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Dynamic System Sustainability Simulation Modelling

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Abstract: Assessing the sustainability of dynamic, open and complex systems with many stakeholders, interrelated components and interactions and forecasting with traditional study methods is a very complicated and has its limitations. The aim of the paper is to create a simulation model for sustainability of a dynamic system in order to assess and forecast the sustainability of the system under alternative development scenarios. The Cesis Palace complex as a tourism site in Latvia was used in the paper for an example of a dynamic system. The result of the work is a computer model that provides an opportunity to assess the sustainability of real-life system and its dimensions. The author concludes that three key factors need to be taken into account in order to improve the model: methodology for evaluating model indicators, data security and integrity and usage of machine learning in simulation modelling.

Key words: Dynamic System, Simulation Modelling, Sustainability

1. Introduction

Assessing the sustainability of dynamic, open and complex systems with many stakeholders, interrelated components and interactions and forecasting with traditional study methods is a very complicated and has its limitations (Johnson, 2011; Mai and Bosch, 2010). Therefore, often researchers, when forecasting the sustainability of a dynamic system, rely on subjective judgment without references to assessment standards or other criteria (Gyou and Ko, 2003). Historically, the concept of sustainable development has been interpreted and defined in very different ways, this has often been a big problem for different policy makers (Bell and Morse, 2008).

Sustainable development researchers offer to build on traditional principles and interlinked dimensions of sustainable development: environment, economic and social, and adapt them to the dynamic system, that is characterized by the interactions between components (Tanguay et al., 2011; Mai and Smith, 2018). One type of study that helps explain such systems is simulation modelling, that is often used when researching the interaction of dynamic systems (Johnson, 2011).

The aim of the paper is to create a simulation model for sustainability of a dynamic system in order to assess and forecast the sustainability of the system under alternative development scenarios. It includes 3 main aspects: how sustainable is the dynamic system and what are the main implications for measurement of sustainability of the dynamic system, what is the level of sustainability of a dynamic system under alternative development scenarios and what additions are needed to improve the functioning of the simulation model.

The Cesis Palace complex as a tourism site in Latvia was used in the paper for an example of a dynamic system, since tourism is both a dynamic system with many interlinked components and equally important are the three dimensions of sustainability for its long-term development. Many researchers believe tourism is much more than just the industry, it is an open, complex and dynamic system with many stakeholders and interrelated components (Johnson, 2011; Mai and Bosch 2010). Tourism is also an economic, dynamic, social and cultural phenomenon that is found in all countries around the world and linked to their population, culture, economic activity and the environment (Elliott, 1997). The link between tourism, people and environment means that tourism long-term existence is closely dependent on the sustainable development, which, in addition to the development of economy, maintains a healthy and functioning natural and cultural environment (Elliott, 1997).

The research question of the paper is: what simulation model can effectively analyse and forecast dynamic system in case of the tourism object Cesis Palace.

2. Theoretical Background

The sustainable development of a dynamic system is characterized by three interlinked dimensions: environment, economic and social, where all dimensions are equally crucial. Some authors also propose fourth and fifth dimensions but most sustainability authors and researchers, as well as institutions (as the European Commission) recognizes only these three dimensions of sustainability (European Commission, 2016; Kļavins and Zaļoksnis, 2010; Tanguay et al., 2011; Connelly, 2007). The concept of sustainable development includes physical conditions, policy concepts, the concept of quality of life and well-being and the optimization of environmental impacts to ensure that its resources are equally accessible to all generations (Kļaviņš and Zaļoksnis, 2010). The concept is based on understanding of three concepts: development, societal needs and the needs of future generations. Sustainable development means that any economic, social or environmental issue must be addressed in such a way that the decision taken is favourable or least detrimental to the development of other dimensions (Kļaviņš and Zaļoksnis, 2010). It is essential that both sides (the environment and the economy) be able to assess and recognize the legitimacy of the other party and respect it (Tanguay et al., 2011).

In order to better understand sustainable development, the authors offer to display it using a Venn chart, which is widely used and is a convenient way to display the interplay between basic components (Connelly, 2007). This interaction is based on three circles containing the basic elements of sustainable development – the economy, society and the environment (Figure 1). That allows it to be easily perceived and understood by different users, can easily be applied in different areas and measuring scales and can be used to create and select sustainability indicators (Connelly, 2007; Tanguay et al., 2011). Key sustainable development indicators cover more than one dimension at a time (Tanguay et al., 2011). Indicators can be defined as part of the recognized basic instruments supporting the implementation of sustainable development policy (Miller, 2001). They consist of information ensuring a significant shift in the development and management of development.

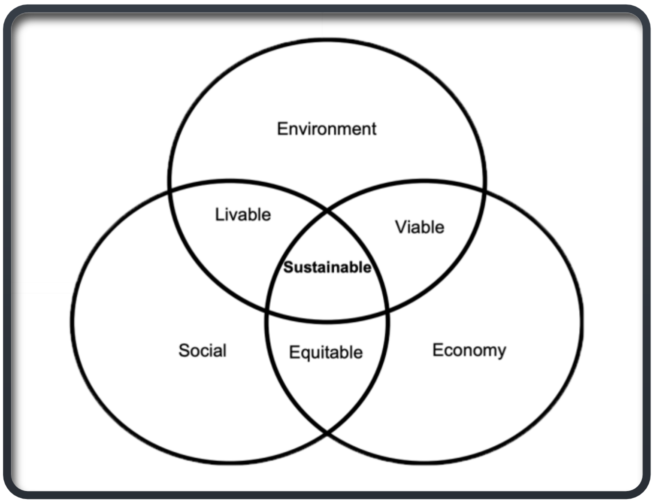

Fig. 1. Conceptualization of sustainable development (Tanguay et al., 2011)

In order to avoid subjective interpretation and "created to measure" definition of sustainable system, sustainable development researchers offer to build on traditional principles and dimensions of sustainable development and adapt them to the dynamic system (Tanguay et al., 2011). A complex system is not characterized by the number of components it consists of but more by the interactions between these components and involves diverse stakeholders, each of whom holds different management objectives. It can be explained by the system dynamics, which essentially relate system behaviour to feedback loops that exist within the system (Mai and Smith, 2018; Mai and Bosh, 2010). The complexity the author observes in system behaviour is due to shifts in the dominance of these feedback loops over time, as well as material and information delays that exist within the system (Mai and Smith, 2018).

One type of study that helps explain such systems is simulation modelling, in which social systems are integrated with information technology systems (Johnson, 2011; Mai and Bosch 2010). It complements traditional methods such as statistics, mathematical models and survey analysis very well. Therefore, simulation modelling is a solution that is often used when researching the interaction of dynamic systems and serves as an alternative method for ones that are currently widely used (Johnson, 2011). The simulation modelling of dynamic systems makes it possible to assess the current situation and look into future development routes and their impact on society, economy and the environment (Kandelaars, 1997). Dynamic simulation modelling imitates an existing or potentially feasible situation to analyse the dynamic relationship between model variables.

Researchers in their studies on dynamic systems often use such simulation modelling types – system's thinking approach, agent-based modelling and simulation modelling in STELLA's environment.

The system's thinking approach is a new way to understand a reality that more accentuates the relationship between parts of the system than the parts themselves (Mai and Bosch, 2010). It's a way to describe important disciplines and to understand complexity and change. In addition, it offers a powerful paradigm with specialized language and methodology that uses computer modelling technologies (Mai and Bosch, 2010). The system's thinking tools are based on four levels of thinking – events, masters, system structure and spiritual models – which provide an approach to cope with complex challenges facing everyday life and work. These tools are conventional circle charts, stock and flow charts, computer simulation modelling and group modelling (Maani, Cavana by Mai and Bosch, 2010).

Agent-based modelling is applied in social sciences to understand and describe the dynamics of social, economic and room systems by simulating the actions and interactions of autonomous agents (Maggi et al., 2011). This approach typically has three basic functions: collecting and analysing data, modelling on the current situation and predicting the future for different development scenarios (Maggi et al., 2011).

STELLA dynamic system modelling environment is an object-oriented graphic programming language, that allows for modelling of dynamic systems and helps to understand the dynamic relationship between the economy, environment and society, and provides the opportunity to analyse development of alternative scenarios (Costanza and Gottlieb, 1998). It demands that the author identify the basic variables, flows and parameters of the system and that the author establish appropriate links between them. Almost unlimited serial and dynamic relationships of quantity and diversity can be modelled on these simple building blocks (Costanza and Gottlieb, 1998).

3. Methodology

The author used sustainability assessment system proposed by Gyou Ko which includes: identify the system, identify basic dimensions, identify basic indicators, establishing a sustainability scale, defining sustainability gradations (scale sectors), developing a map for sustainability, extending the pattern over time and grow up (Gyou Ko, 2003).

Before the data collection, the author at first had to develop and select indicators and their assessment system, which is the base of measurement of sustainability. Both the world tourisms and sustainable development organizations and researchers have developed their own sustainable development assessment system with many indicators. The author critically analysed and evaluated the relevance and usability of the various indicators, which have been most often used and highly valuated in researches and that have been identified by multiple authors and sources – World Tourism Organization, European Commission, Tanguay, Roberts, Tribe, Miller, Choi, Sirakaya and others (Miller, 2001; Jovicic and Ilic, 2010; Tanguay et al., 2011; Roberts and Tribe, 2008; Choi and Sirakaya, 2005; European Commission, 2016). For example, if one indicator was used in only one research and its significance was low, then the author assigned a low weight to this indicator or didn’t used this indicator at all, based on the specific nature of this study system. But if the indicator was used often and its significance was high, the author assigned a high weight to this indicator.

The model and the selection of indicators were based on the three key sustainability dimensions: economy, environment and society/culture, each of which were represented by three groups of indicators which are further broken down into indicators and sub-indicators, as well as impact factors, based on previous mentioned researches and publications. For each indicator and sub-indicator, a sustainability rating scale of 1 to 5 was applied, where 1 is very poor or very low but 5 very high or very good (Gyou Ko, 2003). In order to determine the sustainability of the system and dimensions, the author also used a five-point measuring scale proposed by Gyou Ko: sustainable (excellent) 81-100% or 4-5; potentially sustainable (well) 61-80% or 3-4; interim (average) 41-60% or 2-3; potentially unsustainable (poorly) 21-40% or 1-2; unsustainable (very poor) 1-20% or 0-1 (Gyou Ko, 2003).

The author used multiple data collection methods. In the research author analysed data on visitors from 2009 to 2013, including the number of monthly visitors, the purpose of visiting, the country from which they came, the type of service, etc. In addition, information on the organization's income and expenses from the company's accounting data was also obtained. The organization's development strategy was also analysed.

The second research method was a structured interview with the head of the tourism facility. In the interview, most of the questions were closed types, which ensure a higher objectivity of the information obtained, because the interviewer's freedom is reduced significantly.

The third method used in the study was case study analysis, which has already been successfully practiced in sustainability tourism studies in Latvia. Sustainability indicators were used as criteria for examining the current situation. All Cesis Castle complex objects and their operation were observed and marked for each indicator.

In order to verify the model, an expert interview was also conducted on the created simulation model and its achieved results.

The author used the following data analysis methods to better determine the values and links between indicators: descriptive statistical methods (frequency table, mean, median and graphics analysis) and statistical data analysis methods (correlations and regressions).

To achieve the goal of the research, a model of tourism sustainability simulation model was created using STELLA dynamic system modelling environment, because it allows the creation of a dynamic simulation model to understand the dynamic relationship between the economy, the environment and society, it is possible to analyse a number of scenarios linked to different policies and development pathways. In order to develop a well-functioning model of simulation in STELLA’s environment, it is also necessary to use the system's thinking approach to simplify, clarify and integrate isolated problems related to the sustainability of the system.

4. Results

The result of the work is a computer model that provides an opportunity to assess the sustainability of real-life system and its dimensions by entering data generated in the course of the study. Simulation model consists of a system with three main dimensions of sustainability: economic, environmental and social. Each dimension has its own sustainability indicator groups, indicators and sub-indicators. All dimensions are interrelated so that changes to one dimensional indicator group can affect indicators in other dimensions. The indicators and sub-indicators of each dimension have their own value, from the calculation of these values can get values of dimensions, from whom you can get the system sustainability level. For example (Figure 2), economic dimension contain of indicator groups and indicators: flow of tourists (seasonality, repeated visitors, growth of number of tourists), performance quality (knowledge and capacity of management, quality of employees, knowledge and capacity of organization, operational motivation), profit capability (ratio of income and expenses from economic activity, possibilities for funding, investments).

The author performed dynamic systems sustainability simulations for seven types of scenarios in research. Each scenario was launched 20 times, renewing on each stroke to the starting exit positions. At the beginning, the simulation model was developed for a basic scenario that is a simulation of the real situation of the moment. The other scenarios (Table 1) were policy makers support change scenarios, site attractiveness change scenarios, marketing strategy change scenarios, scenarios for increased pollution and combined scenarios: first (loss of policy makers support, decreased marketing activities, increased pollution, decreasing the attractiveness of the site) and second (gain of policy makers support, increasing the attractiveness of the site and increased marketing activities).

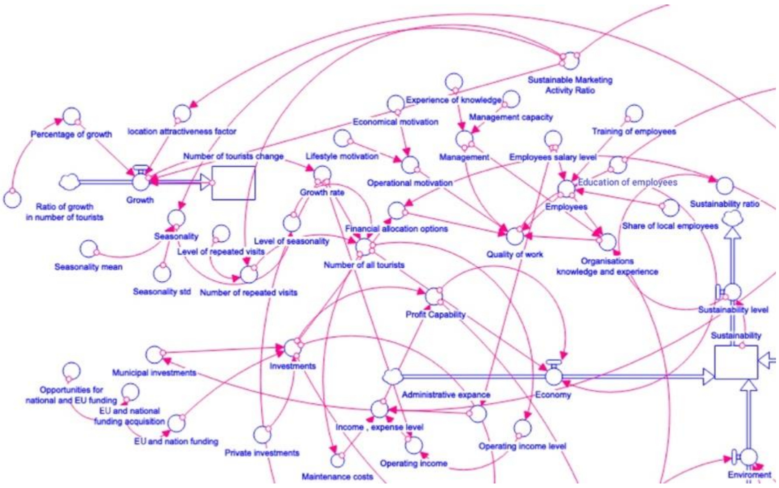

Fig. 2. Economic dimension of simulation model

The study concludes that the tourism object under consideration is potentially sustainable, its sustainability level is good. Therefore, it can be concluded that, in the current situation, the Cesis Castle complex has a good exit position to achieve even higher sustainability indicators in the future, which would increase its competitiveness in both the Latvian and global tourism markets. Following the results of the dynamic systems sustainability simulation, it can be concluded that the strong sides of tourism object are culture, quality of activity and preservation of cultural and historical heritage. However, in order to achieve higher sustainability indicators, it is necessary to improve environmental awareness indicators, reduce the level of seasonality, encourage public involvement in tourism and increase the level of satisfaction with tourism, as well as to cooperate more with local government and business in order to improve the level of accessibility and quality of the social environment and other tourism services.

Manipulating the data can help predict the potential sustainability of a dynamic system under alternative development scenarios. Simulating alternative development scenarios, it can be concluded that the elements of one group of indicators can affect both the sustainability level of their own dimension, as well as the indicators of other dimensions and their sustainability level, as well the sustainability of the system overall. For example, improving the attractiveness of the site increases both the number of new tourists and repeat tourists, which increases income levels and improves economic sustainability, which in turn has an impact on the environmental and social dimension. However, although the impact of the changes was observable, in these scenarios the sustainability of tourism site remained unchanged in the “potentially sustainable” assessment. Significant changes in the system take place in a situation where a number of indicator groups are affected by the changes. This model can be used to predict and examine the potential impact of different risks to the system.

Table 1. Simulation modelling results

Scenario	Sustainability	Economic dimension	Environment dimension	Social dimension
Basic	3,32 – 3,54	3,16 – 3,70	3,21 – 3,26	3,60 – 3,66
Loss of policy makers support	2,97 – 3,23	2,66 – 3,10	2,80 – 3,02	3,45 – 3,55
Improving the attractiveness of the site	3,52 – 3,69	3,37 – 3,84	3,11 – 3,26	4,07 – 4,11
Decreasing the attractiveness of the site	3,06 – 3,24	3,02 – 3,46	3,31 3,36	2,84 – 2,94
Increased marketing activities	3,55 – 3,69	3,90 – 4,14	3,06 –3,18	3,70 – 3,75
Decreased marketing activities	3,22 – 3,29	3,13 – 3,23	3,30 –3,32	3,28 – 3,34
Increased pollution	3,11 – 3,37	3,02 – 3,56	3,17 –3,20	3,15 – 3,35
Combine scenario (I)	2,75 – 2,90	2,52 – 2,96	3,05 – 3,08	2,65 – 2,69
Combine scenario (II)	4,00 – 4,03	4,21 – 4,27	3,29 – 3,31	4,48 – 4,52

5. Discussion and conclusion

On the basis of this model, providing that adjustments are made according to the type of the dynamic system, make it possible to simulate the sustainability of other systems as well. However, in order to be able to use this model by anyone interested in repeating a similar study, it would be necessary to improve the methodology for evaluating model indicators. Similarly, in order to use this model in other dynamic systems, it would be very important to do an in-depth study of required indicators and determining their value and impact. The author, on the basis of this study and literature review on the development of simulation modelling, propose to take data security principles and machine learning methods into account for better selection and evaluation of indicators, as well as for more efficient and accurate model performance.

In order to create a simulation model requires the acquisition, processing and issuing large amounts of data that are exposed to data security and integrity, which may have a negative impact not only on the functioning of the model but also on the system itself. It is therefore necessary to conduct in-depth research, that helps to assess the risks of data security and integrity and to potentially avert them.

There are six stages in the life cycle of data: create, store, use, share, archive and destroy (Kumar et al., 2018). Once the data is created, it can move freely between any stages. Data should be secured in all the stages of its life cycle from its creation to its destruction. Confidentiality, integrity and availability are the three important properties of the data popularly called CIA triad (Kumar et al., 2018; Magnani et al., 2018; Andress, 2014). Confidentiality refers to data privacy where the data is not revealed to unauthorized parties on any occasion. At large, the goal of confidentiality is to stop sensitive data from getting into the wrong hands. Availability refers to information being accessible to authorized personnel as and when it is needed (Kumar et al., 2018; Andress, 2014). These points are becoming more important as distributed and cloud simulation in on rise.

Integrity seeks to ensure the accuracy and validity of information in all life-cycle and it refers to the ability to prevent the data from being changed in an unauthorized or undesirable manner (Kumar et al., 2018; Andress, 2014). This is very important property when there are large amounts of data. There are many concerns about data integrity in researches with big data: what is the origin of the data, who has been responsible for them since their origination, are they fitted to the existing standard of trust and integrity (Lebdaoui et al., 2016)? There are two axes data integrity: end-point validation and filtering; real-time security monitoring (Lebdaoui et al., 2016).

In order to significantly improve the definition, selection, value assignment, and to more accurately identify the importance of interfacing elements and to express future forecasts, the author proposes to evaluate the use of machine learning in simulation modelling. Machine learning algorithms are increasingly used by researchers in mechanical engineering applications, particularly to help detect errors, monitor the conditions and express forecasts (Elbattah and Molloy, 2018; Sobie et al., 2018). Various authors also point out that the increasing complexity of the real world's challenges and problems increasingly requires the use of new technologies and their integration with modelling and simulation, such as machine learning, deep learning, big data, etc. (Elbattah and Molloy, 2018; Tolk, 2015).

In general, three ways can be identified when integrate machine-learning into simulation modelling: before, during and after simulation. Elbattah and Molloy propose three key ideas for integrating simulation models with machine learning: learning to predict the behaviour, identify predictable influential variables and incremental learning to achieve adaptive behaviour (Elbattah and Molloy, 2018):

Learning to predict the behaviour. It is assumed that the actual system produces sufficient amounts of data that can be used for machine learning training. With this combination, a simulation experiment is intended to be guided by machine learning models trained to make predictions on the system behaviour. The predictions would reflect the behaviour of the system’s actors, and how they would have likely reacted in the actual environment setting.

Identify predictable influential variables. It may not seem reasonable to train machine learning models to predict all variables in a simulation model for many reasons. To address these issues, approach follows a simple process for screening variables ahead of building machine learning models. The screening process is particularly concerned with filtering system variables in terms of significance with regard to the system behaviour and predictability. In other words, have to seek variables that have a considerable influence within the problem context, and can be predicted. The authors refer to those variables as Influential Variables. Afterwards, two conditions have to be met. First, there should be enough empirical data for machine learning. Second, the initially screened variables should be presumably predictable.

Incremental learning to achieve adaptive behaviour. The primary goal of this approach is to realize an adaptive simulation model that can adjust its behaviour with minimal human input. The behavioural adjustment would correspond to changes or new conditions in the actual system. This can only be realized if the machine learning training is an incremental process, rather than one-off. The idea of incremental learning is based on the premise that new system states are being continuously captured in timely snapshots of data and added up to an accumulated repository representing the system knowledge. In this manner, machine learning models can be iteratively trained in order to learn about possible changes in system behaviour. The idea of incremental learning can be linked to one of the common concepts in systems modelling, which is the feedback loop. With such data-driven feedback, machine learning models can be continuously trained to reflect the system behaviour. The incremental training of machine learning models can therefore capture knowledge updates. In turn, changes in the system behaviour can be inferred through machine learning predictions.

In order to assess the usage of data safety principles and three machine learning approaches in the modelling of dynamic systems, studies should be carried out in the future. The model of dynamic system sustainability developed in this study can be used as a basis for future studies.

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