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Business Strategy Modeling: System Dynamics Approach

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Abstract:

Purpose: *The article aims to analyze the applicability of computer simulation models built using the system dynamics methodology for studying the effects of various business strategy options.*
Design/Methodology/Approach: *The article focuses on the application of system dynamics simulation, which enables the consideration of feedback loops, time delays, and nonlinearities in enterprise operations. Based on a case study of a transport company, the potential of using a simulation model to support the selection of an investment strategy is presented.*
Findings: *System dynamics models facilitate a comprehensive analysis of various business strategy options, allowing for the evaluation of their impact on the company's key economic and technical indicators. This approach accounts for both macroeconomic and microeconomic aspects, leading to a better understanding of enterprise dynamics and supporting strategic decision-making. The presented simulation experiments demonstrate that implementing the appropriate investment strategy enables a company to achieve business goals more effectively.*
Practical Implications: *The proposed approach supports decision-making in dynamic and complex business environments. It can be employed by both managers and analysts to evaluate and plan business strategies. The presented case study may be particularly useful for decision-making regarding the selection of delivery vehicle brands, including electric models.*
Originality/Value: *The application of system dynamics in designing business strategies captures multi-level interactions and long-term effects of actions, distinguishing this method from traditional analytical tools.*

Keywords: *System dynamics, simulation modeling, strategic management, decision-making.*

JEL codes: *C63, L21, M21.*

Paper type : *Research article.*

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1. Introduction

Business strategy is one of the key elements of the strategic management concept. It represents a framework that outlines the fundamental directions, rules, and tools for a company's operations (Mainardes, Ferreira, and Raposo, 2014; Sammut-Bonnici, 2015; Desai, 2019; Nikolaeva, 2020; Alharbi, 2024). Adopting an incorrect business strategy can have disastrous consequences for a company, potentially threatening its survival as an independent economic entity. Therefore, decisions regarding strategy selection should be based on reliable informational grounds and made after thoroughly analyzing all probable scenarios of economic developments.

The essence of designing a business strategy lies not only in assessing the present or past events but primarily in understanding the potential outcomes of planned actions and, based on this, selecting the best possible option. For this reason, it is recommended to use methods that enable the generation of information about the expected effects of implementing specific decision scenarios (Yang, Kueng, and Hong, 2015; Chijioke, Vu, and Olatunji, 2018; Fuertes *et al.*, 2020).

Typically, decision-making regarding strategy selection relies heavily on financial plans and analyses conducted using electronic spreadsheets. The advantages of this approach include relatively easy access to tools and straightforward operation. However, this method has a significant drawback: it limits the ability to make effective strategic decisions in the rapidly changing and complex environments in which modern businesses operate.

Specifically, the cause-and-effect relationships in analytical models defined within spreadsheets are unidirectional, preventing a thorough representation and understanding of a company's behavior. These models are not equipped to analyze the internal dynamics of a company, which arise from multidirectional feedback loops, time delays, and nonlinear relationships between the core elements describing the company's operations. As a result, the information they generate can be unreliable (Ginsberg, 1997, p. 125; Kononowicz, 2002, p. 16).

A complex economic system, such as a company, can be analyzed more effectively using computer simulation models. These models allow for the dynamic tracking and analysis of changes within a company and its environment, while also providing forecasts of the behavior of fundamental elements that define the company's operational logic. Consequently, the information generated by these models is significantly more reliable than that produced by traditional models (Warren, 2005; Papageorgiou and Hadjis, 2011; Morecroft, 2015).

This article discusses the applicability of computer simulation models built using the system dynamics methodology for studying the effects of different business strategy options. It also presents an example of a model designed to enable a quick assessment of the current and projected situation of a company, supporting the selection of appropriate strategies for its operations.

2. Strategic Management and System Dynamics Modeling

System dynamics is a simulation modeling method primarily used for analyzing poorly structured problems characterized by numerous interdependencies among elements. Originating from the cybernetic approach to system analysis, it enables the description of systems in terms of interactive and combinational connections. The theoretical foundations of the method were developed by J.W. Forrester (1961) and are extensively discussed in various publications (Coyle, 1997; Mayo and Wichman, 2003; Papageorgiou and Hadjis, 2008; Łatuszyńska, 2008; Martinez-Moyano and Richardson, 2013; Morecroft, 2015; Bala, Arshad, and Noh, 2017).

The particular relevance of system dynamics in generating information for strategic management stems from its core characteristics. The method focuses on strategies, policies, management rules, cause-and-effect relationships, and the dynamics of system behavior—elements that are also central to strategic management (Ansoff, 2007; White, 2017; Rothaermel, 2018). Table 1 compares the main features of system dynamics modeling and strategic management, demonstrating their alignment.

Table 1. *Features of System Dynamics Modeling and Strategic Management*

Features of System Dynamics Modeling	**Features of Strategic Management**
Systemic approach	Holistic view of the system
Feedback and behavioral analysis	Analysis of action consequences
System dynamics modeling	Future-oriented tests and ideas
Optimization and decision-making rule quality	Adaptation to uncertain and variable conditions
Transparency of relationships	Understanding and acceptance of principles
System behavior simulation	Development of input and control information
Experimental simulation of periods	Post-factum system period analysis

Source: *Adapted from Coyle, 1997.*

System dynamics models generate a broad range of aggregated, forward-looking information—exactly the type required at the strategic level. These models provide insights into feedback (including feedback loops) among a company's strategic goals, facilitating a better understanding and acceptance of the company's operational logic. Simulation experiments conducted with these models allow for the evaluation of different strategic scenarios, aiding in the selection of the most probable and effective options.

Moreover, continuously updated models using real-time data enable ongoing verification of a company's development directions, goals, and methods for achieving them.

Numerous studies confirm the utility of system dynamics for business strategy modeling and supporting strategic management, including those by Lyneis (1999), Warren (2005), Papageorgiou and Hadjis (2011), Morecroft (2015) and Becerra-Fernandez *et al.* (2022). A comprehensive review of system dynamics applications in strategic management support is provided by Cosenz and Noto (2016).

According to David (2011), the strategic management process consists of three stages: strategy formulation, strategy implementation, and strategy evaluation. System dynamics models are useful at each of these stages (Table 2).

Table 2. *Strategic Management Stages and the Role of System Dynamics Models*

Strategic Management Stage	**Role of System Dynamics Models**
Strategy Formulation (vision, mission, environment, long-term objectives, generation of options, evaluation, and selection of the implementation variant)	Generating data for diagnosing the company's situation and assessing its strategic position. Providing data to evaluate the impacts of planned strategic development directions. Supporting the selection of the most probable and economically efficient strategy implementation scenarios.
Strategy Implementation (annual goals, principles, resources)	Assisting in planning desired and target quantitative and qualitative indicators for achieving the company's strategic objectives. Generating data to assess the company's current situation during strategy execution.
Strategy Evaluation (updating evaluation metrics, corrective actions)	Facilitating the verification of strategic metrics and determining the direction for corrective actions.

Source: *Authors‘ elaboration.*

Strategy formulation involves the following steps: development of vision and mission statements, audit of internal and external environment, long-term objectives and generation, evaluation and selection of strategies (David, 2011) During this phase, system dynamics models can diagnose the company’s situation, assess its strategic position, and simulate scenarios to predict future outcomes under the “do nothing” (continuation of the current strategy) option. Sensitivity analysis for the “do nothing” scenario identifies critical elements of the company’s operational logic, facilitating the design of new strategies. Additionally, models allow for testing various decision options, enabling decision-makers to evaluate and select the most appropriate strategic scenario.

The second stage of the strategic management process, commonly known as strategy implementation, involves activities such as setting annual goals, developing principles for strategy execution across various business functions, and allocating resources (David, 2011). During this stage, system dynamics models can be utilized to continuously incorporate changes occurring in the real system— including those unforeseen during the strategy formulation phase—into the model. Through experimental methods, these models can generate information that serves as a basis for making corrective decisions. This capability allows managers to respond quickly and flexibly to emerging challenges.

The final stage of the strategic management process, strategy evaluation, focuses on implementing changes or corrective actions as well as measuring and assessing performance. To achieve this, it involves the continuous updating of key strategic metrics established during the strategic planning stage and the identification of emerging internal and external factors.

Additionally, it includes comparing actual performance with planned objectives. If key metrics change during the ongoing evaluation or new factors and/or other issues arise, this stage requires corrective actions to be taken (David, 2011). During this stage, system dynamics models can facilitate the verification of strategic metrics and help determine the direction of corrective actions. By incorporating these factors into the model, they allow for the generation of data that illustrates the potential outcomes of such corrective measures, providing decision-makers with valuable insights for effective strategy adjustments.

3. Case study

To illustrate the application of system dynamics simulation for testing different business strategy options, a model of a transport company will be used. The structure of this model is presented in Figure 1. The model is based on the assumptions described below.

The transport company, equipped with a defined fleet of vehicles, provides transportation services. Statistical data indicate that the demand for these services (transportation needs) is increasing. To meet this demand, the company needs to expand its vehicle fleet (number of delivery cars). Investment expenditures are financed both from the company's own resources (company's capital) and bank loans (credit).

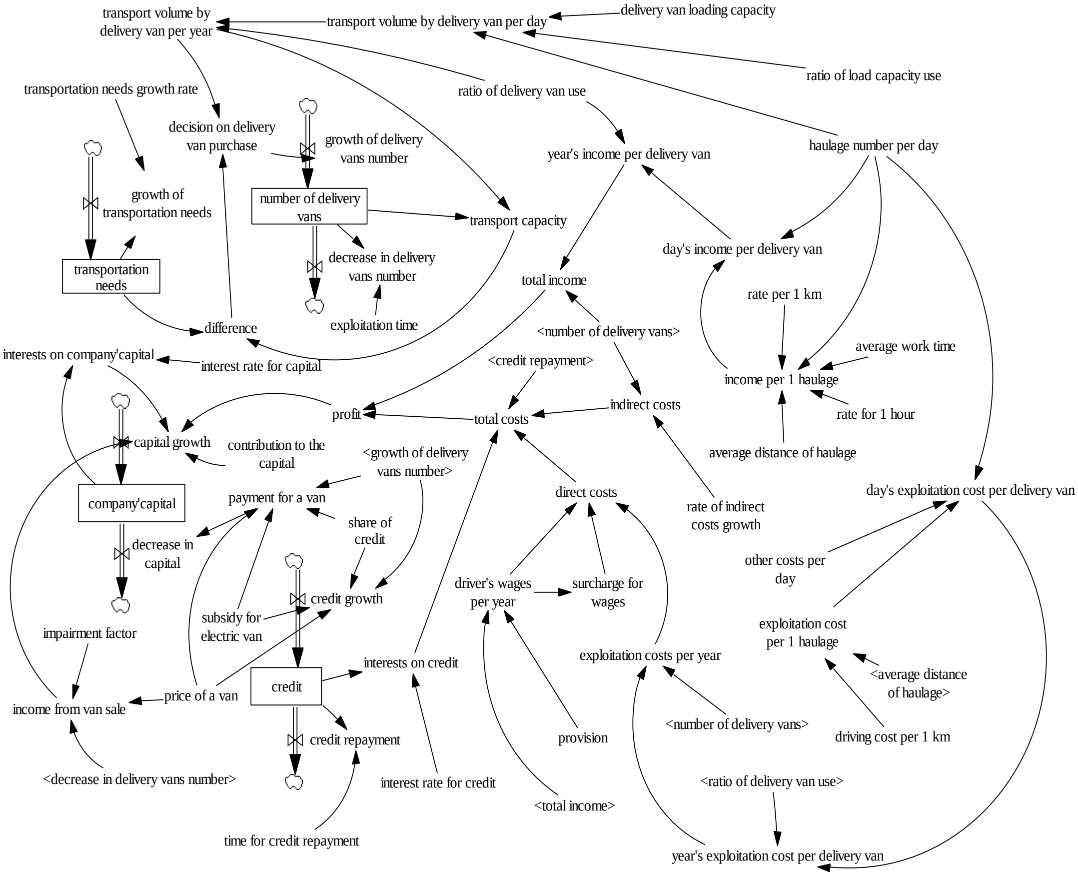
As the number of vehicles increases, the company's potential to generate gross income (total income) and, consequently, profit (profit) also grows. However, loan repayments (credit repayment) and interest payments (interests on credit) reduce the financial resources available in the company's account. Excessive investments in fleet expansion may place an undue burden on the company's budget, increasing the risk of underutilized vehicles due to insufficient demand.

The primary purpose of the presented model is to provide a quick overview of the current and projected state of the company to identify an appropriate business strategy for its development. Simulation experiments conducted with the model can also serve as a source of information regarding the operation of the transport company over time and the impact of specific decisions on its economic and technical indicators.

To design a business strategy that meets the decision-makers' chosen criteria (e.g., profit maximization), various scenarios can be tested based on information derived from the environment. Each scenario should be described using a set of attributes. The attributes of the analyzed transport company, included in the presented model, may include:

- Parameters of available delivery vehicle brands on the market, such as price, average payload, and fuel consumption.
- Loan offers from different banks, characterized by interest rates and repayment terms.
- The proportion of loan financing in vehicle purchases.

Figure 1. *Structure of the transport company model in VENSIM PLE simulation software notation.*



Source: *Authors' elaboration*

To demonstrate the extensive possibilities of testing various strategy scenarios, several simulation experiments were conducted. These experiments aimed to generate information about the impact of different purchasing options (various vehicle brands) on the profitability of the transport company. The attribute values describing each variant used in the simulations are summarized in Table 3. These values reflect conditions specific to the Polish market. It was assumed that entrepreneurs receive subsidies for electric vehicles in accordance with the current national government policy.

Table 3. *Attribute Values for Tested Investment Strategy Variants*

Car Brand	**Engi-ne**	**Price (Net) (PLN)**	**Subsidy for Electric Van (PLN)**	**Load Capa-city (kg)**	**Driving cost/100 km (PLN)**	**Deprecia-tion in 5 Years (%)**	**Daily Costs (Amortiza-tion, Insura-nce, Repairs) (PLN)**
RENAULT Master	Diesel	129 350	-	1130	54.11	38%	124.99
RENAULT Master E-TECH	Elec-tric	237 000	70 000	1050	22.68	48%	142.19
VOLKSWAGEN Crafter	Diesel	161 540	-	1371	51.08	38%	124.99
VOLKSWAGEN e-Crafter	Elec-tric	276 920	70 000	970	32.4	48%	142.19
Mercedes Sprinter 311	Diesel	157 000	-	1338	52.9	38%	124.99
Mercedes eSprinter 312	Elec-tric	277 210	70 000	961	29.16	48%	142.19

Additional notes:

- *Price (Net):* The price considered for each vehicle corresponds to the base model, equipped with the weakest engine and no additional features.
- *Subsidy for Electric Van*: The subsidy value for entrepreneurs declaring increased mileage is set at up to 30% of eligible costs, provided they declare an average annual mileage exceeding 20,000 kilometers) (Portal Gov.pl, 2024).
- *Driving Cost/100km*: Average cost of 1 liter of diesel: 6.08 PLN (AutoCentrum.pl, 2024); Average cost of 1 kWh of electricity: 1.08 PLN (enerad.pl, 2024).
- *Depreciation in 5 Years*: Approximate depreciation rates based on (Struk, 2023).
- *Daily Costs:* Based on (Adamczuk, 2023) (the average costs of operating a passenger car over a period of 4 years, assuming an annual mileage of 30,000 kilometers, are used as a reference.).

Source: *Authors' elaboration.*

The vehicle brands selected for the experiments were based on the ranking published on the *Wybór Kierowców* website (Kozielski, 2024), which recognizes these vehicles as leaders in the large delivery vehicle segment of the Polish market in 2024. These models are distinguished by their reliability, versatility, and the availability of both diesel and electric versions.

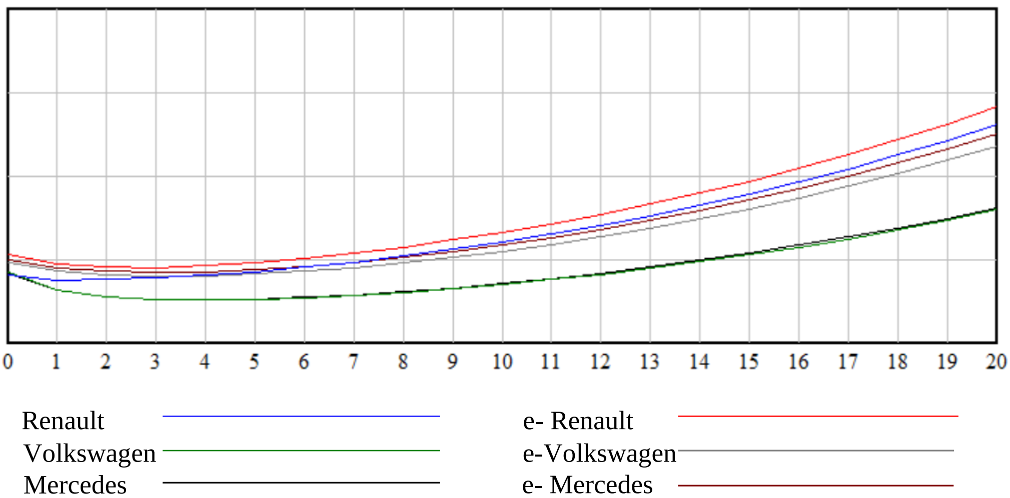
Considering both versions enables an analysis that addresses the diverse operational needs of the company, from long-distance transport to environmentally friendly solutions, aligning with current trends in sustainable development.

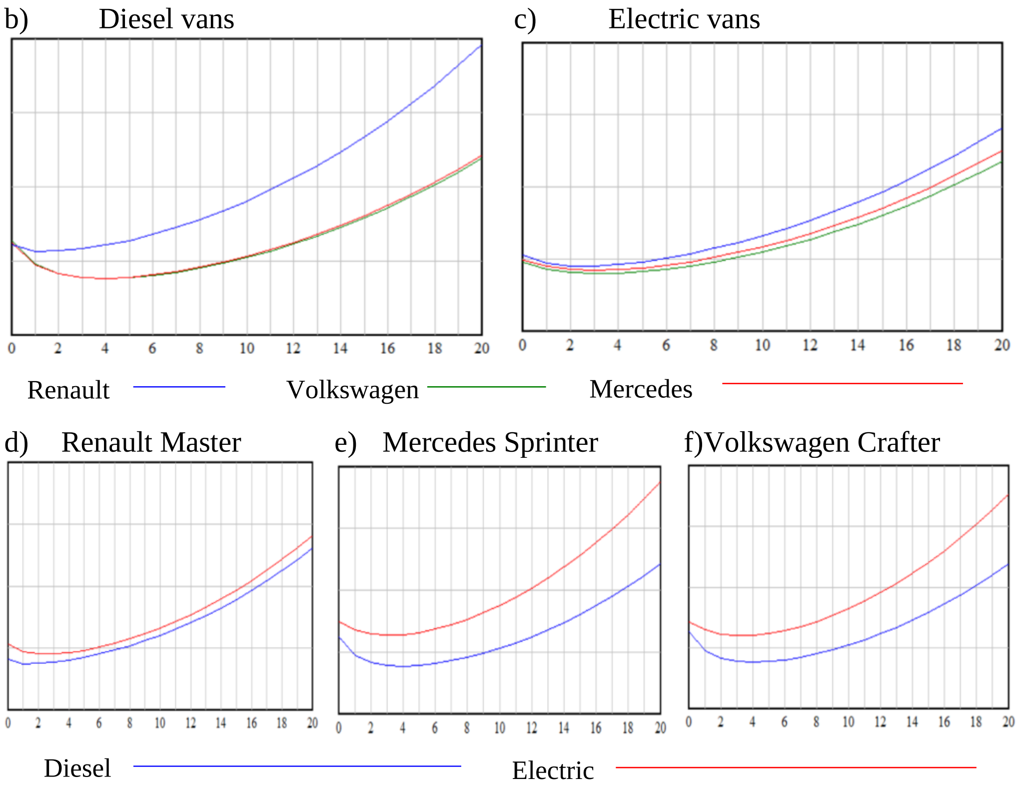
The results of the experiments conducted for a 20-year period are presented in Figure 2. In Figure 2a, the profit achieved by the transport company for all considered options is shown. The findings indicate that the most profitable option is investing in Renault Master delivery vehicles (both diesel and electric versions). The second-best option is Mercedes Sprinter and e-Sprinter vehicles.

In each case, the results highlight the electric versions as more profitable, a difference that is particularly evident in Figures 2d and 2e. Similarly, for Volkswagen Crafter, the electric version yields better profits. However, the simulations suggest that investing in this brand is the least profitable overall, likely due to the higher purchase price and operating costs compared to the other options.

Figure 2. *Profit Trends Under Different Investment Strategies for the Transport Company*

a) All vans





Source: *Authors' elaboration.*

Analysis of Figures 2b and 2c confirms the earlier conclusion that investing in Renault Master vehicles, whether diesel or electric, is the most profitable strategy. The validity of these results is supported by the dominant position of Renault Master in the Polish delivery vehicle market, which the model has maintained since 2018 (Grupa Gezet, 2024).

Recent data for 2023 and 2024 indicate that Renault Master remains the most popular delivery vehicle in Poland (Kozikowska, 2024). In the report by the Polish Automotive Industry Association (PZPM) published in June 2024, Renault Master ranked first in delivery vehicle sales, while Mercedes Sprinter was third, and Volkswagen Crafter ranked ninth (PZPM, 2024). These findings further confirm the credibility of the simulation results and the economic advantage of Renault Master in the studied context.

4. Conclusions

Complex systems, such as enterprises, consist of numerous interacting elements, whose interdependencies often manifest at higher organizational levels, even if they originate at lower levels. Traditional methods are insufficient for capturing all these interconnections simultaneously, especially in the context of rapidly changing internal and external conditions. In contrast, simulation models built using system dynamics methodology provide a robust framework for such analysis. These models allow for:

- Evaluation of long-term trends in elements affecting the company's performance under various strategic decision scenarios.
- Prediction of environmental changes' impacts on the quality and efficiency of core processes within the company.
- As demonstrated by the presented example model, these capabilities make system dynamics models a valuable source of information for designing a company's business strategy.

It should be noted that the experimental setup for the example model is relatively limited compared to what would be required to comprehensively test various possibilities—even within the scope of the six previously mentioned attributes. In a full-factorial design, multiple values would need to be assigned to each attribute (Naylor, 1971, pp. 165-167).

Assigning a single value to each attribute generates one system state. The total number of states in a full-factorial system is the product of the number of possible values for each attribute and the number of attributes considered. If we have k attributes, each taking n values, the total number of system states is n^k. For a transport company model considering six attributes, each with four sets of values, the model would need to be solved for 6^4= 1296 states. This results in a highly time-consuming experimental process.

This inconvenience can be alleviated by implementing a well-designed genetic algorithm, which selects the optimal set of attribute values according to a specified objective function (known in genetic algorithms as the fitness function).

This approach reduces computational complexity while maintaining robust analytical insights. Models developed with this methodology can be further expanded to include additional attributes or variables, making them more flexible and adaptable to the dynamic operating conditions of the enterprise. Future work on the model will continue in this direction.

Additionally, the integration of more advanced analytical techniques, such as machine learning algorithms, could further enhance forecast accuracy and the efficiency of simulation models.

By incorporating such techniques, these tools could support decision-making processes at an even higher level of detail and complexity, improving strategic and operational outcomes for businesses.

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