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Traffic Microsimulation of the Main Junction Connecting the Urban Road Network with the Sea-Port Container Terminal

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ABSTRACT

Efficient transportation connectivity between ports and the hinterland is essential for the functioning of the port, especially for container terminals that predominantly rely on road transport. The integration of port and urban traffic flows, particularly in terminals located near cities, has a double impact on the level of service of urban traffic and the efficiency of the port. This paper examines the effects of a newly built container terminal, with a capacity of less than 1 million TEU per year, on urban traffic in Rijeka, Croatia. A microscopic-level simulation method is used together with traffic network modeling design. The research identifies potential bottlenecks or critical elements in the network with lower performance for the current traffic demand and the future growth scenarios of the container traffic. The study's findings contribute to understanding the dynamic characteristics of port and urban traffic flow correlation, crucial for efficient transportation management and sustainable urban development in port cities.

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1 Introduction

The port's connection with the hinterland through an efficient transport network is of vital importance for the functionality of the port. That especially applies to container terminals, which predominantly use road transport means for the delivery and dispatch of containers as part of the logistics of delivery and dispatch of goods to logistics centres. At terminals located near cities or integrated into the urban environment of cities, there is an integration of port, and urban traffic flows between demand zones and port areas.

Such a situation has a double impact on the level of service of urban traffic and, on the other side, on the efficiency of the port. From the citizen's perspective, the impact on mobility can be seen through the increase in the number of trucks on the city and surrounding roads or may produce traffic congestion with a negative effect on social welfare. From the port perspective, congestion can affect the productivity of the terminal and can lead to cargo delays or loss of schedule. In addition, traffic congestion opens a traffic management problem and creates additional pressure on the environment.

When analysing the transport network and urban traffic flows in the port city area, it is also essential to know what changes can be expected concerning the anticipated growth of port traffic and the impact of such an increase on the future urban traffic condition. Therefore, considering the dynamic characteristics, the correlation between the port and urban traffic flow should be investigated.

Seasonal changes result from tourism oscillations in transport demand, sometimes leading to road congestion at peak hours and bringing the spatial constraints of road infrastructure in the first place. Furthermore, a port in an urban area may attract more tourist trips and generate additional traffic [1].

Several studies have analyzed urban traffic flows in cities where port traffic participates in the transport demand. The impact of high-congestion road traffic on marine container terminals has been studied in [2]. The authors investigate three scenarios, including constructing a new highway and a scenario with increasing container traffic over time. The local urban-port road system and the effects of capacity improvement around the port of

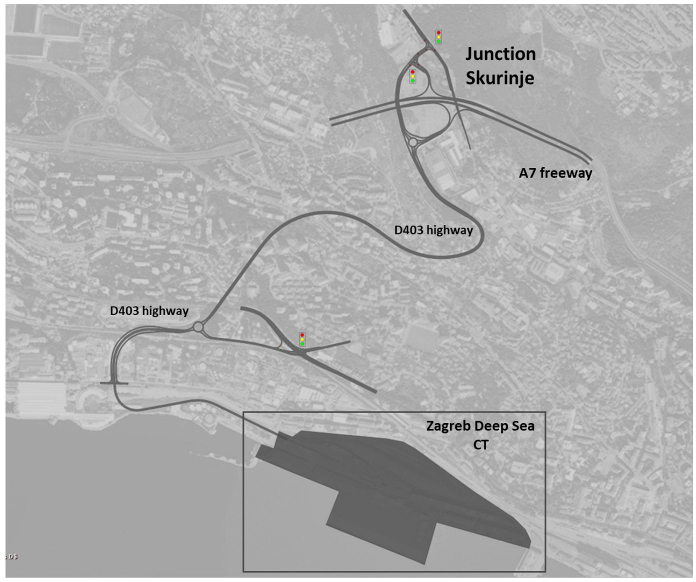

Figure 1 Study area

Source: Authors

Szczecin were research subjects in [3]. Heavy goods vehicles (HGV) used for container transport affect road traffic flow. This effect becomes even more intense if the expansion of the container terminal is planned. Estimation of the impact of HGVs on the traffic flow operation near the Liverpool container terminal was elaborated in [4], and the impact on the emission of HGV traffic heading to the port of Genoa in [5]. Some studies focus on entrance and exit ramps near the terminal gates as the interface between terminal roads and the rest of the network, where congestion may restrict the city traffic flow [6, 7].

There are various options to deal with the traffic challenges that arise in port cities to solve congestion, whether in the current state or a possible future scenario. That may include the construction of a new section of highway, mode shift in favour of train shuttle service, and potential changes in traffic patterns concerning growth in container traffic [2]. In some cases, ITS solutions like LIST Port ITS System Central [8] for best vehicle routing or Variable Speed Limits for control speed near junctions could also be part of the solution for coping with the congestion and preventing off-ramp queues [9].

A systematic approach to measures to be taken by the ports to limit the congestion in the vicinity of the port area has been proposed in [10]. The authors indicate technical measures to improve existing or building new transport infrastructure that link the port area with the rest of the network, as well as innovative measures that have recently been applied in ports Antwerp and Rotterdam, such as "Truck Guiding System" and Car platooning. However, more detailed analyses are needed for each study area depending on the characteristic of the traffic network, port and urban interfaces, and local behaviour to measure the effects of port traffic on urban traffic performance.

In this paper, we investigated the impact of a newly built container terminal with a capacity of less than 1 million TEU per year in the inner-city area on urban traffic. The case refers to the "Zagreb Deep Sea Container Terminal" in Rijeka/Croatia. We investigated the impact with a view to the newly built highway D403 and its connection to the motorway passing through the city area via the junction of Skurinje (Figure 1). The research aims to identify the network's potential bottlenecks or critical elements with lower performance for the current state of the traffic demand and the future growth scenarios of the container traffic.

2 Methodology

2.1 Study area description

Two container terminals are located in the city of Rijeka. They are located on the eastern and western border of the city center and are not connected to each other in functional or organizational aspects. The Zagreb Deep Sea container terminal, which is the subject of analysis in this paper, is functionally connected to the road transport network via the D403 highway, the construction of which is in the final stage at the time of writing this paper. The terminal covers an area of 17.5 ha. The final version will have a 680 m long quay and an estimated capacity of around 600,000 TEU/year. However, the realization of annual traffic will largely depend on the availability of road and rail connections with the hinterland. This means a satisfactory level of services on the city network's main junctions and road ramps. In that context, we have identified potential critical points of the urban road network, including the junction of Skurinje with the connection to the D403 highway and the road ramp connecting with the A7 motorway.

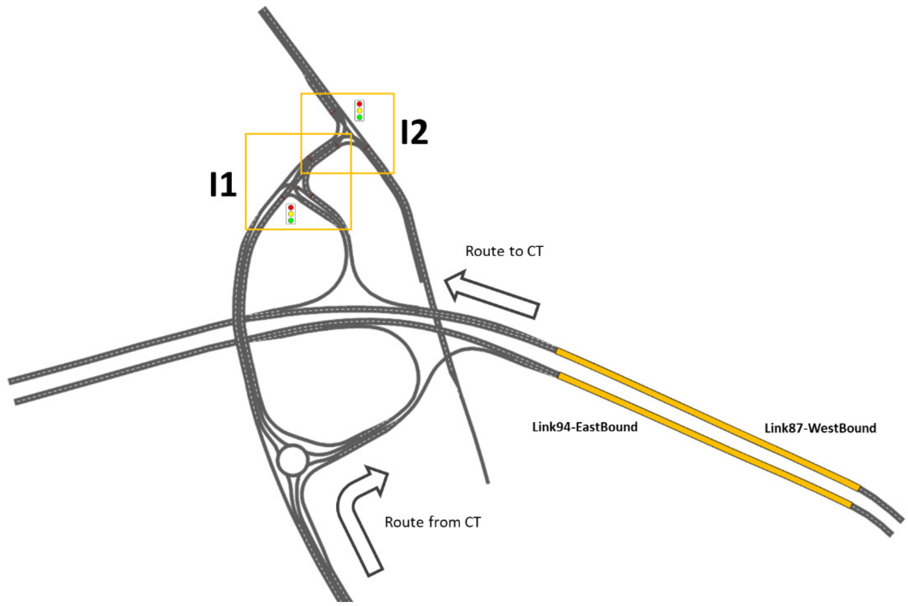

Figure 2 Junction connecting the port of Rijeka through D403 highway with A7 motorway

Source: Authors

The A7 motorway is part of the Adriatic-Ionian corridor and is vital for the city and the port. The Kvarner motorway is part of it that passes through the urban area. Because of several ramps connecting it to the city roads, it is practically part of the city's traffic network, which connects the western and eastern parts with the city center. This road also has a distinct transit character, especially during the summer when many tourist vehicles transit.

The Skurinje junction (Figure 2) is one of the busiest parts of the Kvarner motorway. There are two entry and exit ramps at the intersection, one from the East (direction Zagreb) and one from the West (direction Trieste, Ljubljana), that are linked together at a signal-controlled intersection with three approach legs (I1). The signal plan consists of four phases with a cycle duration of 110 seconds. The primary connection to the city road network is achieved through the T-type intersection (I2) and is directly connected to the previous one, which provides entry/exit from A7. With the construction of the D403 road, the Skurinje intersection was reconstructed with a new roundabout as the main element of the rebuilding that connects the existing junction with the D403 road.

2.2 Microsimulation model design

Identifying traffic flow on the approaching roads heading to the port and the city's main arteries and quantifying and determining traffic flow parameters have been approached through various methodologies. Mathematical and simulation modeling techniques are commonly used among researchers as a primary method, e.g. in [2, 11, 12, 13] or in combination with other strategies for optimization or decision-making [14, 6].

The advantage of microscopic traffic simulation models is that they provide a detailed and accurate representation of traffic dynamics by simulating individual vehicle movements during specific time intervals, making them ideal for analyzing current or future traffic scenarios. These models focus on capturing traffic behaviour patterns, making them an effective tool for studying traffic situations.

The model design (Figure 3) includes the model input of the network with objects, elements, and their attributes, as well as the traffic demand according to vehicle classes and expressed through the target time interval. The input data on traffic demand was extracted from a macrosimulation model developed through a previous project (Figure 4). The model output evaluates two critical network elements: the performance of the interlinked intersections at the junction of Skurinje and the traffic flow on motorway A7 in the entrance-exit ramp zone.

The microscopic model reproduces the present state traffic condition – flow, density, and speed, and measures traffic performances at intersections – delays, queues, and travel times on the links and routes within the predefined zone. After the calibration of the basic network, new modifications have been made, including the model design of the new highway D403. The modifications include the following: a) A change of the intersection geometry; b) Lane discipline adjustment and insertion of two new movements; c) Adaptation of the signal plan with signal stages required for inserted movements; d) Updating the static routes through the junction; e) Updating desired speed control on new model objects. The goal was to analyze performances and critical points of the network, primarily caused by HGVs, with origins and destinations from/to the port for future scenarios depending on the growth rate projection of

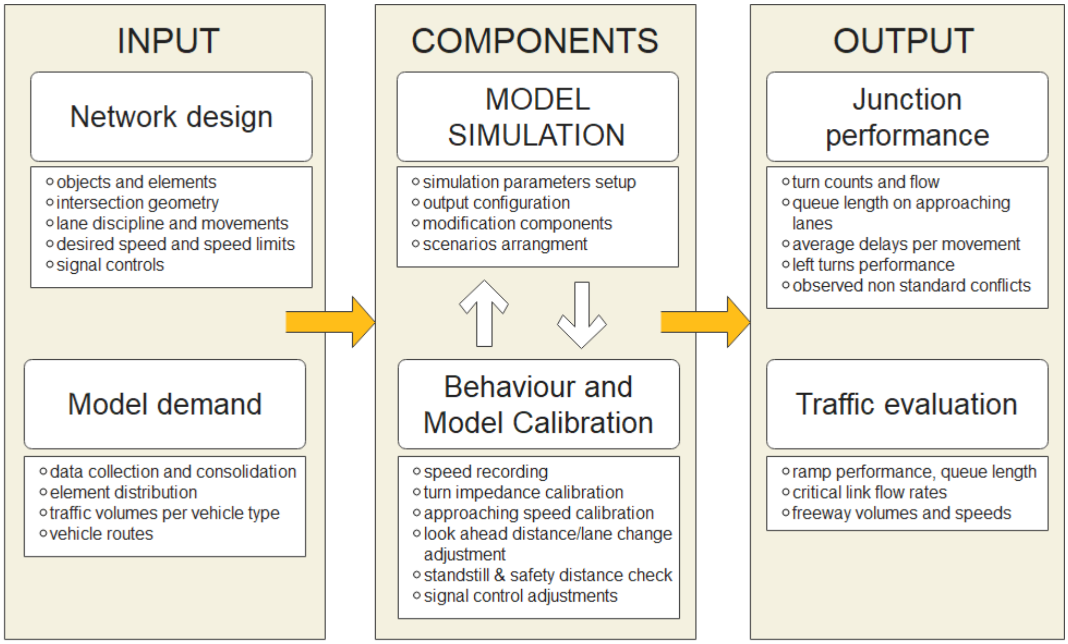

Figure 3 Model design

Source: Authors

Figure 4 Traffic flow at the junction Skurinje – morning peak

Source: Authors, output from the macroscopic model developed in the project "CEKOM-Connected Traffic"

Table 1 Hypothetical container transport demand and generated HGV volumes

Scenario	Zagreb Deep Sea Terminal throughput (hypothetical) in TEU/year	HGV Volume (veh/h)	
		Direction from A7 Zagreb bound CT	Direction from D403 CT bound Zagreb
S1	200.000	12	11
S2	400.000	23	22
S3	600.000	35	31

Source: Authors based on the Zagreb Deep Sea CT and D403 project documentation

port container traffic. For this purpose, three hypothetical scenarios have been created and incorporated with the modifications into the model (Table 1).

To estimate the number of HGVs required to transport the projected annual container throughput, we need to convert the throughput from TEU units to the corresponding number of containers, based on the 20/40-feet rate. According to [15], the dominance of lighter consumer goods in international trade is reflected in the increased use of larger cubic containers and a rise in the TEU ratio up to 1,65. The modal split between road and rail and the daily distribution of traffic demand should also be considered. Once we have these inputs, we can calculate the HGV volumes per hour. The calculation was based on the following assumptions: The ratio of 20/40 foot containers 33/67 per cent or TEU factor of 1,67, modal split 65/35 per cent in favour of road traffic, 350 working days per year, and daily traffic demand distribution over the 10 hours. These presumptions are based on information from the terminal operator and are used to transform TEU in the number of containers. We used the PTV Vissim microsimulation tool for the model design. The whole process can be consolidated through the following steps:

- Designing the traffic network using supply-side data
- Importing the traffic demand data from surveys and macroscopic model outputs
- Defining key performance indicators and their incorporation into the traffic model
- Calibration of the critical attributes
- Network and control element modification with scenario demand management integration
- Evaluation of results

For the model's functionality, it is necessary to set simulation parameters, behaviour attributes, and calibrate movement dynamics and signal plans depending on traffic demand scenarios. The calibration process will be explained in more detail in the next chapter.

2.3 Model calibration

Model parameters need calibration because of impacts on the simulation results. Driver behaviour models have affected the traffic flow as they describe how the vehicles interact with each other and how the driver reacts to the traffic states and traffic control elements. Typically, two main types are the car-following and lane-changing models. Overview and characteristics of the existing behaviour models are systemized in [16]. Their calibration includes speed adjustment, acceleration/deceleration, lane selection and space gap adjustment according to road conditions. Reduced speed areas between approaching and exiting lanes should be additionally calibrated at intersections to adjust the vehicle dynamics of vehicles passing through the intersection. The same applies to the signal controllers, where a proper signal plan must be deployed.

Other microsimulation parameters can be calibrated in the Vissim model according to [17]. The choice of calibration parameters depends on the simulation's specific case and purpose. We set up those model parameters as follows (Table 2).

Table 2 Positions of objects with calibrated speed values

Input parameters	Default	Adjusted	Type
Simulation resolution	5-10	10	System
Number of interaction objects	4	10	Behaviour/Following
Number of interaction vehicles	99	6	Behaviour/Following
Min look ahead distance (m)	0	30	Behaviour/Following
Max look ahead distance (m)	250	300	Behaviour/Following
Average standstill distance (m)	0,5	0,5	Behaviour/Car-following
Additive part of safety distance	2	2	Behaviour/Car-following
Multiplic. part of safety distance	3	3	Behaviour/Car-following
Min. clearance (front/rear)	0,5	0,5	Behaviour/Lane-change
Waiting time before diffusion (s)	60	30	Behaviour/Lane-change
Cooperative lane change	Off	On	Behaviour/Lane-change

Source: Authors

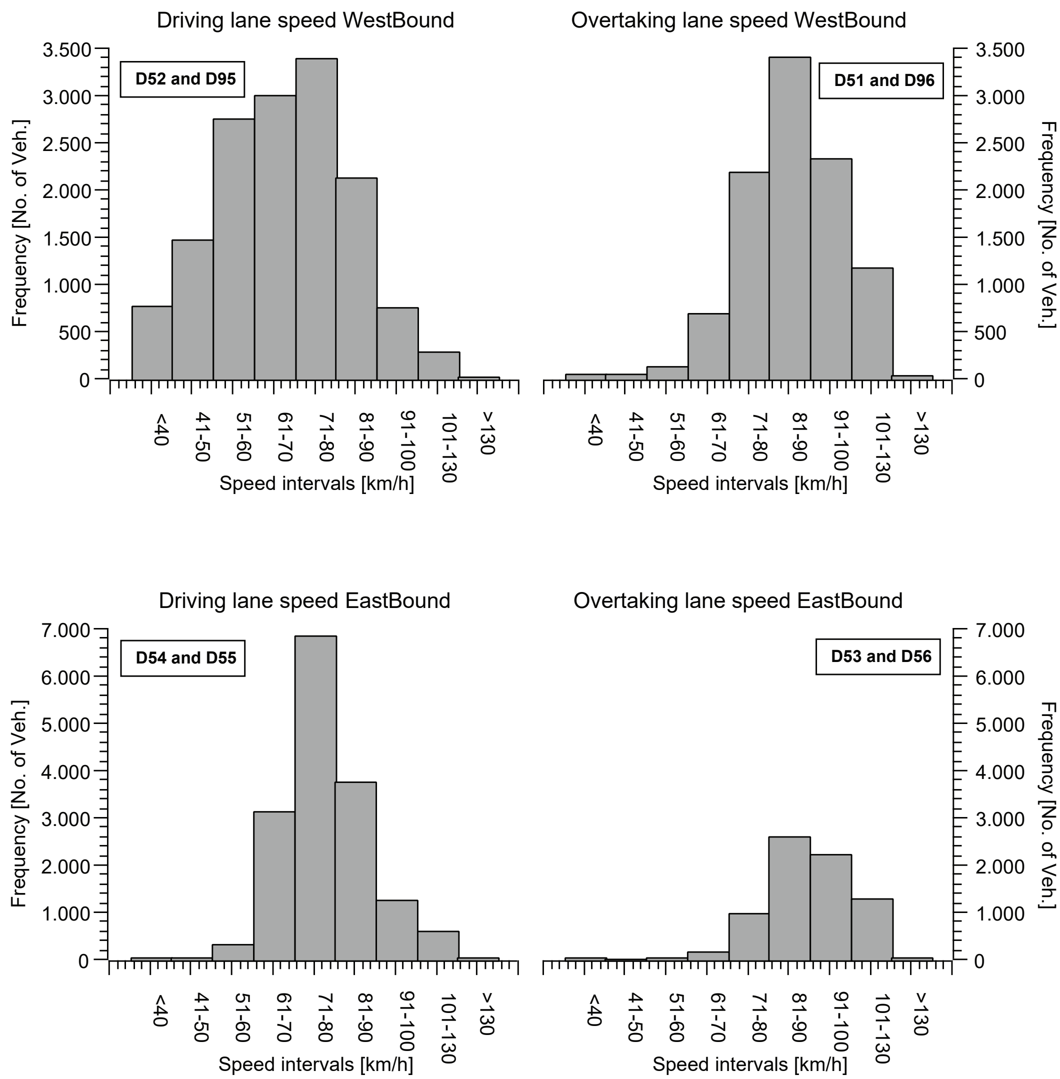

Figure 5 Calibrated speed profiles on the A7 motorway for the Westbound direction (top) and the Eastbound direction (bottom)

Source: Authors

The process of vehicle speed calibration involved setting appropriate speeds for different types of vehicles entering the road network, setting speed limits for cross-sections and ramps, and reducing speeds to ensure the smooth movement of vehicles through intersections. Data from inductive loop traffic detectors were used to calibrate speeds on the A7 motorway. In contrast, the floating car method was used to calibrate speeds on entry-exit ramps and movements through the intersections. According to the detector measurements, different speed profiles were created for driving and overtaking lanes in both directions, westbound and eastbound (Figure 5).

We used the floating car method to measure vehicle speed when crossing intersections. A Garmin GPSMAP tracking device was used for the measurement. Approximately ten passes were made for intersection movements and speed measurements at the connecting ramps. Table 3 and Figure 6 show the positions of speed control objects and calibrated speed values.

Table 3 Calibrated speed values for different VISSIM control speed objects

Decision Speed Obj.		Reduced Speed Obj.	
Position ID	**Mean Speed**	**Position ID**	**Mean speed**
D43	42,65	R46	30,55
D44	45,90	R47	30,80
D45	44,33	R48	27,25
D46	37,50	R49	20,80
D47-D48	40,00	R50	29,95
D49-D50	45,47	R51	33,70
-	-	R52	30,00

Source: Authors

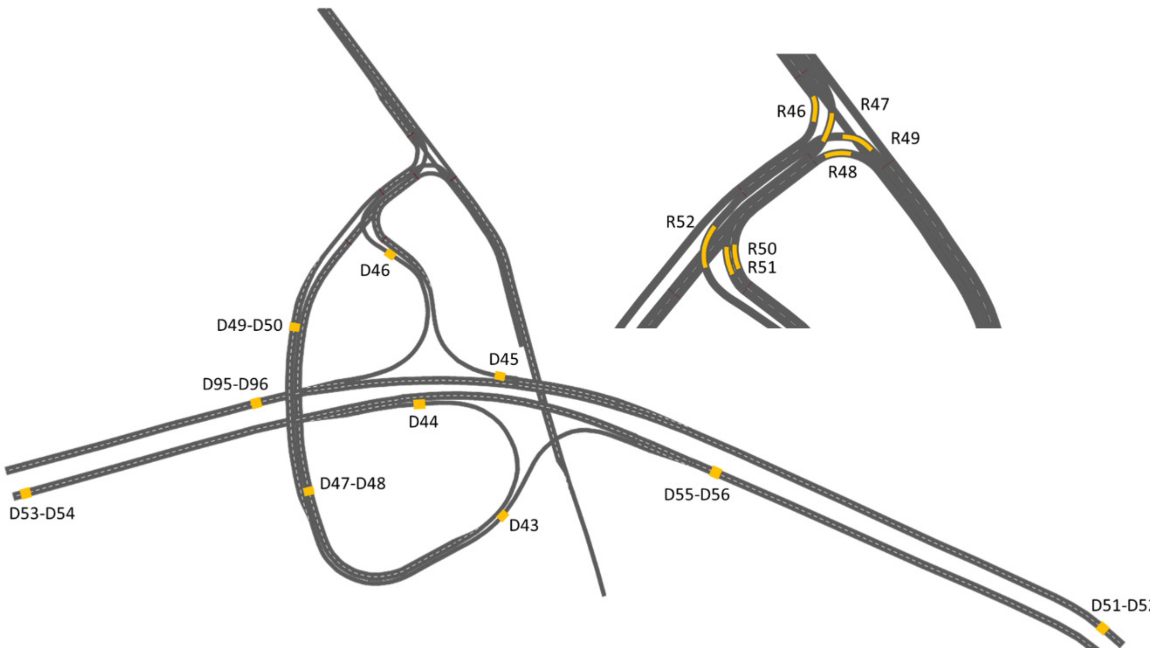

Figure 6 Desired Speed object positions in the network

Source: Authors

3 Results

3.1 Signal plan revision for missing turns at intersections

In this case, the two critical elements of the newly designed network are the existing intersections and entrance-exit ramps connecting the A7 motorway with the D403 highway. Therefore, these elements were evaluated through simulation results. To create a functional solution for connecting both existing and future road networks, the missing turns have been added to the existing intersection, marked as XT1-L and XT2-R (Figure 7). These new turns establish a connection for vehicles coming from the eastbound direction and heading towards the container terminal, as well as for those seeking to access the westbound direction of the motorway from the terminal. The newly designed signal plan combines existing and newly created signal groups to manage the turns in question. The calculation we used is based on Webster's method using flow factor y for the critical movement in each phase and optimum cycle time for minimum delay c_o, given by the formulas:

$$y = \frac{arrival\ flow\ for\ an\ approach\ (q)}{saturation\ flow\ for\ an\ approach\ (s)} \quad (1)$$

and

$$c_o = \frac{1.5L + 5}{1 - Y} \ \ [s] \quad (2)$$

where L is the total lost time per cycle, and Y is the sum of flow factors. Green time is then calculated using an effective green period g according to the expression:

$$g = \frac{y}{Y}(c - L) \ \ [s] \quad (3)$$

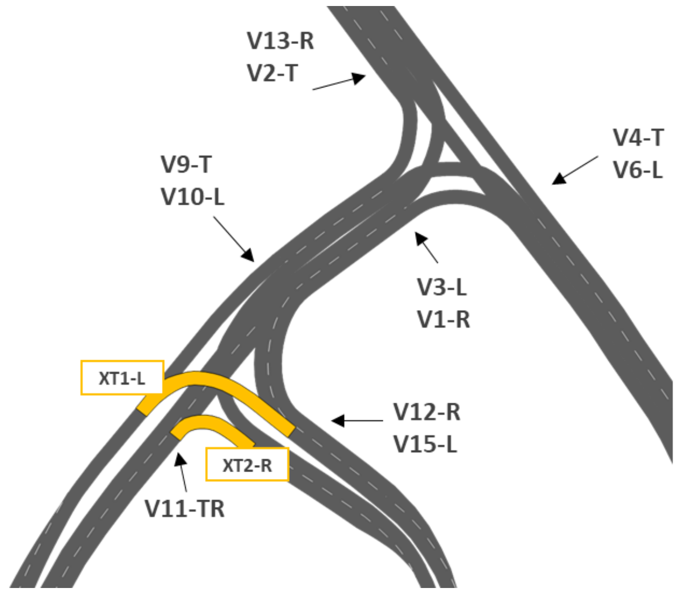

Figure 7 Missing turns and signal groups of the revised signal plan

Source: Authors

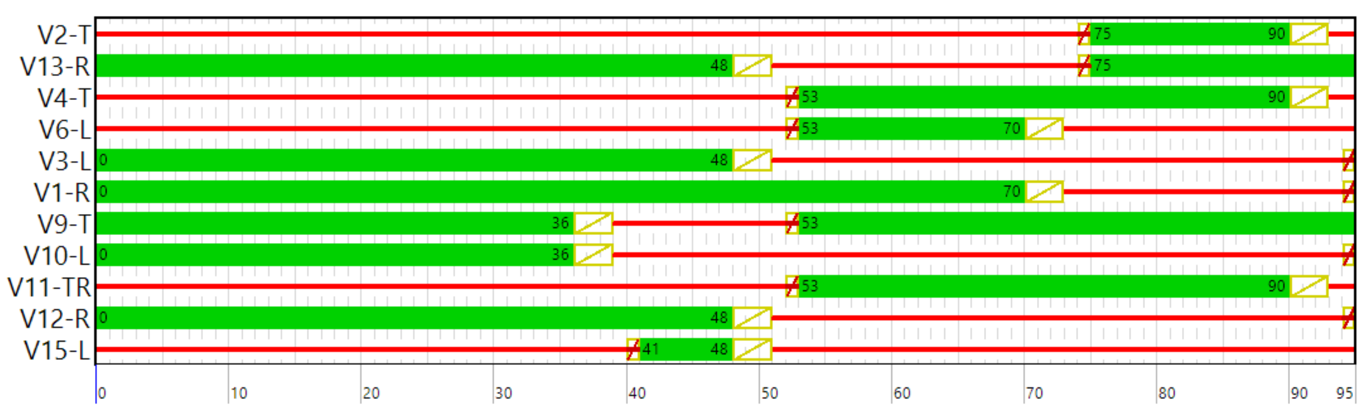

Figure 8 Revised signal control plan

Source: Authors

The scenario with the highest demand was considered when calculating the signal plan. While this scenario corresponds to the highest volume of road container traffic, the relatively short green interval allocated to the V15_L turn is sufficient to accommodate the expected number of trucks heading to the terminal (Figure 8).

3.2 Intersection evaluation results

Three key performance indicators were utilised to evaluate the intersection: queue length (both average and maximum), delay, and number of stops. Data was collected for each turn and approach lane of intersections I1 and I2 for all three scenarios. Evaluation results are presented in Table 4 and Figure 9.

The exit ramp of the A7 road leading to the intersection area is experiencing a noticeable increase in queue length. The reason for this is the HGVs that deliver containers to the terminal and make a left turn at the intersection towards the D403 highway that leads to the container terminal. The impact of changes in demand is most pronounced through this indicator. The southern entrance approach towards junction I1 also shows an increase in queue length in proportion to the demand and records the highest queue length in S3 of over 172 metres. At first glance, this is unexpected because the outgoing truck traffic from the terminal does not pass through the I1 intersection and through that part of the link. The traffic simulation reveals a genuine problem caused by the inadequate space for releasing vehicles from the queue between intersections

Table 4 Performance of the intersections for each movement

	Scenario S1					Scenario S2					Scenario S3				
Movement	Qlen (m)	QLenMax (m)	Vehicles	Stops	Delay (s)	Qlen (m)	QLenMax (m)	Vehicles	Stops	Delay (s)	Qlen (m)	QLenMax (m)	Vehicles	Stops	Delay (s)
V2T	53,3	138,2	122	2,4	50,2	49,7	144,9	123	2,2	48,7	51,3	138,5	119	2,3	50,1
V13R+V10L	53,3	138,2	208	3,6	41,5	49,7	144,9	211	3,3	40,3	51,3	138,5	201	3,6	44,0
V13R+V9T	53,3	138,2	506	2,8	22,9	49,7	144,9	512	2,6	21,9	51,3	138,5	494	2,8	24,5
V4T	29,8	115,7	226	0,6	14,7	32,8	112,3	226	0,6	14,7	33,8	112,2	226	0,6	14,7
V6L+V10L	29,8	115,7	65	3,6	91,9	32,8	112,3	65	3,7	95,1	33,8	112,2	64	4,0	98,0
V6L+V9T	29,8	115,7	158	2,3	63,3	32,8	112,3	159	2,5	69,0	33,8	112,2	158	2,6	70,4
V11T+V3L	71,1	165,8	338	3,9	115,1	68,1	154,2	339	3,8	111,0	76,5	172,8	335	4,1	120,8
V11T+V1R	71,1	165,8	342	2,2	44,4	68,1	154,2	342	2,1	42,3	76,5	172,8	338	2,3	47,2
V11R	71,1	165,8	0	1,8	68,7	68,1	154,2	1	2,1	40,2	76,5	172,8	2	1,8	34,9
V12R+V3L	8,2	73,5	204	1,4	18,2	11,2	92,2	204	1,5	20,6	15,8	121,5	202	1,7	24,5
V12R+V1R	8,2	73,5	217	0,7	9,9	11,2	92,2	217	0,8	10,8	15,8	121,5	215	0,8	12,0
V15	16,6	90,8	12	1,4	34,2	20,7	109,4	22	1,4	36,6	26,8	138,8	35	1,5	40,0

Source: Authors

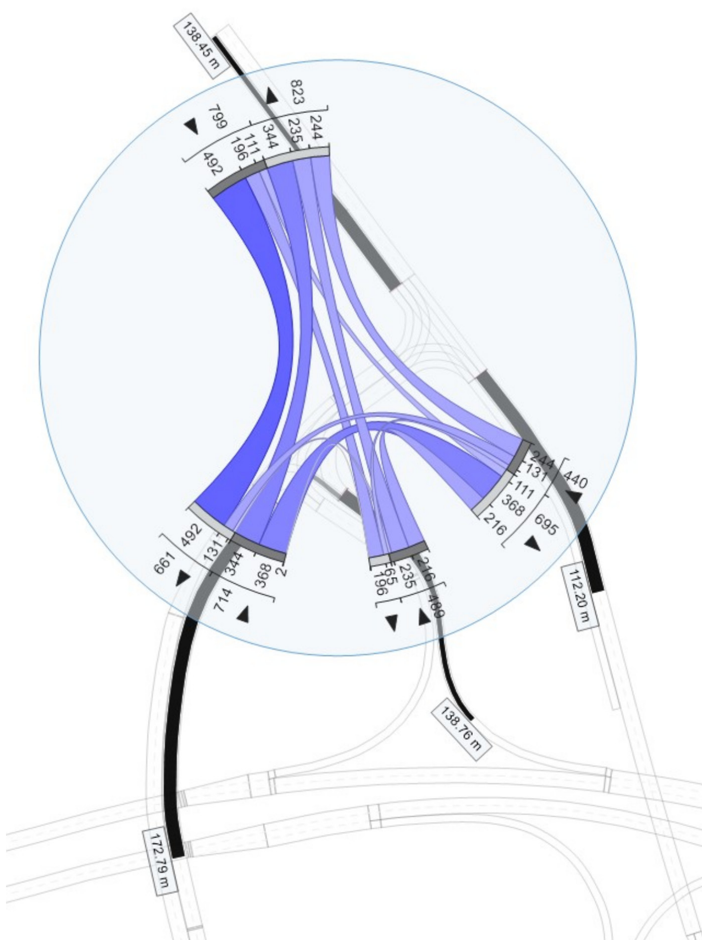

Figure 9 Evaluation of the junction with two joined intersections: Turn volumes and Queue length for S3 scenario

Source: Authors

I1 and I2. As a result of the traffic flow from the exit ramp and the movement of HGVs through the intersection, the total lost time on other approaches increases, which has an impact on the formation of queues.

From the traffic engineering view, the question is whether it is possible to reduce delays by changing the signal control plan. However, according to [18], it works up to when a critical traffic demand is reached. Consequently, in oversaturated conditions, there are no improvements possible and only modifications of the intersection geometry can overcome the problem of traffic congestion [19]. In this case, the coupling of two intersections at a relatively short distance and the insufficient space between the intersections are the main reason for reduced performance.

3.3 Motorway sections evaluation results

During the simulation, the impact of port traffic on the overall traffic volume and performance along a section of the A7 motorway was tested against three primary traffic parameters: flow, density, and space-mean speed measured on the westbound link 87 and eastbound link 94 of the network. The Flow-Density and Speed-Flow diagrams illustrate the results for the S3 scenario, which has the highest predicted demand for road traffic generated by the container terminal (Figure 10). There are no significant differences in the curve shapes of the diagrams between the scenarios. The flow-density diagram shows no signs of flow drop-down. The driving lanes further away from the ramp area have more unused capacity than the driving lanes near the ramp area where outflow and inflow occurred. Considering speeds, a slight reduction in free-flow speed can be observed for the eastbound link, but there is no clear evidence that the breakpoint has been reached. In this case, the inflow from the entering ramp has a greater impact on speed reduction in the driving lane than increasing traffic volume.

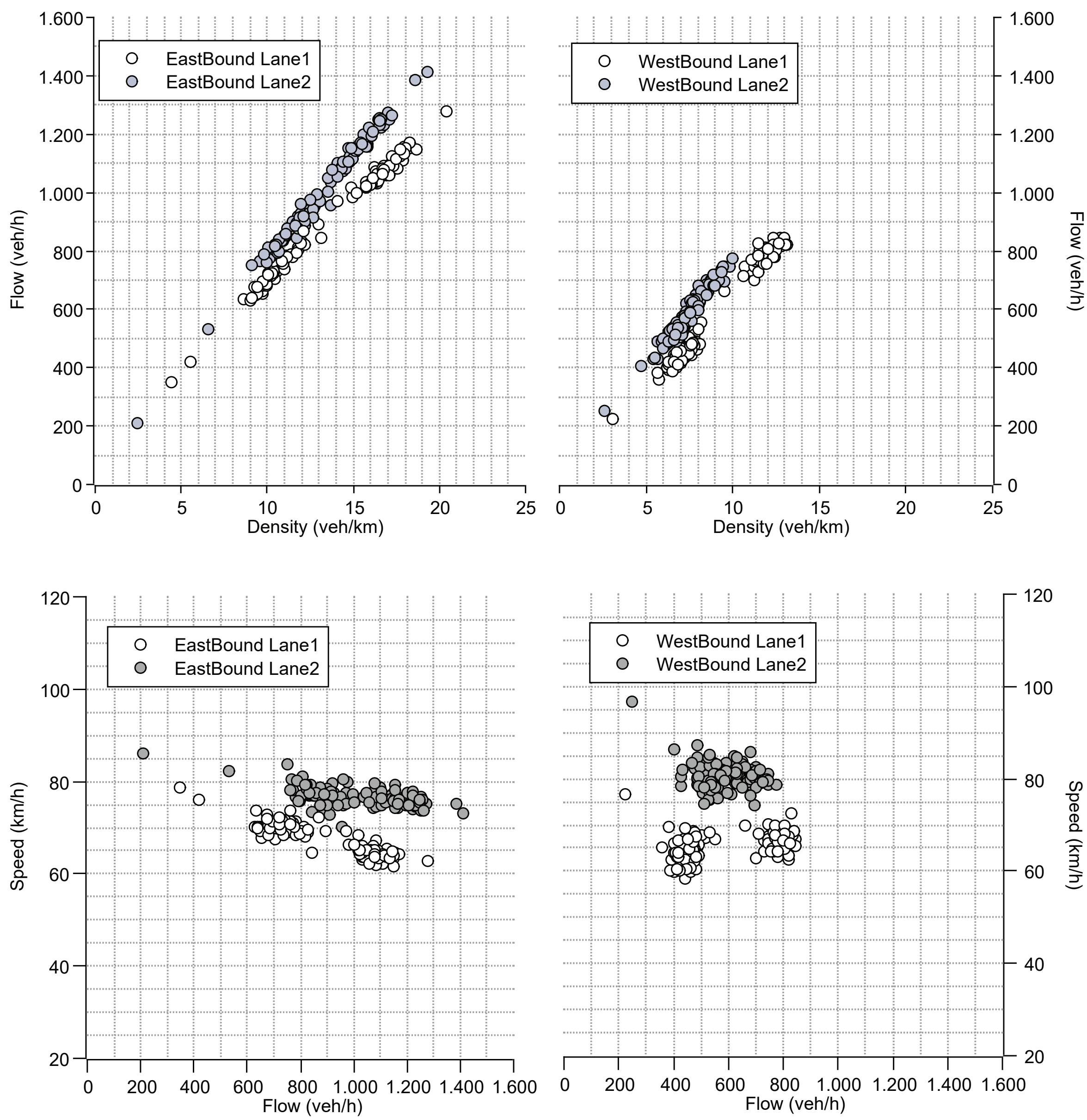

Figure 10 Link evaluation for S3 scenario: F-D diagrams (top) and S-D diagrams (bottom)

Source: Authors

4 Discussion and Conclusion

The findings indicate specific traffic conditions under the influence of hypothetical traffic demand scenarios with uniform temporal and modal share distribution. Alterations of these assumptions could significantly impact the traffic situation caused by container port traffic than the results presented. Two critical elements were identified: the exit ramp from A7, where changes in traffic demand had a more significant effect on performance reduction, and intersection I1, where left turns towards the D403 highway heading to the container terminal caused congestion. If higher percentages of HGVs occur because of changes in transport demand or caused by changes in modal split distribution in favour of road transport than those outlined in the paper, it would be necessary to produce different simulation scenarios with changes in the geometry of the intersection or changes in lane disciplines to validate of such measures on reduce the congestion.

However, the main emphasis of this paper is the examination of the effectiveness of simulation methods in planning future changes in the traffic system characterised by an urban environment and the newly generated port container traffic that changes the existing traffic flows. The research contributes to applying traffic microsimulations as a method for evaluating development projects, measures and traffic solutions and their use in decision-making.

The microsimulation model presented here was adapted to the extent possible to the real traffic situation through calibration. However, the model only tests hypothetical situations and is not intended to predict future traffic demand. In addition, the threshold values at which the speed breakpoint is reached, and saturation occurs should be investigated, considering the impact of container traffic and the effects of increasing other transit traffic, especially during the tourist season. That may be some idea for future research on this topic.

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