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ENTERPRISE STRESS TESTING WITH SYSTEM DYNAMICS: A STATE OF RESEARCH AND CHALLENGES

Abstract: *The paper is to analyse opportunities and limitations of making numerical simulations of the behaviour of non-financial enterprises; the examined models are intended to fit the requirements of risk technics like stress testing. This kind of a model needs to be universal and agile in its use for different enterprises of different sizes, and all of this to a sufficient degree since some industries are highly differentiated from the others. The paper will examine these challenges true the scope of system dynamics modelling, however the paper is to examine the right heuristics where this kind of modelling can be done with different approaches. The goal of this paper is differentiated from the conventional approaches in its pursuit to proposing a model that is adapted for the risk technic, not the other way around. The paper will conduct an observation upon an un-investigated and neglected concept in the world of risk management; which is the development of stress testing analysis for the non-financial sector true a simulation method like system dynamics.*

Keywords: *Risk, System Dynamics, Stress Testing, Uncertainty*

1. Introduction

Executives and managers of international corporations, small and medium companies face many difficulties of managing uncertainty in form of projects, strategies and every day decisions. Globalization that accelerated at the beginning of the 21st century has brought high growth opportunities along with hyper competiveness that usually follows growth opportunities, where miss management of resources by managers and executives delivers high penalties to the enterprise. In mid 60s of the last century, the average tenure of the worlds biggest and most successful companies listed on the Standard & Poor's was 33 years, by 1990, it was 20 years, if the negative trend continues it is expected for the tenure to be 14 years or less by 2026 (Anthony et al., 2018). Another study (Mauboussin et al., 2018) points out that between 1963 and 1982 life span of more the 250,000 US manufacturing firms that were analysed was roughly 65% for 5 years, and only 20% of the manufacturing firms were present for a decade. Companies of different sizes and industries 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 and the life span is the shortest (Luo and Mann, 2011; Dimov and De Clercq, 2006). When observing the

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failure rate of an industry, it can be of great value to observe the dynamics of failure on a micro level inside of a company, where in certain industries the default rate of projects and large scale corporate initiatives can reach close to 70% (Daniels and La Marsh, 2007). With the mentioned rates of default, a question concerning the integrity of our tools for tackling complexity and uncertainty emerges, how efficient are they, and how much value do they add. There is substantial proof of the low reliability of our methods and tools to predict and forecast rare business events and crisis, but most of our risk management focuses on high precision forecasting and predicting the behaviour of complex events and systems (Makridakis, 1981; 1982). There is substantial evidence on low reliability of expert jujment and expert opinion driven predictions. There is ever growing literature that covers this topic, and the research point out to low reliability of these predictions, and the quality of the data generated by expert jujment of potential future success as well as 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). One can come to a conclusion that novel tools need to be developed and continuously tested for better analysis and management of unwanted rare events. There is a consistent increase of data gathering capabilities; however there is a demand for new modelling techniques and heuristics that can facilitate the bottom line decision making process in an ever more data centric world.

2. System Dynamics

System dynamics was invented in the mid-1950s by Jay Forrester (1989; 1995) but the growth of computing power along the growth of available software solutions that can facilitate this approach to modeling has made this modelling method like many others 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 (Forrester, 1990), urbanism, ecology, biology to addressing complex issues in medicine (Gallaher et al., 2016) and epidemiology (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 (Sterman, 2015; Morecroft, 2015; Forrester, 1990). If we observe the modeling approach of system dynamics, we can see that the modeling process is focused on isolating and modeling a particular issue at hand, it is almost never focused on modeling the whole system. When observing modeling in the managerial science world a wide range corporate activities is covered from: logistics and supply chain management, production and inventory (Poles et al., 2013), marketing (Richardson and Otto, 2017), human resources (Aburawi et al., 2005), project management (Lyneis and Ford, 2007) to financial management (Qureshi et al., 2007), strategic management (Snabe and Größler, 2006) to enterprise modeling (Golnam et al., 2010).

As shown in the Fig. 1, system dynamics modelling is conducted in a differantiated way compared to other modeling approaches. Common for system dynamics is a two step process in structuring the model (defining the cosual relationships in the model); a qualitative step where a set of non-quantitative mapping tools can be applied (managerial and systems thinking mapping tools), and a quantitative step od defining the cosual equations and mathematical opertations is applied afterwards. Compared to most approaches to modeling which are conducted by generating programing code in a specialised programming language, system dynamics (Fig. 1) allows for easier interpretation of the model and many model building practices can be done in groups (Jac and Vennix, 1999). System dynamics approach brings a contemporary and in many ways more comprehensive approach to defining, modelling and analysing complex systems (Jovicic et al., 2019).

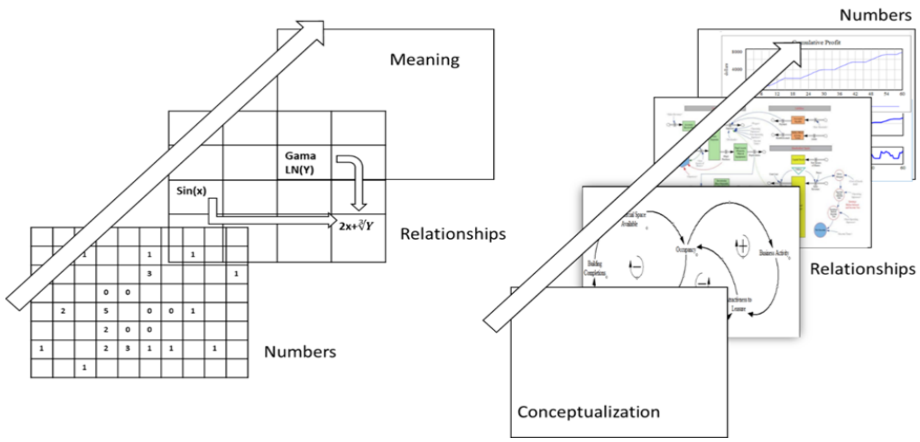

Figure 1. Standard data analytics approach on the left and system dynamics on right

3. Uncertanty and Enterprise Stress Testing

Before defining stress testing there needs to be a further analysis of empirical data on the limitations of conventional risk management, which by most part focused on high precision forecasting in uncontroled real wold systems. Outside of the already mentioned limitations of precision driven tools for risk and uncertainty analysis, there should be a further recollection of whay it is not desirable to focus on these tools.
A summary of the research on this topic conducted by Makridakis and Taleb (2009), outlines the reasons of low reliability when predicting the future:

1. The future should not just be vowed true historical data sets. Historic events positive or negative are not reputable outside of controlled laboratory environment. In real world environment when crises occur, every time they are different is scale and dynamics Statistical models have the limitation of extrapolating or interpolating past patterns to construct future outcomes in an accurate way.
2. Statistical models however simplistic or complex, will ideally fit the past data in an accurate manner, however this does not mean that they will predict the future outcomes with any accuracy. Statistical modelling has proven highly valuable in engineering controlled systems.
3. There is substantial empirical evidence that simple models driven by good heuristics, outperform highly complex statistical models in tackling the uncertainty, these models are more robust in fitting future outcomes then fitting the past data, compared to complex statistical models which do the opposite.

4. Statistical models will outperform in most domains judgmental predictions, do to bihavioral human biases which can be present with the judgmental predictions.

5. When multiple predictions coming from different individuals or groups are averaged out the results are usually improved, however there is little to no improvements in results concerning fat-tailed exposure. This is empirically true for averaging multiple models as well.
6. Statistical modelling underestimates uncertainty, which can lead to overconfidence in decision making. They have the tendency to outperform human judgment of uncertainty. But in the domain of uncertainty, many statistical models can lead to over-optimization which is not well adapted to volatility.

Stress testing is more then a risk method or a tool, it is used and defined across many disciplines, it outlines the integrity and resilience of a particular system or an entity (Cihák, 2007). Stress testing should fundamentaly be characterized and observed as firstly a behavioural analysis of a system to shocks, and different kinds of volatility (Jovicic et al., 2019). In years following the 2008. financial crises, regulators and financial institutions of different kinds and sizes, have recognize the necessity of developing their risk assesment capabilities. Much chritisizam has been directed twords what kind risk assesment capabilities are being developd, but undoubtedly there has been a rapid increase in investment twords stress testing and other risk technologies. Stress testing technologies in particular have seen a rapid increase in investment by insttutions, where some of the largest institutions will invest anywhere between two hundred million to half a billion US Dollars, following the decade after the 08' crises. Ther should be no doubt that this approach to risk is the main pilar that leads the major technological development and investment in the world of risk management. It is essential to point out that the stress testing expenditure for financial institutions which is bigger then the turnover of most companies, should not present this risk approach as unattainable. There are reasons for such high cost of running this type of risk assesment, a single financial institution in most cases will hire multiple consulting companies to conduct the stress testing, and many of these institutions have trillions of US Dollars of assets under management. Outside of the financial institutions, stress testing would probably be one of the least costly risk assesment strategies to implement. The reason for this is that stress tesing doesent require large data sets to be gatehered, it is nos as data intensive as some other tools wich are focused on prediction and big data analytics.

There has been little to no major progress of bringing this risk method to the nonfinancial sector where stress testing can potentially bring even more value in risk mitigation compared to the value it brings to the financial sector. Production and services companies can use stress testing as a strategy centric tool. In other word, strategies that are highly uncertain can be assesed in a different way, along with forming risk driven contengancy strategies. Stress testing can allow better building of operational redundancies and back up systems, along with elimination of weaknesses in the operating models of companies.

There are many industries where the development of stress testing tecnickues can be of grate value: energy sector, comodities, production. These are the sectors which bear the burden of least resiliance to volatility and rare events, and there is a deficiency of risk technicks to better aid the strategies for these sectors.

There are two main reasons whay stress testing has not seen the development outside of the financial sector:

- The sectror that has seen the most rapid development of decision making technologies, risk tools from the end of 20th century to the beggining of the 21st century is the financial sector. In general this is where most of the development in data analytics, artificial inteligance, and other less sofisticated tools for decision making and risk assesment is done.

- There is a deficiency of heuristics and modeling technicks for stress testing outside of the financial sector. With this being said this needs to be the starting point of the early stage research.

4. System Dynamics and Stress Testing

There is limited research on making stress testing models and running them in a system dynamics enviroment. Nevertheless there are high quality models that have been developed and synced in with other tools like machine learning (Islam et al., 2013). When analysing how to develop the stress testing method for non-financial sector we should observe what are the already existing models that can be easily used and modified for the non-financial enterprise. There are publications on system dynamics modeling of accounting equation and the financial statmen modeling (Melse et al., 2006). There is also a more broad research on how to fully construct financial statements, that is how to generate models which combine the accounting data from: cash flow statement, balance sheet and the income statement (Yamaguchi, 2003). The mentoned research is of grate value in constructing the models for stress testing. It is important to mentone that in system dynamics, existing models can be easily combined in to a one larger moded, these leaves oportunities to combine operational management model an a brother stress testing model which is mostly financial. If the accounting model created by Yamaguchi (2003) is analysed it can be observed that there is a part of the model that covers production and inventories, this data is a mandatory part of the financial statement, and this model can be easily expanded to cover the prouction and inventories of a company in a brother maner. It is essential when constructing stress testing models for non-finacial sector to heve the ability to adapt the model to a particular industry. A more deeper analysis of what should be excluded from a stress testing model for a non-finacial enterprise is covered in a previous publication (Jovicic et al., 2019). In esseance the model by Yamaguchi, (2003) is so far the most well constructed system dynamics model for conducting stress testin.

5. Conclusion

The paper has examined a contemporary and highly neglected topics in risk management of the non financial sector. There are many benefits of constructing a stress testing model for a industrial or a service enterprise outside of the financial sector. The benefits of using this approach are that is it not as data intensive as other approaches, and this is of grate importance when analyising highly uncertain strategies or policies. For the non-financial sector a simulation enviroment like system dynamics can be of greate benefits as it allows greate model addaption to the particular sector or a company. There are many sectors that can highly benefit from a stress testing tool as these sectors are highly capital intensive and this requires companies to comit to overoptimization and heavy cost cutting. These companies are higly fragile to volatility and the uncertanty is their gratest adversary. With the development of stress testing technicks, companies can commite to a better way of finding out where their fragilities are and how to mitigate them.

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