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System Dynamics Modeling and Fuzzy MCDM Approach as Support for Assessment of Sustainability Management on the Example of Transport Sector Company

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Abstract: Contemporary challenges for development should involve a sustainable approach. One of the important sectors where such challenges are observed is transport. In a wide range of studies addressing environmental, social, and economic dimensions of sustainability, an approach that combines these dimensions as an integrated technique to assess sustainable development of passenger rail transport organizations is still lacking. The first aim of the presented research is to offer a relatively comprehensive collection of railway sustainability indicators as well as a novel causal loop. The second aim is to assess and improve sustainable management using a case study of a passenger rail transport company. To model the relationships inside and around the transport company, the system dynamics (SD) methodology was chosen, being the primary contribution of the study. Additionally, the Fuzzy-TOPSIS logic is required to find the most appropriate scenarios that may change future strategies by making them more socially and environmentally friendly. The proposed research may support experts in assessing sustainability management in transport companies and improve their performance considerably.

Keywords: system dynamics; MCDM; Fuzzy-TOPSIS; environmental impact; sustainable management; sustainable transport; energy consumption; triple bottom line

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1. Introduction

When the principle of sustainable development was established, extensive studies were conducted in this field. The main idea behind this concept is to produce a sustainable interaction between three dimensions: financial development, social welfare, and environmental concerns [1]. When considering the problem of the development of companies, each of the above three dimensions should be taken into account. This is specific to the transport sector in particular. Companies that transport people and cargo have to change their development strategies and implement more sustainable solutions.

Due to the necessity of minimizing greenhouse gas (GHG) emissions to prevent environmental issues as much as possible, the sustainability of transport has been a problem studied in this century. Sustainable transport may be defined as the transport of products and passengers while simultaneously providing social and economic well-being and in addition to minimizing negative consequences to society and the environment as a whole [2]. Since transport systems play such a significant part in the social and economic development of nations, sustainability in the transport sector is connected to 8 of the 17 Sustainable Development Goals (SDGs) set by the United Nations (UN) [3]. In any given country, transport networks contribute 3 to 5% to its Gross Domestic Product (GDP) and 5 to 8% to the total employment.

Road transport pollution accounts for 25% of carbon dioxide emissions in a large number of countries [4], and transport, in general, has been the only industry in which CO2 emissions have grown since 1990. There is a number of projects and scientific studies relevant to sustainable transport which were carried out by the industry's policymakers as well as by scholars in the previous decade [5]. Furthermore, several policies were developed with the aim of reducing emissions by 90% by 2050 [6] by considerably increasing transport sustainability. The goal set specifically for highways was to encourage zero and low-emission cars as well as the use of alternative fuels. These policies include transition toward sustainable modes of transport, such as railway, as well as curbing the negative consequences of transport to the environment and public health. Thus, rail transport is regarded as the most sustainable mode of transport, and it serves as the foundation for a sustainable transport system [7]. Despite the fact that rail transport is considered sustainable, railway corporations must strive to enhance their sustainability performance, particularly in developing countries [8]. Given this necessity, the rail sector's increasing inclination toward sustainability has received a lot of attention [9].

In spite of the fact that a considerable number of studies have been conducted in the context of a sustainable transport system, very few methods have been proposed for incorporating the sustainability triple bottom line (TBL) [10,11] attributes and using them in determining the sustainability level of passenger rail transport. To address this critical gap, this study seeks to create a benchmark framework by gathering indicators from a comprehensive assessment of the relevant literature and by categorizing them according to several criteria. The dynamic model of transport systems has been discussed in this paper in detail. Therefore, the characteristics and feedback loops are unique to the management of passenger rail transport systems. In the present study, the system dynamics approach is applied in order to analyze transport systems' characteristics using causal loops, mutual interaction, and inter-dependence feedback. Given the fact that road transport is the major competitor of passenger rail transport, and considering the tolls the former requires, the model proposed in the paper proves innovative. As a second aim of the study, the performance of the selected passenger rail transport company has been simulated with a high degree of precision. In order to devise the best scenarios, each and every attribute that affects the total sustainability level has been taken into consideration, and these attributes have been classified according to the Fuzzy-TOPSIS method.

The contributions and advancements in this study are highlighted as follows:

- Policymakers would be able to evaluate the present sustainability level of the passenger rail transport systems using a proposed sustainability evaluation model that takes into account the triple bottom line (TBL) attributes of sustainability, including social and environmental impact. These TBL characteristics were culled from a large body of research on railway transport systems sorted by specialists. This methodology may be used as a solid foundation for implementing fundamental sustainability steps in a variety of passenger rail transport systems;
- Many details of the dynamic model used in transport systems have been provided. For this reason, the features and feedback loops are specific to rail transport management systems. Since road transport tolls have never been considered before, the money paid in order to use any road has been included in the present study among the important indicators;
- In order to determine the best scenarios affecting the future of the selected rail transport company as well as its sustainability, the Fuzzy-TOPSIS method has been used. This method helps managers to identify appropriate strategies for their companies.

This paper is structured as follows. In Section 2, rail transport sustainability and the Fuzzy-TOPSIS logic have been discussed by reviewing a number of studies focusing on the complexity of transport systems and the Fuzzy-TOPSIS theory. The definition of the problems addressed, and the method proposed, are provided in Section 3. Section 4 contains the case study in question. The possible scenarios have been proposed in the subsequent section, while the results of the simulation have been discussed in Section 6. Conclusions and future research objectives are presented in the last section.

2. Background of Sustainability in Rail Transport Systems, System Dynamics, and Fuzzy-TOPSIS Logic

The purpose of this section is to review recent studies on the sustainability of railway transport systems, system dynamics, and the fuzzy theory, all of which have been combined to build the proposed model. It should be noted that these studies have been reviewed in order to highlight similar studies and to demonstrate the need for the method proposed.

2.1. Background of Sustainability in Transport Systems

The railway is a complex transport system affected by factors such as population, the environment, economy, and other modes of shipment and transport [12]. Traditional techniques used to evaluate and analyze train transport businesses are not recommended due to the complexity of the railway transport system [13]. Traditional evaluation of railway transport typically focuses on a single key indicator, such as sales or income, without considering the need for integrity. For this reason, traditional assessment techniques have been widely criticized, causing new evaluation methodologies to emerge [14].

Multi-criteria methods (MCA), cost-benefit analysis (CBA), life cycle assessment (LCA), and other approaches have been used to analyze the sustainability of transport [15]. A number of indicators are used to keep track of activities and trends, as well as to compare various areas, options, strategies, and aims for transport sustainability [16]. There are papers and studies in the literature on transport sustainability that offer a variety of indicators of the concept. In this regard, one could refer to the study of Nicolas et al. [17] suggesting a set of indicators that take into consideration the three aspects of sustainability: economic, environmental, and social. They have reported on the findings of an exploratory study financed by Renault Automobile Manufacturers, which was conducted to determine the feasibility of and utility value of developing such sustainable mobility indicators. The indicators established for comprehensive and sustainable transport planning are discussed by numerous authors, including Litman, and Burwell in [16,18]. Pregl et al. in [19] focus on using transport sustainability indicators to evaluate and analyze transport activities in the European Union (EU). Some researchers propose a country- or city-level indicator system for evaluating and monitoring transport sustainability [15,20–22]. The long-term sustainability of urban passenger transport networks is evaluated using data from most cities in [23,24]. There are studies that employ fewer indicators to assess transport sustainability. Another set of indicators has been considered for the assessment of transport sustainability, considering various systems such as freight transport on a national scale [25–27], road transport [28], urban transport [29,30], transport infrastructure projects [31,32], particular modes of transport [33,34], public transport [26], road and rail systems on a local scale [35], and inland transport on a local scale [24,31,36]. Additionally, a few indicators regarding roads and railways have also been employed to evaluate the sustainability of these systems [37].

With regard to the approaches and methods used to analyze the sustainability of railway transport systems as well as their implications and correlations, one can speak of certain relevant instances mentioned in the literature. Shiau et al. [22] proposed a methodology for assessing indicators of transport sustainability, which was then investigated by structural equation modeling and statistical tests in [29]. Chou et al. [38] also looked at the cause-and-effect relationship between the performance indicators applied in high-speed rail transport. Saleem et al. [39] evaluated the influence of air and rail transport indicators on environmental degradation indicators. In yet another study, social media was used to assess sustainable urban transport indicators [40].

2.2. System Dynamics Modelling

One of the areas of system theory is the dynamics of systems, representing a framework for analyzing and controlling complex feedback systems. These systems may be relevant to a wide range of disciplines, including business, economics, environmental studies, energy management, urban challenges, and other social and human concerns [41,42]. Business environments are changing and becoming increasingly competitive. Consequently, businesses must be more adaptable and flexible in order to keep up with the ever-changing surroundings, giving them an advantage over their competitors [43]. J. Forrester from M.I.T. established the first system dynamics method in the early 1960s [44]. Forrester came up with the concept to design and develop these systems while working on a project for General Electric. The employer's major concern in this project was the factors that affected inventory variations and company-related labor expenses. Forrester's study on that subject led to the realization that the fundamentals employed in systems control in electrical engineering and mechanics may also be used in the analysis of social systems. This method generates a picture of a system based on the existing feedback and feedback loop delays. The behavior of complex physical, biological, and social system dynamics is easily understood [45]. It may be inferred that the most important concept in describing system dynamics is that feedback and delays cause the system's behavior to become dynamic [46].

Outlining issues, creating theories, developing a model simulation, assessing the model, and designing evaluation and policy criteria are all examples of the System Dynamics (SD) methods. Figure 1 depicts the various steps involved in running an SD model as a general approach. Stock elements, flow elements, as well as auxiliary and constant variables are all included in this model, which simulates the flow of resources and the measures taken [47].

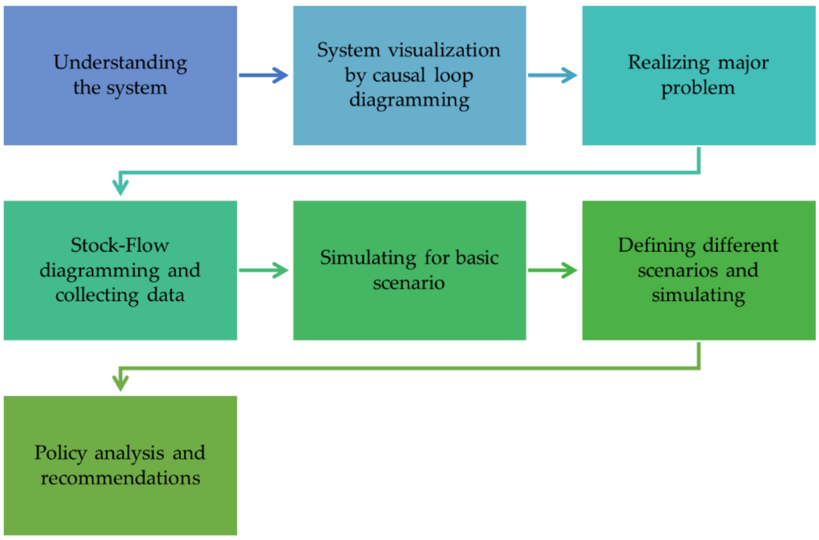


Figure 1. General steps for executing an SD model.

Railway transport is a complex system affected by a number of factors, including the environment, economy, and society. The development of railway transport systems should be coordinated with a comprehensive railway transport assessment [48].

2.3. Fuzzy-TOPSIS Method

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis approach created by Hwang and Yoon in 1981, with updates by Yoon in 1987 and Hwang, Lai, and Liu in 1993. TOPSIS is based on the premise that the best option should be the one with the smallest geometric distance from the positive ideal solution (PIS) and the largest geometric distance from the negative ideal solution (NIS). It is a compensatory aggregation approach that compares a collection of options by assigning weights to each criterion [49].

In multi-criteria situations, the relevant parameters or criteria are frequently in disparate dimensions, which can cause assessment difficulties. As a result, a Fuzzy system is required to prevent this problem [50]. The use of fuzzy numbers in TOPSIS for criterion analysis simplifies the assessment process. In consequence, Fuzzy-TOPSIS is a straightforward, realistic model and compensatory method that includes or excludes alternative solutions based on hard cut-offs [49,51].

3. Proposed Method

3.1. Problem Definition and Proposed Model

Railway transport is critical to a country's economic and social development. However, this mode of transport causes air pollution and consumes energy. The key notion is to strike a balance between the negative and positive features of rail transport in order to reach sustainability. In this approach, eco-sustainable rail transport does not affect the environment or public health negatively. Furthermore, it is capable of adapting to the demands of future generations. Despite the fact that several studies focusing on defining sustainability and its dimensions in passenger rail transport have been done, there is a dire need for a unified method that simultaneously assesses the sustainability performance condition and identifies the challenges and impediments that are reducing total sustainability. The proposed approach will help in filling these gaps. Firstly, a unique measuring tool is proposed based on data collected from various dimensions of sustainability in passenger rail transport systems. It enables the System Dynamics model to be developed. Secondly, the relationship between important indicators related to different dimensions of sustainability is simulated, and their effects on each other are evaluated. This approach also entails simulation of the cause-and-effect relationships between important indicators such as road transport tolls. Thirdly, to ensure that the selection of scenarios is reliable, the Fuzzy-TOPSIS method is used. Thus, the proposed method combines the use of SD for model building and simulation of scenarios with the assessment performed with the use of Fuzzy-TOPSIS. The procedure proposed in this research is demonstrated in the flowchart in Figure 2. It should be mentioned that these methods, like any other [52–54], have some advantages and limitations. Some of them are included in Table 1.

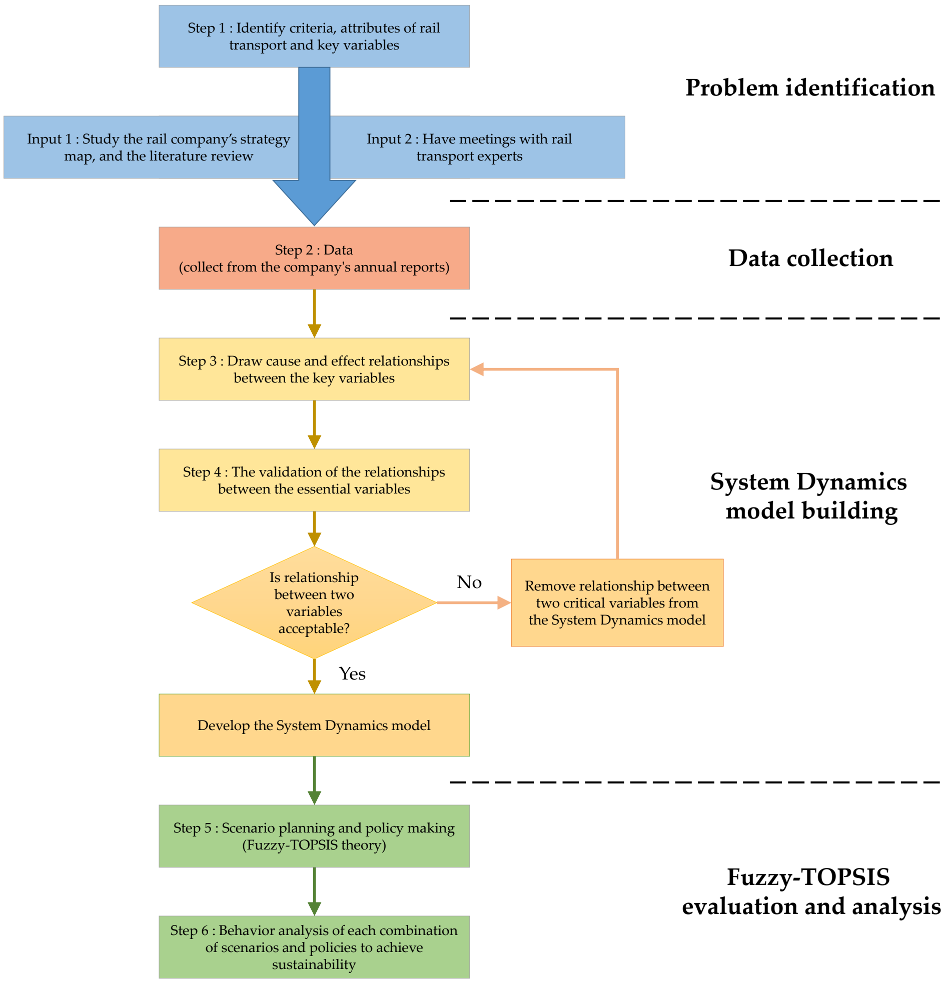


Figure 2. Research procedure.

Table 1. Selected advantages and disadvantages of proposed methods.

Method	Advantages	Disadvantages
System Dynamics	It can be used to solve issues that are deemed to be *data deficient*. The database used to conceptualize and formulate the System Dynamics models is substantially larger than the numerical databases used in operations research and statistics modeling. By drawing progressively complex causal loop diagrams, this strategy can help in obtaining insight and comprehension in a confusing scenario.	Although a System Dynamics model may capture a lot of variation in the changing values of its variables, it can only run one version of a situation at a time. Distinct stakeholders or organizations with different cultural or political agendas may bring different assumptions to the table, resulting in a drastically different image. When modeling real-world scenarios with many variables, a system dynamics diagram may get rather complicated.
Fuzzy-TOPSIS	It simulates a sensible human's logical answer, uses a basic computation procedure, rates all possibilities at the same time, and provides alternative performance measurements.	A significant divergence of one indicator from the optimal solution has a significant impact on the outcomes, and the approach is appropriate when the indicators of alternatives do not differ significantly.

3.2. Key Indicators and Concepts of Railway Sustainability

According to [16], the sustainability metrics applied to transport should comprise indicators representing various impacts, aims, and targets. Indicators ought to be simple to compute, comprehend, compare, measure, and utilize, as well as valuable to stakeholders and relevant to decision and policy makers. It should also be noted that relative significance and mutual causation are essential aspects of the indicators [55]. The sustainability of a railway company depends on a number of aspects, which are grouped into themes (Table 2). Furthermore, these aspects may be categorized as part of the three dimensions of sustainability: financial, social, and environmental. A balance between these indicators should be struck in terms of achieving sustainability of a railway company.

Table 2. Selected rail company sustainability themes and corresponding indicators.

Financial Dimension	Society Dimension	Environmental Dimension
Income from renting wagons [56]	Number of satisfied users [30,57]	Energy consumption [58,59]
Income from selling tickets [56,60]	Quality of services [57,61]	CO_2 emission from railway passenger transport [58]
Energy costs [62,63]	Road transport tolls (railway passenger transport experts)	Density of railway network relative to area [58]
Operating costs [56,60]	Annual number of railway accidents [57]	-
Non-operating costs [62,64]	Number of fatalities [57,65]	-
Investment in buying new wagons and locomotives (Raja's strategy map)	Number of available trips per year [65,66]	-
-	Number of complaints (Raja's strategy map)	-
-	Number of customers [57]	-

3.3. The Cause and Effect Graph

In SD, causal loop diagrams represent feedback loops, causal links, and variables, among other essential parameters. Since cause-and-effect diagrams are straightforward, qualitative interactions among system components and feedback loops are shown via causal loop diagrams. Positive arrows indicate that changes happen in the same direction whereas negative arrows are used to demonstrate that changes occur in the opposite direction. In feedback loops, some variables can affect other variables. In fact, if a variable changes, the whole loop is affected because of the interaction between variables. Positive feedback loops mean that causal processes reinforce the original change whilst feedback loops are named negative when variable changes counter one another [67].

The causal loop diagram provided in Figure 3 indicates inter- and intra-relationships along with the feedback in the financial dimension. R1 reinforces a feedback loop while B1 and B2 represent balancing feedback loops. Ticket prices are dependent on the quality of services and purchasing new wagons. The rationale behind ticket sales is that government policies that determine the rate of road transport tolls should be changed, and the impact of these tolls taken into consideration.

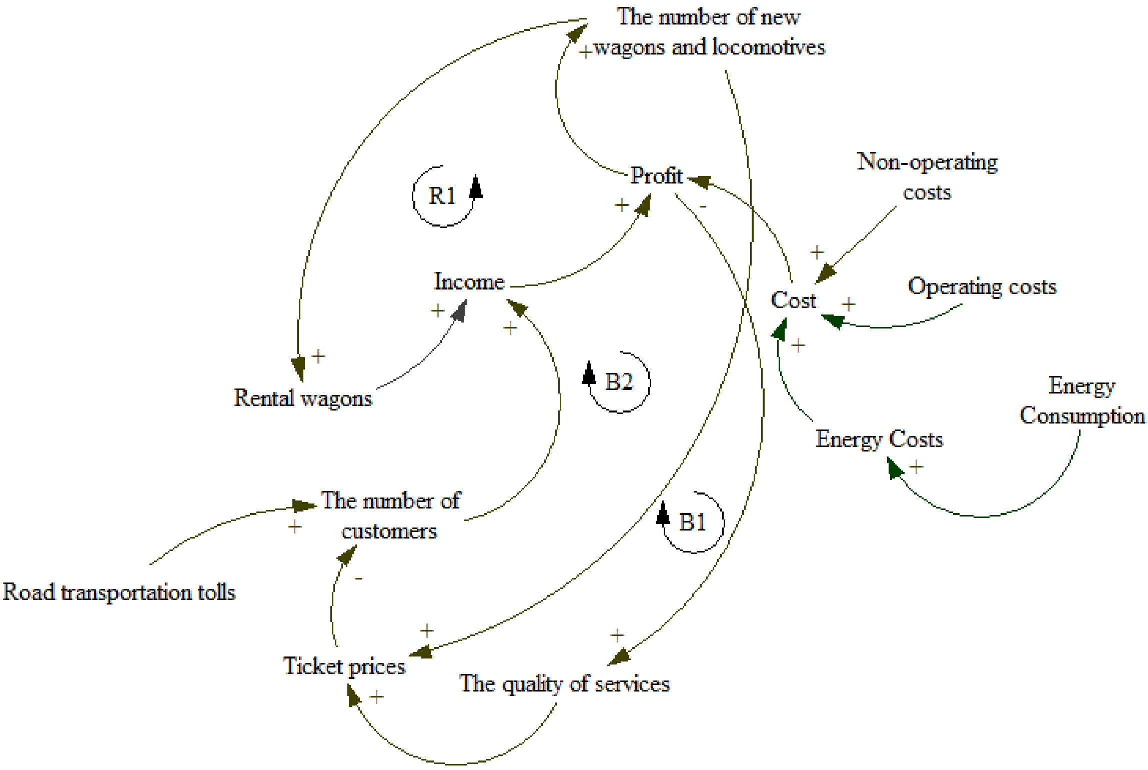


Figure 3. Causal loops in the financial dimension.

R1 is a reinforcing loop which indicates that all indicators in the loop have the same influence on each other ($\xrightarrow{+}$). Whenever the railway company decides to purchase new wagons, the wagon rental income shifts in the same direction as the indicator of new wagon purchase. In reality, as the number of new wagons bought rises, so does the number of renting wagons. Furthermore, when the wagon rental income changes, the income of the entire company changes in the same direction as the income from wagon rental, forming a positive arrow between these two indicators. As a final indicator in this loop, the profit of the company changes in the same direction as the income. In general, if income goes up, profit should rise too. As a consequence, the reinforcing loop is completed when the last indicator, i.e., profit, is adjusted and all arrows between indicators become positive.

B1 is a balancing loop in which at least one indicator is altered in the opposite direction. In this loop, when the railway company purchases new wagons, ticket prices rise ($\xrightarrow{+}$). This means that ticket prices should be determined by considering the types of wagons purchased. The number of consumers falls as ticket prices rise, which is why the number of customers changes in the opposite direction ($\xrightarrow{+}$) of the ticket prices indicator. Additionally, if the number of consumers decreases, the income should drop as well, therefore the income indicator changes in lockstep with the number of customers. Consequently, as income fluctuates, the last indicator, profit, goes up and down in the same direction. As a result of one opposing direction, balancing loop B1 is generated.

The second balancing loop in this diagram is B2, which signifies that when the quality of services improves, the ticket pricing indicator rises ($\xrightarrow{+}$). B2 is similar to B1 in that the number of consumers falls as ticket prices rise, causing the number of customers to fluctuate in the other manner ($\xrightarrow{-}$). As a result, two indicators, income and profit, vary in the same way as the number of customers changes.

In this diagram, road transport tolls, which had previously not been taken into account, are shown to affect ticket prices, which makes the causal loop meaningful.

In Figure 4, the number of passengers is directly related to the number of those who were satisfied as well as to customer loyalty. If a corporation intends to increase its revenue, it should obviously attract more customers, which heavily depends on the quality of its services and the number of new wagons and locomotives.

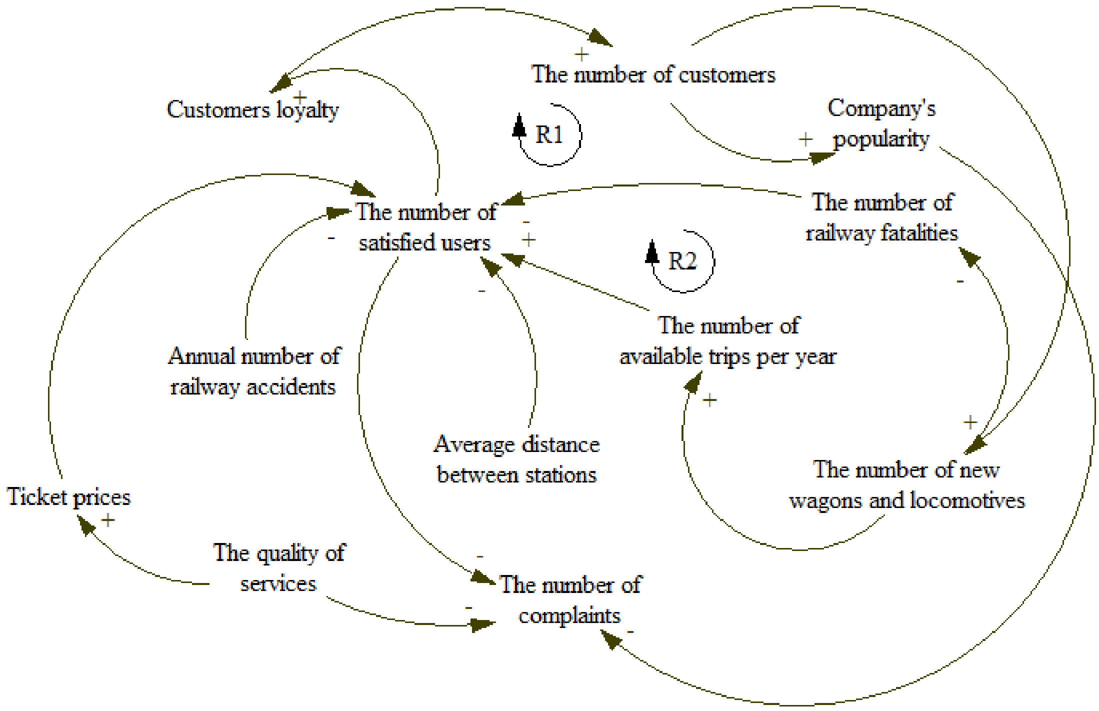


Figure 4. Causal loops in the social dimension.

Once the number of new wagons and locomotives in R1 (reinforcing loop) has been modified, the indicator representing the number of railway fatalities changes in the opposite direction ($\xrightarrow{-}$), meaning that as the number of new wagons and locomotives grows, the number of railway deaths drops. Following a shift in the number of railway deaths, the number of satisfied users follows suit ($\xrightarrow{+}$). When the number of satisfied users changes, two indicators, i.e., customer loyalty and the number of customers, being the last indicators in the loop, shift in the same direction ($\xrightarrow{+}$) as the number of satisfied users.

Loop R2 indicates that if the number of new wagons and locomotives increases, it is possible to achieve a rise in the number of available trips ($\xrightarrow{+}$), also leading to a higher level of satisfaction among passengers. Once the number of satisfied users has changed, customer loyalty and the number of customers, being the last indications, move in the same direction ($\xrightarrow{+}$), as mentioned in R1.

Some variables, such as service quality, ticket price, and customer satisfaction, are defined in the social dimension. They affect the vital component of the number of customers. All these variables along with the types of their effects have been shown in Figure 4.

As shown in Figure 5, the increase in energy consumption leads to growth in railway company costs ($\xrightarrow{+}$), implying that costs have risen in lockstep with changes in the energy consumption indicator. Profits are influenced in the opposite manner ($\xrightarrow{-}$) following cost changes. As a result of decreasing profitability, the number of new wagons and locomotives purchased decreases ($\xrightarrow{+}$). The last indicator, the change in the number of new wagons and locomotives, causes energy consumption to shift in the opposite direction. As a consequence, the R1 causal loop (reinforcing loop) is formed.

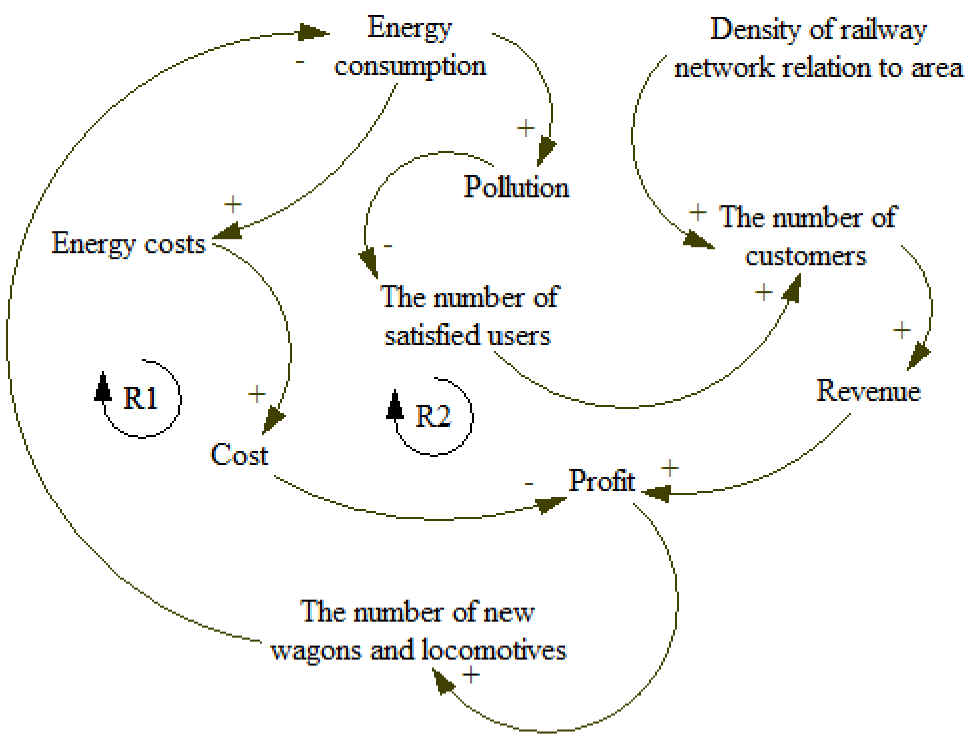


Figure 5. Causal loops in the environment dimension.

In R2 (the second reinforcing loop), when energy consumption increases, the overall average pollution rises ($\xrightarrow{+}$), causing the number of satisfied customers to decrease ($\xrightarrow{-}$). Following a change in the number of satisfied users, the total number of customers changes in the same direction as the indicator of satisfied users ($\xrightarrow{+}$). Altering revenue and profit indicators is the same as changing the number of customers, therefore if the number of customers falls, revenue and profit fall as well. The number of new wagons and locomotives changes in lockstep with the profit indicator, while the effect of new wagons and locomotives on the energy consumption indication is the inverse ($\xrightarrow{-}$).

Explaining and drawing the cause-and-effect graph of a system is essential to designing and analyzing system dynamics. The software used in this study is Vensim P.L.E.

A reciprocating relationship frequently occurs between variables, which means that each variable affects the dynamic increase and decrease of other variables in cause-and-effect relationships. According to the concept of system dynamics, these effects are taken into consideration along with estimated delays, which are included in the design and quantitative calculations performed by the Vensim simulation software as well as in the use of the functions referred to in the following section.

The next step taken while creating a system dynamics model is to convert the cause and effect graph into a state and flow diagram, easily intelligible for computers.

3.4. Passenger Railway Transport Flow Chart

Mathematical relationships between diagram elements are determined by flow charts while a causal loop diagram indicates the feedback between system components [68]. In system dynamics, stock and flow are two essential concepts. The accumulation of stocks over time represents a system's state. Activities, such as income, are characterized by flows that cause stock changes. Flows tend to hold quantities and change stocks invariably. Equation (1) represents the general state of the stock formula.

$$\mathrm{Stock(t)} = \int [\mathrm{Inflow(t)} - \mathrm{Outflow(t)}]\mathrm{dt} + \mathrm{Stock(t_0)}, \quad (1)$$

A generic structure of the stock-flow diagram is shown in Figure 6.

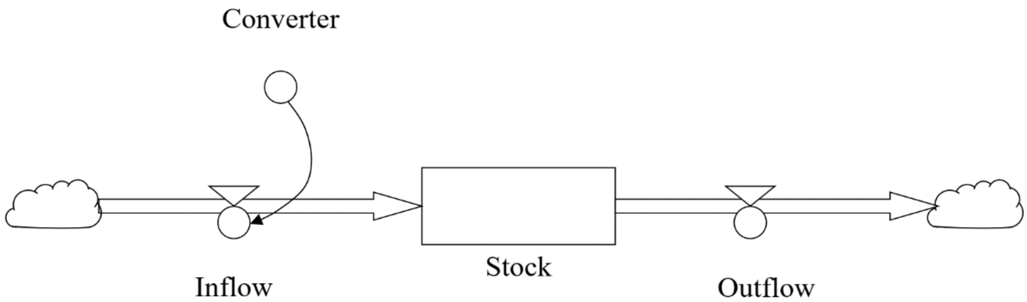


Figure 6. Stock & Flow Diagram (SFD)—generic structure.

Figure 7 consists of two levels and twenty-three auxiliary variables. Level variables are accumulative (rectangular boxes), e.g., profit. Other elements are normal auxiliary variables, which can be rates, or constant, independent and dependent variables. Rates, constant variables, and independent elements are introduced into the system, which can hold statistical data. Dependent variables are calculated based on their relationship with other system elements. There are a host of variables and factors in complex systems, yet we should only consider and focus on the variables and factors which are signs of a problem that one wishes to study. Such a complex system, addressed in the case study provided in this paper, can be broken down into several sub-systems, as shown in Figures 3–5.

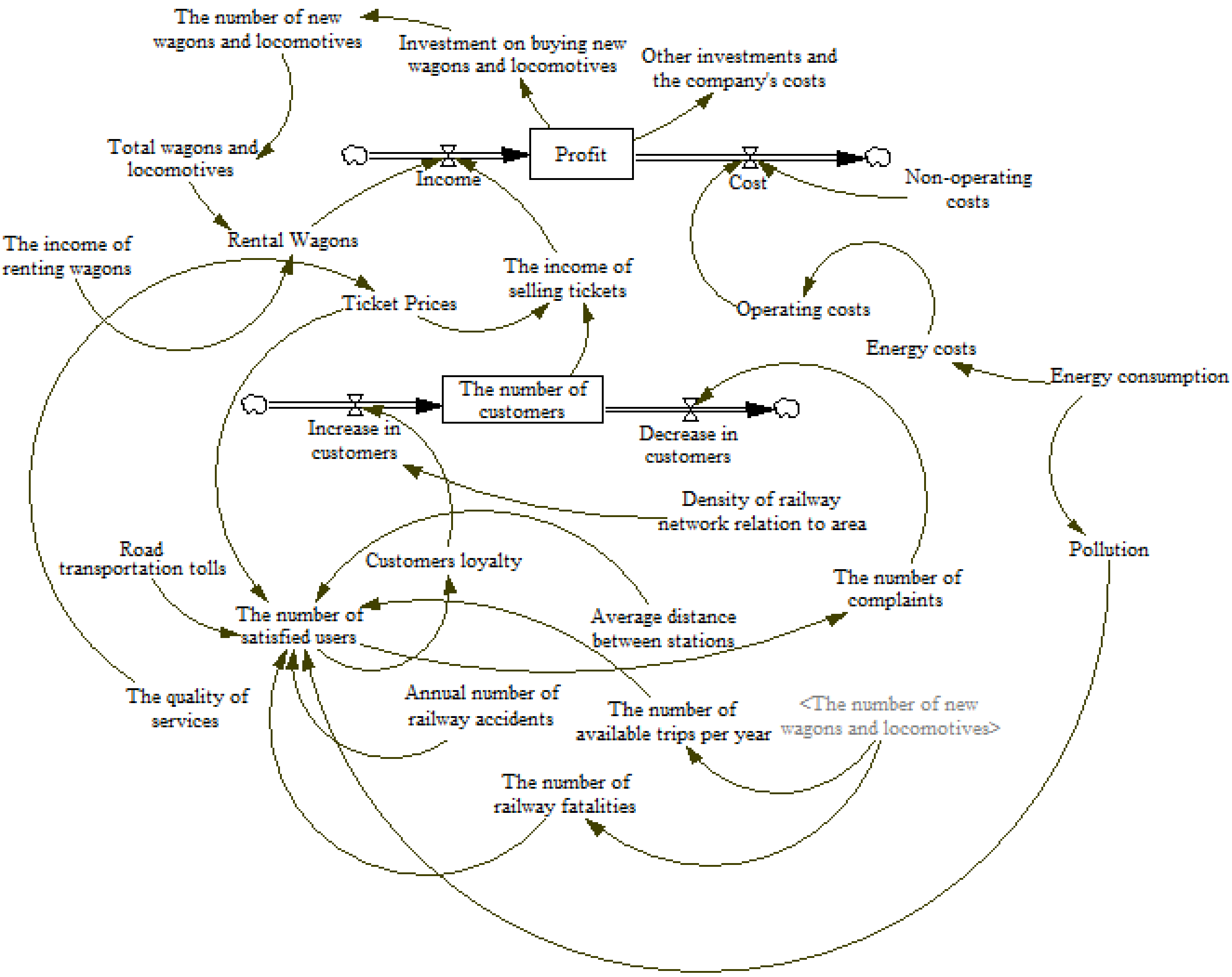


Figure 7. All model dimensions in Vensim.

Self-sustainable management of railway companies comprises three dimensions: (1) financial, (2) social, and (3) environmental. Figure 7 depicts all the dimensions which have causal feedbacks on one another. There are relationships between all dimensions that either bring profits or cause losses. The significant element, i.e., road transport tolls, is considered to show precise relationships between dimensions. Road transport tolls can determine ticket prices, income, and costs. The overall expenditure and income of transport companies, as well as the price of tickets, illustrate the state of a given corporation's sustainable management. These elements have significant effects on other dimensions that determine the rate of profits and losses.

3.5. Ranking of Scenarios—Steps of Fuzzy-TOPSIS

The use of Fuzzy logic and a sustainability index will bring the multi-layered, step-by-step strategy outlined by [69] to a conclusion:

Step 1: it is recommended that the decision-maker readily evaluate the relevance of each criterion and the ratings of alternatives with respect to numerous subjective criteria by using the linguistic variables (given in Tables 3 and 4). A linguistic variable is a variable whose values are natural or artificial language words or sentences. For example, if the values of age are believed to be the fuzzy variables *not young*, *young*, and *very young*, rather than the actual numbers, age is a linguistic variable. The idea of a linguistic variable allows for the approximate representation of events that are too complicated or ill-defined to be described in conventional quantitative terms. The linguistic method has a wide range of applications in humanistic systems, including artificial intelligence, linguistics, human decision processes, pattern recognition, psychology, law, medical diagnosis, information retrieval, economics, and other subjects. For modeling uncertain systems in industry, fuzzy sets and fuzzy logic are valuable mathematical tools. A crisp set gets extended into a fuzzy set. Crisp sets enable either complete or partial membership, whereas fuzzy sets allow partial membership. Depending on the scenario, several fuzzy numbers can be used. Because of their computational simplicity, triangular fuzzy numbers (TFNs) are often used in applications, and they are beneficial in boosting representation and information processing in a fuzzy environment. TFNs are used in the fuzzy TOPSIS approach in this study. Triangular fuzzy numbers are defined as a triplet (a, b, c), with the parameters a, b, and c indicating the smallest possible value, most promising value, and largest possible value, respectively, that characterize a fuzzy event. These fuzzy ratings and the weight of each criterion are linguistic variables that can be described by triangular fuzzy numbers, $\widetilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\widetilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$.

Table 3. Linguistic variables for the importance weight of each criterion.

Very Low (VL)	(0, 0, 0.1)
Low (L)	(0, 0.1, 0.3)
Medium Low (ML)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium High (MH)	(0.5, 0.7, 0.9)
High (H)	(0.7, 0.9, 1)
Very High (VH)	(0.9, 1, 1)

Table 4. Linguistic variables for the ratings.

Very Poor (VP)	(0, 0, 1)
Poor (P)	(0, 0, 1)
Medium Poor (MP)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Medium Good (MG)	(5, 7, 9)
Good (G)	(7, 9, 10)
Very Good (VG)	(9, 10, 10)

Step 2: if a group of decision-makers comprises K members, the relevance of the criteria and the ranking of options based on each criterion may be computed as follows:

$$\widetilde{X}_{ij} = \frac{1}{K}\left[\widetilde{X}_{ij}^{1}\ (+)\ \widetilde{X}_{ij}^{2}\ (+)\ \ldots\ (+)\ \widetilde{X}_{ij}^{K}\right], \tag{2}$$

$$\widetilde{W}_{ij} = \frac{1}{K}\left[\widetilde{W}_{ij}^{1}\ (+)\ \widetilde{W}_{ij}^{2}\ (+)\ \ldots\ (+)\ \widetilde{W}_{ij}^{K}\right], \tag{3}$$

where $\widetilde{X}_{ij}^{K}$ and $\widetilde{W}_{ij}^{K}$ are the Kth decision maker's rating and importance weight.

Let $A_1, A_2, \ldots, A_m$ be possible alternatives and $C_1, C_2, \ldots, C_n$ be criteria with which alternative performances are measured. A Fuzzy multi-criteria decision-making method for selecting problems can be concisely represented in matrix format as:

$$\widetilde{D} = \begin{bmatrix} \widetilde{X}_{11} & \widetilde{X}_{12} & . & \widetilde{X}_{1n} \\ \widetilde{X}_{21} & \widetilde{X}_{22} & . & \widetilde{X}_{2n} \\ . & . & . & . \\ . & . & . & . \\ \widetilde{X}_{m1} & . & . & \widetilde{X}_{mn} \end{bmatrix}$$

$$\widetilde{W} = \left[\widetilde{W}_1, \widetilde{W}_2, \ldots, \widetilde{W}_3\right]$$

where $\widetilde{X}_{ij}$, $\forall$i,j is the fuzzy rating of alternative Ai (i = 1, 2, ... , m) with respect to criterion C_j, and $\widetilde{W}_j$ (j = 1, 2, ... , n) is the weight of criterion C_j.

Step 3: the linear scale transformation is used to turn the numerous criterion scales into a comparable scale in order to provide compatibility between objective criteria assessment and linguistic ratings of subjective criteria. As a result, we can obtain normalized fuzzy decision matrix R as:

$$\begin{gathered} \widetilde{R} = [\widetilde{r}_{ij}]m * n \\ \widetilde{r}_{ij} = \left(\frac{a_{ij}}{C_j^*}, \quad \frac{b_{ij}}{C_j^*}, \quad \frac{c_{ij}}{C_j^*}\right), \ j \in B,\ \widetilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \quad \frac{a_j^-}{b_{ij}}, \quad \frac{a_j^-}{a_{ij}}\right), \ j \in C \\ C_j^* = \max c_{ij} \text{ if } j \in B, \\ a_j^- = \min a_{ij} \text{ if } j \in C, \end{gathered} \tag{4}$$

where B and C are the set of benefit criteria and cost criteria, respectively.

The property that the ranges of normalized fuzzy numbers correspond to [0, 1] is preserved using the normalizing approach outlined above.

Step 4: compute the weighted normalized fuzzy decision matrix.

$$\widetilde{V} = (\widetilde{v}_{ij}),\ \widetilde{v}_{ij} = \widetilde{r}_{ij} * \ wj \tag{5}$$

Step 5: compute the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS). The FPIS and FNIS are calculated as follows:

$$A* = (\widetilde{v}_1^*, \widetilde{v}_2^*, \ldots, \widetilde{v}_n^*), \text{ where } \widetilde{v}_j^* = \max\{v_{ij}\} \tag{6}$$

$$A- = (\widetilde{v}_1^-, \widetilde{v}_2^-, \ldots, \widetilde{v}_n^-), \text{ where } \widetilde{v}_j^- = \min\{v_{ij}\} \tag{7}$$

Step 6: compute the distance from each alternative to the FPIS and FNIS.

$$d_i* = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^*\right),\ d_i- = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^-\right) \tag{8}$$

Step 7: compute the CC_i closeness coefficient for each alternative. For each alternative Ai, we calculate the closeness coefficient CC_i as follows:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \tag{9}$$

Step 8: rank the alternatives. The alternative with the highest closeness coefficient represents the best alternative.

4. Case Study

In order to make the proposed method clearer, a computational example was prepared. A single country in the Middle East and North Africa (MENA) region, namely Iran, was selected as the research area. To make the study more interesting, the largest passenger rail corporation in Iran, i.e., Raja Railway Transport Corporation (RRTC), was chosen. The company was founded in 1997, and it carries around 16 million people annually [70]. Within Iran, this corporation accounts for roughly 7% of all passenger transport [70]. Raja's policy is based on optimizing facility usage, continuous improvement, boosting efficiency to increase organizational excellence, attracting a higher number of passengers, and enhancing the quality of passenger service.

Moreover, according to the insights of the transport professionals consulted at Raja, road transport is the main competitor for rail transport. In Iran, passenger rail transport companies face a lot of issues because of the low rates of road transport tolls. Being the largest rail transport company and an operator of one of the most important means of transport for the cities in Iran to develop, Raja has suffered considerable losses on account of such low road transport tolls. Large passenger rail transport companies stand a chance to negotiate the rates of road transport tolls with government policymakers. Indeed, when a variety of rail transport companies are not able to make a profit, government policymakers should change their strategies accordingly to determine adequate rates of road transport tolls. Finding appropriate strategies to minimize sudden, unexpected, and negative changes is another problem that Raja should address.

Iranian railway companies are considerably affected by the rates of road transport tolls. Still, the government maintains them at a low level, which makes passenger rail transport companies, such as Raja, incapable of attracting higher numbers of passengers. For this reason, governmental transport policies have a negative effect on Raja's profits.

The case study is based on data from 2016 to 2019. Data from 2020 and 2021, as in most other transport companies, were distorted due to the COVID-19 pandemic. The behavior of travelers during this time changed significantly. Part of them abandoned traveling by public transport, while some companies chose to work from home, which also reduced the number of trips. Therefore, analyzes of the pandemic period require separate studies, such as in [71].

The fixed values of individual parameters have been provided in Table 5.

Table 5. Fixed values assumed for the model [70].

Lower Limit	Variable	Upper Limit
30,000	Energy consumption (thousands of liters)	35,000
1000	Road transport tolls (rials (Iran's currency))	1200
13,000	Non-operating costs (million rials)	60,000
40	Annual number of railway accidents (people)	50
42	Quality of services (percent)	55
250	Income from wagon rental (thousands rials)	400
60	Average distance between stations (km)	70
0.9	Density of railway network relative to area (1/km)	1

Once the fixed values had been determined, selected formulas were defined for independent variables, for example, the equation for wagon rental shown in Figure 8, which is affected by the income from the rental of wagons and the total number of wagons and locomotives. Since other companies rent half of the wagons and locomotives, the relevant number should be multiplied by 50 percent.

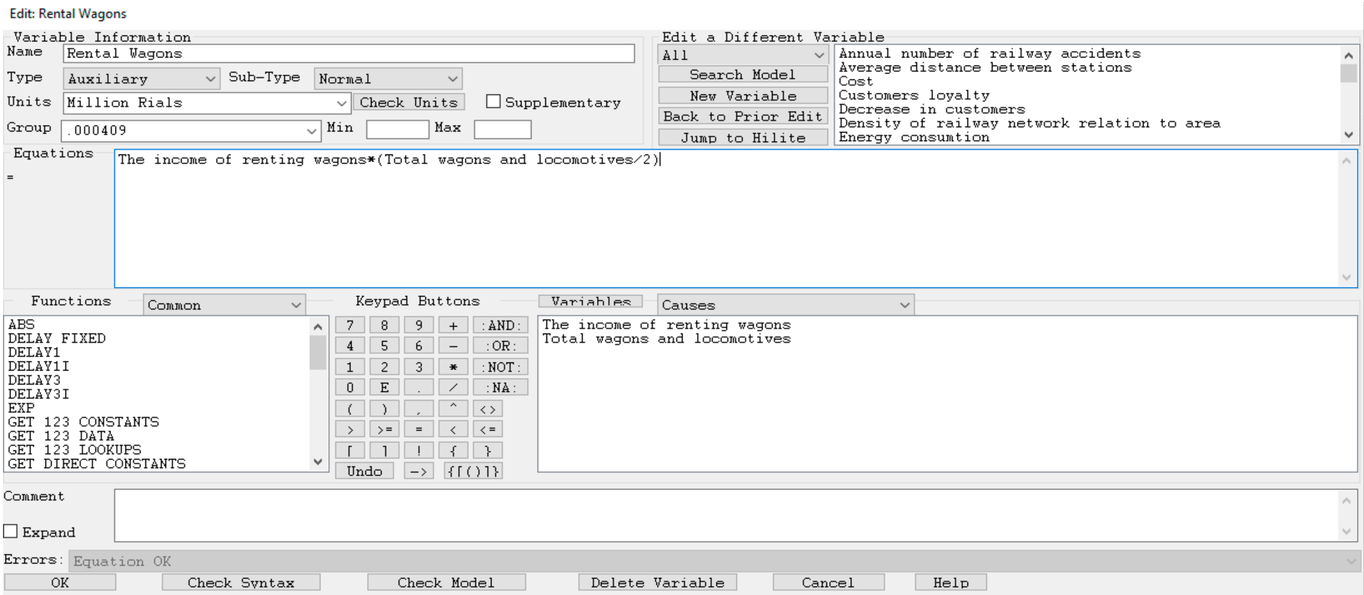


Figure 8. The equation for wagon rental at Vensim.

Raja's simulation model is a simplified representation of a real system which shows that thorough evaluation or validation of a model is impossible. Therefore, validation of Raja's model is done in relative terms. This section addressed the relative model validity. The outputs of the simulated model for financial, social, and environmental dimensions and their actual values from 2016 to 2019 were compared, and the relevant results have been provided in Tables 6–9. There is not much difference between the actual and the predicted values provided in this section. Once the relative reliability of the model results is ensured, this model can be used for simulation. The road transport toll rate, being essential for determining the number of customers, is zero in the actual model. Raja never considered this to be an element that determined the rate at which the number of passengers increased or decreased.

Table 6. Comparison of actual and predicted results for the financial year 2016.

Description	Unit	Actual Performance [67]	Predicted Results of the Dynamic Model	Error ∣(Predicted-Actual)/Actual∣
Profit (Loss)	Million Rials	1,795,441	2,000,000	0.110
Income	Million Rials	6,027,974	6,011,420	0.003
Cost	Million Rials	4,232,533	6,499,350	0.540
Number of customers	Million People	10.20	9.00	0.120
Number of satisfied customers	Million People	10.80	11.23	0.040
Customers' loyalty	Per cent	68	64	0.060
Number of railway fatalities	People	42	40	0.050
Quality of service	Per cent	49	50	0.020
Income from selling tickets	Million Rials	2,592,540	2,010,004	0.220
Number of complaints	Number	870	1000	0.150
Number of new wagons and locomotives	Number	38	42	0.110

Table 7. Comparison of actual and predicted results for the financial year 2017.

Description	Unit	Actual Performance [67]	Predicted Results of the Dynamic Model	Error | (Predicted-Actual)/ Actual |
Profit (Loss)	Million Rials	3,770,080	1,512,070	0.600
Income	Million Rials	9,867,234	10,917,400	0.110
Cost	Million Rials	6,097,154	6,466,711	0.060
Number of customers	Million People	14.9	15	0.010
Number of satisfied customers	Million People	12.00	11.18	0.070
Customers' loyalty	Per cent	65.00	63.48	0.020
Number of railway fatalities	People	44	41	0.070
Quality of service	Per cent	53	48	0.090
Income from selling tickets	Million Rials	3,791,191	3,625,980	0.040
Number of complaints	Number	1004	999	0.005
Number of new wagons and locomotives	Number	28	30	0.07

Table 8. Comparison of actual and predicted results for the financial year 2018.

Description	Unit	Actual Performance [67]	Predicted Results of the Dynamic Model	Error | (Predicted-Actual)/ Actual |
Profit (Loss)	Million Rials	7,703,537	5,962,741	0.230
Income	Million Rials	14,472,728	15,707,004	0.090
Cost	Million Rials	6,769,191	6,081,032	0.100
Number of customers	Million People	19.86	21.70	0.090
Number of satisfied customers	Million People	11.00	11.05	0.005
Customers' loyalty	Per cent	62	63.41	0.020
Number of railway fatalities	People	39	42	0.080
Quality of service	Per cent	54	53	0.020
Income from selling tickets	Million Rials	5,424,343	5,158,810	0.050
Number of complaints	Number	990	998	0.010
Number of new wagons and locomotives	Number	110	119	0.080

Table 9. Comparison of actual and predicted results for the financial year 2019.

Description	Unit	Actual Performance [67]	Predicted Results of the Dynamic Model	Error | (Predicted-Actual)/ Actual |
Profit (Loss)	Million Rials	11,162,043	15,588,700	0.400
Income	Million Rials	17,193,753	18,596,071	0.080
Cost	Million Rials	6,031,710	5,356,900	0.110
Number of customers	Million People	25.00	28.00	0.120
Number of satisfied customers	Million People	12.50	11.17	0.110
Customers' loyalty	Per cent	68	66	0.030
Number of railway fatalities	People	39	41	0.050
Quality of service	Per cent	50	51.47	0.030
Income from selling tickets	Million Rials	698,615	614,046	0.120
Number of complaints	Number	995	990	0.010
Number of new wagons and locomotives	Number	121	120	0.010

The Mean Absolute Error (MAE) for the period from 2016 to 2019, as shown in Equation (2), has been calculated at 0.099, which indicates the high accuracy of the simulated dynamic model [72].

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} = \frac{\sum_{i=1}^{n} |e_i|}{n} \tag{10}$$

It is thus an arithmetic average of the absolute errors $|e_i| = |y_i - x_I|$, where I is the prediction and I_i is the true value.

5. Scenarios for the Simulated Model

The main goal of this study is to improve sustainable development at Raja by creating a sustainability indicator and identifying significant roadblocks. This can be accomplished by considering the quality of each dimension. The selection and application of appropriate strategies have a direct impact on the improvement in these dimensions. In order to select relevant scenarios having crucial effects on strategies, this article introduces the Fuzzy-TOPSIS logic. Using this method to select the most appropriate scenario is unique to this study. Table 10 identifies Raja's railway transport sustainability dimensions, sustainability strategies, and scenarios.

Table 10. Raja's sustainability dimensions, strategies, and scenarios.

Railway Transport Sustainability Dimensions	Raja Sustainability Strategies (Criteria)	Scenarios
Social Sustainability	Popularity of the corporation (S_1)	Increase in road transport tolls (S_{11})
		Decrease in the number of complaints (S_{12})
	Safe travel (S_2)	Reduction in the number of railway fatalities (S_{21})
		Reduction in the annual number of railway accidents (S_{22})
Financial Sustainability	Financial development (F_1)	Increase in ticket prices (F_{11})
		Increase in purchase of new wagons and locomotives (F_{12})
		Reduction in operating costs (F_{13})
Environmental Sustainability	Pollution prevention (E_1)	Reduction of energy consumption (E_{11})
		Reduction of air emissions (E_{12})

Following the steps described in Section 3.5, significant scenarios were determined for Raja. In order to find the best scenarios, four experts participated in the judgment of criteria and scenarios.

The decision-makers (D_1, D_2, D_3, and D_4), who are transport experts working at Raja, evaluated the relevance of individual criteria, as provided in Table 11, using the linguistic weighting variables defined in Table 3. Table 12 provides the fuzzy weight of each computed criteria.

Table 11. Linguistic variables determining the relevance of the weights of Raja's criteria.

Criteria \ Decision-Makers	D_1	D_2	D_3	D_4
$\mathbf{S_1}$	VH	VH	VH	VH
$\mathbf{S_2}$	H	VH	MH	H
$\mathbf{F_1}$	VH	VH	H	H
$\mathbf{E_1}$	MH	MH	H	MH

According to Table 3, the abbreviations mean: MH (Medium High), H (High), and VH (Very High).

Table 12. Fuzzy weight of each computed criterion.

Criteria	Weight		
S_1	0.900	1.00	1.00
S_2	0.700	0.875	0.975
F_1	0.800	0.950	1.00
E_1	0.550	0.750	0.925

The decision-makers assessed the rating of alternatives with regard to each criterion, as provided in Table 13, using the linguistic rating variables defined in Table 4. The fuzzy normalized matrix and its weighted matrix were computed as shown in Tables 14 and 15.

Table 13. Linguistic variables for the ratings.

	S_1				S_2				F_1				E_1			
	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4
S_{11}	VG	VG	VG	VG	MP	F	MP	F	VG	VG	VG	VG	P	P	P	VP
S_{12}	MG	G	MG	MG	G	G	G	G	P	P	VP	VP	P	VP	VP	VP
S_{21}	G	MG	MG	MG	VG	VG	VG	VG	P	P	P	P	VP	VP	VP	VP
S_{22}	G	G	G	G	VG	VG	VG	VG	P	VP	VP	VP	P	P	P	P
F_{11}	F	MP	MP	F	P	P	P	MP	VG	VG	VG	VG	VP	P	VP	P
F_{12}	VG	VG	G	G	VG	G	G	VG	VG	G	G	VG	G	G	VG	VG
F_{13}	P	MP	P	MP	G	G	G	G	G	G	VG	G	F	F	F	G
E_{11}	P	P	MP	MP	P	P	P	P	VP	VP	P	P	VG	VG	VG	G
E_{12}	F	F	P	P	P	VP	VP	P	P	P	P	P	VG	VG	VG	VG

According to Table 4, the abbreviations mean: VP (Very Poor), P (Poor), MP (Medium Poor), F (Fair), MG (Medium Good), G (Good), and VG (Very Good).

Table 14. Fuzzy normalized matrix.

	S_1			S_2			F_1			E_1		
	L	M	U	L	M	U	L	M	U	L	M	U
S_{11}	1.000	1.000	1.000	0.220	0.400	0.600	1.000	1.00	1.000	0.000	0.075	0.250
S_{12}	0.610	0.750	0.925	0.770	0.900	1.000	0.000	0.050	0.200	0.000	0.025	0.150
S_{21}	0.610	0.750	0.925	1.000	1.00	1.000	0.000	0.100	0.300	0.000	0.00	0.100
S_{22}	0.770	0.900	1.000	1.000	1.00	1.000	0.000	0.025	0.150	0.000	0.100	0.300
F_{11}	0.220	0.400	0.600	0.000	0.075	0.250	0.770	0.900	1.000	0.000	0.050	0.200
F_{12}	0.880	0.950	1.000	0.880	0.950	1.000	0.880	0.950	1.000	0.880	0.950	1.000
F_{13}	0.050	0.200	0.400	0.770	0.900	1.000	0.830	0.925	1.000	0.440	0.600	0.775
E_{11}	0.050	0.200	0.400	0.000	0.100	0.300	0.000	0.050	0.200	0.940	0.975	1.000
E_{12}	0.160	0.300	0.500	0.000	0.050	0.200	0.000	0.100	0.300	1.000	1.000	1.000

L—the lowest value, M—medium value, U—the highest value.

Table 15. Fuzzy weighted matrix.

	S_1			S_2			F_1			E_1		
	L	M	U	L	M	U	L	M	U	L	M	U
S_{11}	0.900	1.000	1.000	0.156	0.350	0.585	0.800	0.950	1.000	0.000	0.900	1.000
S_{12}	0.550	0.750	0.925	0.544	0.788	0.975	0.000	0.048	0.200	0.000	0.550	0.750
S_{21}	0.550	0.750	0.920	0.700	0.875	0.975	0.000	0.095	0.300	0.000	0.550	0.750
S_{22}	0.700	0.900	1.000	0.700	0.875	0.975	0.000	0.024	0.150	0.000	0.700	0.900
F_{11}	0.200	0.400	0.600	0.000	0.065	0.240	0.620	0.855	1.000	0.000	0.200	0.400
F_{12}	0.800	0.950	1.000	0.620	0.830	0.975	0.710	0.903	1.000	0.488	0.800	0.950
F_{13}	0.050	0.200	0.400	0.540	0.788	0.975	0.660	0.870	1.000	0.240	0.050	0.200
E_{11}	0.050	0.200	0.400	0.000	0.088	0.292	0.000	0.048	0.200	0.519	0.050	0.200
E_{12}	0.150	0.300	0.500	0.000	0.044	0.195	0.000	0.095	0.300	0.550	0.150	0.300

L—the lowest value, M—medium value, U—the highest value.

The Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) were computed as per Table 16. Table 17 identifies the distance from each alternative to the FPIS and FNIS. Finally, Table 18 provides the values of the CC_i closeness coefficient for each alternative.

Table 16. Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS).

FPIS	0.900	1.000	1.000	0.700	0.875	0.975	0.800	0.950	1.000	0.550	0.750	0.925
FNIS	0.050	0.200	0.400	0.000	0.043	0.195	0.000	0.023	0.150	0.000	0.000	0.092

Table 17. Distance from each alternative to FPIS and FNIS.

S_{11}	S_{12}	S_{21}	S_{22}	F_{11}	F_{12}	F_{13}	E_{11}	E_{12}
2.250	3.720	3.470	3.190	4.180	0.420	2.410	4.610	4.380
3.950	2.530	2.750	3.038	2.069	5.810	3.860	1.580	1.810

Table 18. Closeness coefficient CCi for each alternative.

S_{11}	S_{12}	S_{21}	S_{22}	F_{11}	F_{12}	F_{13}	E_{11}	E_{12}
0.6373	0.4047	0.4418	0.4877	0.3310	0.9318	0.6156	0.2549	0.2923

According to Table 18, the rank of individual alternatives (scenarios) is as follows:

$$\mathbf{F_{12} > S_{11} > F_{13} > S_{22} > S_{21} > S_{12} > F_{11} > E_{12} > E_{11}}$$

The most relevant scenario, as demonstrated by the Fuzzy-TOPSIS method, is an increase in the purchase of new wagons and locomotives. According to the experts, the age of the wagons and locomotives in use is so high that the rail corporation loses a lot of customers on this account. Reduced energy consumption is considered less relevant. This conclusion indicates that experts believe Iran has a large number of low-cost energy resources, making energy consumption less essential than in other countries.

6. Results and Discussion

The simulation results were illustrated using several key variables and performance indicators to evaluate the system behavior evoked as a result of the interactions between the financial, social, and environmental dimensions. More importantly, the contribution of road transport tolls to the formation of the system behavior was taken into consideration and discussed to define relevant implications for the management of rail transport in terms of sustainability. Finding the best scenarios in order to select meaningful strategies is an important problem for Raja, however, using Fuzzy logic solves this issue.

In order to achieve sustainable management at Raja and sustainable transport in general, the following policies are proposed according to the ranking of scenarios: 1. increasing the number of new wagons and locomotives (F_{12}); 2. taking into consideration the impact of road transport tolls on the model's dimensions (S_{11}); 3. reducing operating costs (F_{13}).

6.1. The First Scenario

As per the first scenario, according to the opinion of transport specialists, the rate at which the number of new wagons and locomotives is increased is set at 20% and 30% per year (Figure 9a). Aspects such as ticket prices, the number of satisfied customers, the number of passengers travelling by train, the income obtained from selling tickets, the income from the rental of wagons, as well as the profit all change following the growth of the fleet of new wagons and locomotives being purchased. The model was simulated in line with the changes mentioned above, covering a period until 2026.

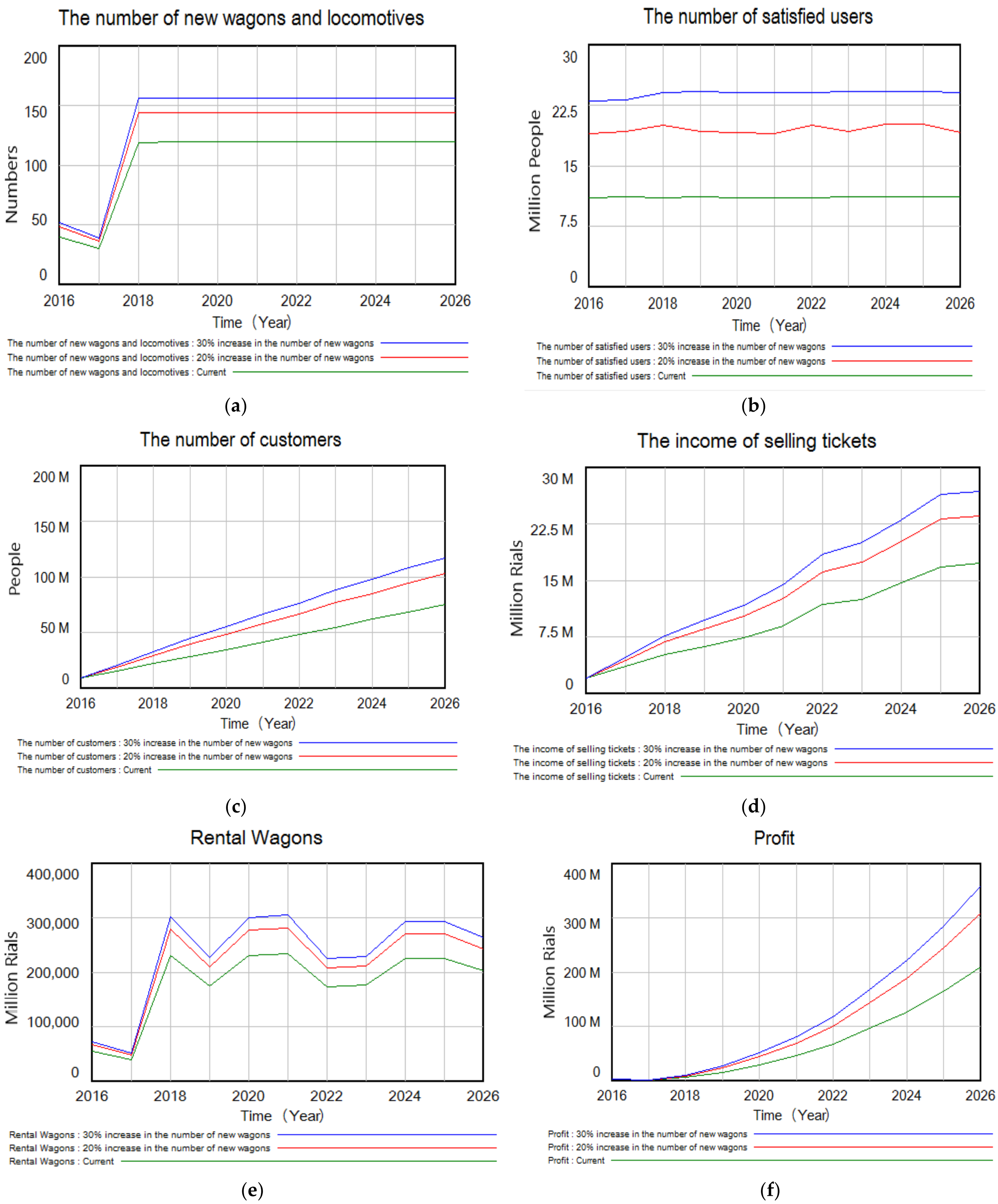


Figure 9. The first scenario. (**a**) The number of new wagons and locomotives; (**b**) The number of satisfied users; (**c**) The number of customers; (**d**) The income of selling tickets; (**e**) Rental wagons; (**f**) Profit.

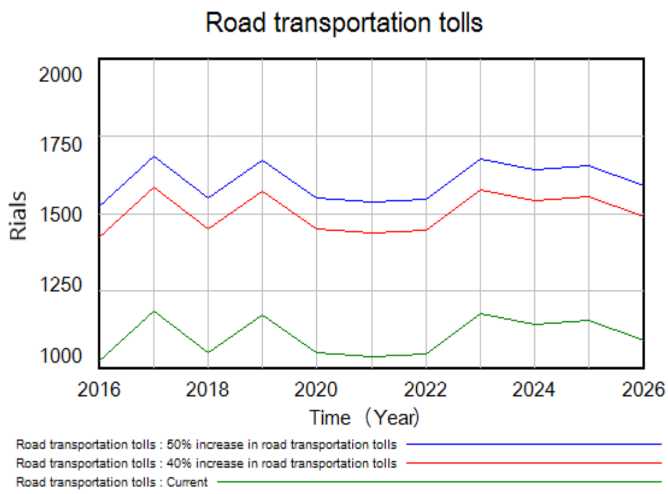
Following the first scenario, taking into account the impact due to increasing the number of new wagons and locomotives purchased on the sustainability dimensions, Raja will make huge profits (Figure 9f). Raja can obtain significant profits in the near future by expanding the purchase of new wagons and locomotives, which is one of the characteristics of sustainability. With just a 30% increase in the stock of new wagons and locomotives, this corporation can attain about 350,000,000 million rials in profit. Therefore, the rate at which the number of new wagons and locomotives purchased is to be increased plays a significant role in profit-making. Because of the high quality of new wagons and locomotives, purchasing new ones plays a vital role in attracting new customers as well as in maintaining loyalty among the present customers. Passengers are willing to purchase tickets at higher prices on the condition that they could travel by high-quality wagons. Moreover, companies that rent wagons and locomotives from Raja will gladly pay more for them. Figure 9b,c implies that as the number of new wagons and locomotives grows, so the number of satisfied customers, as well as the total number of customers, increases sharply, having a direct impact on the income from selling tickets. As shown in Figure 9b, there is a significant difference in the number of satisfied users between the current situation and one in which the number of new wagons and locomotives would be increased by 30%. After adding 30% more wagons and locomotives, the number of satisfied users might reach almost 23 million, and after adding 20% more wagons and locomotives, it could reach nearly 19 million. The influence of satisfied users on the total number of customers is clear, as shown in Figure 9c, and according to the simulation, the total number of customers may climb to 100 million once the number of satisfied users has been raised to 23 million in 2026. As a result, the income from selling tickets should increase (Figure 9d). Another important benefit that Raja can enjoy from buying new wagons and locomotives is the income gained from renting them out, which is shown in Figure 9e.

6.2. The Second Scenario

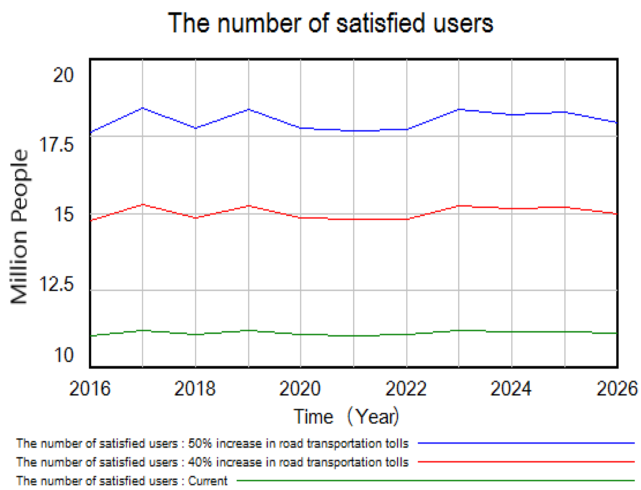
In the second scenario, another important element that influences profits in considerable amounts is road transport tolls. Managers of railway passenger transport companies need to provide conditions in which the government enacts new policies to determine real road transport tolls. In order for Raja to be profitable, it is highly advisable to determine road transport tolls in actual amounts. Road transport tolls affect the number of satisfied customers, the total number of passengers, customer loyalty, the income from selling tickets, and profits. In this scenario, the rate of increasing road transport tolls is 50% and 40%. Increases of 50% and 40% for road transport tolls are not excessive, because the price of road transport tolls in Iran is too modest.

In the second scenario, the innovation in System Dynamics approaches, road transport tolls have been considered, and their amounts have been increased. With the rise in road transport tolls, the number of rail transport users increases (Figure 10b–d). The number of satisfied users rapidly grew after increasing road transportation tolls by 50%, as illustrated in Figure 10b. It is obvious that as road transportation tolls rise, many more passengers will opt for railroad transportation, bringing the total number of satisfied users to nearly 18 million, a significant increase from the current time in 2026. Furthermore, according to Figure 10d, loyal travelers to railroad transportation are expected to increase by more than 90%, bringing the total number of customers to 100 million Figure 10c by 2026. This demonstrates that, in 2026, the policy of raising road transportation tolls will attract 25 million more passengers than the existing policy. As a result, the income from selling tickets and profits, in general, are affected (Figure 10e,f). If the government increases road transport tolls by 50%, customer satisfaction and customer loyalty increase dramatically (Figure 10b,d), and Raja's profits will be about 300,000,000 million rials in 2026 (Figure 10f).

The results of considering road transport tolls in the proposed model are shown in Figure 10.



(**a**)



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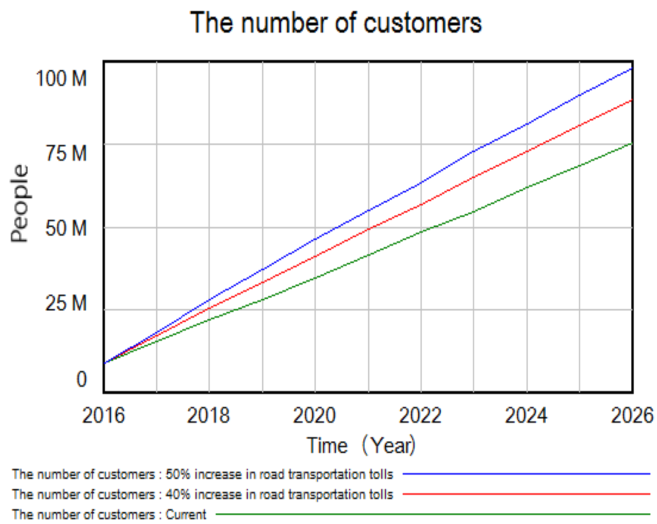

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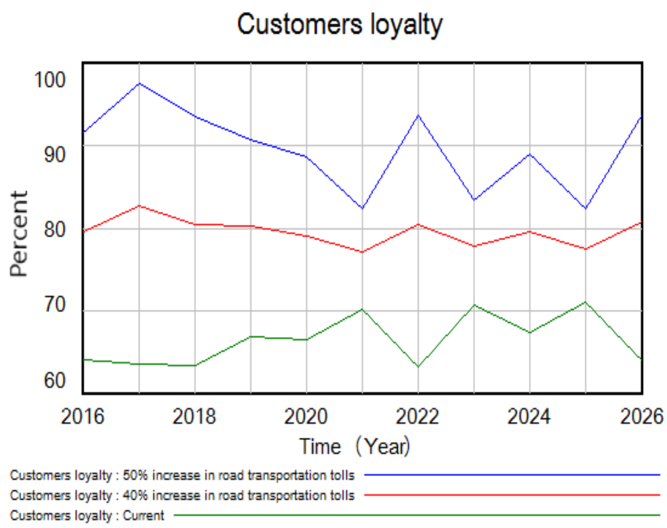
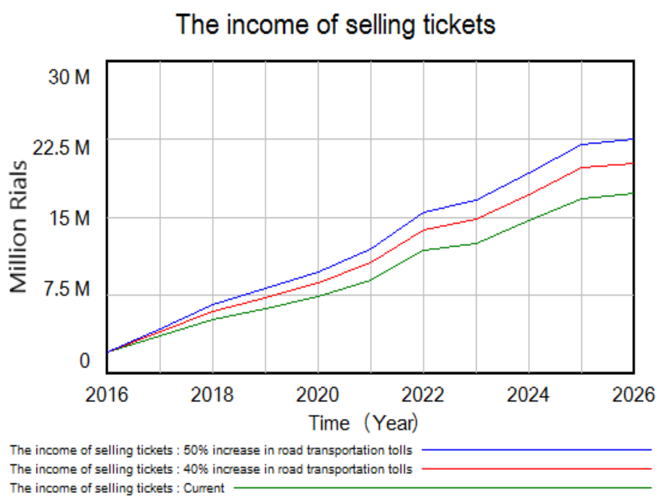
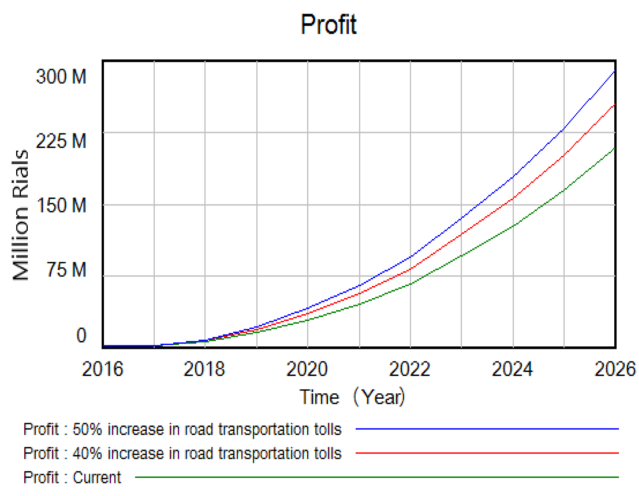


(**d**)



(**e**)



(**f**)

Figure 10. The second scenario. (**a**) Road transportation tools; (**b**) The number of satisfied users; (**c**) The number of customers; (**d**) Customers loyalty; (**e**) The income of selling tickets; (**f**) Profit.

6.3. The Third Scenario

The third suggested scenario considers operating costs as an integral part of the financial dimension. Operating costs affect many other components, such as profit, the number of satisfied passengers, the investment in buying new wagons and locomotives, and the total number of wagons and locomotives. In this scenario, operating costs decrease by 30% and 40% (Figure 11a), and the model of these changes has been simulated. The results are shown in Figure 11.

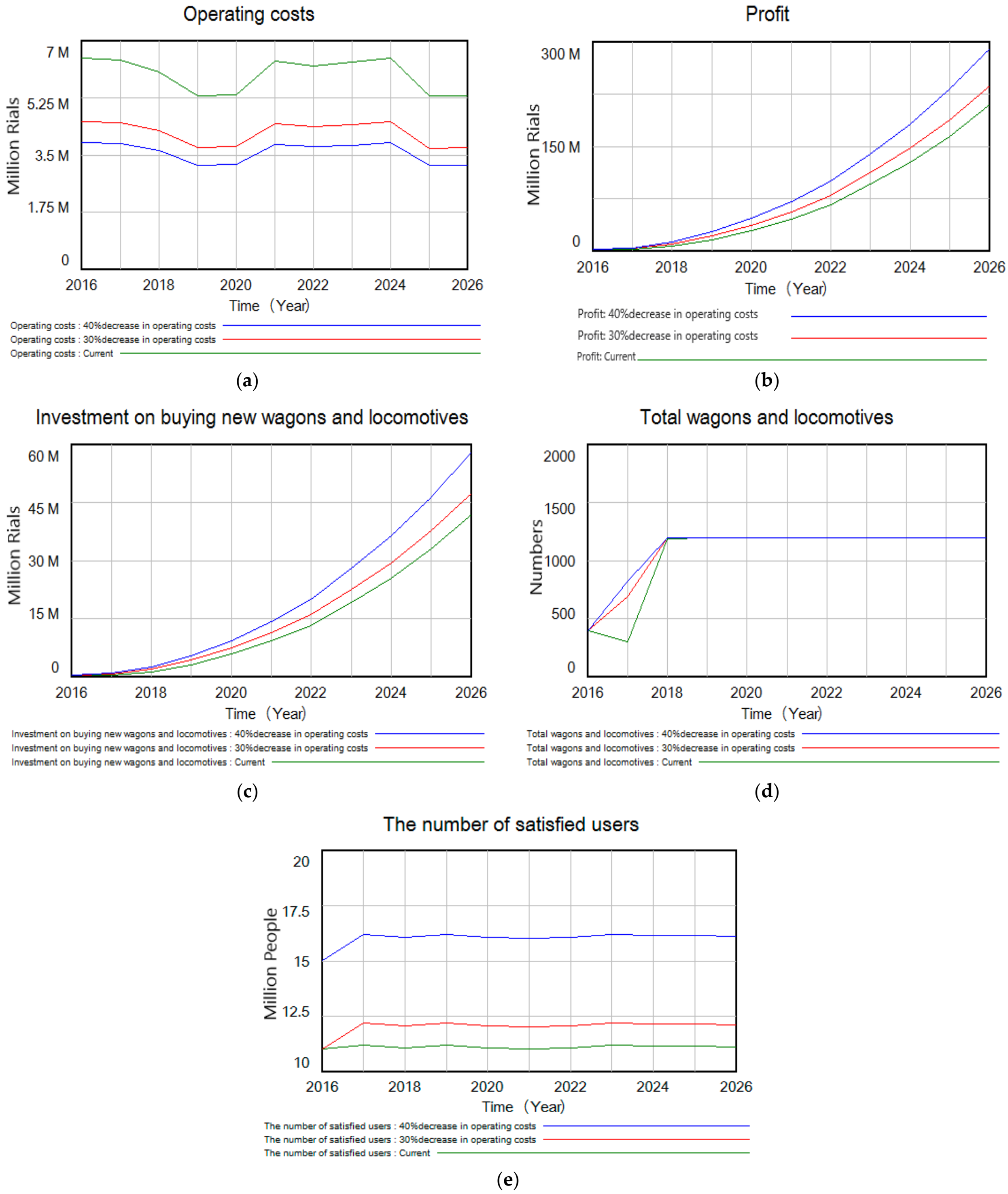


Figure 11. The third scenario. (**a**) Operating costs; (**b**) Profit; (**c**) Investment on buying new wagons and locomotives; (**d**) Total wagons and locomotives; (**e**) The number of satisfied users.

According to Figure 11a, operating expenses can be less than half of what they are now following a 40% reduction, implying that a large profit can be achieved after this reduction in operating costs. In 2026, the profit might reach 300,000,000 million rials. Managers want to invest in new wagons and locomotives as a result of increased profits, thus the total investment in 2026 might be almost 60,000,000 million rials (Figure 11c). The number of satisfied users would increase significantly as a result of the purchase of new wagons and locomotives (Figure 11e). Passengers clearly prefer to travel by modern wagons since they are considered more pleasant. As a consequence, by 2026, the number of satisfied users may have reached about 16 million.

6.4. Summing up Discussion

An SD model for sustainability management in transport integrates a complex set of institutions, processes, people, and procedures. This means that many rules with various categories and classifications may be developed to manage these parameters. These policies can act alone or together, in parallel or in succession. Some of the policies have straightforward variables and methods that can be easily modified, but others need integration. The SD model suggested in this study is adaptable, easy to comprehend, and capable of being further enhanced by adding additional subsystems, logical, and mathematical relationships. This makes it possible to establish additional policies (Table 19), simulate their effects, and investigate the reactions of more variables. Some of these have been discussed in this work, but additional areas need to be studied for a more comprehensive, well-defined, and interactive analysis of such policies. Table 19 presents the scope of the policies covered in this paper.

Table 19. Scope of the policies covered.

Policy Example	Direct Variables Involved	Covered in This Paper	Comment
Purchasing new wagons and locomotives	Income, Profit, Ticket price, Rental wagon, Number of satisfied users, . . .	✔	The policy may bring huge profit in the near future
Road transportation tolls	Number of customers, Income, Profit, Number of satisfied users, Customers loyalty, . . .	✔	The policy may affect the number of customers, resulting in increased profits
Operating costs	Profit, Buying new wagons and locomotives, Number of satisfied users, . . .	✔	Might be considered to reduce costs in order to make profits

7. Conclusions and Further Research Directions

On the one hand, transport companies, like any other businesses, are forced to change internal management in an adequate manner. On the other hand, this sector performs a special function—moving people. Additionally, this process should be as environmentally friendly as possible. Railways play a critical role in the sustainable development of transport networks, contributing to any given country's economic prosperity. Railway companies should guide their progress toward sustainability in order to attain and maximize their full potential. Passenger rail transport supports economic, environmental, and social development, which will, in turn, positively influence the quality of life in general. The sustainable approach to management is vital for the effective operations of passenger rail transport companies. While numerous studies have focused on various transport dimensions, limited efforts have been made to develop models that can both evaluate and analyze strategies within the self-sustaining model by incorporating system dynamics into the socio-political, financial, and environmental dimensions. Inter-disciplinary studies are required to fully comprehend the complexity of the transport industry. This research indicates the role of road transport tolls, and their effects on the number of satisfied railway users as well as on profits while proposing a selection of appropriate scenarios so as to achieve sustainable management of passenger rail transport companies. Therefore, the main contributions of this paper can be listed as follow:

- Proposing new indicators for establishing the sustainability of passenger rail transportation management;
- Considering three dimensions of sustainability in passenger rail transport at the same time, despite the fact that the literature on the subject is scarce;
- Applying innovative feedback loops and System Dynamics in passenger rail transportation management;
- Taking road tolls into account as an important and unique indicator in establishing the sustainability of passenger rail transport;
- Applying the Fuzzy-TOPSIS approach to select the optimal scenarios and policies.

This study discusses both the manner in which sustainable management is performed at a passenger rail transport company (using Raja's example) and its complexity attributable to feedback loops, showcasing the role and the effects of various dimensions on individual strategies. Causal loops are developed to illustrate the system's complexity and the interactions between its elements, while the feedback loops apply to the socio-economic, environmental, and financial dimensions, and are used to model the relevance of feedback loops and complex inter-connections in managerial decisions. The impacts of these interactions between elements can be evaluated by using mathematical formulas. The complex system dynamics model developed to enable assessing the performance of passenger rail companies as well as the Fuzzy-TOPSIS method used to choose the relevant scenarios are considered novel in this study. Different scenarios have been proposed to investigate the effect of feedback loops and dynamic interactions on Raja's performance and finances.

Passenger rail transport companies operating in Iran are unable to produce adequate revenues, and their management is unsustainable. Furthermore, given that road transport tolls are among the most significant indicators in the model, accurate findings may be obtained even if one of the largest train passenger companies has issues with the established road transport tolls. In reality, experts believe that it is for the low rates of the tolls that people prefer travelling by car or by bus. As a consequence, one of the largest passenger rail transport companies in Iran, Raja, has been chosen as a subject for a case study illustrating a pursuit of sustainability in Iran's passenger rail transport sector.

The outcomes of the system dynamics model show that in the case study considering road transport tolls, operating costs, as well as the purchase of new wagons and locomotives, play a significant role in the sustainable management of passenger rail transport companies. According to the first scenario, buying new wagons and locomotives, affecting customer satisfaction, was taken into account in the study as the means to achieve sustainability. Raja may make significant profits in the near future by increasing the number of wagons and locomotives purchased, which is one of the sustainability characteristics. This company can make roughly 350,000,000 million rials in profit with just a 30% rise in the number of wagons and locomotives. Road transport tolls are assumed to increase by either 40% or 50% in the second scenario, and its outcomes indicate that a 50% increase in the rate of road transport tolls would create sufficient conditions for Raja to achieve high profits in the year 2026. Moreover, the number of loyal railway travelers is predicted to grow by more than 90%, increasing the total number of consumers to 100 million. With regard to the third scenario, operating expenses are reduced by 30% and 40%, respectively, implying that Raja must be profitable. In the social dimension, if operating expenses fall by 40% and managers decide to invest in new wagons and locomotives as a result of higher revenues, the number of Raja's satisfied customers will rise as well. Passengers certainly prefer travelling by newer wagons since they are simply more comfortable. Consequently, by 2026, the number of satisfied railway users may have surged to almost 16 million.

The main aims of the study have been achieved. The study provides a collection of railway sustainability indicators as well as a novel causal loop for rail transport companies. As a result of the calculations, individual scenarios were chosen. However, in order to take these scenarios into account vis-à-vis sustainable management, Raja and other passenger rail transport companies also need to consider the government's policies and use logical methods to select the best strategy.

Regarding future research, reviewing governmental policies and examining their impacts on the performance of transport companies as well as analyzing the results thus obtained should be taken seriously for effective decision-making, which may improve the reputation of these organizations. The authors are also planning to conduct research regarding the effect of the COVID-19 pandemic on transport companies and to compare different scenarios aimed at reducing such an impact in the future.

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