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Approach Draft to Evaluate the Transport System State—A Case Study Regarding the Estimation Ratio Model of Transport Supply and Demand

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Abstract: The article suggests a system dynamics model for estimating the demand for public transport. Traditional scientific and technical transport modeling approaches involve coherent systems, meticulously considering other impactful variables for transport modeling. The vastness of the variables and their combinations hinder us from grasping all possible system interactions. This research aims at proposing a model that comprises decisive factors in relation to the supply and demand in various modes of transport, designing likely scenarios of the transport system development in a specific transport territory. The model uses system dynamics tools to explore the interaction between individual system elements and transport subsystems. A wise choice of crucial system elements, well-adjusted relationships and behavior settings, as well as system dynamics tools, allow for a considerable simplification of an otherwise complex system. The article works with a principle of stock and flow diagrams for forecasting supply and demand in public transport. We take into consideration the implementation of a 'demand index' in public and car passenger transport with a subsequent comparison. This innovative approach monitors the development of a regional or municipal transport system while assessing its sustainability. Suggested demand indexes may serve as indicators for a sustainable municipal system. The suggested model reflects data from the South Bohemian region in the Czech Republic and may involve other elements and indicators of a sustainable transport system.

Keywords: transport behavior; transport demand; transport supply; system dynamics; stock and flow diagram

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1. Introduction

Transport development depends on many changeable factors, including improving means of transport and travels in the past. The transport infrastructure relies heavily on regional and global trade practices.

In the last two decades, the Czech Republic has seen a dramatic increase in traffic caused by massive economic changes. The opening of the domestic market to foreign trade allowed exporting goods and services westwards. Cars have become mass-produced and cheap goods, offering a wide selection to satisfy owners' ravenous appetites. On the other side, this intensified transport industry had to consider a housing boom that came with changes in the economic and political regime. These alterations include new economic activities, interconnection of micro-regional and macro-regional centers, and strengthening relationships between the core and its background or suburbanization.

Microscopic factors also influence traffic, heavily burdening local transport networks. Experts must plan transport constructions to lessen a negative traffic impact on the locality.

The supply and demand for transport services involve many intertwined factors, calling for innovative tools for improving transport-related systems and disclosing interrelations. The presented study explores solutions for modeling transport systems using system dynamics tools (stock and flow diagrams) in a specific place and time. The model mimics the daily journeys of citizens in a locality, closely linking to socio-economic spheres. The research aims to a multi-factor model influencing the supply and demand in distinct modes of transport and simulates likely scenarios of the transport system development. The survey also includes the advancement in different locations involved in supply and demand rates in transportation. The approach designed is innovative in maintaining sustainable transport system development in a region or municipality. Suggested indexes may also reflect the sustainability of the municipal system.

Stock and flow diagrams are suitable for macroscopic modeling overlapping multiple disciplines that affect observed variables. When set correctly, these models integrate various subsystems, including environmental, social, and economic sectors, and can deal with specific transport problems. Miller and Clarke (2007) designed a simple model for measuring the capacity of airport runways under various external conditions [1]. Most systems illustrate the dynamic system behavior rather than forecast future system development.

The remainder of this work includes the following sections. First, a comprehensive literature review embracing numerous topic-related literature sources was elaborated. Thereafter, pertinent data and methods related to the major objective of this manuscript are described. Subsequently, the most important section of the conducted research is processed, wherein the very findings, as well as the accompanied discussion, are presented. Last but not least, conclusions from the results obtained, along with the recommendations for further research in an addressed topic, are outlined.

2. Literature Review

Many studies and publications have dealt with transport supply and demand. The survey [2] explores whether public transport is available, pointing to essential system quality indicators in the sector. The publication [3] warns about cumbersome passenger traffic inconsistency with its sustainability. Other works examine the involvement of transport networks and optimizing algorithms [4] or periodical means of transport and their optimization [5]. The article [6] tackles multiple traffic restraints, such as intersections or vehicle capacity, using various algorithms and models, whereas the studies [7,8] analyze implementing empirical designs into transport planning using travel time and traffic levels as interdependent variables. The literature sources [9,10] emphasize crucial qualitative factors for the selected location. Accurate time and space settings involve an essential attribute for quality public transport. The study [11] argues that slipping behind the timetables harms the reputation of the transport services, while article [12] claims that reliable municipal transit and exact schedules help users better plan their activities. The study [13] presents logistics models of global places, exploring their pros and cons based on secondary analyses of multiple case studies. Another survey [14] investigated public transport, suggesting a mathematical method for iteratively solving the math formulation of the integrated timetable. On the contrary, the publication [15] deals with the connectivity of transport infrastructure, applying transport policies to a specific case study. Analysis [16] unveils relations between perceived mental health and a municipal transport system, illuminating socioeconomic aspects in our research. The experiment [17] expounds upon a scientific model of the public transport system, including buses, trams, and local trains, explaining emergencies in the sector. According to the studies [18,19], the researchers and companies work on new applications of intelligent transport systems, emphasizing the integrity of transport connectivity, as it has a synergic effect on assessing the quality ratios [20]. In our study, we also involved the consumer demand for travels. The article [21] reflects this variable, exploring developing and growing municipal zones highly susceptible to changes in the transport infrastructure.

System dynamics dates to the 1950s when J. Forrester from American MIT introduced this method [22]. The system involves standard causal loops and feedback for formulating a system dynamics hypothesis based on qualitative system models. These qualitative designs go through quantitative models (stocks and flow diagrams) for validation.

The system dynamics was first used in business management, spreading among other spheres such as governmental, regional, or municipal decision-making processes, health care, the automotive industry, or urban planning [23].

Pfaffenbichler et al. introduced the MARS LUTI concept for quantifying the system dynamics of zoning or transport infrastructure [24]. Experts use the model for feedback on the implementation of zoning projects and assessing their impact, evaluating zoning and traffic planning decisions and their repercussions 30 years in advance. Haghani et al. created a regional model based on causal relationships, loops, and feedback, integrating numerous physical, socioeconomic, and political decision-making variables [25]. Wang et al. devised a sophisticated instrument measuring the interaction between the population, registered vehicles, environment, gross national product indicators, and supply and demand in transport [26]. The author applied the model to Dalian Region in PRC.

3. Materials and Methods

3.1. Causal Loop Diagrams (CLDs)

Causal loop diagrams (CLDs) allow visualization of interrelations in the system, ensuring a quality system analysis. Economic enterprises use them for evaluating system processes, covering all system concepts.

Causal loop diagrams help better understand the complex system, allowing scientists to measure its interrelationships and validate their hypotheses on system dynamics models.

CLDs comprise a set of words (nodes) and edges (arrows) modeling causal relationships between the variables. A change in the causal variable alters the effect variable, be it positive or negative. A link marked + is positive, showing a causal relationship when an increase (or decrease) of the causal variable brings an increase (decrease) in the effect variable. A link marked - illustrates a negative correlation when an increase (or decrease) in the causal variable leads to a decline (or increase) in the effect quantity. All links between the two variables are testable hypotheses [23].

Polarity of causal links and graphic is illustrated in the following Table 1.

Table 1. Polarity of causal links and graphic illustration [23].

Causal Link	Illustration	Formula
Positive (+)		$\partial Y/\partial X > 0$ in the event of propagation $Y = \int_{t_0}^{t} (X + \ldots) ds + Y_{t_0}$
Negative (−)		$\partial Y/\partial X < 0$ in the event of propagation $Y = \int_{t_0}^{t} (-X + \ldots) ds + Y_{t_0}$

The polarity of causal links refers to the system structure, revealing potential consequences if a change occurs. It does not describe the behavior of variables, i.e., the actual effect.

The causal loop involves a chain of causal links where a variable disturbs one or more quantities, retroactively affecting the causal variable. We call them feedback loops or closed loops, as it describes a closed situation. If the cycle is not sealed, we call it an open loop. As with the causal links, loops have either positive or negative polarity:

Reinforcing Loops–labeled with R or '+'

Balancing Loops–labeled with B or '−'

Reinforcing loops are when the sum of negative causal links equals zero or an even number, and the variables in the loop grow exponentially. Balancing loops occur when the total negative relations equals an odd number and variables strike a balance. If the quantity is in a positive and negative loop at a time, the exponential growth moves toward equilibrium.

Oscillating behavior is common in causal loops (marked with a double strikethrough in diagrams) in variables (mainly in balancing loops) with delayed responses.

3.2. Stock and Flow Diagrams

A stock and flow diagram, the most common causal loop diagram, combines polarity and stocks and flows quantitatively; it describes the behavior of the dynamic system by mathematic definitions of stocks and flows.

Quantifying stocks and flows allows for other system constituent variables, constants, and inflow or outflow levels, including input data from an external source into the model and model output data. The external source may be a submodel generator of input data, whereas the output data involve a consumer outside the model (sink). If we use the correct language, these elements give us the breeding ground to describe any system (22).

Basic relationships and elements in the stock and flow diagram are depicted in the following Figure 1.

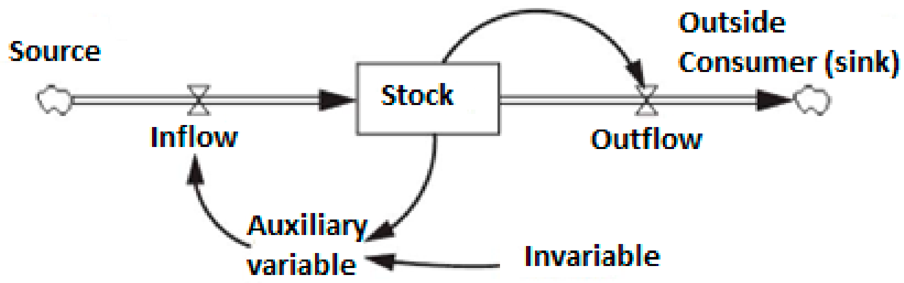

Figure 1. Depiction of basic relationships and elements in the stock and flow diagram [27].

Stocks represent a variable at a point in time. An increase or decrease in the stock reflects flow levels in the stock. Based on specific variables, the flow levels comprise functions of other interdependent model elements [27]. Constants are numerical values that remain invariant unless disturbed by a particular model variable.

Stocks intertwine with existing and past flows. The formula for describing stock levels at a point in time is as follows [27]:

$$stock(t) = stock(t-1) + (inflow(t) - outflow(t)) \tag{1}$$

The net change in a stock can therefore be represented by a differential equation:

$$\frac{d(stock)}{dt} = inflow(t) - outflow(t) \tag{2}$$

Therefore, the stock levels may also involve an integral equation as follows:

$$stock(t) = \int_{t_0}^{t} [inflow(x) - outflow(x)]dx + stock(t_0) \tag{3}$$

where *inflow*(x) and *outflow*(x) represent the level of the inflow and the outflow at time x between the initial time t_0 and the current time t. The value of the stock at time t is the net difference between the inflow and the outflow between time t_0 and t plus the initial value of the stock at time t_0. Flow can be determined in various ways, including constants, mathematical functions of stocks and auxiliary variables, and graphical representations. Auxiliary variables combine the illustrated variables, allowing potential corrections or smooth flow control.

The supply and demand transport estimation model involves Vensim PLE freeware from Ventana Systems Company. The free version allows a comprehensive analysis of discreet variables using multi-agent modeling [28].

3.3. Theory of the Suggested Model

The following model is an example of a stock and flow diagram, exploring the system behavior where essential variables enter the system, determining the supply and demand for transport in a location (e.g., municipality). This simplified model ignores other crucial factors, such as generators of local travels. Based on the research, we included interconnected elements in the dynamic model. Its logical background allows for an extension to other constituents or input subsystems, which yields more accurate results. The model contains only two transport modes: passenger car transport (*PCT*) and public transport (*PT*). The reduced design includes an element quantifying the state of the transport system by comparing supply and demand in the sector. The transport supply means an immediate daily capacity of means of transport, whereas the transport demand involves a sum of all possible journeys that residents can take daily. For both kinds of transport, the comparative estimate of supply and demand can be expressed as follows:

$$the\ ratio\ of\ the\ supply\ and\ demand\ in\ transport = \frac{transport\ capacity\ supply}{demand\ for\ travels} \quad (4)$$

The transport supply and demand ratio refers to the state of a local transport sector. Higher values reflect greater flexibility, satisfying the demand without problems. By applying this ratio to each transport mode, we obtain an acceptable level of sustainable transport (*PT*) in the model and can compare it with the situation in car transport. Figure 2 depicts one part of the model structure with individual variables connected with generating car travels within the region.

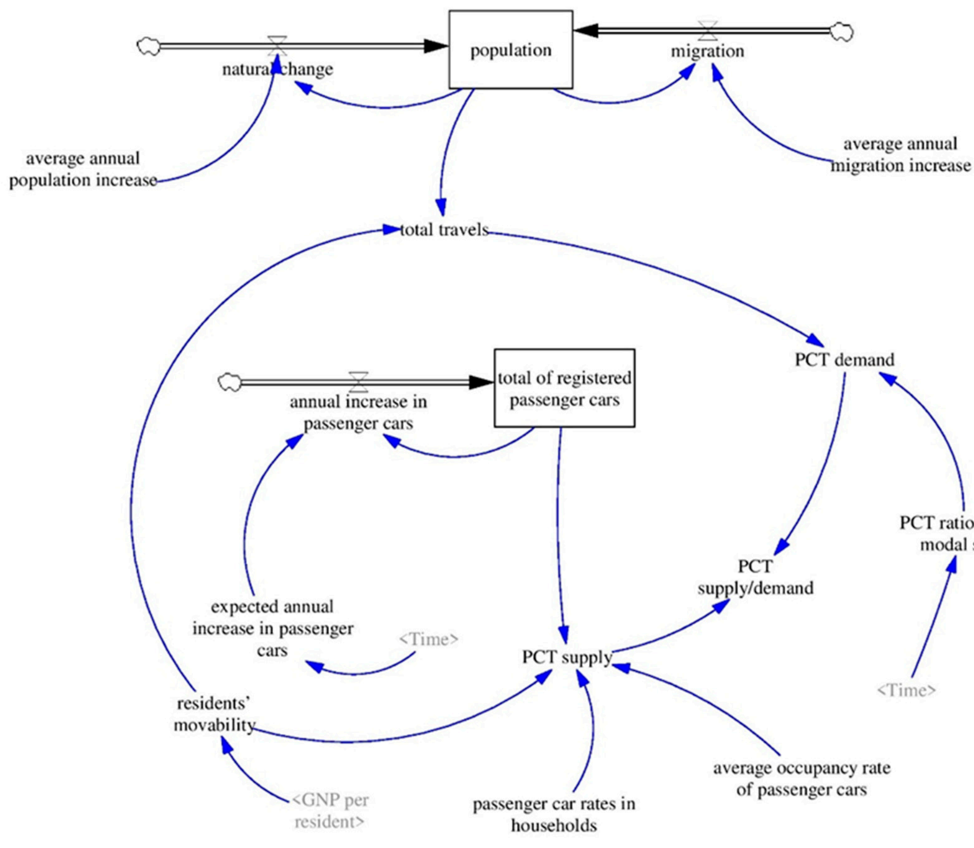

Figure 2. Supply and demand estimation model in CT and PT–first part of the model (source: Authors).

The model describes basic stocks, flows, variables, and measurable interrelationships. In this case, the stocks involve the total population in the locality, *GDP* rates in the region, the number of means of transport in *PT*, and the number of registered cars. These stocks are susceptible to flows and other variables analyzed below.

For measuring initial variable values, the model involved partly factual data (statistical data from the South Bohemian Region in the CZ) and partly expertly estimated data upon consulting with relevant professionals. For that reason, we could not validate the model, suggesting only an applied theory of system dynamics from the transport sector.

The regional population stock comprises hard data on the population, natural population growth/decline and migration increase/decrease. The formula for exploring the relationships between the population, natural change, and migration are as follows:

$$population(t_n) = \int_{t_0}^{t_n} natural\ change(x) + migration(x)dx + population(t_0)\ [population] \quad (5)$$

The population in time (t_0) represents the initial value of the data-checked population in the model. This simplified submodel of the population stock in time allows for an annual population increase. The 'inflow' of the stock displayed as a natural population change reflects the average annual population growth. The degree of the change is as follows:

$$natural\ change = \frac{population \times average\ annual\ population\ growth}{100}\ [population] \quad (6)$$

A percentage constant derived from the local statistical data represents the average annual growth. As applied by analogy, if the migration triggers the population change, it is reflected in the average year-to-year migration increase. A percentage constant from the statistical data again reflects the increment in our simplified model.

The *GDP* stock involves the initial *GDP* value and 'inflow' levels expressed by the *GDP* annual growth in CZK. The formula for quantified relationships between *GDP* rates and *GDP* growth is as follows:

$$GDP(t_n) = \int_{t_0}^{t_n} GDP\ growth(x)dx + GDP(t_0)\ [CZK] \quad (7)$$

The simplified submodel contains a percentage constant that reflects the average annual *GDP* growth. We again rely on the statistical data over a period. The formula for the year-to-year *GDP* growth is as follows:

$$GDP\ growth = \frac{GDP \times average\ annual\ GDP\ growth}{100}\ [CZK] \quad (8)$$

The submodel for determining a stock of the number of means of transport in PT and then supply in the PT intertwines with the mentioned economic submodel. In Figure 3, you can see the second part of the model, which is connected with generating the means of PT, and finally, the supply/demand ratio estimation in PT.

The formula for *GDP*-funded investments in transport includes the average year-to-year funds allocated to the transport sector and the actual *GDP* rates:

$$transport\ investments = \frac{GDP \times average\ annual\ GDP\ funds\ allocated\ to\ the\ transport\ sector}{100}\ [CZK] \quad (9)$$

The correlation suggests that a percentage value from the *GDP* reflects the average year-to-year investments in the transport sector. From the funds allocated to transport, we can estimate the money spent on purchasing new means of transport in *PT*. The formula for calculating the relationship between the funds invested in the sector and the costs of new vehicles in *PT* is as follows:

$$investments\ in\ new\ means\ of\ PT = \frac{transport\ investments \times average\ costs\ for\ purchasing\ new\ vehicles}{100}\ [CZK] \quad (10)$$

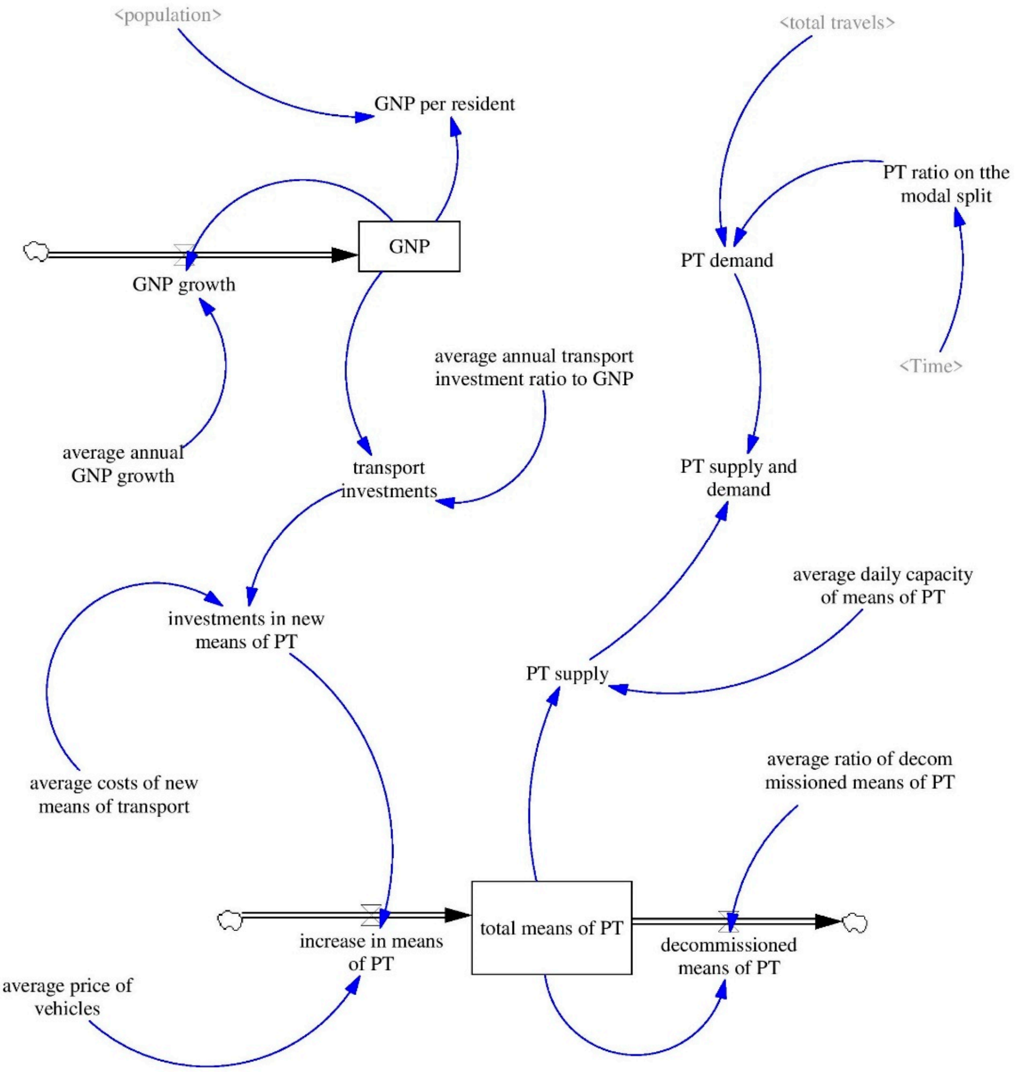

Figure 3. Supply and demand estimation model in CT and PT–second part of the model (source: Authors).

The total money spent on new means of transport in *PT* comprises the initial value of a variable influencing the annual increase in PT vehicles. This rate represents a stock change. The formula for measuring the relationship between investments in new *PT* machines and the average price per piece allows for the stock change represented by the increment in means of transport:

$$increase\ of\ means\ of\ transport = \frac{investments\ in\ new\ vehicles}{average\ price\ of\ vehicles}\ [vehicles] \tag{11}$$

This change refers to the year-to-year increment in *PT* vehicles derived from the formula above. We also must consider other effects (variables) that move the submodel toward the real-life situation. Adding time depletion to the stock involves 'outflows' represented by decommissioned *PT* vehicles. These write-offs reflect the number of means of public transport in the year and a simplified percentage constant that suggests a year-to-year ratio of discarded *PT* vehicles to the total means of PT:

$$decommissioned\ PT\ vehicles = \frac{PT\ vehicles \times average\ ratio\ of\ decommissioned\ PT\ vehicles}{100}\ [vehicles] \tag{12}$$

The formula for the relationship between the year-to-year increase in *PT* vehicles, the decommissioned ones, and the stock expressed as the total means of *PT* for all steps (years) of the model is as follows:

$$PT\ vehicles(t_n) = \int_{t_0}^{t_n} increase\ in\ PT\ vehicles(x) - decommissioned\ PT\ vehicles(x)dx + PT\ vehicles(t_0)\ [vehicles] \quad (13)$$

To put it precisely, we included only means of *PT*, ignoring railways. The supply and demand in PT within the model apply only to road PT vehicles. The involvement of *PT* on travels (see the following text) imitates the survey of the residents' transport behavior, including buses. We did not involve regional rail transport.

The number of registered cars in the region embodies the following stock ensuring the transport supply. Information on registered cars comes from statistical data comprising another submodel. Although the literary research proved causal links between the year-to-year car increase and socio-economic variables, the submodel is independent of other socio-economic submodels [29]. However, a direct causal link between the year-to-year car increment and the GDP does not exist.

For illustration, we replaced the average percentage year-to-year car growth with values expected for the next 20 years. In the Vensim program, we achieve the expected trend in passenger cars by a graph. Figure 4 suggests a Vensim program graph containing real-life values of a year-to-year car increase between 2012 and 2019. As of 2020, we expect the car growth rate will slow down. The Czech Statistical Office provided historical data on the year-to-year increment in passenger cars. These demonstrative figures relate only to the South Bohemian Region [30].

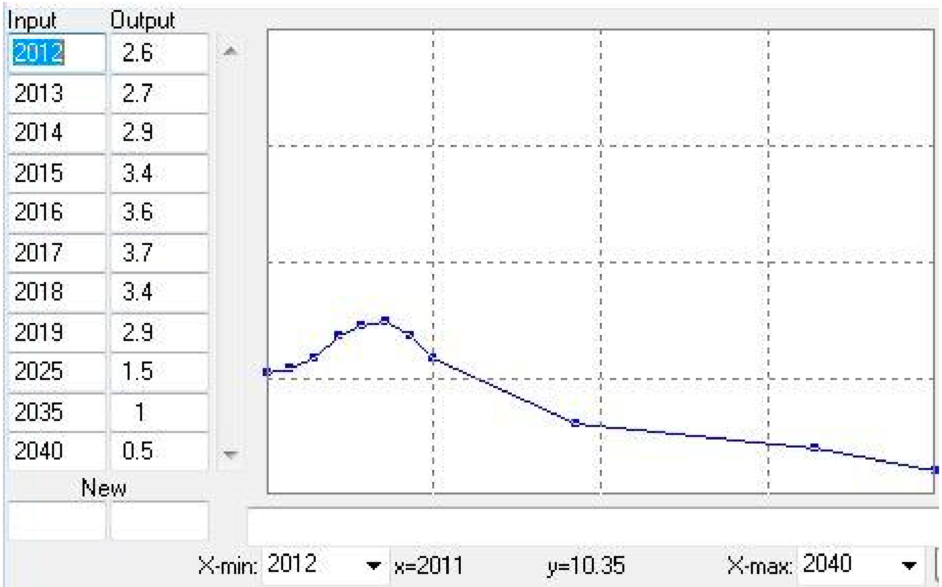

Figure 4. Trend in the car growth over the years.

The variable 'expected year-to-year car growth' is susceptible to the time factor depicted as the 'shadow' 'Time' variable in the diagram. The percentages affect the subsystem dynamics that generate year-to-year numbers of passenger cars. Strictly said, the subsystem produces an absolute value that impacts the stock 'inflow,' indicating a year-to-year increase in passenger cars and a link between the total of registered vehicles and expected annual car growth. The formula is as follows:

$$annual\ car\ growth = \frac{registered\ cars \times expected\ annual\ car\ growth}{100}\ [cars] \quad (14)$$

The number of registered cars is a stock variable representing an integral of the year-to-year car increment in time:

$$registered\ cars(t_n) = \int_{t_0}^{t_n} annual\ car\ growth(x)dx + registered\ cars(t_0)\ [cars] \quad (15)$$

The supply of all possible *PT* travels in the model reflects the total capacity of means of PT in the transport network per working day. We calculate the overall *PT* capacity using the average daily volume of means of *PT*, considering the daily usage of *PT* vehicles and their passenger capacity. The average daily volume of means of *PT* and their total number allow for the overall supply of *PT* travels.

$$PT\ supply = PT\ vehicles \times average\ daily\ capacity\ of\ PT\ vehicles\ [passenger] \quad (16)$$

The supply of all possible travels for *PCT* corresponds to the current number of registered cars in the region, residents' movability within the transport network, average passenger capacity when using the regional travels, and the ratio of automobiles in personal ownership to the total of registered cars in the region. The formula for the relationship between the variables is as follows:

$$PCT\ supply = \frac{registered\ cars \times ratio\ of\ cars\ in\ households \times resident's\ movability \times average\ occupancy\ rate}{100}\ [travels] \quad (17)$$

We present the percentage of cars in personal ownership to the total registered vehicles in the model, covering only the residents' personal travels. We chose the average passenger capacity to specify the submodel for assessing the *PCT* supply instead of also viable maximum passenger capacity as in the event of *PT* supply. The residents' movability reflects the high flexibility of passenger car transport independent of the timetable, unlike *PT*. The supply involves a working day, indicating the resulting supply rates (as in the event of demand) that reflect all available travels.

Residents' movability rates in the model sway the supply and demand for potential travels in analyzed transport modes. Although the residents' mobility is constant in time, it has recently increased due to improved living standards [31]. The model integrates residents' movability with *GDP* per capita. Simple linear regression helped us reveal a direct correlation between statistical significance and annual regional *GDP* rates per resident and residents' mobility rates in the region (Figure 5).

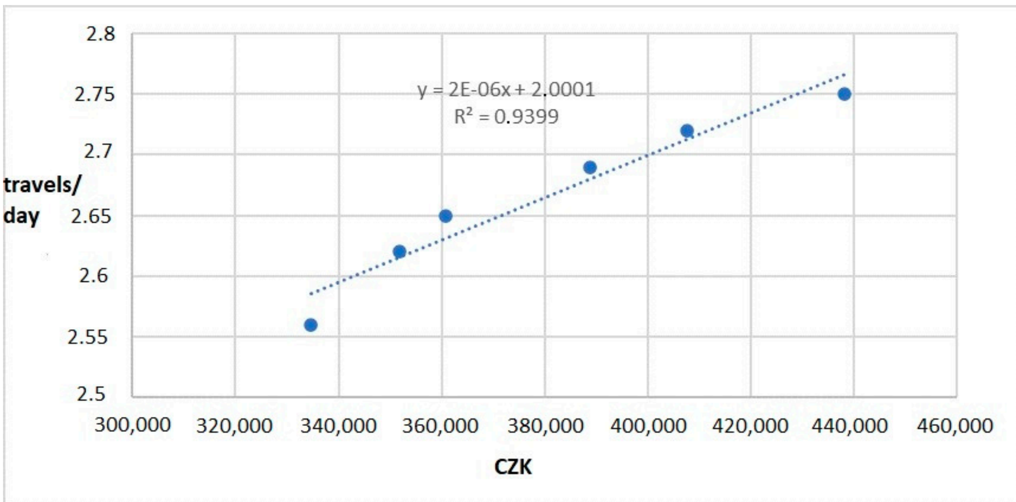

Figure 5. Regression line describing a correlation between residents' movability and GDP per capita.

The regression line tracks data of two variables in the South Bohemian Region from 2014 to 2019 [30]. Obtained values reflect historical statistical data, whereas residents' movability rates rest on a survey of transport behavior over the period [32]. The model with regional *GDP* per capita explains 94% of the variability in residents' mobility.

This example allows applying the regression line linking residents' movability and regional *GDP* per capita to a demonstrative model of system dynamics in the following way:

$$resident's\ movability = 2 \times 10^{-6} \times GDP\ per\ capita + 2.0001\ [travels/day] \quad (18)$$

The modeled residents' movability trend emerges from the regression line relating to the South Bohemian Region. The relationship for determining the *GDP* per capita comes from measuring stocks of both submodels (*GDP* rates and regional population). Its formula is as follows:

$$GDP\ per\ capita = \frac{GDP}{population}\ [CZK/inhabitant] \quad (19)$$

Residents' movability sways the demand for travels, including separate transport modes. The formula for measuring the quantity comprises the total of travels and a link between movability rates and the population in the region [33]:

$$total\ of\ travels = resident's\ movability \times population\ [travels/day] \quad (20)$$

The total travels suggest theoretical demand rates for all tours, irrespective of means of transport, splitting into two observed transport types-*PCT* and *PT*. The model applies total journeys to the ratio of the kind of transport to all existing travels [33].

Although the model relies on the data-based average constant for the ratio of separate transport modes to the total travels in the region, we chose the apparent trend for the following years to demonstrate the variable. The discernible tendency of the ratio of means of transport to the residents' journeys reflects the graphical paired data comparison provided by a flow diagram of the Vensim software [34]. We forecast a gradual decline in *PCT* rates to the overall modal split within the following 20 years, where the initial 40% indicates results from a survey on residents' transport behavior in the South Bohemian Region in 2019 [30]. Figure 6 illustrates the required *PCT* rates for the modal split.

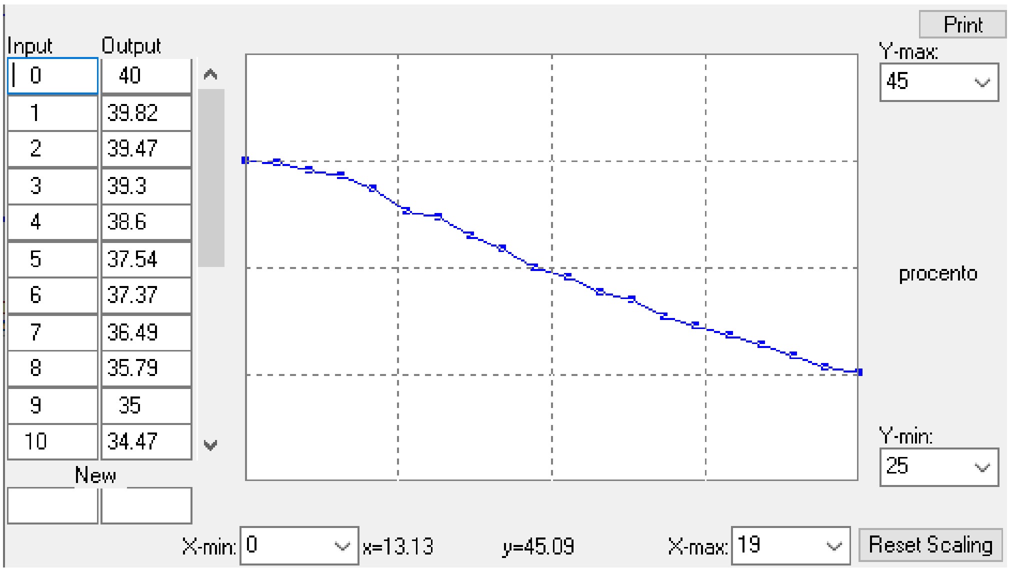

Figure 6. Vensim software: graphical depiction of the expected trend of PT rates for residents' demand for travels.

The graph suggests a likely scenario, including a steady annual decline in *PCT* rates to 30% in 2040. A simulation allows for mimicking the schemes and detecting changes in the system dynamics. As applied by analogy, we indicated the trend in '*PCT* ratio to the division of transport work', predicting a consistent growth from 10.8% in 2020 to 12.72%

in 2040. Higher *PCT* rates of the division of transport work occur in large municipalities, where PT has a fair share in the municipal transport network.

The formula for measuring rates of monitored transport modes and assessing relationships between the total travels in the region, *PT* rates of all travels, and *PCT* ratios to all journeys in the model is as follows [35]:

$$PT\ demand = PT\ rate\ on\ the\ modal\ split \times total\ of\ travels\ [travels/day] \quad (21)$$

$$PCT\ demand = PCT\ rate\ on\ the\ modal\ split \times total\ of\ travels\ [travels/day] \quad (22)$$

The link between the demand for transport and supply of the transport capacity in observed modes imitates the correlation (3), measuring the relationships between variables as follows:

$$PT\ supply\ and\ demand\ rate = \frac{PT\ supply}{PT\ demand}\ [dimensionless] \quad (23)$$

$$PCT\ supply\ and\ demand\ rate = \frac{PCT\ supply}{PCT\ demand}\ [dimensionless] \quad (24)$$

PT supply and demand closely relate to road means of transport in public transport. *PT* rates of residents' traveling ventures reflect the survey of people's transport behavior using regional buses and *PT*, ignoring railways when dividing regional transport work [32].

4. Results and Discussion

The described model tracks 20 years, spanning over 2021 and 2040. Initial values of the model variables reflect statistical data of the South Bohemian Region from 2019, studies and surveys conducted on behalf of clients archived in the South Bohemian Region or the chartered city of České Budějovice, and internal materials of the transport coordinator in the South Bohemian Region or The Public Transport Company of České Budějovice [30]. Due to the demonstrative nature of the model, the applied stock and flow diagrams to the transport sector did not go through any validation.

The Vensim program allows a simulation of various scenarios and interactive experiments, diversifying initial values of input variables. We initiated two schemes for analyzing the system dynamics [36]:

- Scenario A–The supply and demand trend in the selected modes will be the same as in previous years (reflecting current historical data of measured variables)
- Scenario B–The supply and demand trend in *PT* will be growing in the subsequent years, calling for a supply increase in means of transport and higher utilization rates. This enhancement involves new lines, purchasing more equipment, and so on, moving the value toward the average daily *PT* vehicle capacity. On the other side, *PT* usage rates will mount to 14.5% in 2040 to satisfy the predicted demand (see Table 2).
- Scenario C–We are considering a growing trend in *PT*, but with a lower value of *GDP* increase each year (from the current 3.5% annual growth, a drop to the growth of 2.5% on average). The rest of the variable values remain the same as in scenario B.
- Scenario D–We are considering a growing trend in *PT*, but with a lower value of *GDP* increase each year (from the current 3.5% annual growth, a drop to the growth of 1.5% on average). The rest of the variable values remain the same as in scenario B.

The initial variable values reflect a region or municipality, constructing possible scenarios and studying system behavior in time. Table 2 summarizes the initial values used in the simulation of trends of variables in time.

The simple simulation involved four scenarios, modifying values of selected variables directly linked to the supply and demand in *PT*. Submodels suggesting the numbers of cars, local population, and regional *GDP* went unchanged when measuring the variables and model structure of scenarios A and B [37]. In both scenarios, demand in *PCT* for travels indicated a downward trend of the *PCT* ratio to the division of transport work to 30% in 2040, showing the same tendency in *PCT*.

Table 2. Input model values for calculating supply and demand ratios for transport [30].

Variables in the SD Model	Input Value–Scenario A	Input Value–Scenario B	Input Value–Scenario C	Input Value–Scenario D	Units
population	643,630	643,630	643,630	643,630	residents
average annual natural population increase	0.5	0.5	0.5	0.5	%
average annual natural population migration increase	0.8	0.8	0.8	0.8	%
GDP	$281{,}771 \times 10^6$	$281{,}771 \times 10^6$	$281{,}771 \times 10^6$	$281{,}771 \times 10^6$	CZK
average annual *GDP* growth	3.5	3.5	2.5	1.5	%
average annual investment rates in transport per *GDP*	2.3	2.3	2.3	2.3	%
average costs of purchasing new means of transport	3	3.5	3.5	3.5	%
average price of a means of public transport	8,500,000	8,500,000	8,500,000	8,500,000	CZK
total of means of public transport	500	500	500	500	vehicles
average ratio of decommissioned *PT* vehicles	0.5	0.5	0.5	0.5	%
average daily capacity of means of PT	300	400	400	400	passengers/day
total of registered vehicles	375,657	375,657	375,657	375,657	vehicles
expected annual car growth	1.71	1.71	1.71	1.71	%
car ratio in households	70	70	70	70	%
average car occupancy rate	1.3	1.3	1.3	1.3	passengers/cars
PT rates in the division of transport work	10.8 upward trend to 12.5	10.8 strong upward trend to 13.5	10.8 strong upward trend to 13.5	10.8 strong upward trend to 13.5	%
PCT rates in the division of transport work	40	40	40	40	%

Residents' movability is also the same for both schemes, suggesting the trend from the relationship (17). The variable does not involve the initial value. Rather than that, it tracks an underlying tendency indicating *GDP* rates and population in the region. While 2019 saw the residents' movability in the South Bohemian Region at 2.75 travels per day, the estimate for 2021 amounts to 2.8 travels/day and 3.3 travels/day in 2040, considering the model parameters (scenarios A and B) [32]. Given the hypothesis that *GDP* per capita correlates with residents' movability, scenarios are tested where *GDP* per capita will grow in a more moderate trend in coming years (scenario C assumes an average annual growth of 2.5%, scenario D assumes an average annual growth of 1.5%). The crucial factor in the model is the value of "stocks" in the form of *GDP* volume. In general, a relationship between *GDP* growth and population mobility is proven [31].

The residents' movability in the case of scenario C will increase over the 20 years, from a value of 2.8 travels per day to a value of 3.1 travels per day. Regarding scenario D, the increase is slower to a value of 2.9 travels per day in the final year. Figure 7 depicts the trend of residents' movability over the 20 years.

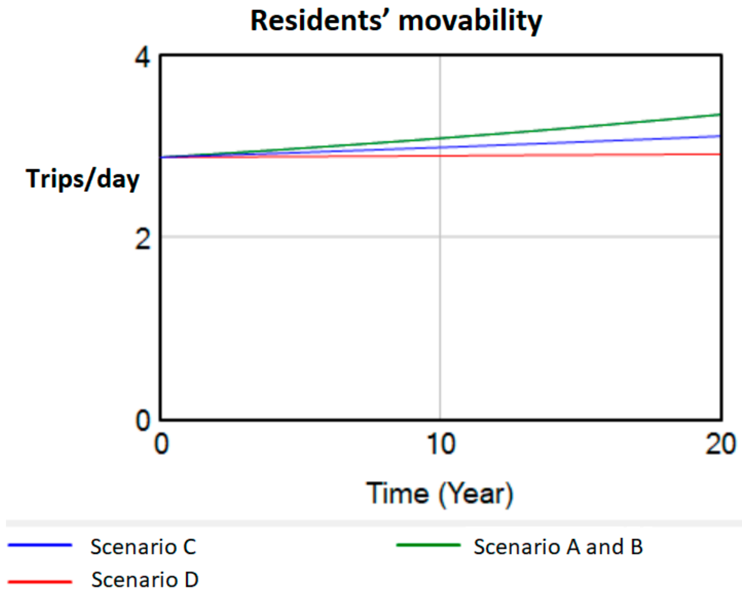

Figure 7. Residents' movability trend over the 20 years.

The linear movement of the residents' movability reflects the Equation (17). A regression line measures the correlation between the movability variable and *GDP* per capita. The *GDP* per capita involves the comparison of two submodels-*GDP* rates and total population in the South Bohemian Region. Results complied with both scenarios when scenario B included only selected variables from supply and demand in *PT* with diversified parameters. We simplified the results yielded by submodels within 20 years, considering a year-to-year percentage increase. The resulting average values reflect historical data on the population and *GDP* of the South Bohemian Region, predicting a steady upward trend. We can also add other impactful elements to the demonstrative model, aiming for more reliable results. The submodel generating final population figures may split the regional population trend into specific population groups by, for example, socio-economic status. Figure 8 illustrates the movement of *GDP* rates and total population in the South Bohemian Region.

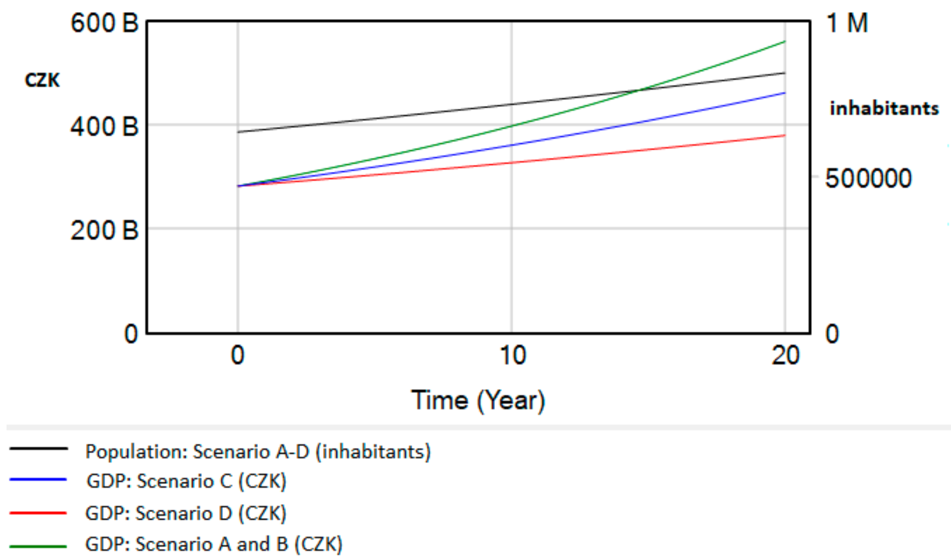

Figure 8. *GDP* and population trends over the 20 years.

The numbers of registered cars and supply and demand for *PCT* indicate an upward trend regarding the parameters and influential factors [38]. We considered the downward movement of the annual percentage car growth when referring to the number of registered cars. Despite being only speculation, this scenario appears very likely, based on the current trend in the automotive industry. Unpredictable effects can dramatically disturb the foreseen flow. The final simulation phase generated a logarithmic curve settling at 430,127 cars, compared to 375,567 in the beginning.

Demand also indicates an increasing trend, although suffering from plummeting *PCT* rates of the division of transport work. We intentionally involved a downward movement of *PCT* rates in the modal split from the current 40% (beginning phase of the simulation) to the expected 30% at the end of the period. The increasing supply and demand for *PCT* travels range from 1.32 and 1.56 dimensionless. The former reflects the change in the residents' movability and the number of registered vehicles, significantly surmounting demand despite the limiting scenarios. Figure 9 suggests the trend in registered cars and supply and demand rates in *PCT* according to the simulation.

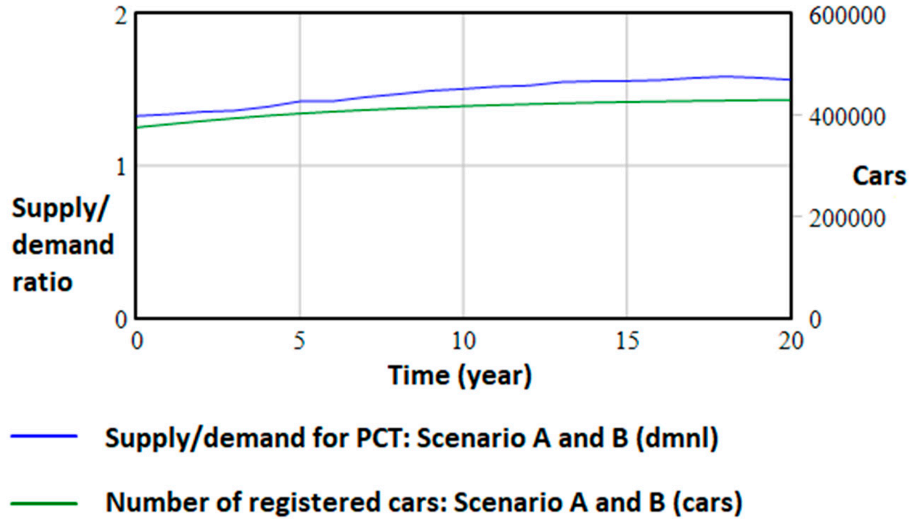

Figure 9. Trend in registered cars and supply and demand rates in *PCT* (dimensionless-Dmnl).

The submodel yielding the numbers of road means of *PT* in the South Bohemian Region demonstrates a different approach to interpreting the situation. The increment in new *PT* vehicles reflects an algorithm from the *GDP*, integrating various (simplified) scenarios based on which we can calculate vehicles purchased in a year [39]. The measuring works again with relevant input variables from historical statistical data. On the contrary, the stock outflow involves the number of road *PT* vehicles removed from the annual records of transport companies. The stock value indicates the average rate of decommissioned vehicles in *PT*. Road means of transport include regional and municipal buses. Figure 10 depicts the results of the simulation.

Five hundred *PT* vehicles are the default number for both scenarios, indicating 1000 means of transport in the final simulation phase (scenario B suggests 1191 pieces), provided that *GDP* growth, as well as investments in transportation and funds for the acquisition of new vehicles in *PT*, will be constant year-on-year, which is very unlikely. Furthermore, the transport system involves other variables determining its quality, offer, and demand. We added average daily *PT* vehicle capacity, including average passenger capacity and everyday utilization of transport lines.

The modeled demand for the daily public transport capacity surpasses the supply, mimicking the trend of recent years. Scenario A indicates supply and demand rates at 0.75 at the beginning and 0.94 at the end of the simulation. Scenario B involves an increase in the daily *PT* capacity and higher numbers of new vehicles in the initial simulation phase. The supply and demand rates begin at 1.02 and close at 1.26. Figure 11 suggests the trend in supply and demand rates in *PT*.

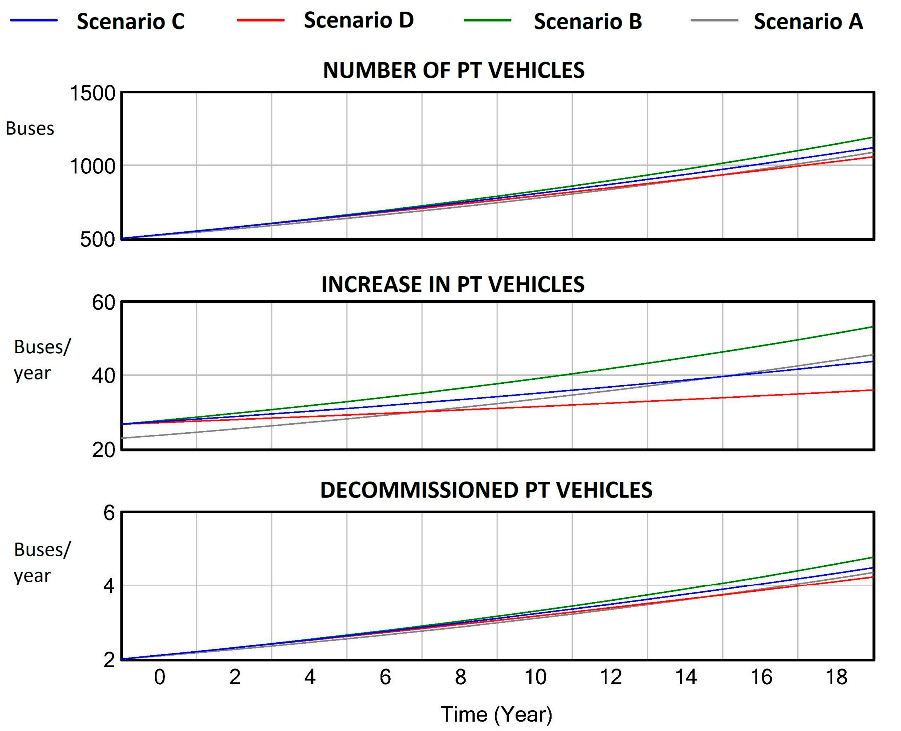

Figure 10. Trend of selected submodel values 'number of *PT* vehicles'.

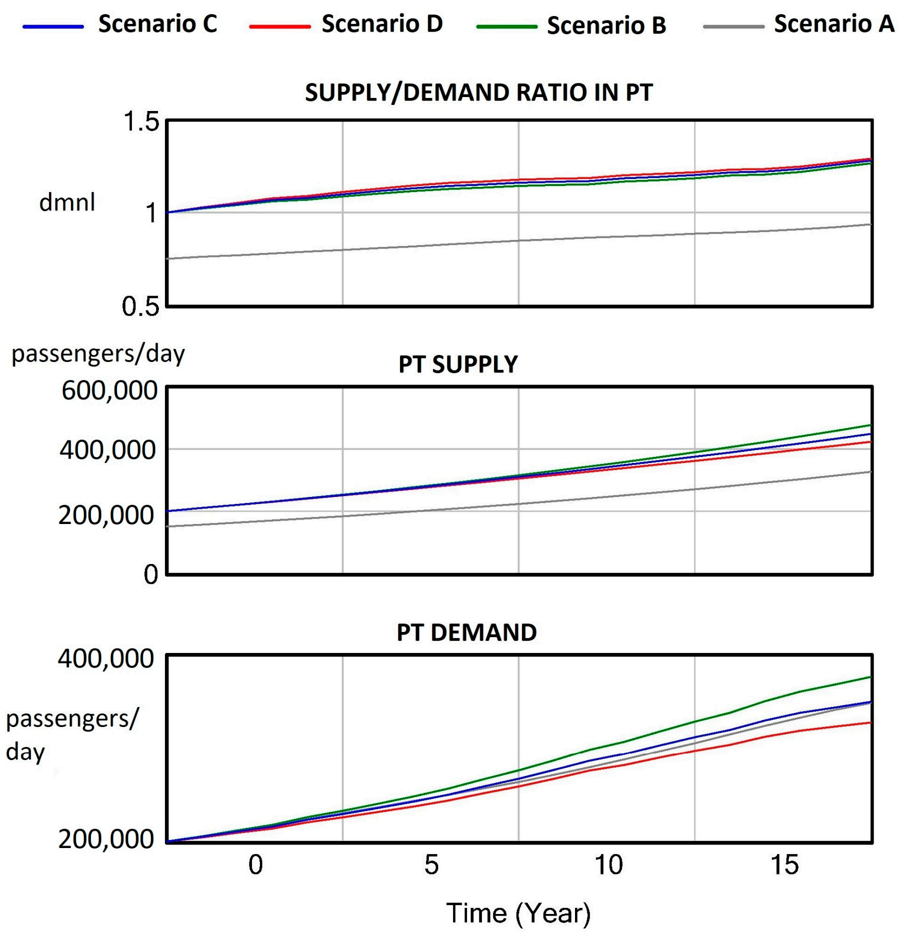

Figure 11. Trends in supply and demand in PT.

Scenario C and scenario D show a similar trend in the supply and demand index in public transport, which is given by the demonstrative model parameter set in this way. The result of the model testing shows that it is appropriate to specify other variables in order to simulate the resulting values of the index based on the vehicle fleet's current state, the setting of the traffic rules and measures, as well as other factors related to the planning of transport capacity in public transport.

The supply and demand for *PT* reflect regional infrastructure. The model for estimating its rates allows a simplified demonstration of how system dynamics tools work in the transport sector [40]. When the model expands into other specific variables, the model estimates the final supply and demand rates. Ratios below the limit indicate that the public transport sector cannot satisfy the demand for *PT*, whereas rates above the ceiling, yet not reaching one, show that the *PT* system meets customer needs in certain situations. In rush hours or emergencies, the infrastructure suffers from deficiencies. Our model does not count factors behind heavy traffic, including everyday supply and demand.

Supply and demand rates above 1 suggest that the *PT* network fully meets public demand. However, if the rates exceed the outer limit, we should consider optimizing and adjusting public transport processes. Cutting the excessive supply will prevent economic losses.

The addressed index supply/demand ratio in public transport can be deemed as one of the indicators quantifying the state of a sustainable transport system. Different versions of potential indicators and their measures for describing a strategy or sub-system of sustainable mobility and sustainable transport system exist. An important criterion for these indicators is represented by the fact that they should define all connections with the goals of sustainable mobility as succinctly and clearly as possible. Indicators can be of different types; see them as follows:

- quantitative and qualitative data;
- individual indicators (e.g., individual opinions within questionnaire surveys);
- ratio indicators;
- relative indicators.

Based on the findings demonstrating the connections of various factors affecting the resulting transport demand and supply, the indicators can be used for further extensive research. In this case, it would be a matter of compiling indicators respecting the pillars of sustainable mobility, namely factors affecting traffic volumes on roads. In deeper considerations and perspectives, the transport system state is taken into account with the goals of strategic land use planning, with the goals of integrated transport modes aimed at increasing safety and reducing the negative impact on the environment so that costs are spent effectively (i.e., effective development of a sustainable urban environment). At the same time, we try to integrate as many indicators as possible, which could be of maximum help towards decision-making processes concerning sustainable development.

5. Conclusions

The article investigates dynamic trends in multi-modal transport systems, surveying system dynamics tools such as stock and flow diagrams. System and subsystem elements intertwine, being suitable for transport systems.

We researched scientific literature focusing on possible effects on demand for public transport and using modelled system dynamics tools. Our results show that the instruments, stock, and flow diagrams in particular, successfully describe complex transport systems.

The value-added and the novelty of the research conducted lie, in particular, in introducing an index in the form of demand and supply ratio in different transport modes. This index appears to be a suitable indicator of some kinds of the transport system state, due to which it is possible to analyze options to improve the efficiency of the entire transport system. The manuscript further demonstrates a model based on system dynamics that can be used to determine the abovementioned index of transport demand and supply ratio.

Such a demonstrative model can be applied in practice, above all, in transport planning, with a special emphasis on increasing the mobility level towards sustainable development.

We devised a demonstrative model for estimating the trend in supply and demand for travels in passenger cars and public transport. The design involved data from the South Bohemian Region (Czech Republic), including a simulated estimate of supply and demand for transport in the selected sectors. The experiment involved two scenarios based on the available statistical data from the region, reflecting the trend for the following twenty years. We further analyze our findings in the Results and Discussion chapters.

Our study revealed that the supply and demand ratio reflects a 'condition' (economic, operational, etc.) of the transport system. Further research will focus on upper and lower transport supply and demand limits that ensure a 'balance' in the transport infrastructure of the whole transport system. In the following phases, we will involve other variables and indicators to better estimate the resulting transport supply and demand ratio.

This percentage also indicates system sustainability in the municipality or region. Since road traffic volumes correspond with figures of activities of the involved subjects (systematic transport variations), causal loop diagrams of stock and flow succeed when determining the total vehicles in the network. Models can serve as an auxiliary tool for zoning or strategic planning of sustainable mobility, evaluating changes in time, or assessing the impacts of adopted strategies on the local transport and environment.

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