Design of a Model of an Information and Communication System for Solving the Problem of Preventing Car Collisions

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Abstract: Vehicle-to-vehicle (V2V) communication is a special type of vehicular ad-hoc network communication that has attracted much attention from researchers, industries, and the government due to its important application to improve driving safety for the next generation of vehicles. However, if the warning comes too late, the vehicle behind may not have enough time to stop smoothly or slow down. Especially when it comes to car accidents involving multiple vehicles. The collision warning system is important for avoiding rear-end collisions. When the vehicle in front slows down or the risk of a rear-end collision increases, the system sends a warning. Fast-moving vehicles and unreliable wireless communication links can lead to communication difficulties between vehicles, affecting the performance of multi-vehicle systems. The article describes the general perspective of the development of automobile networks. This material examines the possibilities of communication modeling and the possibility of looking at development problems, as well as researching and solving issues of network operation, the behavior of driver assistance applications and the interaction of many cars. A model of system operation based on the "receiver-transmitter" principle for BSM transmission using DSRC communication was created using MATLAB/Simulink software. The resulting model allows for various analyzes of the system for the future improvement of information and communication systems in cars.

1 INTRODUCTION

The rapid development of transportation systems has brought many conveniences to our daily lives, allowing the safe and reliable transportation of both people and goods within the country and abroad. It is estimated that more than one billion cars are owned by people around the world. It is estimated that this number will double within a decade or two. However, a number of issues related to this growth cause concern. From a safety perspective, more than 42,915 people were killed in US highway crashes in 2021 [1].

Vehicle-to-vehicle (V2V) communication between multiple connected vehicles improves the safety and efficiency of our transportation systems.

This is achieved through the use of traffic management systems that rely on on-board sensors and V2V communication. Communication mainly provides real-time status information (e.g., acceleration, speed, location) of the front vehicle or vehicles [2].

Assessments regarding the importance of this technology:

- Improving road safety. V2V communication allows cars to exchange information about their location, speed and other parameters in real-time. This helps to avoid accidents, reduce the number of collisions and improve the response to danger. For example, the system can warn drivers about possible risks, such as an emergency situation on the road, obstacles or dangerous overtaking.
- Reducing congestion and improving traffic flow. V2V technology helps drivers choose the optimal route and speed to avoid traffic jams. This can improve traffic flow and reduce travel time.

- Accident reduction. Thanks to V2V communication, cars can share information about dangerous road conditions, such as slippery asphalt, limited visibility or bad weather. This helps drivers adapt their driving style to specific conditions and reduces the risk of accidents [3].

Demand for advanced driver assistance systems (ADAS) [4] – those that help perform monitoring, warning, braking, and steering tasks - will grow over the next decade, driven largely by regulatory and consumer interest in safety programs that protect drivers and to reduce the number of accidents.

Currently, ADAS systems are seen as an ever-evolving industry that continues to improve and evolve. Although there are already many different ADAS systems on the market, they are constantly being improved and supplemented with new features. At the system development stage, various challenges and problems arise, such as interaction between systems, data security, compliance with regulatory requirements, integration with other systems and car components, intelligent data management, and others.

The development of ADAS systems is a complex and multifaceted process that requires a detailed study of various aspects, from technical capabilities to socio-economic and legal aspects.

In this study, we focus on services that create or correlate with one-time messaging, especially using a V2V communication platform.

2 LITERATURE REVIEW

Based on the literature, we present various applications of V2V communication, classified according to two broad purposes: security purposes and non-security purposes. The main goals in this category are to minimize safety problems by providing directions or other information to the driver to prevent or predict traffic accidents, such as pre- or post-crash situations, blind spot prediction, intersection assistance, etc.

Vehicle-to-vehicle messaging aims to minimize potential crashes and enhance safe in-car driving with driver assistance features for both autonomous and non-autonomous vehicles. In addition, V2V communication will enhance safety support in five-level autonomy in autonomous vehicles, where the combination between artificial intelligence, vehicle technology, the Internet of Things and communication capabilities will accelerate the mass adoption of autonomous vehicles in the [5].

Nowadays, with V2V communication through technologies such as IEEE 802.11p-based DSRC and new 5G solutions, various IFTs become possible as a vehicle can communicate with vehicles outside its immediate environment [6].

If we take the characteristics of the transmission channel itself, there is a possibility of improving communication by interfering with the structure of the 802.11p protocol, which covers the field that has the value of the size of the information packet. Work [7] focused on developing a powerfully adaptive packet size structure that depends on the value of the signal-to-noise ratio. There are neural network controls that are trained by potential packet size values derived from an equation obtained by practical testing of the multiple relationship between packet error rates and packet size values [8]. Adjusting the size of the information packet results in a reduction of the packet transmission error rate.

The paper [9] proposes a predictive distributed model predictive control (DMPC) method for multi-vehicle system control in switched communication topologies. An open-loop optimization problem is formulated, in which penalties and constraints for neighbor deviation and self-deflection are included to ensure stability. The DMPC algorithm is designed for systems with multiple vehicles subject to switching topologies. As a result, a system control controller with several vehicles in switching communication topologies was created.

For example, the goal of developing person-based adaptive signal control (PB-ACA) was to investigate optimal signal plans on an isolated connection. In this study, as a decentralized coordinated control, the coordinated person-based signal control (C-PBC) algorithm allows the local controller at each intersection in the road network region to independently control the PB-ACA based on the data of the connected vehicle within the wireless range to optimize personnel-based signal plans. For each intersection, the communication range is defined as a circle with a radius of 250 m from the center of the intersection, and the planned intersection can only receive data within this communication range [10].

With the rapid development of wireless communication technologies, the behavior of the driver in front of the vehicle can be transmitted to the following vehicle to improve the performance of the system.

This paper proposes a forward collision warning (FCW) system that detects the driving intention of the preceding vehicle and transmits the information to the following vehicle using V2V communication technologies. The proposed driving intention recognition method provides better performance of the FCW system and gives the following vehicle additional time for smooth braking [11].

In all these cases, modeling is an important stage in the development and testing of systems. The paper [12] describes a mathematical model of V2V, overtaking and minimum overtaking distance analysis using fuzzy logic. Experiments were designed using PreScan/MATLAB. The model shows the effectiveness of the created algorithm.

In this work, the collision warning system was created using the information and communication data transmission model based on wireless communication technology using MATLAB/ Simulink [13].

3 MATERIALS AND METHODS

Wi-Fi technology, known as Dedicated Short-Range Communication (DSRC) between each vehicle, and GPS technology, which offers detailed positioning by exchanging data with similarly equipped vehicles. DSRC is a special-purpose communication tool designed for a vehicle to provide short-range communication with a neighboring vehicle or with the environment to achieve a shared driving situation. DSRC uses 75 MHz spectrum for automotive communications and uses IEEE 802.11p-based radio technology with a bandwidth of 3 to 27 Mbps [14]. Several components are required to provide V2V communication:

1) DSRC is a special radio unit that works as a data receiver and transmitter;
2) GPS receiver [15], responsible for determining the position of the car in space and time; this data will be the input data for DSRC;
3) OBU (On-Board Unit), which collects vehicle status data such as speed, steering angle, acceleration, brake status, etc. It also installs an application and a screen for displaying interface information.

We model communication (V2V) and build a model based on the "receiver-transmitter" principle (Figure 1). The model is an integral part of the project and has a pre-prepared "scene" (model of the road surface with obstacles for the transmitter), "scenario" (route of movement) and "actors" (transport with defined characteristics). The model uses DSRC basic radio transmission safety message (BSM) [16] message.

Communication relies on channel characteristics to determine the probability of successful message reception.

The Transmitter V2V subsystem generates a Basic Security Message (BSM) for each target vehicle using the received information for that actor. The transmitter reads the "actor" information and passes it through the Inertial Navigation System (INS) and the Global Navigation Satellite System (GNSS) to apply noise to the "actor" information. The subsystem also transforms the spatial location information of target vehicles from Cartesian coordinates to geographic coordinates using "scene" information. The subsystem then generates BSMs for all target vehicles. The SendMessage block inside the transmitter converts the signal into a Simulink message and delivers it to the object queue. Queues are organized as first-in-first-out (FIFO) queues.

The V2V receiver subsystem implements the behavior of the vehicle object receiver. The receiver receives the precomputed channel characteristics as the mask parameter and the transmitted BSM, scene, and car information as input. When a transmitter delivers a message to an object queue, it triggers the V2V receiver subsystem. For each target vehicle, the receiver calculates the distance from that target vehicle to its vehicle and then finds the corresponding bandwidth using the precomputed channel characteristics.

When the bandwidth exceeds the generated random number, the receiver receives the BSM and stores it on the output bus BSMOut. A FIFO queue models a message receiving interface that works based on message availability.

The received message is further forwarded to the message processing unit, which converts the BSM input data into physical values and generates object detection reports for the input data to track multiple objects [17].

4 THE RESULTS

The results of the model show the dependence between the distance from the transmitter to the receiver and the signal-to-noise ratio (SNR) [18] for different transmission bands (Figure 2). In this example, a difference of 50 and 150 m is compared. We can also see the relationship between distance and bandwidth for the specified range (Figure 3).

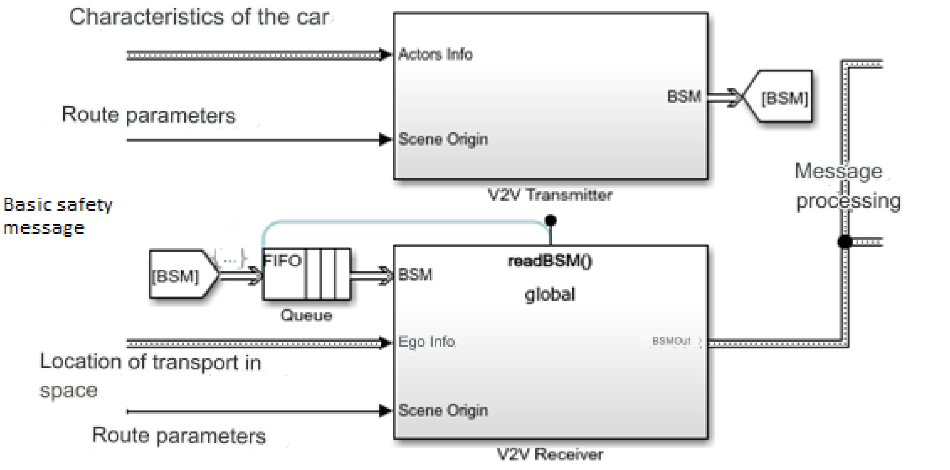


Figure 1: Vehicle to Vehicle Communication model.

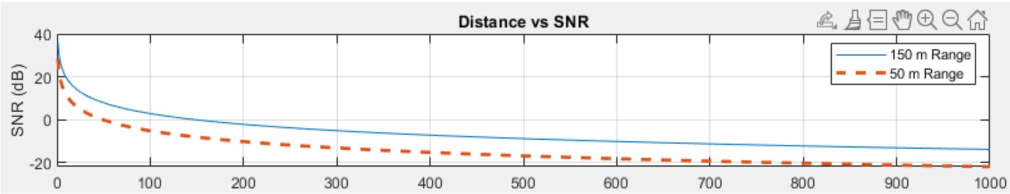


Figure 2: Dependence of distance and signal-to-noise ratio.

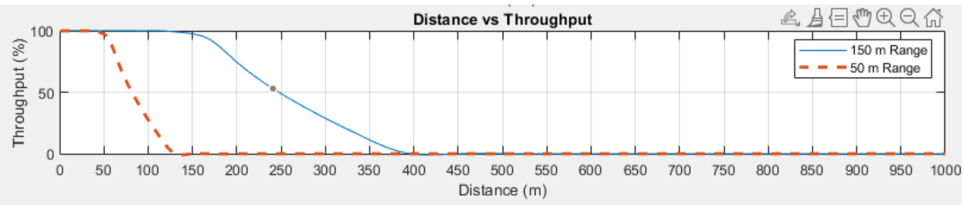


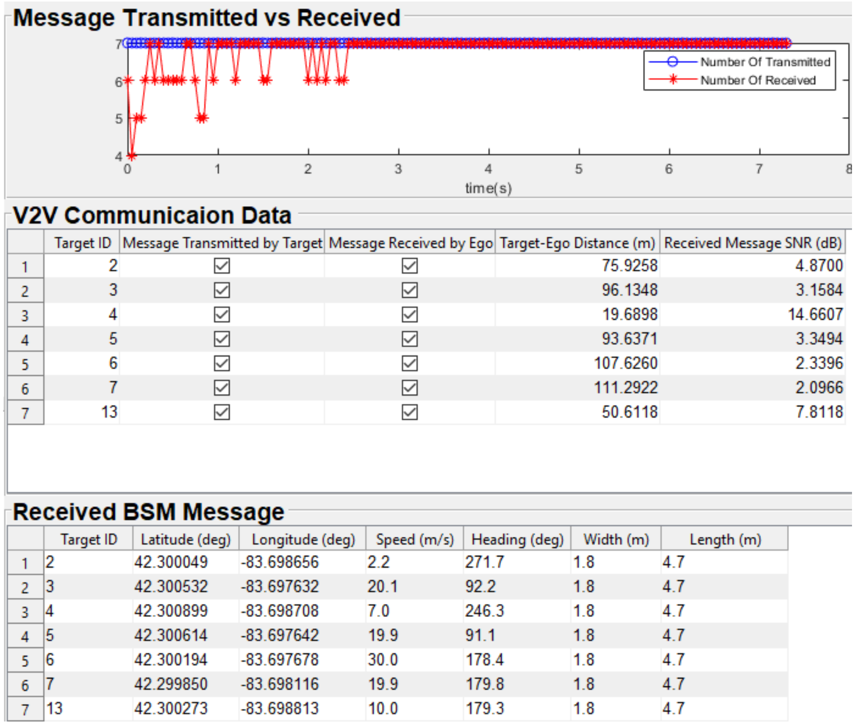
Figure 3: Dependence versus bandwidth relationship.

Throughput means the expected probability of detecting a packet. When the range is 150 m, the graph shows that the probability of packet detection is almost 100% up to 150 m, and then it gradually decreases until it reaches 0% at about 400 m, the probability of detecting a package decreases faster and at a distance of 150 m is close to 0%. During operation, the model visualizes important data and issues the following information (Figure 4):

- The ratio of transmitted and received messages, which reflects the number of transmitted and received messages at each time step.
- V2V Communication Data - Displays information about the transmission and reception of BSM data and the signal-to-noise ratio for each message received.

BSM Message Received – Displays latitude, longitude, speed, course, longitude, and latitude for each target whose BSM message is received.

After receiving the BSM to generate a possible collision warning, the paths for the target and neighboring vehicles are estimated using their current position, speed, and heading angles. The estimated trajectory of each vehicle is a straight line connecting the vehicle's initial position and its predicted position 20 seconds later. To assess the collision risk, the analyzer checks whether the estimated path of the neighboring vehicle intersects with the estimated path



Message Transmitted vs Received

V2V Communicaion Data

	Target ID	Message Transmitted by Target	Message Received by Ego	Target-Ego Distance (m)	Received Message SNR (dB)
1	2	☑	☑	75.9258	4.8700
2	3	☑	☑	96.1348	3.1584
3	4	☑	☑	19.6898	14.6607
4	5	☑	☑	93.6371	3.3494
5	6	☑	☑	107.6260	2.3396
6	7	☑	☑	111.2922	2.0966
7	13	☑	☑	50.6118	7.8118

Received BSM Message

	Target ID	Latitude (deg)	Longitude (deg)	Speed (m/s)	Heading (deg)	Width (m)	Length (m)
1	2	42.300049	-83.698656	2.2	271.7	1.8	4.7
2	3	42.300532	-83.697632	20.1	92.2	1.8	4.7
3	4	42.300899	-83.698708	7.0	246.3	1.8	4.7
4	5	42.300614	-83.697642	19.9	91.1	1.8	4.7
5	6	42.300194	-83.697678	30.0	178.4	1.8	4.7
6	7	42.299850	-83.698116	19.9	179.8	1.8	4.7
7	13	42.300273	-83.698813	10.0	179.3	1.8	4.7

Figure 4: Visual display of received and transmitted messages from actors.

Table 1: Warning level according to time conditions.

Actor Arrival Time Condition	Time Gap Condition	Warning Level
ActArrivalTime < minArrivalTime	timeGap < minTimeGap	High
ActArrivalTime < minArrivalTime	timeGap >= minTimeGap	Moderate
ActArrivalTime >= minArrivalTime	timeGap < minTimeGap	Low
ActArrivalTime >= minArrivalTime	timeGap >= minTimeGap	Low

of the target. In the case of an intersection, the collision warning analyzer calculates the arrival time of the "actor" at the intersection point and determines the absolute difference between the arrival time of both vehicles at the intersection point.

Next, the arrival time of the "actor" and the value of the time interval are compared with the corresponding predetermined threshold values. Based on the results of the comparison (Table 1), the corresponding warning level is set [19]. Medium and high warning levels require driver awareness and response.

5 CONCLUSIONS

In this work, a communication system was proposed in the problem of warning about a possible collision. Communication parameters rely on channel characteristics to determine the probability of successful message reception. V2V technology was used to implement wireless transmission and reception of information between cars. The result of the work is receiving information from connected vehicles in the range of the system and the reaction of the information system to the processed data in the form of external signals [20-24]. At the same time, the research in this paper also accelerates the use of V2V technology in the field of intelligent vehicles and improves the ability of intelligent vehicle to perceive the environment.

As for improving the performance of driver assistance systems, some solutions already exist. In the case of solving the task of ensuring message transmission for the frontal collision warning system, DSRC technologies were used. The results of the FCW experiments demonstrated that the system provided earlier warning than the previous result [24, 25]. This proposed system not only provided early warnings to prevent rear collisions, but also contributed to more effective braking [11].

Thanks to recent breakthroughs in wireless control networks, the quality of wireless communication can be controlled in a predictable manner [19, 26, 27, 28], which opens the door for the collaborative design of a wireless car network [6].

Thanks to the joint control of the movement of several vehicles connected by wireless communication, some or all of the following advantages of the transport system are possible:

1) The capacity of the road can be increased by reducing the gaps between vehicles;
2) Energy consumption and pollutant emissions can be reduced by reducing unnecessary speed changes and aerodynamic drag of following vehicles;
3) Driving safety is potentially improved as detection and response times are reduced compared to manually operated vehicles;
4) Consumer comfort can be improved because system behavior is more responsive to changes in traffic, and shorter following intervals can deter the inclusion of other vehicles [2].

The model shows the operation of the system based on the "receiver-transmitter" principle using DSRC communication using MATLAB/ Simulink software [29]. The obtained model allows conducting various system analyzes for the future improvement of information and communication systems in cars.

REFERENCES

[1] USDOT. "Progress Report on the National Roadway Safety Strategy", 2023, [Online], Available: https://rosap.ntl.bts.gov/view/dot/66387.

[2] Z. Wang, Y. Bian, SE Shladover, G. Wu, SE Li, and M.J. Barth, "A Survey on Cooperative Longitudinal Motion Control of Multiple Connected and Automated Vehicles," in IEEE Intelligent Transportation Systems Magazine, vol. 12, no. 1, pp. 4-24, Spring 2020, doi:10.1109/MITS.2019.2953562.

[3] H. Xie, Y. Wang, X. Su, S. Wang, and L. Wang, "Safe Driving Model Based on V2V Vehicle Communication," in IEEE Open Journal of Intelligent Transportation Systems, vol. 3, pp. 449-457, 2022, doi: 10.1109/OJITS.2021.3135664.

[4] "SAE: Taxonomy and definitions for terms related to on-road motor vehicle automated driving systems", SAE On-road Automated Vehicles Standards Committee and others, 2021, [Online], Available: https://www.sae.org/standards/content/j3016_202104.

[5] K. Bintoro, "A Study of V2V Communication on VANET: Characteristics, Challenges and Research Trends". JISA (Jurnal Informatika dan Sains).no. 4. pp. 46-58, 2021, doi:10.31326/jisa.v4i1.895.

[6] S.E. Li, et al., "Dynamical Modeling and Distributed Control of Connected and Automated Vehicles: Challenges and Opportunities," in IEEE Intelligent Transportation Systems Magazine, vol. 9, no. 3, pp. 46-58, 2017, doi: 10.1109/MITS.2017.2709781.

[7] S. Alyassri, M. Ilyas, A. Marhoon, and O. Bayat, "Reduction of Packet Error Rate in V2V Communication Based on Machine Learning," 2021 International Conference on Communication & Information Technology (ICICT), Basrah, Iraq, pp. 110-115, 2021, doi: 10.1109/ICICT52195.2021.9568487.

[8] J. Ploeg, E. Semsar-Kazerooni, G. Lijster, N. van de Wouw, and H. Nijmeijer, “Graceful degradation of cooperative adaptive cruise control,” IEEE Trans. Intel. Transp. Syst., vol. 16, no. 1, pp. 488-497, 2015, doi: 10.1109/TITS.2014.2349498.

[9] K. Li, Y. Bian, S. Li, B. Xu, and J. Wang, "Distributed model predictive control of multi-vehicle systems with switching communication topologies," Transportation Research Part C: Emerging Technologies, vol. 118, 2020, doi: 10.1016/j.trc.2020.102717.

[10] Z. Wu, B. Waterson, and B. Anvari, "Developing and evaluating a coordinated person-based signal control paradigm in a corridor network," Transportation Planning and Technology, vol. 45:6, pp. 498-523, 2022, doi: 10.1080/03081060.2022.2134128.

[11] W. Yang, B. Wan, and X. Qu, "A Forward Collision Warning System Using Driving Intention Recognition of the Front Vehicle and V2V Communication," in IEEE Access, vol. 8, pp. 11268-11278, (2020), doi: 10.1109/ACCESS.2020.2963854.

[12] C. Mo, Y. Li, and Z. Ling, “Simulation and Analysis on Overtaking Safety Assistance System Based on Vehicle-to-Vehicle Communication”, Automotive Innovation. vol. 1, 2018, doi:10.1007/s42154-018-0017-9.

[13] The MathWorks, Inc., Automated driving toolbox. Automated Driving Toolbox Documentation, 2023, [Online], Available: https://ch.mathworks.com/help/driving/index.html?s_tid=CRUX_lftnav.

[14] J.B. Kenney, "Dedicated Short-Range Communications (DSRC) Standards in the United States," in Proceedings of the IEEE, vol. 99, no. 7, pp. 1162-1182, 2011, doi: 10.1109/JPROC.2011.2132790.

[15] L. Cheng, B. Henty, D. D. Stancil, F. Bai, and P. Mudalige, "A fully mobile, GPS enabled, vehicle-to-vehicle measurement platform for characterization of the 5.9 GHz DSRC channel," 2007 IEEE Antennas and Propagation Society International Symposium, Honolulu, HI, 2007, pp. 2005-2008, doi: 10.1109/APS.2007.4395917.

[16] SAE J2735, V2X Communications Message Set Dictionary; SAE International DSRC Committee, Warrendale, PA, USA: 2022, [Online], Available: https://www.sae.org/standards/content/j2735set_202211/.

[17] B.S. Karpishen, "Modeling work information and communication systems on cars", Computer technologies and mechatronics. Collection scientific works by materials of the V international scientific and methodical conferences, Kharkiv, Khnadu, pp. 17-20, 2023.

[18] H. Farahneh, F. Hussian, and X. Fernando, “De-Noising Scheme for VLC-Based V2V Systems”; A Machine Learning Approach, Procedia Computer Science, vol. 171, pp. 2167-2176, 2020, [Online], Available: https://doi.org/10.1016/j.procs.2020.04.234.

[19] Z. Hongwei, C. Xin, L. Xiaohui, and J. Xi, “Adaptive Instantiation of the Protocol Interference Model in Wireless Networked Sensing and Control”. ACM Transactions on Sensor Networks (TOSN), vol. 10:2, pp 1-48, 2014, doi: 10.10.1145/2530286.

[20] L.M. Karpenko, S.R. Koev, N.B. Kashchena, V. Grushko, and A. Khorosheniuk, “Formation of the stakeholders account model in conditions of sustainable development”, Academy of Accounting and Financial Studies Journal, vol. 23, no. 2, pp. 1-7, 2019, [Online], Available: https://repo.btu.kharkov.ua/bitstream/123456789/9297/3/Kashchen%d0%b0_Formation_of_the_Stakeholders_article_2019.pdf.

[21] N., Savytska, V., Babenko, H., Chmil, O., Priadko, and I., Bubenets, “Digitalization of Business Development Marketing Tools in the B2C Market”, Journal of Information Technology Management”, vol. 15, no. 1, pp. 124-134, 2023, doi: 10.22059/jitm.2023.90740.

[22] N. Bezrukova, L. Huk, H. Chmil, L. Verbivska, O. Komchatnykh, and Y. Kozlovskyi, “Digitalization as a Trend of Modern Development of the World Economy’, WSEAS Transactions on Environment and Development, vol. 18, pp. 120-129, 2022, doi:10.37394/232015.2022.18.13.

[23] D. Solokha, N. Trushkina, L. Potemkin, and R. Mirkurbanova, “Use of multi-agent simulation modeling for predicting the sales of wholesale trade companies”, Journal of Management Information and Decision Sciences, vol. 22, no. 4, pp. 483-488, 2019, [Online], Available: https://www.abacademies.org/articles/use-of-multi-agent-simulation-modeling-for-predicting-the-sales-of-wholesale-trade-companies.pdf.

[24] V. Babenko, M. Pasmor, Ju. Pankova, and M. Sidorov, “The place and perspectives of Ukraine in international integration space”, Problems and Perspectives in Management, vol. 15, no. 1, pp. 80-92, 2017, doi: 10.21511/ppm.15(1).2017.08.

[25] V. Babenko, N. Chebanova, N. Ryzhikova, S. Rudenko, and N. Birchenko, "Research into the process of multi-level management of enterprise production activities with taking risks into consideration", Eastern-European Journal of Enterprise Technologies, vol. 1, no 3 (91), pp. 4-12, 2018, [Online], Available: https://doi.org/10.15587/1729-4061.2018.123461.

[26] K.A. Pylypenko, I.V. Babiy, N.V. Volkova, L.K. Feofanov, and N.B. Kashchena, “Structuring economic security of the organization”, Journal of Security and Sustainability, vol. 9, no. 1, pp. 7–38, 2019, [Online], Available: https://doi.org/10.9770/jssi.2019.9.1(3).

[27] V.A. Babenko, “Formation of economic-mathematical model for process dynamics of innovative technologies management at agroindustrial enterprises,” Actual Problems of Economics, vol. 1, no. 1, pp. 182-186, 2013.

[28] Y.V. Batygin, S.F. Golovashchenko, and A.V. Gnatov, “Pulsed electromagnetic attraction of sheet metals - Fundamentals and perspective applications”, Journal of Materials Processing Technology, vol. 213, no. 3, pp. 444-452, 2013, [Online], Available: https://doi.org/10.1016/j.jmatprotec.2012.10.003.

[29] A. Galkin, L. Obolentseva, I. Balandina, E. Kush, V. Karpenko, and P. Bajdor, “Last-mile delivery for consumer driven logistics”, Transportation Research Procedia, vol. 39, pp. 74-83, 2019, [Online], Available: https://doi.org/10.1016/j.trpro.2019.06.009.