 2013). This is especially true for highly uncertain initiatives like the switch to a circular economy operating model. The purpose of the circular economy is to develop ways to minimize waste within industries and the overall economy. As the name indicates the goal is to make the economy resemble a closed loop circular system, compared to the linear economy that has the final stage of waste disposal, where this final stage does not allow energy or used parts to go back to the producers in an efficient manner (Ellen MacArthur Foundation, 2013).

The concept of a more circular economy started to gain serious recognition in both industry and academia after its adaption as one of the primary competiveness strategies by the European Union in 2014 (Avdiushchenko, 2018). If a search analytics tool like Google Trends is applied for the term circular economy for the period from the beginning of 2014 to the end of 2018, with the purpose of analysing the web searched trends on a platform like Google, a sharp increase in popularity can be observed. Other important ramifications can be observed as well, like the top searched queries are associated with the regulations (concerning circular economy) from the European Commission and the search for scholarly articles on this topic. The recognition of the circular economy concept by academics and policy makers is apparent; however, it is of the highest importance for the most waste generating industry within the economy to recognize and implement this concept.

In the period from 1998 to 2001 it was estimated that the Europe region was generating 2.2 billion tons of waste annually. Increase of waste produced by the economies is a rigorously studied phenomenon, and the initiation for research came from the increase of production capacities worldwide. For example in 1950s global production of plastic was around 2 million per year, however, the production capacity for the next sixty-five years was growing annually by around 8.5 % to reach global production of around 380 million tons per year in 2015 (Muthmann et al., 2003; Gourmelon, 2015; Geyer et al., 2017). There are other concerns that follow the issues of global waste build up, and they have to do with the slow technology transfer of waste management technologies from the developed world to the emerging economies (Ragossnig and Vujić, 2015; Vujic et al., 2017). The 21st century has started as the era of high technology devices that are made of complex materials which are not biodegradable; and these devices are intended to be changed by the user for the upgraded version when that product arrives to the market. This is one of the concerning facts that drives the push for a more circular economy. With the rapid economic growth in the developing countries the production capacity will have to meet the demand in new and more sustainable ways (World Economic Forum, 2017).

When proposing to an industry or a particular company to transition to a system where production and product disposal are integrated in a new circular way for the goal of minimising waste, both the needs and the risks associated with a system need to be recognized. There are a few early proposed concepts for this shift: product life extension, integrating resource recovery operations to the supply chain, creating sharing platforms, and incentivizing other participants in the supply and distribution networks to integrate to the circular model.

Many of these concepts are not new, and have been proposed in different forms in the past for the purposes of sustainable development schemes and better integration of recycling and waste management within large scale value chains (Nikolić and Perović, 2008). This is particularly true for different forms of recourses recovery and product recovery management where these strategies have been integrated in the past with different companies and industries. However, the goal of making a circular economy operating model work, many of the above mentioned concepts like the product life extension along with all of the distribution and supply side changes need to be adapted through trial and error testing with the operating model of the company. The reason for this is the fact that many of the above mentioned changes have the potential to financially break the enterprise, while the economic benefits to transitioning to a more circular economy would show in the long run. In the short run there are eminent high costs, along with other risk associated with transitioning to new operating models.

Many industries are structurally restricted to large shifts that present sizable upfront costs for future benefits due to large capital intensity along with shifting profitability across the industry. One of the largest and most important industries in the world having impact on the economy is the automotive industry; this industry has been targeted as one of the most important industries to make a shift to a more sustainable way of operating. However, it is important to point out that this is an industry that is highly fragile to regulatory, commodity, financial, or competitive volatility (Alvarado-Sieg and Huerbsch, 2019). With this being said, one of the key components to pursuing ambitious policies of a more circular economy is the use of right tools and methods that will allow companies to experiment and pursue goals that have high risks in the short term. The goal of this paper is to examine the novel tools for risk planning that can prove useful with highly uncertain changes and events that are not predictable.

This paper will observe the decision making and analysis instruments true System Dynamic simulations modelling. Despite the maturity of almost fifty years, the rise of popularity of this simulation modelling method accelerated in the beginning of the 21st century, partly due to the rapid development of software solutions and platforms that can support this type of modelling. System dynamics was invented in the mid-1950s by Jay Forrester (1989; 1995), but the development of commercial software solutions has made this modelling method accessible to wider use.

System dynamics studies complex systems and how they change over time, it has a strong recognition in many fields ranging from managerial sciences and economics, urbanism, ecology (Rogers et al., 2016), and biology for addressing complex issues in medicine and epidemiology (Forrester, 1990; Homer and Hirsch, 2006). The paper will not go any further in defining system dynamics modelling as there are many great textbooks and publications that cover this field of simulations modelling (Angerhofer and Angelides, 2000; Morecroft, 2015; Sterman, 2015). If a popular simulations modelling approach such as system dynamics is observed, the focus lies on isolating and modelling a wide range corporate activities ranging from: logistics, supply chain management (Richardson and Otto, 2017), marketing (Aburawi, 2005), human resources (Lyneis and Ford, 2007), project management to financial management (Qureshi, 2007; Poles, 2013), production and inventory system (Snabe and Größler, 2006), strategic management (Shafiei et al., 2015), energy systems (Kafeel, 2012; Hosseini and Shakouri, 2016), solid waste management (Arnold and Wade, 2015), system thinking (Golnam et al., 2010), and enterprise modelling (Trimble, 2014). There is a deficiency of research on the topic of modelling the whole enterprise, where the model simulates the behaviour of the enterprise with adequate precision and it has a high degree of universal applicability, and a wide spectrum of analytical approaches can be used and built around that model. The goal is finding a model that can be defined as a risk centric driven model of an enterprise, where the model is bottom up adopted for these purpose.

2. System Dynamics Approach

As shown in the Fig. 1, system dynamics has very differentiated approach compared to standard approaches in the corporate planning world. It usually has two steps in structuring the model (defining the relationships) a qualitative step where a set of non-quantitative mapping tools can be applied, in most cases a casual loop diagram is used, and a quantitative process is applied afterwards. Compared to most approaches to simulations, which are mostly focused on writing code in a specialised programming language, system dynamics (Fig. 1) allows easier interpretation of the model and many model building practices are done in groups (Jac and Vennix, 1999). This approach brings a differentiated and in many ways more comprehensive approach to modelling and analysis of complex systems.

A large emphasis in system dynamics is placed upon understanding the problem or the system first and not just crunching the numbers, like in the case of many purely statistical approaches to planning that are overly focused on forecasting and optimizations (Richardson and Otto, 2017). The brilliance of this modelling language is that

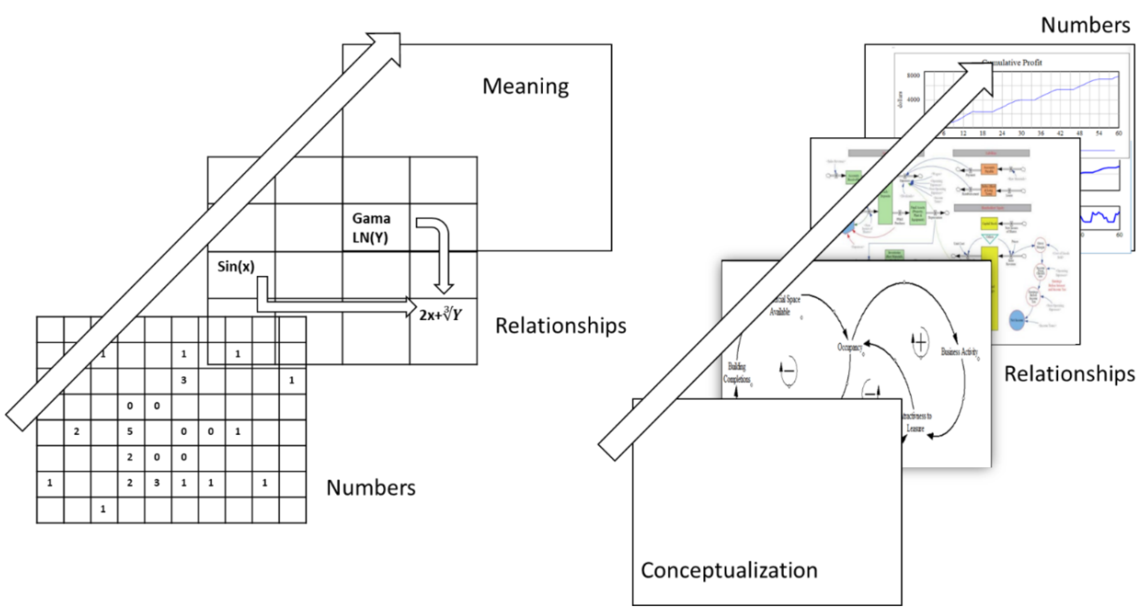

Figure 1. Standard data analytics approach on the left and system dynamics on right

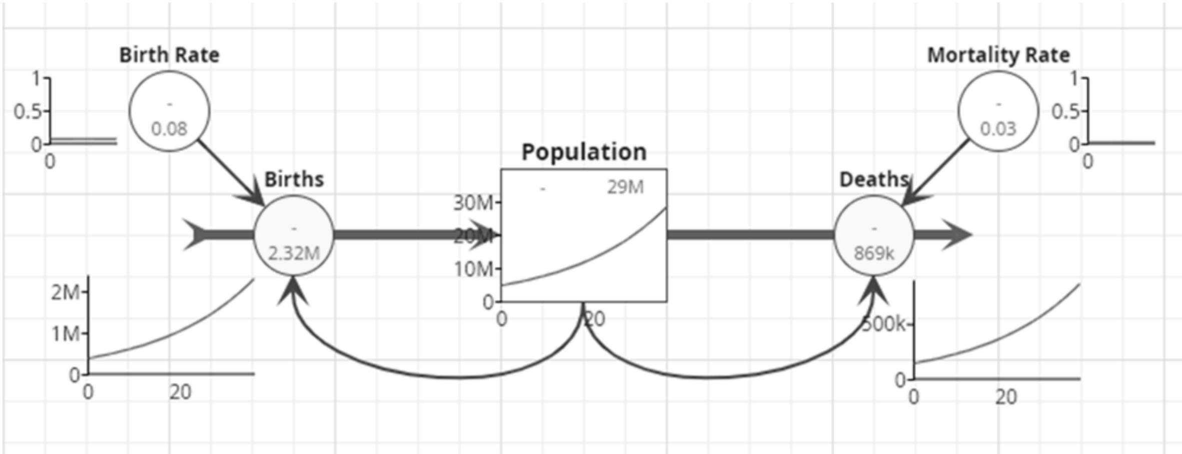

Figure 2. Simplified system dynamics population model

you can define any system from a supply chain to a biological ecosystem with a few visual tools as shown in Fig 2, and then you can derive a simulation model out of that. But the most important segment of system dynamics lies in the focus on modelling feedback loops (the positive and negative feedback loop) within the system and analysing the nonlinear behaviour of the system. A feedback system has a closed loop structure that brings results from past actions of the system back to control future actions (Angerhofer and Angelides, 2000). It should be acknowledged that real world complex systems function in this way and that they are nonlinear systems, when observed outside of controlled laboratory settings.

In managerial sciences standard approach in system dynamics is to simulate a specific part of a company like a production and inventory system, or to simulate a specific strategic initiative or a problem that is being solved (Snabe and Größler, 2006; Shafiei et al., 2015) with well-defined boundaries (Trimble, 2014). So it can be said that approach such as system dynamics modelling is not focused on modelling the whole system (whole economic system, industry or an entire company), but instead it is a specific goal and specific problem oriented. There are many reasons why this approach of isolation is sufficient, and one of the key reasons is complexity. If we chose to model all segments of an enterprise in great detail, we will get a highly complex mathematical model with an extremely large number of interconnections. One of the key elements of a successful modelling process is defining boundaries of the model, in other words deciding what to exclude from the model in some cases is of greater importance than deciding what to include. In system dynamics many use model boundary diagrams to optimize the scope of the model, and to avoid inconsistency due to complexity and bad data (Cihák, 2007; Moyano and Richardson, 2013).

3. Stress testing

As stated at the beginning of the paper, the focal point is risk, in particular stress testing, and the macro model of the enterprise needs to be adapted to this risk approach but also it should be applicable to other business analysis tools. The stress testing is a highly popular and essential risk assessment approach to financial enterprises, with an ever rising development of applications and capabilities. But this approach to risk has not been developed or used for the non-financial sector; a lack of research on optimal modelling approaches that can facilitate this approach is to be blamed. In this paper the focus will be placed on the model that can support this kind of risk approach. This kind of a model can be named the Macro Model of an Enterprise (MME) and this model would be intended for analysts, risk managers and top managers interested at observing the performance and analysing long term corporate strategies. The MME needs to have sufficient simulation capabilities (to adequately simulate the behaviour of the company), but more importantly, there has to be a level of agility to this model, where other models and analytical approaches can be built around the MME for different intended purposes.

There is a large demand for this type of models with the raise of novel risk approaches like stress testing (Forrester, 1995; Rogers et al., 2016) and managerial concept like resilience (Sheffi, 2007, 2017). Managers need a robust heuristics on the model development process and how to apply the risk assessment.

Stress testing is a concept that is used across many disciplines and it defines the stability and resilience of a particular system or an entity (Cihák, 2007). Stress testing should be characterized as a behavioural analysis of a system, and its reactions to shocks and different kinds of volatility. In years following the ‘08 financial crises, governments and financial institutions have recognize the importance of a more aggressive spending towards risk assessment technologies. Stress testing has seen a rapid growth in use by the financial institutions, where some of the largest institutions will invest anywhere between two hundred million to half a billion US Dollars. It can be said that this approach to risk leads the technological development for the world of risk management. However, the expenditure for financial institutions should not present this risk approach unattainable. A single financial institution will hire in many cases multiple consulting companies to conduct the stress testing, and many of these institutions have trillions of US Dollars of assets under management. There has been no development of this approach in the nonfinancial sector where stress testing can potentially bring more value in risk mitigation compared to the conventional approaches. A non-financial company can use stress testing to build redundancies, eliminate weaknesses in its operating model and combine stress testing with other analytical approaches.

Stress testing can potentially prove to be most valuable to energy, commodity, bricks, and motor companies. There are two main reasons why this approach has not been developed outside the financial world. Firstly, there are no state of the art theoretical heuristics for conducting stress testing for non-financial companies; and secondly, there are no best practices modelling technics developed to support the theoretical heuristics. As stated before, the paper will not focus on approaches on how to conduct a stress test as there can be multiple approaches, and in the case of nonfinancial enterprises, special customizations can be made to a particular industry. However, what kind of a model should be developed for this use will be examined.

4. Selecting the right model for stress testing

Borshchev and Filippov (2004) make a comparison of tree major modelling approaches: system dynamics, agent based, and discrete event modelling. All these approaches have their ideal domain of competence as shown in Fig 3. System dynamics is used for high abstraction, macro, and strategic level modelling.

However, you can use system dynamics for the operational and tactical level modelling, not just the strategic level. The model for the stress testing of non-financial enterprises would ideally include some data from the tactical and operational level. Such model will have parts that will be differentiated in abstraction and level of detail. We must recognize the diversity of data that would go into a model which will adequately simulate the behaviour of a particular company. This model could include data from different abstraction levels from Fig 3. Highly detailed low abstraction data from the financial reports can be included, and high abstraction and less reliable market and competitive forces data can be analysed in the model as well.

If the main analogy from Fig 3 is considered, of having micro level low abstraction and macro level high abstraction, and if we add a horizontal axis for reliability of the model, then a simplified segmentation in Fig 4 will be generated. There will be different kinds of models and data that we might want to include in our stress testing model, and the decision of what should be excluded must be made. Some would argue that if there is a need to simulate the behaviour of a non-financial company, a sub-model that generates the behaviour of a market, competition, or new technology diffusion should be included. It can be argued that from a strategic perspective companies have a reactive behaviour to these factors. However these models are highly unreliable by their nature, as they are mostly forecasts of highly volatile and uncertain phenomenon.

The focus should not be placed upon the top right corner, as it is unclear whether these models bring any value whatsoever, due to the fact that they are modelling highly uncertain and unpredictable events. The upper right corner models have proven to be highly unreliable, as there is no research for best practices modelling with a proven long term record of predicting market behaviour

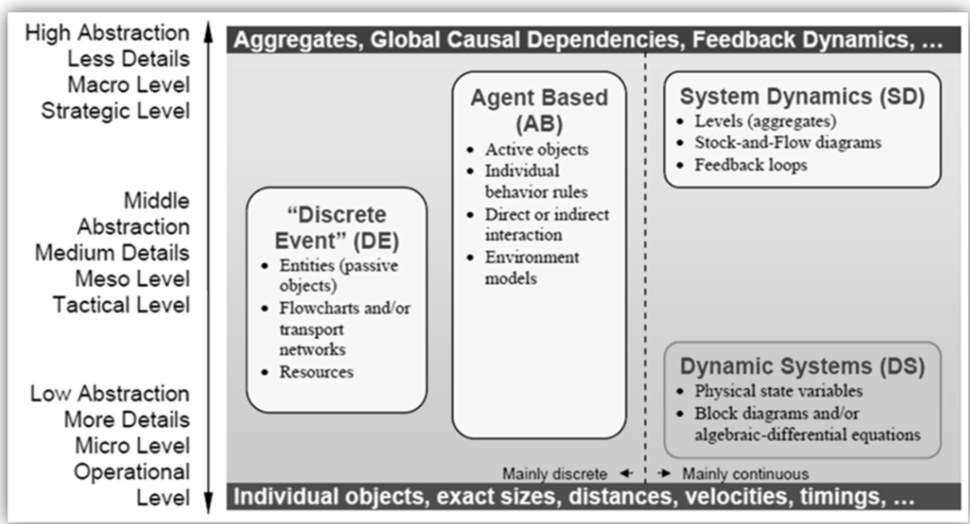

Figure 3. Simulations approaches and abstraction level scale (Borshchev and Filippov, 2004)

or robust behavioural analysis of new technologies or competitive forces. With that being said, the paper will mostly focus on modelling the bottom left part of the Fig 4, due to the fact that the main goal of our model is to be accessible to universal data like the financial statements data and the operational data. Process of gathering and using this data is well defined unlike in the case of the top right part of the diagram in Fig 4. Also it should be noted that it is possible to have a part of the model that simulates operations of the company derived from the financial statement data.

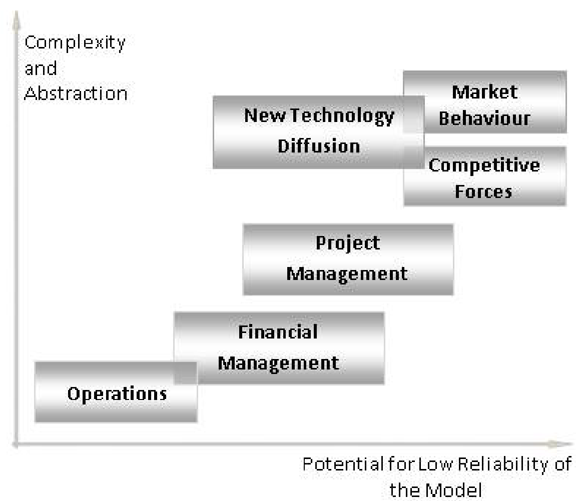

Figure 4. Different modelling segments and their characteristics

A question emerges whether or not system dynamics is suitable for modelling financial data, as this is not the main use of this simulations modelling approach and other approaches are more used for these endeavours.

Modelling of the company's operations from micro to macro level, as shown earlier in the text, is highly functional in system dynamics, compared to alternative methods, but can this be said for financial data as well? System dynamics does not have structural limitation for this kind of financial data. There is a universe of specialized software for financial and accounting data management, modelling accounting data can pose difficulties and complexity due to the double entry book keeping system that accounting is based upon. Spread sheet modelling solutions are mostly used as they are uncomplicated and universally accepted, but system dynamics can accommodate these kinds of models in a more effective way. There is limited research on this topic in system dynamics. Melse (2006) defines the structure of a system dynamics financial accounting model, which can be integrated with other models, and the model is structurally coherent with the accounting equation and the double entry system.

The model that is required has to have a comprehensive use of the financial statement data: balance sheet, cash flow, and income statement data. More importantly it needs to integrate all tree parts of the financial statement in one coherent model. The reason for using all three parts of the financial statement is to have a robust overview of the enterprise, but also to allow the model to be extended in simulating operations. The model that integrates the whole financial report into a single model will be a large model with a large number of interconnections; however, it will be a highly calibrated and structurally reliable model, where there will be no uncertainty on how the parts are connected.

As pointed before there is limited research on this topic, nevertheless, there is a model and a modelling protocol that meets our early requirements. Yamaguchi (2003) outlines the modelling protocol for a comprehensive accounting model that combines the balance sheet, income statement, and the cash flow statement. The model is large and has multiple layers (sub-models), and has parts that cover production, inventory and sales, as these parts can easily be derived from the financial statement. In Fig. 5 a part of the model that covers the balance sheet is outlined. In the language of system dynamics all the elements from the balance sheet will be stocks (rectangular objects), and the elements from the income statement and the cash flow statement will be inflows and outflows.

The model has parts that simulate the operations of the enterprise in a superficial way, but the model can be easily extended to cover operations to a more sophisticated level. In Fig. 5 just one layer of the enterprise model is showed, which is derived by the modelling of the all three parts of the financial statement. This model fits the needs for the stress testing purposes of non-financial enterprises.

The examined model would need to go through smaller adaptation for stress testing analysis. These adaptations also depend on the industry that the enterprise originates from. There is no difficulty to adapt this model for other analytical approaches as well. The proposed model by Yamaguchi already has a sub model for some of the basic ratio analysis tools as shown in Fig. 6. Ratio analysis such as liquidity ratio, profitability ratio, and leverage ratio are used for stress testing purposes, but further analytical operations would need to be adapted around this model.

System dynamics offers a robust platform for conducting stress testing. However, stress testing modelling is at early stages in system dynamics as there are only two publications which have conducted a stress test of a financial institution (Anderson et al., 2011; Islam et al., 2013). Islam et al. (2013) outlines an advanced approach of using a system dynamics model supported by a machine learning algorithms, to conduct stress testing of a banking institution. The model proposed in this publication for stress testing of non-financial services by Yamaguchi (2003), aligns structurally with the model by Islam et al. (2013). The main difference between the models (Yamaguchi, 2003) and

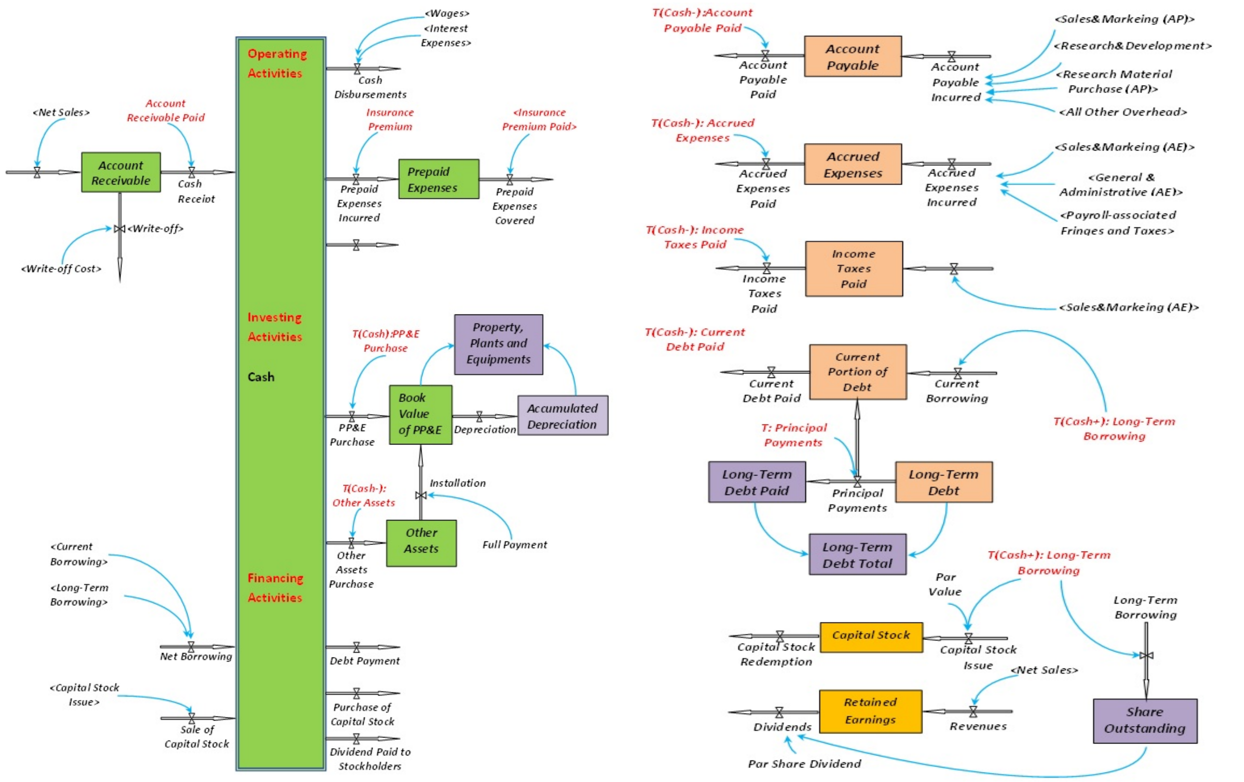

Figure 5. Balance sheet model (Yamaguchi, 2003)

(Islam et al., 2013) is that the model (Islam et al., 2013) is an in-depth balance sheet model that is specially adapted for a banking institution. As mentioned before, being able to adapt the model to the specific industry is of great importance. When it comes to financial institutions, the model should cover the inter-bank lending like in the case of Islam et al. (2013), as well as adding elements to the balance sheet which might not be present with a non-financial institution. In Fig 4 we have covered what kind of data should be potentially excluded from a stress testing model of a non-financial enterprises, the model proposed in this publication developed by Yamaguchi, leaves high optionality of how the model can be expanded to meet the stress testing needs of a specific industry. Publication by Islam et al. (2013) proves the versatility of the system dynamics modelling as a tool for stress testing as well as the proficiency of system dynamics to incorporate financial data.

As mentioned before, corporate transformations to a more environmentally sustainable business model, or a more profit driven one, carries a great deal of risks. Whether or not an enterprise is pursuing goals of sustainable development, goals of cutting costs and raising profits, or any form of high impact transformation, the probability for failure and value destruction is higher than the probability for success (Ward and Uhl, 2012).

Most of the companies pursuing innovative policies such as the circular economy shift or other policies defined in the area of sustainable development, should firstly observe how much up front, as well as later operational risks they can sustain. Focus on forecasting what risk will happen in the beginning stages or later stages of corporate transformations is highly insufficient.

When transitioning to a circular economy system, operating the risk analysis needs to be focused on the up front losses which might occur, and there should be a sophisticated method like stress testing to see how much volatility the enterprise can take, and what redundancies should be built to better manage that volatility. It is important to note that with the operationally uncertain concepts like circular economy, there can be heavy volatility later when the company starts operating under this concept. With well-defined concepts like lean supply chains and agile supply chains, the types of volatility are well defined as these systems are implemented across industries. This is not the case with many emerging concepts with sustainable development and circular economy. The rise of machine learning and commercial data visualization tools may offer elimination of many bottlenecks in complex supply chains that need to facilitate better waste management, especially when it comes to material tracking and agile optimizations (Vujić and Milovanović, 2012). However these are tools that have a purpose of making the supply chain more efficient, the largest weight still falls on having an effective risk system to observe and analyse the durability of the overall system.

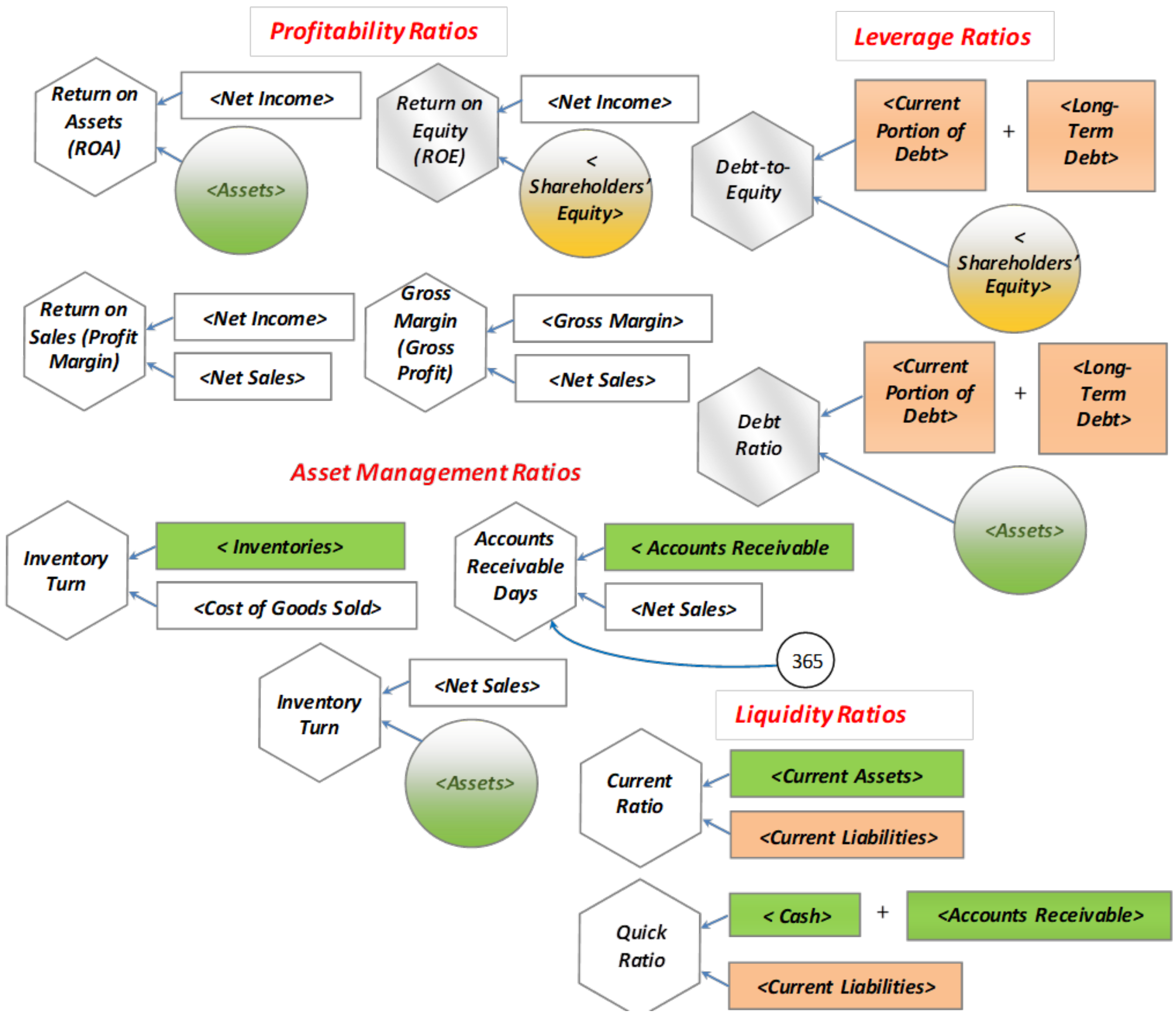

Figure 6. Ratio analysis part of the model (Richardson and Otto, 2017)

5. Conclusion

The paper has examined a contemporary and highly neglected approach to risk for non-financial enterprises, as stress testing outside of the financial industry has not been explored as a practical option for risk mitigation. It should be pointed out that there was a monumental increase in the analytical capabilities of companies and corporation from the end of 20th century and the beginning of the 21st century, however, the failure rate of projects and strategies within companies has not improved, and neither have the tools for risk planning. There is more data, along with higher than ever gathering and processing capabilities, but the tools for risk and planning that use this data need to evolve as well. This is the main reason for proposing stress testing development for the nonfinancial sector along with using system dynamics for it. New risk tools need to be explored, since new ways of operating, such as the sustainable development and circular economy, are emerging as the essential ways of managing the firm's assets. Considerable changes in the operating model of the company like the shift to circular economy model should be vowed as large up front stressor for the company, and this will be a huge barrier for implementing the circular concept with industries with high capital intensity. Stress testing can potently aid in the development of these highly uncertain policies, as many standard risk techniques require large sets of previous data, and when it comes to circular economy and other similar policies that data is not available, due to the fact that these policies are not widely implemented.

The paper presents an early introduction to this unexplored topic, since, along with the stress testing, system dynamic has not been used for risk management problems. The paper has conducted the analysis of the state of current research, and proposed a well-grounded model that should be used for stress testing in the non-financial sector. Future research on the topic of stress testing in the non-financial sector needs to explore what are the insights and capabilities that stress testing offers, in comparison to the standard approaches to risk which are mostly anchored to forecast and prediction. The proposed approach for risk could have a notable effect on risk management in the non-financial sector, but this is only possible if the future research exemplifies the high standard of risk management research conducted in the financial sector.

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Stres test metoda za kompanije kroz dinamiku sistema: Predlog nove metodologije za upravljanje rizikom za tranziciju ka cirkularnoj ekonomiji i održivom razvoju

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I Z V O D

Cilj publikacije je da istraži trenutno stanje u objavljenim istraživanjima o optimalnim metodama kreiranja matematičkih modela koji simuliraju ponašanje preduzeća kao usklađene celine, sve to ka cilju analize rizika sa fokusom na stres test metodu. Stres test metoda može doprineti u procenama stabilnosti u visoko neizvesnim tranzicionim politikama, poput ostvarivanja više ekonomske cirkularnosti u kontekstu cirkularne ekonomije, kao i u analizi rizika visoko uticajnih aktivnosti u sferi održivog razvoja. Publikacija ima za cilj da istraži ovaj problem kroz matematičko modeliranje primenom dinamike sistema. Glavni cilj je sagledavanje univerzalne heuristike i teorije rizika koja se može primenjivati i u drugim oblastima. Pri predlaganju novog koncepta poput prelaska na cirkularnu ekonomiju, niz ekonomskih i drugih benefita se očekuje u dužem vremenskom periodu, međutim, ne treba zanemariti moguću pojavu kratkoročnih gubitaka. Ova publikacija istražuje inovativne pristupe na dva nivoa: u predlaganju matematičkog modela za ciljnu upotrebu metode dinamičkog modeliranja preduzeća, kao i u samom predlaganju stres test metode za koju se može reći da je zanemarena u upotrebi izvan finansijskog sektora.