Modes of operation of toll gate lanes on toll roads

A Dombalyan1,2, E Shatalova1,3, E Semchugova1,4, and I Solodovchenko1,5
1Don State Technical University, 1 Gagarin sq., Rostov-on-Don, 344000, Russia

E-mail: 2anzhelika-888@mail.ru, 3ls77@mail.ru, 4semelena67@mail.ru, 5irina863-timur@mail.ru

Abstract. The article presents a detailed analysis of the modes of operation of toll gate lanes on toll roads. The toll gate lane has such operating modes as manual and automatic. Also, the lane can work in free mode – any vehicles can pass without classification and payment. The lane in closed mode does not accept vehicles. Ways of charging for each option are described, namely manual, automatic, and electronic. The stages of passing through the lane in different modes and their transport capacity are presented. The characteristic features of toll systems are highlighted and described. The purpose of the lane equipment elements is to control the flow of vehicles through the toll gate, as well as to accept tolls using various payment methods. The selection of toll system and locations of toll gates is based on an assessment of economic feasibility and taking into account the estimated traffic and traffic flow structure, the number and location of traffic interchanges. Special attention is paid to the criteria for selecting a toll system, which is to maximize profits from the operation of a toll road.

1. Introduction
Russian toll highway management systems are striving for the best European analogues in its development, that support a wide range of modern technical solutions to optimize passing through checkpoints and ensure the highest possible transport capacity.

Modern achievements in transport modelling have produced satisfactory results at the sub-regional, regional, state and interstate levels. In this regard, the results of efficiency studies of checkpoints on toll roads can be added to the issues of transport modelling, in particular, the selection of a toll system and the mode of operation of a checkpoint lane [1-3].

2. Materials and methods

2.1. Features of the toll system
The toll system requires specially equipped toll gates along a highway. All equipment, mechanisms, and platforms designed to collect tolls are referred to as a toll system. The use of common technological principles for creating technical support systems allows avoiding the costs of further expansion of the highway infrastructure, simplifying equipment modernization, and reducing the total operating costs of various systems [4-5].

The selection of toll system and locations of toll gates is based on an assessment of economic feasibility and taking into account the estimated traffic and traffic flow structure, the number and location of traffic interchanges. The main criterion for selecting a toll system is to maximize the profits from the operation of a toll road.

The traditional (with an auto barrier) method of charging tolls has the following methods of charging:
manual method of charging tolls means that a vehicle stops next to the pavilion with the staff
duty and a driver hands out money, receives a bill and, if necessary, change. The manual
method may also include paying by credit card. Charging can be accelerated by handing out
pre-purchased tickets. The transport capacity of the manual system is 120 cars per hour per
lane (experienced personnel can also pass up to 160 cars per hour);
• the automatic method of charging involves the use of automatic machines that can accept
cards (magnetic), contactless smart cards, and tokens. After stopping the vehicle, drivers pay
the toll without leaving the car. The transport capacity of the automatic toll system is from 350
to 600 vehicles per hour per lane;
• the electronic tolling method can be implemented in two ways:
• according to the first method, a vehicle with a transponder moves in a common flow with cars
along a lane that operates in automatic mode, i.e. with a stop (transport capacity of up to 600
cars per hour);
• according to the second method, a separate lane is allocated for vehicles with transponders,
along which they can cross the toll gate at reduced speed (without stopping) if the transponder
is in all respects valid; if the transponder is invalid (fake, stolen, the account has no funds,
etc.), the barrier on a dedicated lane is not raised and the vehicle is stopped or redirected to
another lane, where toll is taken in a different way: cash, credit card, signing debt statement[6].

3. Discussion and results
Systems that do not require stopping the vehicle can pass 850-900 vehicles per hour. Thus, in
traditional toll systems, the lowest transport capacity is provided by manual toll systems (120-160
autos/hour per lane), then automatic (400-600 autos/hour per lane), then electronic (800-900
autos/hour per lane). In non-stop traffic, the transport capacity is limited only by the transport capacity
of the highway – 1,800-2,300 vehicles per hour. To calculate the delay of vehicles on the toll gates, the
following indicators are used, obtained on the basis of statistical data on the operated toll gates
(average duration of the transaction operation on a toll gate in seconds), which are presented in Table
1.

| Item No. | Vehicle type | Delay of vehicles at toll gates by cash payment | Delay of vehicles at toll gates by non-cash payment |
|----------|--------------|-----------------------------------------------|---------------------------------------------------|
| 1        | Motor cars   | 25                                            | 10                                                |
| 2        | Two-axle commercial vehicles | 25                  | 15                                                |
| 3        | Two-axle commercial vehicles with a trailer | 40                  | 15                                                |
| 4        | Two-axle trucks | 40                  | 15                                                |
| 5        | Two-axle trucks with a trailer | 40                  | 15                                                |

Process of driving a car through a toll gate when paying with smart cards and in case of non-stop
payment can be illustrated by graphs (Figure1, Figure2).
Figure 1. Travelled distance-time curve when driving a car through a toll gate with stopping to pay a toll.

A - Constant speed of 100 km/h
B - Slowing down to 30 km/h (-0.3 g)
C - driving at 30 km/h
D - Acceleration from 0.25 g (2.5 m/s²)
E - Constant speed of 100 km/h
Delay 8 sec

Figure 2. Travelled distance-time curve when driving a car through a toll gate at a speed of 30 km/h.

A - Constant speed of 100 km/h
B - Slowing down from 0.3 g (2.9 m/s²)
C - “Stop and pay”
D - Acceleration from 0.25 g (2.5 m/s²)
E - Constant speed of 100 km/h
Zone 1, Zone 3 - Zones for maneuvering
Zone 2 - toll gate
Delay 16 sec
Toll gate lanes modes of operation:

The toll gate lane has the following operating modes: manual and automatic. Let’s look at each of them separately. Also, the lane can work in free mode – any vehicles can pass without classification and payment. The lane in closed mode does not accept vehicles [7,8].

Manual mode of lane operation:

The cashier-operator receives permission from the shift manager to open the shift. He enters his unique name and password into the system and activates the manual mode of lane operation.

The cashier-operator changes the sign on the entrance traffic light of the lane from restrictive (red cross) to allowing (green arrow) and opens the entrance barrier. The lane is open for operation and ready to pass vehicles (Figure 3).

First stage:

When entering the toll gate lane, the vehicle enters the zone of the entrance presence loop, the controller of which in turn initiates the launch of the classification system and the creation of a new report file on the vehicle’s passage.

The vehicle classification system (video classification) works on the principle of comparing a static background image from a classification video camera at a certain interval with the image of a passing vehicle. It is required to rescan the background image periodically because it may change over time (daily changes, time of year, weather conditions).

A special grid of graphic marks is applied to the image transmitted from the camera using a software. Marks are positioned on the camera image in such a way as to control vehicle parameters such as height, continuity, and the ability to determine the number of axes.

When the vehicle passes by the classification camera, the image from the camera becomes different from the previously recorded background image. The classification program, by comparing the recorded background image with the image transmitted in real time, determines the change in the background image at the control points. Based on these changes at the control points, the program determines the dimensions of the vehicle and the number of axes. Data about the vehicle class determined by the software package on the classification server is sent to the controller of the toll gate lane where this vehicle is located, and tariffing is made based on this data.

This system is flexible and classifies both motor vehicles and trucks, buses, longer combination and oversized vehicles.

![Figure 3](image-url)
High-sensitivity cameras with frame rates up to 100 are used. To classify more precisely, two video cameras are used, located on both sides of the toll gate lane. Also, an additional measure to improve the accuracy of classification is the use of infrared spotlights, which allow classification in the dark and prevent cameras from being illuminated by vehicle headlights [9].

Second stage:
The vehicle enters the payment zone (Figure 4). The inductive presence loop records the vehicle on the payment axis and the system launches the toll payment process. Based on the data received from the pre-classification system, the operator either confirms the vehicle class or changes it to the correct one if the classification system has determined it incorrectly. Based on the vehicle class, the system calculates the required amount to be paid, which is shown on the operator’s display. The confirmed class and the calculated amount are displayed on the driver’s information board.

The driver of the vehicle chooses the preferred payment method. The following payment methods are available on the lane in manual mode:

- cash payment;
- payment by credit cards;
- payment by contactless cards;
- payment using transponders

![Figure 4. Vehicle entry into the payment area.](image)

Third stage:
If the transaction is correct, the traffic light turns green and the exit barrier opens. The vehicle enters the exit zone and gets into the exit presence loop zone, which records the vehicle, the exit traffic light turns red, informing subsequent drivers of the vehicles about the ban on entering the exit zone. The post-classification system is activated.

Post-classification is similar to pre-classification. The control system compares the vehicle class obtained by pre-classification, post-classification, and defined by the operator. If rejected, the system reports it to the control center, where the corresponding record is made. The video camera records the vehicle at the time of payment and the time of leaving the lane, and puts the video image in the video archive in the control center. The post-classification system completes the operation. The system is ready to serve a new vehicle.

Violation on a manual mode lane:
Any crossing of the inductive presence loop, when the traffic light is red or the traffic light is turned off, shall be recorded as a violation, except for vehicle leaving after the correct payment. In this case, as well as when hitting the exit barrier boom, a light and sound alarm goes off, and the video event is recorded in the archive with the corresponding mark [10].

Lane automatic mode of operation:
The shift manager of a toll gate turns on this mode. The shift manager changes the sign at the traffic light on the lane to a green arrow and opens the entrance barrier. The lane is open for operation and ready to pass vehicles.

First stage:
The vehicle gets into the entry zone and drives over an inductive presence loop, which records the vehicle and launches the pre-classification system. The pre-classification is similar to the one when the lane operates in manual mode. Information from the pre-classification system gets to the lane controller, and the system determines the vehicle class based on it. Based on the vehicle class, the system calculates the required
amount to be paid. The confirmed class and the calculated amount are displayed on the driver’s information board.

Second stage:
The vehicle enters the payment zone. The inductive presence loop records the vehicle on the payment axis.
The driver of the vehicle independently chooses the preferred payment method. The following payment methods are available on the lane in automatic mode:

- cash payment;
- payment by credit cards;
- payment by contactless cards;
- payment using transponders;

Third stage:
If the transaction is correct, the traffic light turns green and the exit barrier opens. The vehicle enters the exit zone and gets into the exit presence loop zone, which records the vehicle, the exit traffic light turns red, informing subsequent drivers of the vehicles about the ban on entering the exit zone. The post-classification system is activated. Post-classification is similar to pre-classification. The control system compares the vehicle class obtained by pre-classification, post-classification, and defined by the operator. If rejected, the system reports it to the control center, where the corresponding record is made. The video camera records the vehicle at the time of payment and the time of leaving the lane, and puts the video image in the video archive in the control center. The post-classification system completes the operation. The system is ready to serve a new vehicle.

Violation on a lane in automatic mode:
Any crossing of the inductive presence loop, when the traffic light is red or the traffic light is turned off, shall be recorded as a violation, except for vehicle leaving after the correct payment. In this case, as well as when hitting the exit barrier boom, a light and sound alarm goes off, and the video event is recorded in the archive with the corresponding mark.

Closed mode of a lane:
The operator turns on the closed mode of a lane after receiving permission from the shift manager, or the shift manager himself from the control center.
The lane is closed for operation. Entrance barrier is closed. There is a red cross on the traffic light on the lane, indicating that entry is prohibited. Any crossing of the inductive presence loop, as well as the hitting the boom of the barrier in the entrance area, is recorded as a violation.

4. Conclusions
The purpose of the lane equipment elements is to control the flow of vehicles through the toll gate, as well as to accept tolls using various payment methods [11].

Standard of efficiency of the user’s maintenance equipment is called the state, namely the operation and debugging state (maintenance). In the state of operation, the amount of the payment acceptance operation is charged and taken into account. In the debugging state, the operator simulates the entire payment procedure, but no entries are made in the periodic profit reports. Tickets issued on the entry lane have special signs, so they cannot be used in the working exit lane.
Vehicle driving depends on the operating mode: closed mode, manual mode, automatic mode, free mode. In closed, manual and automatic mode, if a car passes through the system lane without completing the payment procedure, each such passage shall be considered a “violation.”
In manual mode, the operator sets all the parameters of the operation manually: determining the type of vehicle and its adjustment, and selecting the allowed payment method.
In automatic mode, monitoring is performed only by a remote terminal installed at the toll station. All normal operations are performed automatically (automatic recognition of the vehicle type, payment method selection, and subsequent vehicle monitoring). The intervention of a shift manager is only needed in controversial cases. The system lane operating in a free mode is designed to work with the flow of vehicles without paying a toll. Each of these vehicles is assigned a payment method “free of charge”. This right is practiced by employees of operational, medical and rescue services on duty [12].
In light of the above, we conclude that the automatic mode of operation of the toll gate lane with an electronic or contactless payment method is the most convenient and optimal.
Currently, most developed countries of the world have toll roads, while there is an increase in their length and the formation of interconnected systems of toll highways. The positive experience of creating toll road systems is becoming increasingly common in the world.

References
[1] Naumova N A, Zyryanov V V 2015 A method of computing the traffic flow density distribution in the network with new flow-forming objects being put into operation. Journal of Theoretical and Applied Information Technology vol 78 no 1 pp 76-83
[2] Features of the application of the main traffic flow diagram at the network level VV Zyryanov Bulletin of the Volgograd State Technical University 2013Vol 7 No 21 (124) S 71-74.
[3] Dombalyan A V 2014 Development and improvement of the toll road management system. Scientific Review No.10-3 pp 823-826
[4] The use of modeling for the assessment of transport infrastructure projects Zyryanov VV, Kocherga VG Collection of scientific papers of JSC “GIPRODORNII”. 2012. No. 3. S. 7-12.
[5] Zhankaziev S V 2016 Intelligent transport systems: textbook. allowance MADI, 120s.
[6] Zyryanov V V, Mirotin L B 2008 Modeling of traffic flows as a method of logistic management of transport processes in megalopolis and a method of rational planning of a road network to cities // Bulletin of transport No. 1 pp 37-44
[7] Zyryanov V V 2013 Methods for assessing the adequacy of modeling “Engineering Bulletin of the Don”, No 2 -
[8] Dombalyan A V, Shatalova E E 2015 The development of intelligent transport systems in the world In the collection: Construction Construction. The roads. Transport materials of the International scientific-practical conference S 81-82
[9] Dombalyan A, Kocherga V, Semchugova E, Negrov N 2017 Traffic forecasting model for a road section Collected: Transportation Research Procedia pp 159-165
[10] Dombalyan A V, Mironchuk A A, Solodovchenko I Yu 2016 World experience in the creation and operation of toll roads In the collection: TECHNOLOGIES OF TRANSPORT PROCESSES FOR THE DON Pp 83-86.
[11] Dombalyan A V 2014 Analysis of throughput and security of toll collection points. Scientific Review. No 11-2 S 617-620
[12] Dombalyan A V, Shatalova E E 2016 The influence of speed limits on the amount of emissions of pollutants from vehicles. In the collection: TECHNOLOGIES OF TRANSPORT PROCESSES FOR THE DON 2016 P 86-89