Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 113 **2021**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2021.113.9

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Kurganov, V., Gryaznov, M., Timofeev, E., Polyakova, L. Key factors for reducing live poultry losses during transportation. *Scientific Journal of Silesian University of Technology. Series Transport*. 2021, **113**, 115-131. ISSN: 0209-3324.
DOI: https://doi.org/10.20858/sjsutst.2021.113.9.

Valery KURGANOV[1], Mikhail GRYAZNOV[2], Egor TIMOFEEV[3], Liliya POLYAKOVA[4]

KEY FACTORS FOR REDUCING LIVE POULTRY LOSSES DURING TRANSPORTATION

Summary. The results of this study on the loss of live poultry at various stages of delivery from the farm to the processing plant by road are given. A factor analysis of the reasons for the loss of livestock delivered from the farm to the processing plant was carried out. The dependencies of livestock losses on loading delays and the duration of the movement of the loaded poultry farm to the processing plant were established. Methodological recommendations for rationing the number of injuries observed during delivery were developed. The study of losses of live birds during delivery to the processing plant from the density of stocking in shipping boxes was carried out; the economic and mathematical model for optimizing the landing of live birds in shipping boxes was proposed. The calculation of the economic impact of the implementation of the results of the study is given.

Keywords: road transport, live poultry transportation, death and injury of livestock, shipping boxes, poultry transport vehicle, industrial poultry farming

[1] Tver State University, Zhelyabova 33 Street, 170100 Tver, Russia. Email: glavreds@tvcom.ru. ORCID: https://orcid.org/https://orcid.org/0000-0001-8494-2852
[2] Nosov Magnitogorsk State Technical University, Lenin 38 Avenue, 455000 Magnitogorsk, Russia. Email: gm-autolab@mail.ru. ORCID: https://orcid.org/0000-0003-3142-1089
[3] LLC «Sitno-Product», Laznik 19 Street, 455007 Magnitogorsk, Russia. Email: wolf_tea@mail.ru. ORCID: https://orcid.org/0000-0002-6187-5121
4 Nosov Magnitogorsk State Technical University, Lenin 38 Avenue, 455000 Magnitogorsk, Russia. Email: lilitmgm@mail.ru. ORCID: https://orcid.org/0000-0002-9990-7694

1. INTRODUCTION

A substantial part of the total mortality of live birds, which affects the efficiency of the poultry processing company, without considering the losses from the spread of infections, occurs at the stage of poultry transportation by road from the farm to the processing plant. Delays in the delivery of poultry to slaughter lead to an increase in their death and injury. There are losses from downtime or idle operation of slaughter and processing lines, downtime of rolling stock, and a decrease in personnel productivity.

This justifies the relevance of the topic of this study, which is aimed at reducing losses in the cultivation and processing of live poultry from delays in its delivery to the processing plant. The purpose of this study is to develop effective logistics for the supply of live poultry to processing plants, as well as to save production costs in the technology of industrial poultry farming. The aim of the study is achieved by the following tasks:

- factor analysis of the reasons for the loss of poultry delivered from the farm to the processing plant;
- establishing the dependence of the number of dead livestock on delays during loading, on the duration of movement of a loaded poultry truck to the processing plant;
- rationing of livestock injuries observed during delivery;
- development of an economic and mathematical model for optimizing the density of stocking live birds in shipping boxes;
- calculation of the economic effect from the implementation of research results.

The object of this research is the process of delivery of live poultry by road from the farm to the processing plant. While the subject of this research is the dependency of the losses of the poultry stock transported to the slaughterhouse on the parameters of the delivery process.

Modern scientific works contain guidelines for determining the influence of factors of the transport process on the safety of transported live birds. Among a large number of such studies, it is necessary to mention the following works. Czech scientists have investigated the factors influencing bird mortality, among which are: method of catching, transport temperature, the density of poultry planting in transport packaging, living weight, breed, and time spent in transit [14].

The influence of the transportation distance on the total loss of chickens has been substantiated [1]. However, to ensure that the conclusions are correct, it would be advisable to consider the dependence of bird mortality not only on the distance of transportation but also on the time of movement, since the same distance can be covered in a different amount of time. Similarly, it is important to consider environmental factors such as ambient temperature.

Studies have been published on the impact of stress on meat quality and the yield of marketed produce on birds before slaughter, including during transport [2, 5, 9]. It is advisable to consider the recommendations for reducing the stress experienced by birds during transport by following the guidelines for the maintenance and raising of breeders [4].

The relationship between the mortality rate of the poultry population and the organizational and technological parameters of its transportation from the farm to the processing plant has been established [3, 6, 8, 10, 12, 15]. In particular, the conditions affecting the bruising and mortality of broilers during capture and transportation were studied, and the average percentage of birds killed on arrival at the slaughterhouse was established. The mortality rate during transportation of broilers from farms to processing plants was investigated and the relationship between the season and the mortality rate of transported poultry was established. Furthermore, it has been proved that the difference in the value of the studied indicator for herds of maintenance reaches 1.4 times. Czech and Italian experts have shown that a marked increase in chicken mortality can be observed in short-distance transport during the cold season [13].

Conservation problems associated with the transport of chickens intended for commercial production of eggs, slaughtered after their economically viable lives have been studied. The mortality rate during the transportation of broilers, turkeys, ducks, and geese to slaughter was investigated and the category of poultry most susceptible to stress due to non-optimal transportation conditions was determined [7].

Studies conducted by the All-Russian Poultry Research Institute have substantiated a model for the classification of factors adversely affecting the quality of poultry meat during its production, delivery, and processing. It has been established that failures in the performance of technological operations of loading, transporting, and unloading poultry during its transfer to the processing plant are some of the significant factors. The method of cost estimation of losses is proposed. Based on the proposed simulation model, the optimal combination of transport and technological machines for the delivery of live birds for processing with floor and cage rearing systems was determined.

Our review found a scientific interest in the issue of the safety of transported live birds in the transport process, as well as a high degree of sophistication of the issue. At the same time, there are still unresolved issues related to the establishment of the dependence of the losses of the livestock transported to slaughter on the duration of technological delivery operations, the development of methods for economic and mathematical optimization of the density of poultry stocking in shipping boxes for delivery from the farm to the processing plant.

2. METHOD OF RESEARCH AND VERIFICATION

Theoretical studies were carried out based on the analysis of scientific and regulatory technical literature, systemic, statistical, factorial, technical, and economic analysis, economic and mathematical modeling of the transport process. The analysis of the scientific and regulatory literature has made it possible to establish the depth of the problem of improving the efficiency of road transport of live birds and formulate the objective of this study.

Experimental research in operating farm conditions using the methods of probability theory and mathematical statistics, computer modeling, technical and economic analysis, and in situ observations was carried out. Using these research methods, the authors obtained a set of basic data necessary for calculations and developed an economic-mathematical model of optimization of the density of stocking live birds in shipping boxes.

Using computer modeling, the dependence of the number of dead livestock on delays in loading, as well as on the duration of delivery to the processing plant was established. The correctness of the established dependencies is ensured by the results of the conducted factor analysis, which made it possible to determine the reasons for the loss of live poultry delivered from the farm to the processing plant and to reduce the complexity of the calculations. The adequacy of the empirical dependencies obtained in the work is confirmed by the assessment according to the Fisher criterion. The feasibility study made it possible to calculate the economic impact and justify the practicability of implementing the results of the study.

The reliability of the results obtained in the work is confirmed by the validity of the assumptions made in the development of a mathematical model, by the coincidence of the results of our theoretical and experimental studies with the data of already published scientific works.

3. FACTOR ANALYSIS OF THE CAUSES OF LOSS OF LIVESTOCK DELIVERED FROM THE FARM TO THE PROCESSING PLANT

According to the results of processing statistical data, it has been established that, in absolute terms, 85% of total losses of poultry is caused by a zootechnical flaw and veterinary factors. However, the accumulated cost of keeping a livestock unit reaches the maximum value (55%) during delivery to the processing plant due to delays in processing operations (Figure 1).

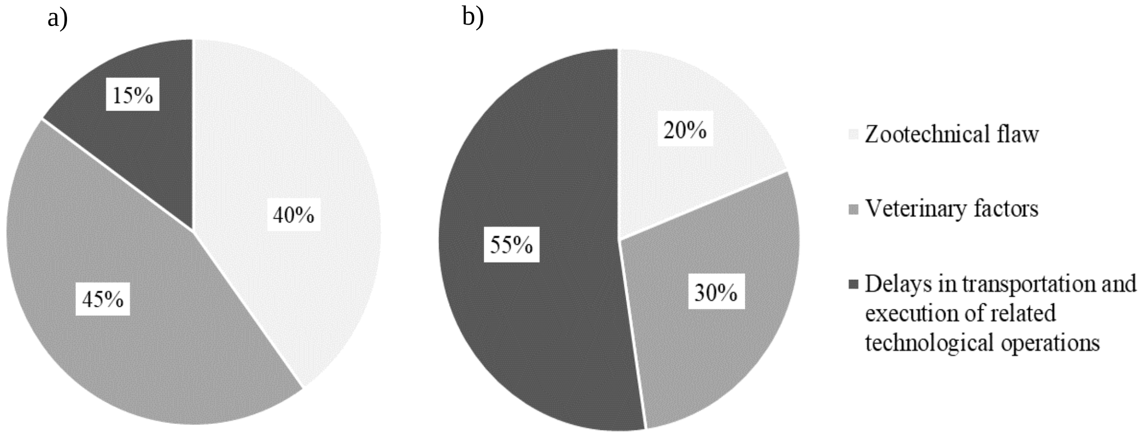


Fig. 1. Structure of the causes of total livestock losses by number of heads (a), and accumulated costs (b)

Consequently, given the accumulated costs, the significance of the loss of livestock due to delays in delivery and the performance of related technological operations increases significantly. The reasons for these delays are shown in Figure 2. Among the factors that determine the loss of poultry in the process of delivery to the processing plant and the performance of related technological operations are highlighted the following: mechanical stress, exposure to stress from the presence of poultry in unusual conditions, ambient temperature, and stocking density in transport boxes.

The distribution of the total number of reasons for delay that determine the impact of a given factor is shown in Table 1. The proportion of the causes was calculated as a percentage of the number of deaths or injuries of poultry caused by the factor considered, to the total number of livestock killed or injured during delivery and related operations. Table 2 shows the results of assessing the significance of the factors under study.

Factors of high relevance include transport box density, bird exposure to stress from unfamiliar conditions, and ambient temperature. To carry out further calculations, it is necessary to establish the quantitative indicators of the factors under study.

The vulnerability of the bird to stress from being in unusual conditions is closely related to its health condition. A healthy bird is much more stable in coping with stress. In livestock production, one of the most objective indicators of the health of the livestock is its preservation. This indicator is the ratio:

$$\rho = \frac{N_{moveimto} - N_{defect}}{N_{moveimto}} \cdot 100\%, \quad (1)$$

where $N_{moveimto}$ – the size of populated livestock per farm, pcs.; N_{defect} – the size of the rejected livestock (dead, sick, injured) in the process of growing up to the day of slaughter, pcs.

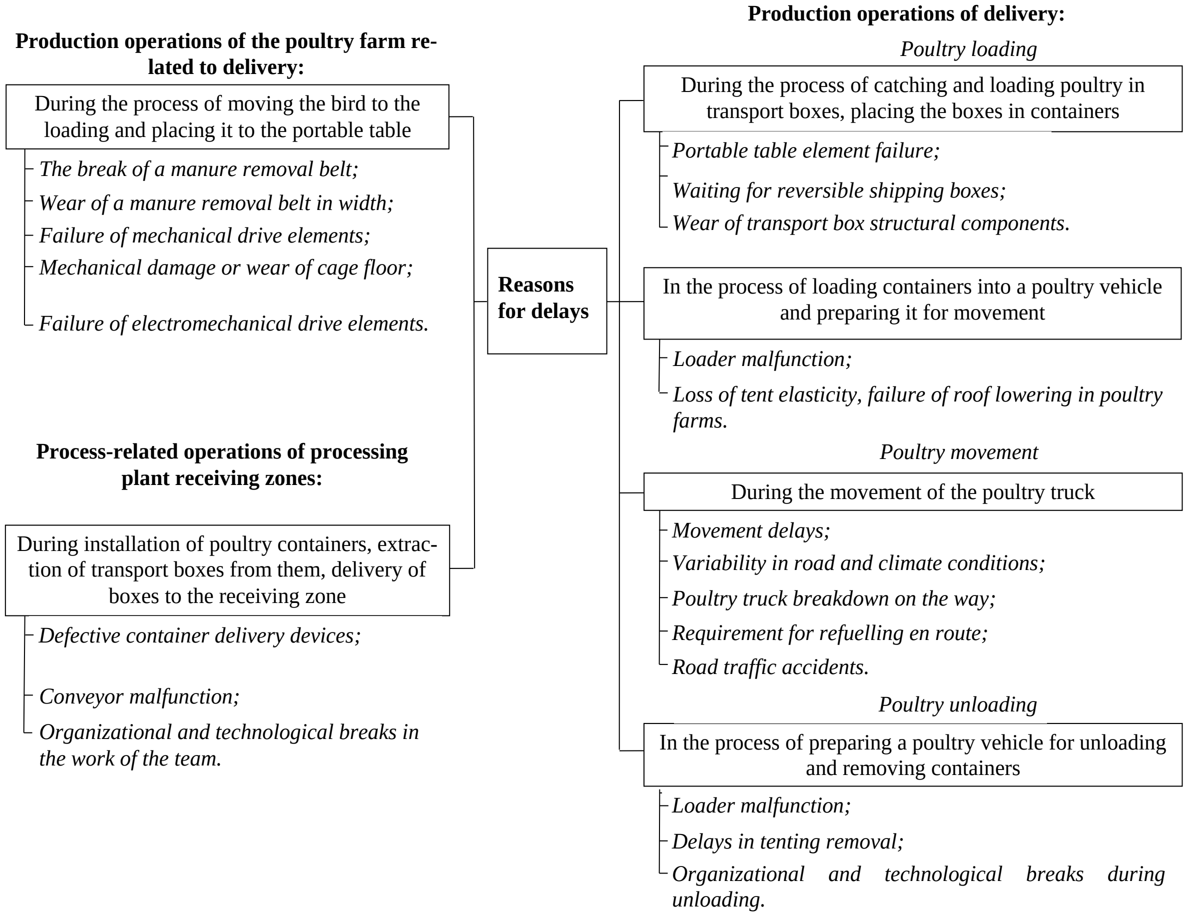


Fig. 2. Reasons for delays in the delivery of live poultry and delivery-related operations

Tab. 1

Distribution of factors affecting livestock losses in delivery and delivery-related operations

Place in the technological chain	Factor influencing the loss of livestock	Share of reasons, %
Poultry farm	Mechanical impact	1,20
	Exposure to stress from being in unfamiliar conditions	5,51
	Ambient temperature	0,26
	The density of landing in transport boxes	0,00
Delivery	Mechanical impact	1,19
	Exposure to stress from being in unfamiliar conditions	24,55
	Ambient temperature	6,77
	The density of landing in transport boxes	31,94

The reception area of the processing plant	Mechanical impact	0
	Exposure to stress from being in unfamiliar conditions	0
	Ambient temperature	0
	The density of landing in transport boxes	28,58
	Total	100

Tab. 2

The significance of the investigated factors

Factor influencing the loss of livestock	Size of reasons, %	Factor significance
Mechanical impact	2,4	Low
Exposure to stress from being in unfamiliar conditions	30,06	High
Ambient temperature	7,03	High
The density of landing in transport boxes	60,52	High
Total	100	-

Livestock losses, including dead and injured birds during delivery, were determined based on the following safety factors: less 85%; 85-90%; 90-95%; more 95%.

The concept of effective temperature, which is one of the bio-geological indices characterizing the complex effect of the action of temperature and humidity of the air and wind speed on a living organism, was used to account for the temperature of the environment properly. The effective temperature calculation is based on the empirical Steadman model [11]:

$$T_{effective} = -2,7 + 1,04 \cdot T + 2 \cdot P - 0,65 \cdot V, \quad (2)$$

where T – air temperature, ^{0}C; P – partial water vapor pressure, kPa; V – wind speed 10 m above ground, km/h.

Livestock losses were set for effective temperature values within the range - 350 ... + 50°C with an interval of 50°C. The measure of the density of the poultry landing in unified transport boxes used in the proposed optimization economic-mathematical model is their filling with poultry in pieces.

4. MODELING

Losses from delays in loading at the farm. The target was based on a statistical analysis of the number of dead birds awaiting loading on the farm. Based on the results of calculations for different values of ρ the dependencies were constructed (Figure 3).

The dependence of the number of dead livestock on delays in loading at the farm was based on the following considerations. The minimum shipment time in this data set was 7 hours and 10 minutes. This time, in addition to installing transport boxes with poultry in the poultry carrier, includes the removing of the cage floor from the growing cages, dropping the poultry onto a conveyor belt to remove droppings, further moving the livestock to a mobile table, and filling the transport boxes with poultry. This time was taken as the reporting point, as the poultry was shipped immediately on that date. Providing that the number of livestock shipped to the processing plant is the same across the farms, the shipment of a longer duration is delayed. Using the equations of exponential functions (Figure 3), the number of birds killed from delays during loading is calculated at 15-minute intervals. The results of the calculation are shown in Figure 4.

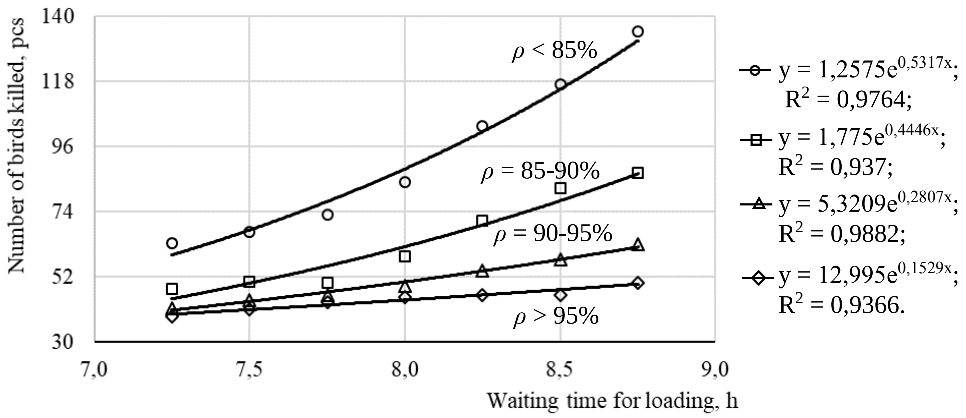


Fig. 3. Dependences of the number of dead livestock on the duration of shipment of a batch

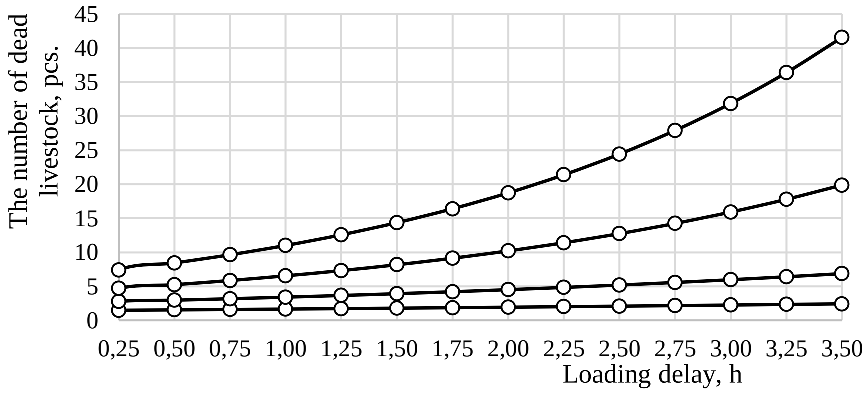


Fig. 4. Estimated dependence of the number of dead livestock on delays when loading on the farm

Using the established dependence, the damage caused to the farmed livestock from the death of birds due to delays in loading is calculated. The results of this calculation are given in relative terms in Table 3.

Tab. 3

Damage to livestock from delays in loading on the farm (cumulative), %

Delay interval, min	Value ρ, %			
	Less than 85	85 - 90	90 - 95	More than 95
0 - 15	0,008	0,005	0,003	0,002
15 - 30	0,018	0,011	0,006	0,003
30 - 45	0,028	0,018	0,010	0,005

45 - 60	0,041	0,025	0,014	0,007
60 - 75	0,054	0,033	0,018	0,009
75 - 90	0,070	0,042	0,022	0,011
90 - 105	0,089	0,052	0,027	0,013
105 - 120	0,109	0,063	0,032	0,015
120 - 135	0,133	0,076	0,037	0,017
135 - 150	0,191	0,106	0,049	0,022
150 - 165	0,227	0,124	0,056	0,025
165 - 180	0,267	0,144	0,063	0,027
180 - 195	0,267	0,144	0,063	0,027
195 - 210	0,313	0,166	0,070	0,030

As Table 3 shows, every 15 minutes of loading delays are added to the total livestock losses of 0.002-0.024% depending on the vulnerability of the poultry to stress, which is a significant loss over the year. The unloading of poultry is the responsibility of the consignee and is outside the competence of the carrier, so in this article, the damage to the livestock during the unloading of the poultry at the processing plant was not investigated.

Losses due to delays in the movement of loaded poultry farms. Based on the available statistical information, a sample was drawn up containing data on the duration of the processing operations of the poultry operators involved in transporting live poultry from the farm to the processing plant. This information was compared with data on the safety of livestock ρ by farms, as well as with the values of the average daily temperature, air humidity, and wind speed at the date of delivery, after which the effective temperature was calculated. Further, by calculation, the dependences of the number of poultry killed for a round trip on the duration of movement of a loaded poultry carrier were obtained (Figure 5).

The analysis of the results obtained made it possible to establish that for every 15 minutes a loaded poultry vehicle spends on the way, an average of 0.08% is added to the total loss of livestock.

The results of the statistical analysis did not establish a correlation between the number of livestock injured during the delivery to the processing plant and the influencing factors. Therefore, it is proposed that the number of injured birds per shift flight be normalized according to the formula:

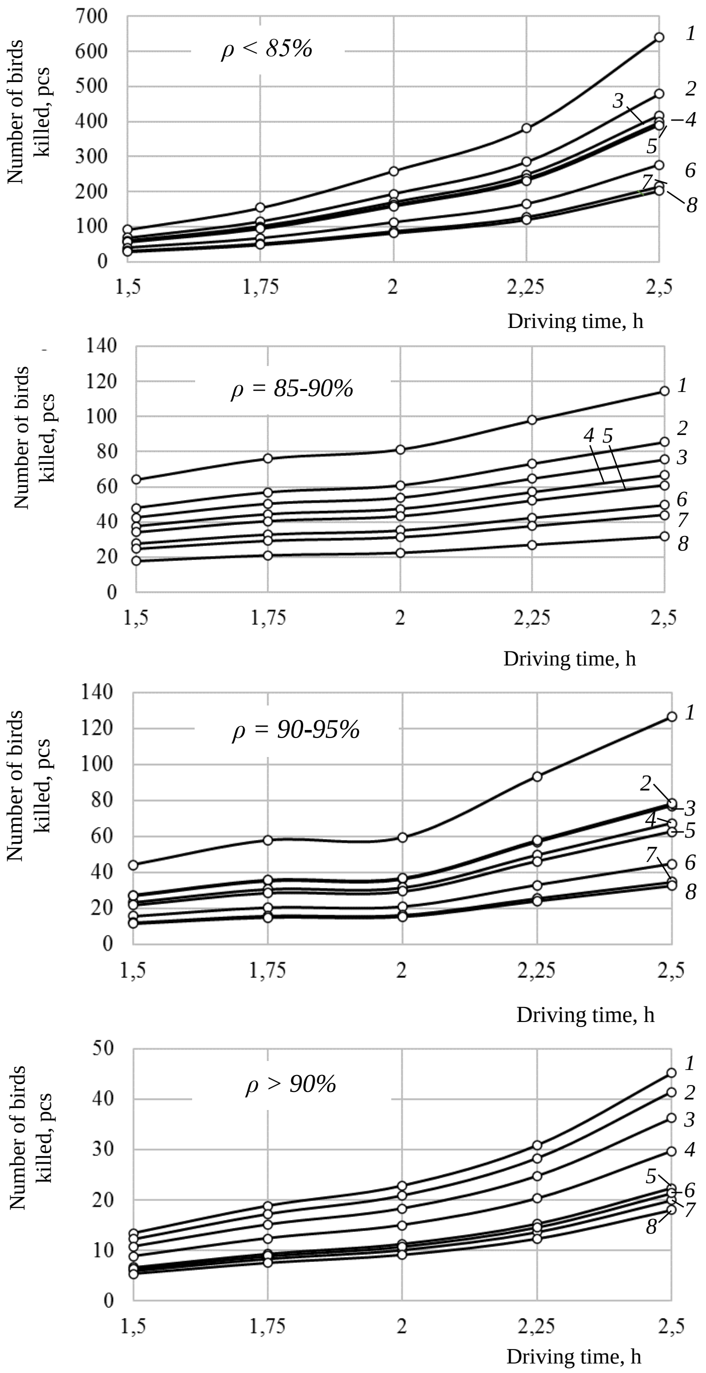
$$N_{injury}^{norm} = \overline{N}_{injury} \cdot \kappa_{unevenness}, \tag{3}$$

where $\overline{N}_{injury}$ – the mathematical expectation of the number of injured poultry during a turnaround trip by sampling, p.; $\kappa_{unevenness}$ – coefficient of the unevenness of the number of injured livestock in the process of delivery to the processing plant.

The coefficient of unevenness is calculated by the formula:

$$\kappa_{unevenness} = \frac{N_{injury}^{\max}}{\overline{N}_{injury}}, \tag{4}$$

where N_{injury}^{max} – maximum number of injured poultry population for a round trip in the sample, pc.



1) –(35-30)^{0}C; 2) –(30-25)^{0}C; 3) –(25-20)^{0}C; 4) –(20-15)^{0}C;
5) –(15-10)^{0}C; 6) –(10-5)^{0}C; 7) –(5-0)^{0}C; 8) +(0-5)^{0}C

Fig. 5. Calculated dependences of the number of dead livestock per trip on the duration of the movement of a loaded poultry carrier

Consequently, the standard number of poultry stock injured upon delivery to slaughter is determined by the equality:

$$N_{injury}^{norm} = N_{injury}^{\max}, \quad (5)$$

Figure 6 shows the results of the rationing.

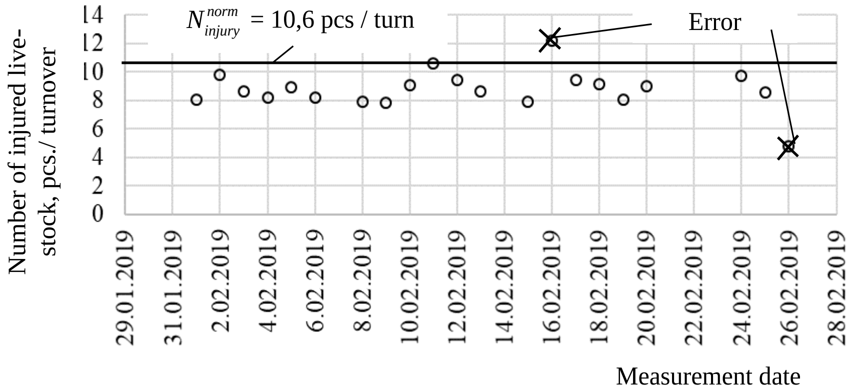


Fig. 6. An example of rationing of injured live birds per flight upon delivery to the processing plant

Based on N_{injury}^{norm}, the damage caused by the injury to the birds during its delivery to the processing plant on a turnaround trip is normalized:

$$d_{injury}^{norm} = \frac{N_{injury}^{norm} \cdot 100\%}{N_{plant}}, \quad (6)$$

where N_{plant} – number of livestock delivered to the processing plant during the working day, pcs.

Using the standard value N_{trauma}^{norm}, as well as the diagrams shown in Figure 5, the damage to the livestock from the death and injury of the birds during the delivery to the processing plant is calculated. The results of this calculation for one round trip of a poultry carrier are shown in Table 4.

Tab. 4

Livestock damage from death and injury to poultry in the process of delivery to the processing plant (for a round trip with a cumulative total), %

$T_{effective.}$, ^{0}C	Delivery time, h				
	1,5	1,75	2	2,25	2,5
ρ less than 85%					
-(35-30)	0,1139	0,2852	0,4713	0,7230	1,1457

-(30-25)	0,0882	0,2165	0,3557	0,5441	0,8605
-(25-20)	0,0785	0,1905	0,3120	0,4765	0,7527
-(20-15)	0,0755	0,1823	0,2983	0,4552	0,7187
-(15-10)	0,0739	0,1782	0,2914	0,4446	0,7018
-(10-5)	0,0560	0,1301	0,2106	0,3195	0,5023
-(5-0)	0,0461	0,1036	0,1661	0,2506	0,3925
-(0-5)	0,0442	0,0985	0,1574	0,2372	0,3711
ρ = 85-90%					
-(35-30)	0,0833	0,1679	0,1869	0,2111	0,2478
-(30-25)	0,0652	0,1285	0,1427	0,1607	0,1881
-(25-20)	0,0591	0,1150	0,1276	0,1436	0,1678
-(20-15)	0,0535	0,1029	0,1140	0,1281	0,1495
-(15-10)	0,0499	0,0949	0,1050	0,1178	0,1374
-(10-5)	0,0428	0,0795	0,0877	0,0982	0,1141
-(5-0)	0,0394	0,0719	0,0792	0,0885	0,1026
-(0-5)	0,0317	0,0551	0,0604	0,0671	0,0772
ρ = 90-95%					
-(35-30)	0,0608	0,1249	0,1418	0,1814	0,2561
-(30-25)	0,0417	0,0807	0,0910	0,1151	0,1606
-(25-20)	0,0379	0,0719	0,0809	0,1020	0,1417
-(20-15)	0,0421	0,0817	0,0921	0,1166	0,1627
-(15-10)	0,0361	0,0678	0,0762	0,0958	0,1328
-(10-5)	0,0291	0,0516	0,0576	0,0715	0,0978
-(5-0)	0,0252	0,0427	0,0474	0,0582	0,0785
-(0-5)	0,0245	0,0410	0,0454	0,0556	0,0748
ρ more than 95%					
-(35-30)	0,0268	0,0477	0,0582	0,0716	0,0964
-(30-25)	0,0255	0,0447	0,0543	0,0665	0,0893
-(25-20)	0,0238	0,0406	0,0491	0,0598	0,0798
-(20-15)	0,0217	0,0354	0,0423	0,0511	0,0675
-(15-10)	0,0193	0,0296	0,0348	0,0414	0,0537
-(10-5)	0,0185	0,0277	0,0324	0,0383	0,0493
-(5-0)	0,0189	0,0288	0,0338	0,0401	0,0519
-(0-5)	0,0178	0,0262	0,0304	0,0357	0,0457

For the convenience of operational planning, it is recommended to calculate the ratio of the number of dead and injured poultry in the process of delivery to the processing plant, considering the changes in influencing factors.

Losses from suboptimal stocking density of birds in transport boxes. In the course of field observations of the transportation of livestock, a hypothesis about the presence of an optimal density of stocking of birds in transport boxes, which determines the minimum losses, was proposed. The hypothesis required experimental confirmation.

The experiment was conducted on a working farm and included the following steps. The containers carried by the pilot poultry carrier were loaded with transport boxes with different densities of poultry stocking. At the end of the working day, the loss of livestock in each container was recorded. Based on the data obtained, a diagram was built (Figure 7).

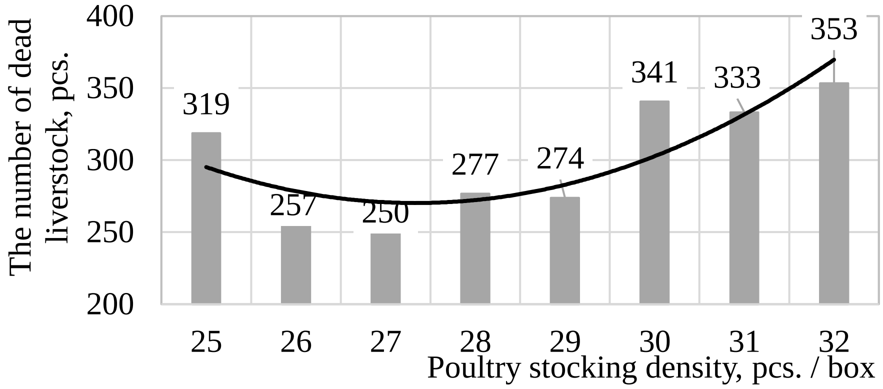


Fig. 7. The number of birds killed in the process of delivery to the processing plant of livestock at different stocking densities in shipping boxes

According to the graph, we can see that the stocking size at which the number of dead birds is minimal is 27. This confirms the proposed hypothesis.

We calculated the optimal stocking density based on the proposed mathematical and economic model, whose optimization criterion is the minimum of losses, including the cost of the livestock that died in the process of delivery to the processing plant C_{death} and the losses from the processing and sale of traumatized poultry L_{trauma}:

$$C_{death} + L_{injury} \to \min, \tag{7}$$

The value of C_{death} is determined by the formula:

$$C_{death} = \left(N_{death}^{delays} + \sum_{i=1}^{n_{turn}} N_{deathi}\right) \cdot m_{mean} \cdot \frac{v_{meat} \cdot P_{meat} + v_{co\text{-}product} \cdot P_{co\text{-}product}}{100\%}, \tag{8}$$

where N_{death}^{delays} – number of livestock died due to delays in loading, etc.; N_{deathi} – number of dead livestock in the delivered batch of poultry for the i-th round trip, pcs.; n_{turn} – total number of turnaround trips for the period under review; m_{mean} – the average weight of poultry sent to slaughter, kg; v_{meat}, $v_{co\text{-}product}$ – accordingly, the yield of meat and co-products from unit of livestock, %; P_{meat}, $P_{co\text{-}product}$ – accordingly, the trade value of meat and co-products, USD/kg.

The value of L_{trauma} is determined by the formula:

$$L_{injury} = m_{mean} \cdot \sum_{i=1}^{n_{turn}} N_{injury_i}) \times$$
$$\times \left[P_{meat} - \frac{P_{secondgrade} \cdot (\kappa_{hematoma} + \kappa_{skindefect}) + P_{processing} \cdot (\kappa_{tear} + \kappa_{broken})}{100\%} \right], \quad (9)$$

where N_{injury_i} – number of injured birds per *i-th* turnaround trip, pcs.; $P_{secondgrade}$, $P_{processing}$ – accordingly, the cost of implementation of a second-class eviscerated carcass and the cost of a carcass sent for industrial processing, $\kappa_{hematoma}$, $\kappa_{skindefect}$, κ_{tear}, κ_{broken} – the proportion of the number of birds injured during transportation, which received hematomas, skin ruptures, loss of limbs, fractures, %.

The productivity of a poultry carrier is directly proportional to the density of stocking of birds in transport boxes; therefore, to master the planned volume of transportation, with different stocking densities, a different number of return flights will be required:

$$n_{turn} = \frac{N_{plant}}{Q_{car}} = \frac{N_{plant}}{Q_{box} \cdot N_{box} \cdot N_{conteiner}}, \quad (10)$$

where Q_{car} – performance of a poultry carrier for a round trip, heads; Q_{box} – stocking density of poultry in transport boxes, pcs / box; N_{box} – number of shipping boxes in one container for transporting live birds, pcs.; $N_{container}$ – number of containers in a poultry truck, pcs.

The system of restrictions of the proposed economic and mathematical model considers the following conditions. The stocking density of the poultry should correspond to the carrying capacity of containers for placing shipping boxes and the carrying capacity of the poultry carrier. A poultry carrier arriving for unloading should be provided with a set of reusable containers to avoid downtime while waiting for the end of the suspension of a batch of poultry, subsequent washing, and disinfection of empty shipping boxes and containers. The duration of the work of the poultry carrier on the route should not exceed its time in the order, noting the driver's lunch break and the margin of time for zero mileage. The system of restrictions has the following form:

$$\begin{cases} q_{container} \leq (Q_{box} \cdot m_{mean} + m_{box}) \cdot N_{box} \\ q_{car} \leq \left[(Q_{box} \cdot m_{mean} + m_{box}) \cdot N_{box} + m_{container} \right] \cdot N_{container} \\ A_{tara} = 1 + A_{car} \\ t_{turn} \cdot N_{turn} \leq T_{tourofduty} - t_{dinnerbreak} - t_{zerromileage} \end{cases}, \quad (11)$$

where $q_{container}$ – carrying capacity of a container for transporting live poultry, kg; m_{box} – weight of an empty transport box, kg; q_{car} – carrying capacity of the poultry, kg; $m_{container}$ – empty container weight, kg; A_{tara} – number of sets of returnable containers, pcs; A_{car} – number of poultry transport vehicles on the route, pcs.; t_{turn} – time of a round trip of a poultry carrier, h; N_{turn} - the number of return trips performed by one poultry carrier per working day, units; $T_{tourofduty}$ – time of a poultry carrier on duty, h; $t_{dinnerbreak}$ – the duration of the driver's lunch break, h; $t_{zerromileage}$ – zero mileage time, h.

5. REDUCED COSTS DUE TO REDUCED LOSS OF POULTRY DURING TRANSPORT

The calculation of the economic effect is based on the difference between the total economic loss from the delays in the delivery process before and after the implementation of the proposed recommendations. Losses before the implementation of the proposed recommendations were analyzed in the case of the slaughter of one of the largest agricultural holdings in the Russian Federation during the first quarter of 2019. The choice of the analyzed period was determined by the availability of statistical information.

The losses of the livestock delivered to the processing plant after the implementation of the proposed recommendations were determined for the same delivery conditions as under the existing option. However, it considered the optimization of landing poultry in shipping boxes, as well as a decrease in delivery delays by 5, 10 and 15%, respectively, due to the development of the management of the agricultural holding operational measures to reduce these delays within the limits of their competence. The annual economic effect was calculated in rubles, noting the cost of poultry meat on the domestic market of the Russian Federation and transferred at the current exchange rate at the beginning of the current year into US dollars. The calculation results are shown in the form of a diagram in Figure 8.

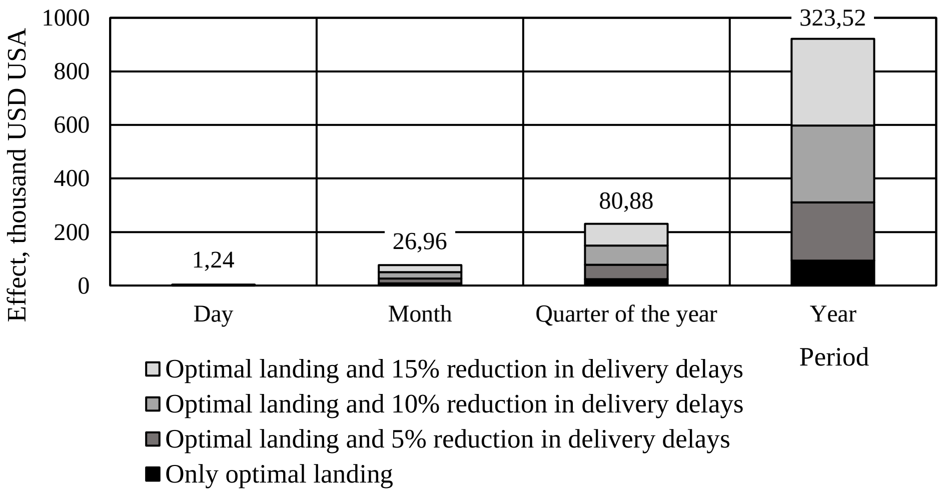


Fig. 8. Annual economic effect on reporting periods

Significant savings in production costs are provided by measures aimed at a relatively small reduction in delays in the delivery process (up to 5-10%). The development of such activities is based on organizational decisions to transform and coordinate business processes and requires no special training from the management of the agricultural holding, and does not need a large resource supply and investment in the main production from the owner of the food business.

6. CONCLUSIONS

Based on the research carried out, it is proposed to solve the current scientific and practical problem of reducing losses in the cultivation and processing of live poultry from delays in its delivery to the processing plant. The main findings and results of the research are as follows:

1. In absolute terms, zootechnical flaws and veterinary factors account for the main losses of the number of poultry grown, 40 and 45%, respectively. Taking into account the accumulated maintenance costs, the significance of the reasons for the loss of livestock in the process of its delivery to the processing plant and further processing increases significantly, since the value of the poultry at this stage is maximum.
2. Key factors influencing livestock losses from the farm to the processing plant include transport density (60.52%), exposure to stress (30.06%), and ambient temperature (7.03%). Quantitative measures of the factors studied in this work were chosen for the following:
   - for the susceptibility of birds to stress from being in unfamiliar conditions – the safety of the livestock, determined by the ratio of the difference between the sizes of the livestock populated and culled before the slaughter to the size of the populated livestock (percentage);
   - for ambient temperature – an effective temperature which additionally considers the influence of air humidity and wind speed (degrees Celsius);
   - for the density of poultry stocking in unified transport boxes – their filling with the transported poultry (pieces).
3. The number of dead birds was found to be directly proportional to the delays in loading at the farm. The resulting dependence is represented by four nonlinear calculated curves for each considered value of the livestock safety.
4. By calculation, the dependences of the number of dead livestock per trip on the duration of the movement of a loaded poultry carrier, depending on the safety of the transported livestock and the effective temperature, were obtained. The analysis of the results revealed that every 15 minutes that a loaded poultry vehicle spends on the way adds an average of 0.08% to the total loss of livestock.
5. The results of the statistical analysis did not allow establishing a correlation between the number of livestock injured during the delivery to the processing plant and the influencing factors. Therefore, it is proposed that the desired parameter be normalized by the mathematical expectation and the coefficient of the unevenness of the number of injured birds per return trip when they are being delivered to the processing plant.
6. In the course of in situ observations of the transportation of poultry, a hypothesis was proposed about the presence of an optimal stocking density in shipping boxes, which determines the minimum losses of the transported livestock. Experimental confirmation of this hypothesis provided the development of an economic and mathematical model for optimizing the density of poultry stocking in shipping boxes and was presented by:

- target function, whose optimization criterion is the minimum loss from death and injury to the poultry in the process of delivery to the processing plant;
- a system of restrictions providing for the correspondence of the gross mass of the transported cargo to the carrying capacity of transport containers and poultry carriers, the availability of an additional set of returnable packaging, ensuring the ability of drivers to carry out transportation tasks without violating the requirements of labor legislation. The calculations have proved the feasibility of a practical implementation of the research results. The annual economic effect from the use of the proposed recommendations for one farm varies in the range of 93 - 323 thousand USD due to the optimization of the stocking of livestock in transport boxes and the implementation of measures to reduce delivery delays.

References

1. Arikan M., A. Akin, A. Akcay, Y. Aral, S. Sariozkan, M. Cevrimli, M. Polat. 2017. “Effects of transportation distance, slaughter age, and seasonal factors on total losses in broiler hickens”. *Brazilian Journal of Poultry Science* 19(3). DOI: 10.1590/1806-9061-2016-0429.
2. Gregory N. 1996. “Welfare and hygiene during preslaughter handling”. *Meat Sci* 43(Suppl.S): 35-46. DOI: 10.1016/0309-1740(96)00053-8.
3. Gregory N., S. Austin. 1992. ”Causes of trauma in broilers arriving dead at poultry-processing plants”. *Vet Rec* 131: 501-503. DOI: 10.1136/vr.131.22.501.
4. Guidelines for keeping and rearing parent stock. Breeding bird. Available at: https://www.cobb-vantress.com/assets/Cobb-Files/product-guides/184e9d775d/0f19f6c0-0abc-11e9-9c88-c51e407c53ab.pdf.
5. Jayaprakash G., M. Sathiyabarathi, M. Arokia Robert, T. Tamilmani. 2016. “Transportation stress in broiler chicken”. *International Journal of Science, Environment and Technology* 5(2): 806-809. Available at: https://www.ijset.net/journal/936.pdf.
6. Kanan G., J. Heath, C. Wabeck, M. Souza, J. Howe, J. Mench. 1997. “Effects of crating and transport on stress and meat quality characteristics in broilers”. *PoultSci* 76: 523-529. DOI: 10.1093/пс/76.3.523.
7. Newberry R., A. Webster, N. Lewis, C. VanArnam. 1999. ”Management of spent hens”. *Appl Anim Welf Sci* 2: 13-29. DOI: 10.1207/s15327604jaws0201_2.
8. Nijdam E., P. Arens, E. Lambooij, E. Decuypere, J. Stegeman. 2004. “Factorsnfluencing bruises and mortality of broilers during catching, transport and lairage”. *PoultSci* 83: 1610-1615. DOI: 10.1093/пс/83.9.1610.
9. Owens C., A. Sams. 2000. “The influence of transportation on turkey meat quality”. *PoultSci* 79: 1204-1207. DOI: 10.1093/ps/79.8.1204.
10. Petracci M., M. Bianchi, C. Cavani, P. Gaspari, A. Lavazza. 2006. “Preslaughter Mortality in Broiler Chickens, Turkeys, and Spent Hens Under Commercial Slaughtering”. *Poultry Science* 85(9): 1660-1664. DOI: 10.1093/ps/85.9.1660.
11. Steadman R. 1984. “A universal scale of apparent temperature”. *Journal of Applied Meteorology and Climatology* 23(12): 1674-1687. DOI: 10.1175/1520-0450(1984)023<1674:AUSOAT>2.0.CO;2.

12. Tabbaa M., K. Alshawabkeh. 2000. "Some factors affecting preslaughtering mortality and damage to broilers and interaction during transportation to processing plants". *Dirasat Agric Sci* 27: 375-384. Available at: https://www.cabdirect.org/cabdirect/abstract/20003022162.
13. Vecerek V., E. Voslarova, F. Conte, L. Vecerkova, I. Bedanova. 2016. "Negative trends in transport-related mortality rates in broiler chickens". *Asian-Australas J Anim Sci* 29(12): 1796-1804. DOI: 10.5713/ajas.15.0996.
14. Voslazhova E., B. Yanachkova, L. Rubeshova, A. Kozak, I. Bedashova, L. Steinhauser, V. Evener. 2007. "Mortality Rates in Poultry Species and Categories during Transport for Slaughter". *Acta Veterinaria Brno* 76: 101-108. DOI: 10.2754/avb200776S8S101.
15. Voslazhova E., Z. Hanazalek, V. Vecherek, E. Strakova, P. Suchy. 2006. "Comparison between laying hen performance in the cage system and the deep litter system on a diet free from animal protein". *Acta Veterinaria Brno* 75(2): 219-225. DOI: 10.2754/avb200675020219.

Received 23.09.2021; accepted in revised form 11.11.2021