Model of system dynamics to study the effects of unmanned vehicles introduction in the economic environment

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Abstract. The article is devoted to the study of problems appearing from the introduction of unmanned vehicles in the economic environment. The authors propose an approach to visualize and study the mutual influence of factors causing the emergence of such problems, based on cause-effect diagrams of system dynamics. The main factors investigated are: the investment advisability, the activity of trade unions and the main components of the sustainable development concept. The interaction of the described factors was modeled using Anylogic environment flowcharts, the results were obtained. The study showed that the transition to unmanned vehicles will reduce the costs of transport companies and the intensity of emissions on the background of social conflict and increasing drivers union activity.

1. Introduction
Nowadays, unmanned vehicles of companies such as Tesla and Google, are already actively used in the US and EU countries. However, with the introduction of unmanned vehicles in the real economic environment, appears a large number of specific factors that are important not only by themselves, but also interact with each other. [1-3]. This problem is given much attention in different countries of the world. [4]. There is a need to study and visualize this interaction, as it plays the greatest role in making management decisions regarding the development of approaches to the introduction of unmanned vehicles.

2. Research Method
All complex systems include variables that interact with each other through positive and negative feedback loops. As a means of visualizing the variables interaction, it is proposed to use cause-effect diagrams used in system dynamics [5, 6]. The diagram serves as a visual aid on the interaction and role of variables. In case of the positive relationship, increasing / decreasing the first element contributes to increasing / decreasing the second element. The results that can be obtained from cause-effect diagrams are limited by their qualitative, conceptual role. [7]. However, the diagram allows to conclude about the functioning principle of the system, which is very useful in studying the modern digital technologies influence on the environment.

3. Results and discussion
Obviously, each new unmanned vehicle in the company's park will be equivalent to one dismissed driver. Increasing the number of layoffs leads to an increase in driver dissatisfaction in the company, which may influence management decisions through a trade union organization inside the enterprise,
strikes, absenteeism and other leverage. Thus, a conflict arises: on the one hand, replacing a traditional fleet with an unmanned vehicle leads to fuel consumption reduction. But on the other hand, a huge number of people involved in the motor vehicles management will remain without work. [6]. The investment advisability increases depending on the number of new cars, and the whole process will have an exponential growth pattern. Therefore, a balancing feedback loop should be present in the dynamic model, preventing the exponential growth. The result is an increase in the discontent degree of dismissed drivers and an increase in the activity of trade union organizations. The consequence is an incentive for strikes and other levers of influence on the management of the enterprise. (Figure 1).

![Figure 1. The interaction of the balancing and amplifying cycles.](image)

The process of replacing the fleet will also form a balancing feedback loop, due to the processes occurring in the organization. Its formation can be explained by the following logic - with each new driver dismissed, a growing degree of discontent in the society of drivers will take place, and trade union organizations will have an ever-increasing impact on the company's management, preventing the replacement of the fleet. Reduced fuel consumption leads to lower exhaust emissions. (Figure 2).

![Figure 2. Cause-effect diagram illustrating the reduction of fuel consumption effect](image)

Transportation costs decrease as salary fund decreases. This will reduce the price of the finished product and thus allow to occupy a larger market share. Increasing the number of customers forms the economies of scale effect, which again reduces the price and makes possible to take even greater market share. This cycle is a company growth accelerator due to the introduction of autopilot systems. The insurance cost depends on the frequency (probability) of getting into a traffic accident. Thus, companies should expect a reduction in vehicle fleet insurance costs. [8].

In that way the positive aspects of digital technologies in transport will be weakened by rising activity of drivers trade unions, which can eventually lead to social conflicts in society. The drivers have the ability to influence management decisions, trade union organizations, strikes, absenteeism and other leverage. In case if most of the cars function autonomously, then with much greater probability the above losses will be less.
Table 1. Elements used in the flow diagram.

| Element name                        | Symbol | unit of measurement |
|-------------------------------------|--------|---------------------|
| Drivers on staff                    | $V$    | person              |
| Dismissed drivers                   | $C$    | person              |
| Rate of dismissal                   | $U$    | person / month.     |
| Investment advisability             | $inv$  | transport units     |
| Salary fund                         | $Fond$ | ruble               |
| Novelty factor                      | $K$    | -                   |
| Average salary of drivers           | $Z_{ср}$ | ruble              |
| Number of cars in the park          | $K_{парк}$ | Units of transport |

Staff and dismissed drivers were taken as accumulators, between which there is a discharge rate. (Figure 3):

$$\frac{C(t)}{dt} = U$$  \hspace{1cm} (1)

$$\frac{V(t)}{dt} = -U$$  \hspace{1cm} (2)

We introduce the coefficient of novelty $K$. The enterprise management has the right to decide for itself how many cars to replace at the initial stage depending on financial possibilities and the strategy being implemented: this can be either one car or the entire fleet at once. [9]. Thus, this parameter adds flexibility to the model being developed:

$$1 < K < K_{парк}$$  \hspace{1cm} (3)

Obviously, the feasibility of investing a project that does not bring any benefit is 0. In the object under study, the dismissal of employees contributes to saving money and, consequently, increasing the company's revenue to $Z_{ср}$ per month. In order to determine the benefits of investing, we must also have data on costs. Let us assume that the project’s profitability is high and the implementation of the technology is based on the project implementation period minimizing criteria. Then the process of introducing cost-effective investments will be a snowball, in which the volume of current investments depends on the previous value. Therefore, we assume that the replacement of one car increases the feasibility of investing in one car more:

$$\text{Inv} = K + \frac{Fond}{Z_{ср}}$$  \hspace{1cm} (4)

Thus, there is all the necessary data for the compilation of the subtotal. In our example, the following parameters: model time: months; staff of drivers: 100 people. According to the simulation results, with given parameters, after 3.5 months all drivers in the enterprise will be dismissed and the monthly salary savings will be equal to the value of the variable $Fond$, as a result of modeling that is 5 300 000 rubles.

We believe that the dismissed drivers can influence employees on staff. We introduce some additional parameters presented in Table 2.
Table 2. Additional elements of the model

| Element name                                      | Symbol | unit of measurement |
|--------------------------------------------------|--------|---------------------|
| Degree of discontent drivers                     | $N$    | -                   |
| The average number of people in the immediate vicinity of one driver | $O$    | person              |
| Power of influence                                | $F$    | -                   |
| Union activity                                    | $A$    | person              |
| Fuel economy                                      | $FE$   | ruble               |
| The probability of finding a driver in the company | $\alpha$ | %                   |
| Emission reduction                                | $Gas$  |                      |

For a general understanding of the picture we will reveal the significance of some elements: $N$ - degree of drivers discontent. This variable has two parameters that characterize the degree of discontent: $O$ – communication. The average number of people with whom one driver communicates. Let the driver communicate with 5 people on average: $O = 5$. $F$ – power of influence. Parameter taking value in the interval $1/1000 < F < 1$. Assume that the value of this parameter is $1/500$: $F = 1/500$ (5)

Thus, from the accumulator C “dismissed drivers” there is a positive connection to the variable $N$, which depends on communication and the strength of influence. It is necessary to add a variable that reflects degree of driver discontent and the likelihood that the dismissed driver does not have a repeated effect.

$$\alpha = V/100$$ (6)

$$N = C \cdot \alpha \cdot O \cdot F$$ (7)

In that way $N$ takes a value from 0 to 1. At the maximum value of this variable, the activity of the trade unions becomes the greatest. Therefore, it is true that the more displaced drivers a transport company has, the more they influence people who have access to leverage. In this regard, it is necessary to enter the parameter of trade unions activity $A$, denoting the number of people who cannot be dismissed at a given time. After part of the drivers dismissed, social tensions increase in the work team. Therefore, the more drivers dismissed, the greater the degree of discontent is, but as the number of drivers in the company becomes smaller, they can not be so active as before:

$$A = V \cdot N$$ (8)

Suppose autopilot trucks use less fuel by 6%. Based on this, we introduce a new variable $FE$ - fuel savings that will have one parameter $p1$ – current fuel consumption of 15 liters per 100 km.

$$FE = 0.06 \cdot p1 \cdot C$$ (9)

Dynamic variable $FE$ will serve as a source of information on the amount of fuel saved. An important factor has been and remains the reduction of exhaust emissions due to reduced energy consumption. To determine a quantitative estimate of emission reductions, we introduce a new variable $Gas$ – CO2 reduction and $p2$- conversion rate. In this way:

$$Gas = FE \cdot p2$$ (10)

The result of reducing exhaust emissions is the amount of fuel saved multiplied by the conversion factor.

Now lets model the created flowchart in the Anylogic environment. (Figure 4).
Table 3. A general summary of the model’s elements and their formulas

| Element | Element type   | Formula or value                     | unit of measurement |
|---------|----------------|--------------------------------------|---------------------|
| V       | accumulator    | \( V(t)/dt = -U \)                   | person              |
| C       | accumulator    | \( C(t)/dt = U \)                    | person              |
| U       | flow           | \( inv = -A \)                       | person              |
| Fond    | dynamic variable | \( Fond = -C \cdot Z_{cp} \)    | ruble               |
| Zcp     | parameter      | 53000                               | ruble               |
| inv     | dynamic variable | \( inv = K + Fond/Z_{cp} \)     | person              |
| K       | parameter      | 3                                   | person              |
| N       | dynamic variable | \( N = C \cdot \alpha \cdot O \cdot F \)  | -                   |
| \(\alpha\) | parameter       | \( \alpha = V/100 \)                | %                   |
| O       | parameter      | 5                                   | person              |
| F       | parameter      | \( 1/500 \)                         | l/person            |
| A       | dynamic variable | \( A = V \cdot N \)               | person              |

Let’s list the simulation results of the interaction between the contours of the balancing and amplifying cycles in Table 4.

Table 4. The simulation results of the interaction between the contours of the balancing and amplifying cycles

| Symbol | Result | unit of measurement |
|--------|--------|---------------------|
| \(T_{kon}\) | 8.0806 | months              |
| CC     | 100    | person              |
| V      | 0      | person              |
| Fond   | 5 300 000 | ruble                |
| N      | 1      | -                   |
| U      | 100    | person/month        |
| A      | 0      | person              |

The simulation results showed that with an increase in the activity of trade unions, dismissal takes place over a long period, during which the effect of the balancing loop is observed. At a certain point in time, a crucial situation occurs when the activity of trade unions begins to fall sharply. During this period, there is a rapid increase in the number of layoffs. This is due to the drivers loss of leverage on the company. Considering the transport infrastructure of digital economy, it is important to take into account the flow of processes in dynamics, observing the mutual influence of factors that will inevitably accompany the introduction of automation innovations in practice. [10,11].

4. Conclusion
The results of the study showed that the management of transport, trade, logistics companies and the government of the country should be ready for social conflicts in society related to the implementation
of automated systems. We should highlight that different regions and climatic zones have a significant impact on the automation growth rate. The influence of weather conditions can be taken into account by introducing the corresponding dynamic variable into the model.

In 2019, six organizations are planning to begin trial operation of highly automated cars in Russia - PJSC KamAZ, Avrora Design Bureau LLC, Scientific-Design Bureau of Computing Systems, University Innopolis, Moscow Automobile and Road State Technical University (MADI) and Yandex. In this regard, we can conclude that the validation of the model will be possible in the near future. However, today the automation technologies development is far ahead of the development of legislation in this sphere. Therefore, the speed and success of the autopilot vehicles introduction will largely depend on the creation of an appropriate legislative framework, which should be created as soon as possible.

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