Modelling based approach for attracted transport readiness trips estimation to the site

N. Zenina, A. Romanovs, and Y. Merkuryev

Abstract**—**Accessibility can be evaluated as a measure of demand, supply and readiness. This research is focused on third measure, readiness. Readiness is expressed as a number of incoming traffic flow to the commercial site taking into account transport access alternative design, number of generated trips with correction for local conditions, delay per vehicle and level of service. To select appropriate transport access alternative isolated intersections (unsignalized, signalized, signalized with allowed left turn from shoulder; roundabout) and system of two intersections (two signalized, two roundabouts and mixed with one signalized and one roundabout) were analyzed. Number of generated trip was calculated based on rate methods taking into account sustainable parameters such as mixed use, public transport, employment and others. Based on transport access design analysis and number of generated trips five variants of the signalized intersections with left turns from shoulder were selected for further analysis and modeling. Transport simulation model was built for each considered transport access alternative according to the four stages of transport planning model with additional restriction – level of service for each model cannot exceed D/E level. Each transport access simulation model was verified and validated. Minimum volume ellipsoid and minimum covariance determinant estimator were used to detect outliers in simulation output results.

Keywords**—**Level of service, modeling, readiness, verification, validation.

I. INTRODUCTION

SUSTainable transportation network and accesses can improve transport accessibility and enhance sites development possibilities. There are developed many strategies and methods of how to improve transport accessibility (smart transport and vehicles, optimized signal timing, mixed used development, person trips redirection from private cars to other modes such as public transport, bicycles) [1, 2, 3]. But mostly all proposed ways are devoted to ability to reduce travel time, trip distance or offer better connection (cost effective) from point A to B.

In this study accessibility was analysed from another point of view as a measure that allows to monitor changes in generated traffic flows for different developments based on traffic access design to the site and level of service. In [4] was proposed to evaluate the accessibility for commercial site as a function of three parameters: demand, supply and readiness. Demand was estimated as number of incoming generated trips to the site according to ITE rate methods with additional correction to local conditions, mixed used and availability of different transport modes (cars, public transport, and bicycles). Supply initially was observed by survey for base alternative and for others alternatives supply was estimated according to “ideal” origin – destination pair’s pattern for primary trips and pass-by trips. Incoming traffic flow readiness was considered as number of incoming traffic flows from road network to the commercial site based on traffic organization scheme (access design) within site (one or two intersection distance), road capacity, signal timing (only for signalized accesses), pedestrian and bicycling flows at accesses, heavy vehicle and public transport amount distribution at road network.

This study is devoted to third accessibility parameter: incoming traffic flow readiness. The process of estimation of incoming traffic flow readiness for different transport access alternatives are presented. Transport access alternatives for the site were selected based on additional interaction analysis between transport intensity during peak hour and delay per vehicle on isolate intersection and on intersections systems with two intersections, business requirements and available land space for the site. To estimate incoming traffic readiness traffic simulation model was built and Synchro / Simtraffic 6.0 simulation tool was used for this purpose. Commercial site in one Saturday peak hour from 10:00 to 16:00 was selected for analysis based on [5].

II. ESTIMATION PROCESS OF INCOMING TRAFFIC FLOW READINESS TO THE SITE

To estimate the incoming traffic flow readiness, the transport simulation model was built for each considered transport access alternative according to the four stages of transport planning model [6]. But before select considered transport alternatives, separate analysis of isolate intersection and system of two intersections was made to evaluate 1) the interaction between transport intensity and delay per vehicle and 2) how this interaction can influence on transport access alternative design.

Each simulation model results were verified and validated based on GEH Statistic, Minimum volume ellipsoid and Minimum Covariance Determinant estimator. For each

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simulation model stopping criteria was defined based on transport accesses level of service (HCM2010). The whole process of incoming traffic flow readiness estimation is presented in Fig. 1.

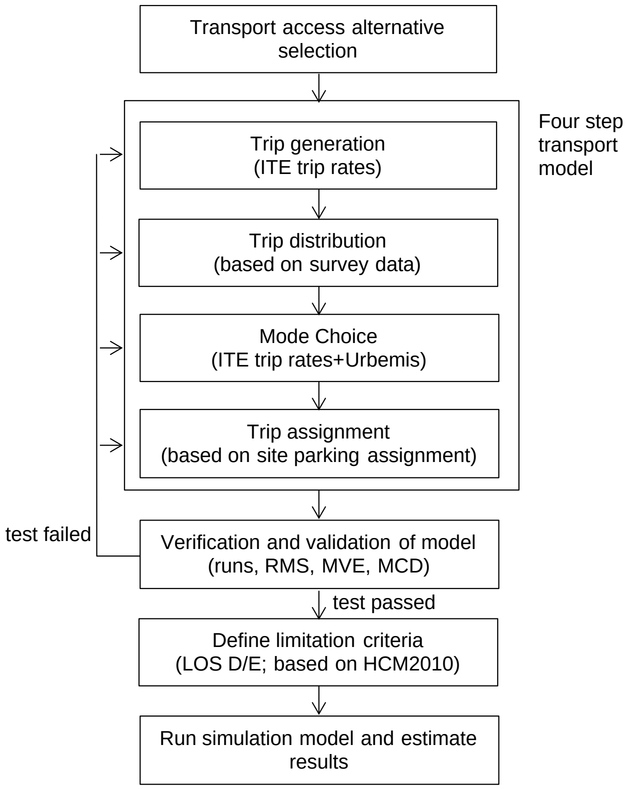


Fig. 1 Whole estimation process of the Incoming traffic flow readiness to the site

A. *Selection of transport access alternatives*

Effective transport access alternative design without obstacles to traffic participants is one of the parameters that determine quality of life, economic growth and road safety. To select transport access alternatives for further traffic flow readiness evaluation to the site, the influence of transport intensity and delay per vehicle on transport access alternative (isolated and intersection systems) were analyzed. Isolated intersection considered if the distance between intersections is more than 300m. If distance is less then intersections can not be analysed separately and should be analysed as intersection system.

The following isolate intersections and intersection systems were analyzed:

1) Isolate intersections: unsignalized intersection, signalized intersection, signalized with left turn from shoulder and roundabout.

2) Intersections systems: intersection systems with two signalized intersection with allowed left turn from the shoulder, two roundabouts and two intersection with one signalized intersection with left turns from shoulder and one roundabout were considered.

To evaluate influence of transport intensity and delay per vehicle on transport access alternative the following steps were done:

1) Geometry and intensity of isolated intersections were selected. For these purposes more than 50 intersections in city centre area were analyzed and data about intersection geometry and intensity were collected. Based on collected data the common intersection geometry with two lane in one direction and with one lane in another was selected (Fig. 2.).

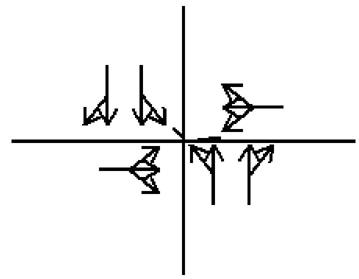


Fig. 2 Common intersection geometry based on collected data

2) Growth factors from 0.65 to 1.20 was used for common collected transport intensity and was applied for each considered transport access alternative.

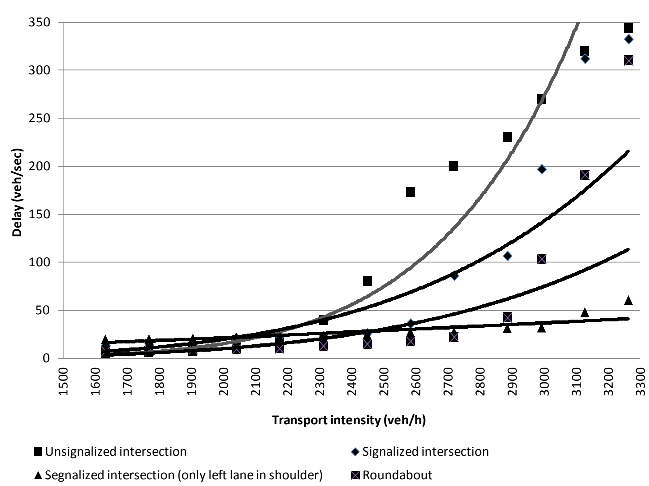
3) Each transport access alternative with growth factor was modelled during the one hour.

4) Number of runs for each isolated intersection and intersections system was estimated based on confidence interval.

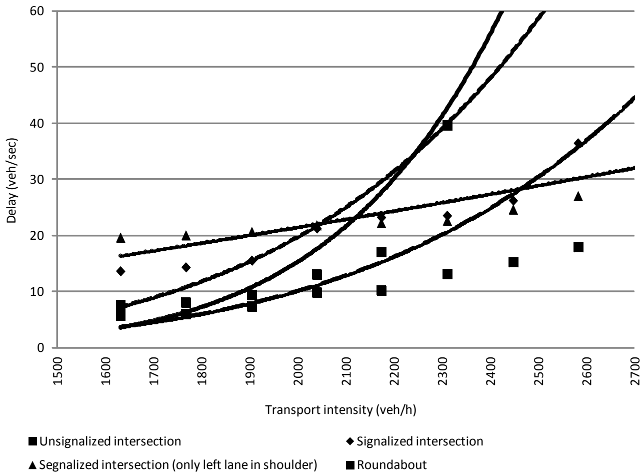
5) Delay per vehicle was determined for each modeled transport access according to HCM 2010.

6) The interaction between transport intensity and delay per vehicle based on modelling results for each of four isolate intersections are presented in (Fig. 3).

Unsignalized isolated intersection showed good results - small delay per vehicle for low transport intensity at isolated intersection. Increasing transport intensity up to 2 150 vehicle per hour, unsignalized intersection should be changed to signalized intersection with left turns from shoulder.



(a) Isolate intersection data



(b) Isolate intersection data in details

Fig. 3 Interaction between transport intensity and transport delay at isolated intersections

If there are not enough space for left turn shoulder and transport intensity at intersection exceed 2 250 vehicle per hour, the signalized intersection can be used.

Signalized intersection with left turn from shoulder is not effective in case of low transport intensity comparing with other intersection alternatives.

Increasing transport intensity up to 2 450 vehicle per hour, signalized intersection with left turn from shoulder is the best solution to minimize transport delay per vehicle and increase level of service.

Roundabout intersection preferable to use within low transport intensity, it's showed small delay. But main roundabout restriction is available space, not always it is place for roundabout organization near the perspective site. Increasing transport intensity up to 2 450 vehicle per hour, roundabout becomes ineffective.

After isolated intersections analysis, three intersection system with two intersections were modeled and analyzed (Fig. 4, Fig.5, Fig. 6). Delay per vehicle was estimated for two cases:

1) two intersections considered as one intersections system (solid lane at Fig. 4 - 6) and

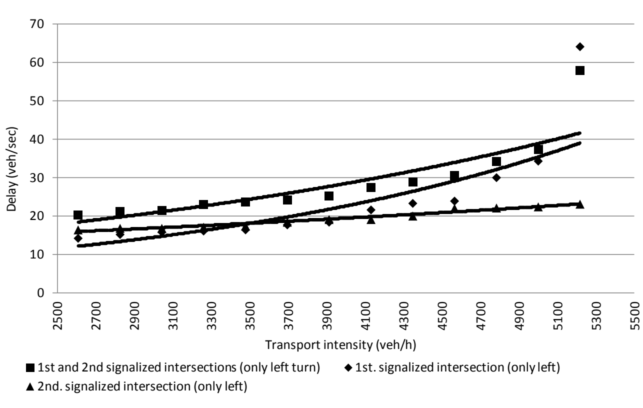


Fig. 4 Delay at intersection system with two signalized intersections (left turn from shoulder)

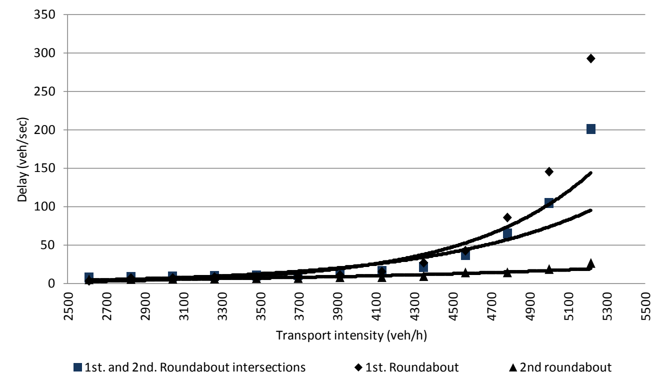


Fig. 5 Delay at intersection system with two roundabout intersections

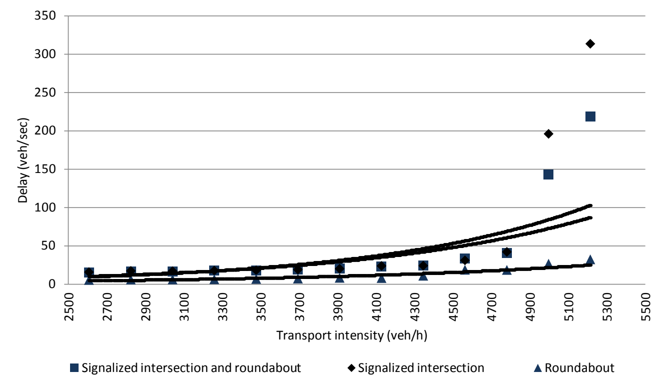


Fig. 6 Delay at intersection system with two intersections (signalized with left shoulder and roundabout)

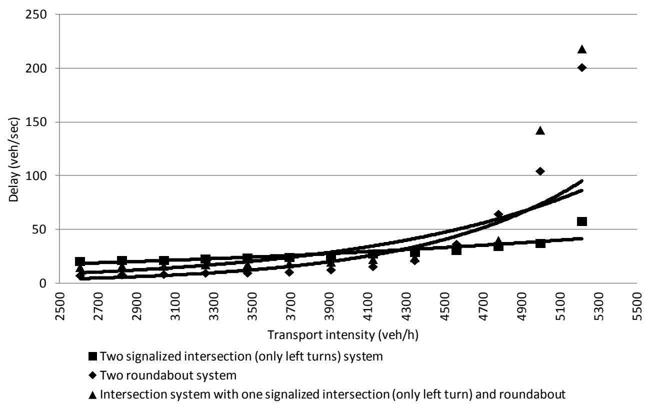
2) delay for each transport access in case of two intersections were considered isolated one from another (dash and square dot lanes at Fig. 4, Fig.5, Fig. 6).

It can be seen that in case of intersections are considered separated one from another and distance between intersections is less than 300m then delay per vehicle for different transport access alternatives is overestimated or underestimated.

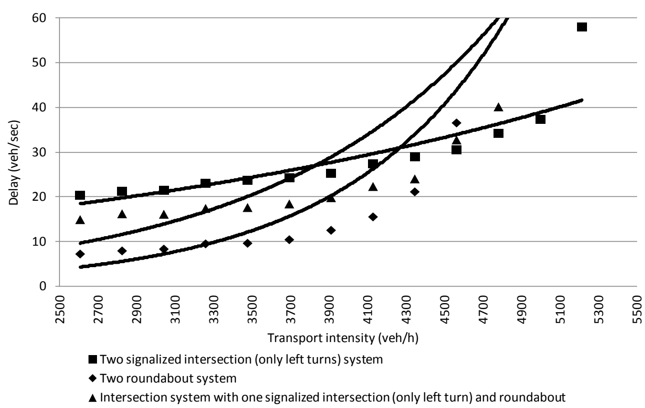
Delay is higher for system with two signalized intersections with shoulder for left turn (Fig. 4; dot lane) than if these two intersections were considered separately. For low intersection intensity (till 3 600 vehicles) the first signalized intersection showed higher delay per vehicle, but after intensity exceeded 3 600 vehicle then the second signalized intersection showed the higher delay and worse level of service.

System intersection delay (Fig. 5; dot lane) for two roundabouts are between delays for the first and second roundabouts. It means that if intersections were considered separately then the first roundabout delay per hour would be overestimated.

System delay at intersections system with one signalized intersection with left shoulder and roundabout showed the similar results with system intersections with two roundabouts (Fig. 6; dot lane).



(a) Data of intersection system with two intersections



(b) Data in details of intersection system with two intersections

Fig. 7 Interaction between transport intensity and transport delay at intersection system with two intersections

Analysis of intersections systems with two intersections showed that the most effective transport access design with low transport intensity is system with two roundabouts.

When intersections system with two roundabouts reaches up to 2 650 vehicle per hour the system becomes ineffective compare with another considered intersection systems.

If number of transport intensity exceeds 2 650 vehicle, then better to use system with two signalized intersection with left turns from shoulder.

Intersection system with one signalized intersection with shoulder for left turn and one roundabout showed low delay for low transport intensity, but in case transport increase to 2 300 and more vehicles, then better to use system with two signalized intersection with left turns from shoulder.

B. Four step transport model

Initially number of generated trips was determined by ITE trip generation rates. ITE rates evaluate number of generated trips by linear regression equations based on historical data. Taking into account that ITE historical data are collected only on USA territory, additional corrections to generated transport trips were made according to URBEMIS. Corrections included mixed land use, index of public transport, number of employment in study area, geometry of analyzed traffic access and pedestrian activity [7].

The linear regression used for commercial site is showed in (1).

$$Y = e^{0.65*LN(X)+3.78} \quad (1)$$

Where x – commercial site leasable area and y -number of total generated trips (incoming and outgoing) for weekend peak hour trips.

The distribution of estimated generated trips was done based on driver survey at the commercial site parking. Drivers were asked about their origin and destination and the name of the street/access that was used to come to commercial site. Based on this data percentage distribution of generated trips by each origin and destination was made.

The number of generated trips by car was taken as ITE generated trips with corrections. And the number of non-car trips was determined as difference between generated trips by ITE and generated trips by ITE with correction to URBEMIS and converted to person trip.

Generated trips was assigned to road network based on commercial site parking assignment. Two parameters were considered: number of parking places and parking capacity at weekend peak hour.

C. Simulation of Traffic access alternatives

Traffic organization schemes were chosen according to calculated number of total generated trips (2.2 section), number of background transport, analysis in 2.1 section, business requirements and available land space:

1) Initially number of generated transport trips to the site was calculated including sustainable development corrections described in 2.2 section. For 100 000m2 of GLA, more than 4 000 transport trips are expected.

2) Generated transport trips were summed to background (existing trips) transport trips. In result it is expected more than 5 000 transport trips per hour.

3) Based on transport access alternative analysis (2.1 section) the most appropriate transport access design for isolate intersection is signalized intersection with left turn from shoulder and for system is two signalized intersections with left turns from shoulder. These designs provide the smallest delay per vehicle for expected transport intensity.

Additional taking into account business requirements the following traffic access designs at access to the commercial site were considered: signalized access with allowed left turns and 4-out lanes (access design 1; Fig. 8), signalized access with allowed left turns and 2-out lanes (access design 2; Fig. 9), signalized access with allowed left turns, 2-out lanes and new additional access (access design 3; Fig. 11), two signalized accesses with allowed left turns and 2-out lanes in T-lane intersection (access design 4; Fig. 10) and two signalized accesses with allowed left turns and 4-out lanes (access design 5; Fig. 12).

Simulation model was built for each of traffic access alternative. Two simulation tools Synchro and Simtraffic 6.0 were used to build simulation model. Synchro mainly was used to enter data to model and to adjust different parameters (saturated flows, speed, signal timing, heavy vehicles, bus blockages and etc.) for each access alternative.

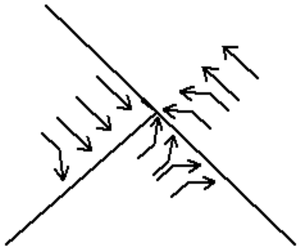


Fig. 8 Signalized access with allowed left turns and 4-out lanes

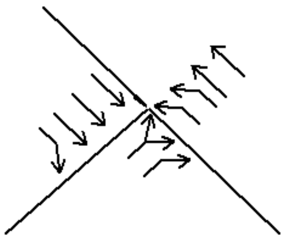


Fig. 9 Signalized access with allowed left turns and 2-out lanes

Simtrafic was used for entering driver behavior data, vehicle characteristics and to simulate data. Simtraffic was selected because it can model complex situation: intersections with bottleneck effect, car-following changes, signaltiming. Each access alternative was modeled according to these data.

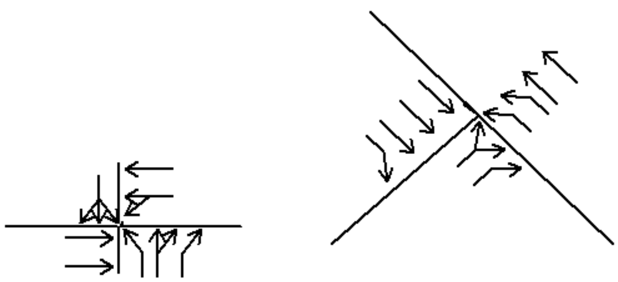


Fig. 10 Two Signalized accesses with allowed left turns and 2-out lanes in T-lane intersection

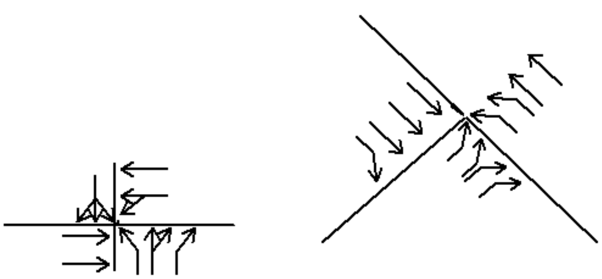


Fig. 11 Two signalized accesses with allowed left turns and 4-out lanes

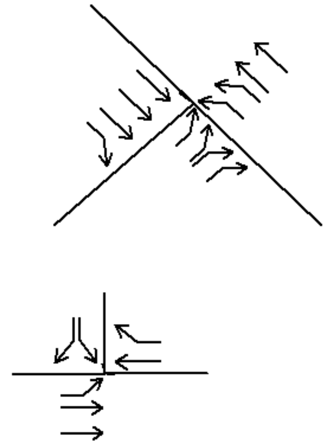


Fig. 12 Signalized access with allowed left turns and 2-out lanes and new additional access

D. *Verification and validation of simulation models*

Verification and validation were done for each considered traffic access alternative. Firstly all input data, accesses geometry, road marking, signal timing were checked and compared to observed data. For the next stage model internal parameters such as growth factor, driver behavior, percentage of public and heavy transport were analyzed for model sustainability. As example models were run n-times by changing percentage of heavy vehicle, changing drivers parameters (yellow and green react time) to view how these changes will influence on models results and would it not be received unexpected results.

Number of necessary runs for each access alternative was calculated according to 95% confidence interval, average values and variance. To measure distance between observed incoming traffic flows and evaluated from simulation models root mean error was calculated for each model. Example for design alternative 2 is showed in Fig. 13.

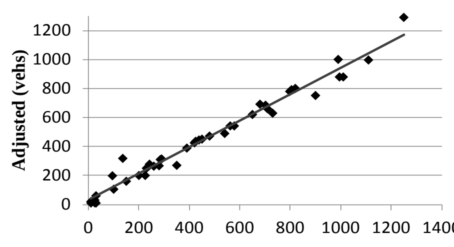


Fig. 13 Results of simulation model verification

Additionally GEH statistic (2) was calculated for access alternatives for each entering and leaving link at intersection. GEH statistics was used to compare observed data for background flows and generated trips data for commercial site with simulated data.

$$GEH = \sqrt{\frac{2(s - o)^2}{s + o}} \qquad (2)$$

Where s – observed data and o – simulated data.

Validation is passed if GEH values are between 0 and 5 (good fit) and test is failed if GEH values is exceed 10. Values within 5 and 10 required additional analysis. The results of GEH statistics are shown in Table 1.

Table 1 GEH statistics for five access alternatives, Saturday peak hour

Access alternatives	GEH < 5	5< GEH < 10	GEH > 10
Design 1 (Fig. 8)	81%	16%	3%
Design 2 (Fig. 9)	77%	17%	6%
Design 4 (Fig. 10)	80%	17%	3%
Design 5 (Fig. 11)	86%	13%	<1%
Design 3 (Fig. 12)	79%	15%	6%

GEH statistics were calculated after the simulation models for access alternatives were verified and the root mean square was calculated. RMS was within 5% - 15% depending on selected access alternatives.

To pass the GEH test it is recommended (by The British Design Manual for Roads and Bridges, DMRB) to have GEH < 5 for at least 85% of links and GEH within 5 - 10 for at least 90% of links. As can be seen from results more than 77% of links expressed in number of vehicles have GEH <5 that is not consistent with DMRB recommendation. In turn of second recommendation the more that 90% of links have GEH within 5 to 10.

One of the reasons why at least 85% of links have not GEH <5 can be in fact that not all vehicles reached their destinations (links) taking into account congestion at intersection, road capacity or signal timing. Another possibility can be related to fact that in GEH statistics were analyzed incoming and outgoing links, but generated flows entered to model do not correspond to number of vehicles that entered or exited the site, because of road network incapability. To avoid such situations it was proposed to use minimum volume ellipsoid (MVE) and minimum covariance determinant estimator (CDE) [10] to detect outliers in simulation results and then recalculate GEH statistics.

a) Minimum volume ellipsoid and minimum covariance determinant estimator

Minimum volume ellipsoid and minimum covariance determinant estimator are used to improve the finding point's algorithm at the crossing of convex sets convergence. The algorithm starts from development of sufficient large ellipsoid in the space and considered all possible values of vector. After the first observations are received, ellipsoid that crossing border of large ellipsoid and developed in accordance with convex polytope can be find.

Minimum volume ellipsoid was introduced by Rousseeuw (1985) and can be used for outlier detection in multidimensional data. The following steps were performed to calculate MVE for access alternatives:

1) Subset H0 was randomly selected from X with the number of points less than (3), where p is the number of predictors.

$$h = \frac{n+p+1}{2} \quad (3)$$

2) Covariance matrix (4) and average values (5) were calculated for subset H0, where n is the number of observations.

$$C_m = \frac{1}{n}\sum_{i}^{N}(x_i - \bar{x}_i)(x_i - \bar{x}_i)^T \quad (4)$$

$$\bar{x}_i = \frac{1}{n+1}\sum_{i}^{N} x_i \quad (5)$$

3) Mahalanobis distance was calculated as distance between given point and mass centre divided by the ellipsoid width in the given point direction. Calculation is based on dispersion (6), if distance from given point to two reference points is equal then given point will be assign to the cluster in which the dispersion of selected set is greater.

$$d_i = \sqrt{(x_i - \bar{x}_i)^T C_m^{-1}(x_i - \bar{x}_i)} \quad (6)$$

4) The smallest h distance was selected for new subset H01. Steps listed above were repeated until initial subset Ho was not smaller or equal to subset H0n. As the result subset with the smallest values was selected to the cluster.

Minimum volume ellipsoid was used for different simulation results of access alternatives and expressed as simulated number of vehicle and average speed (km/h) on road link. The result for two alternative can be seen in Fig. 14 and Fig. 15, where x is the number of vehicle per hour at road link and y is the average speed at road link.

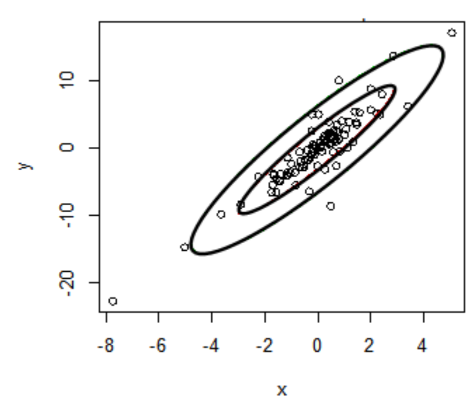


Fig. 14 Minimum volume ellipsoid. Access design 1

Minimum covariance determinant estimator estimates the average and shape of the cluster. Noisy observations are not included in the average and shape of the cluster calculations and can be determined as outliers.

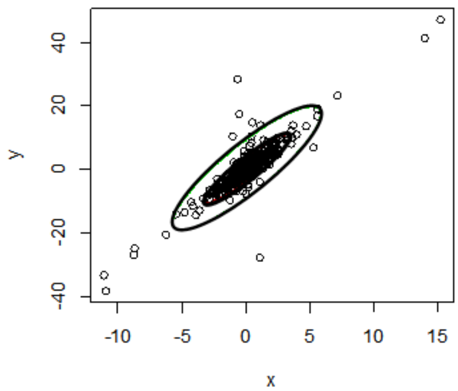


Fig. 15. Minimum volume ellipsoid. Access design 5

The following steps were performed to estimate minimum covariance determinant estimator:

1) The first step was equal to MVE and included the selection of subset H from random X with number of point between (3).

2) Search for observations was done where h is smaller than n and in which observations the covariance matrix has the smallest value of predictor (7).

$$M_{cd} = (\bar{x}_i, C_m) \tag{7}$$

3) Average for h (5) and covariance matrix (4) were calculated.

Minimum covariance determinant estimator like minimum volume ellipsoid was calculated for different access alternatives and results for two alternatives are shown in Fig. 16 and Fig. 17, where x is the number of vehicle per hour at road link and y is the average speed at road link.

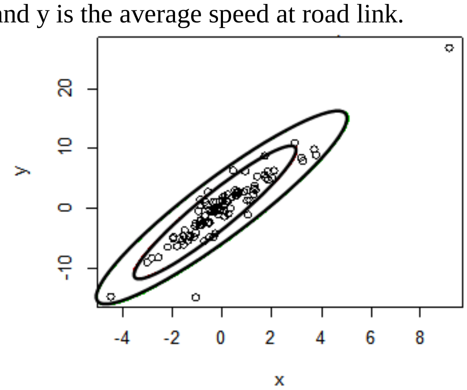


Fig. 16 Minimum covariance determinant estimator. Design 1

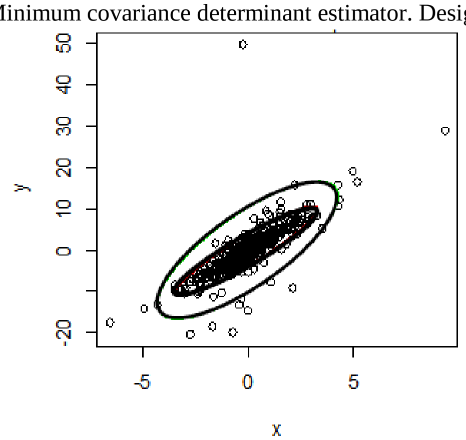


Fig. 17 Minimum covariance determinant estimator. Access design 5

A. Stopping criteria for simulation model

As a stopping criteria of simulation intersection level of service D / E was selected according to Highway capacity manual 2010 [9] for analyzed time period. Level of service is estimated from average control delay calculation per vehicle for each lane group. It means that for variants with signalized access control delay should be in range of 35 – 80 seconds per vehicle and for variant with unsignalized intersection control delay time should be 25 – 50 seconds per vehicle.

B. Stopping criteria for simulation model

As a stopping criteria of simulation intersection level of service D / E was selected according to Highway capacity manual 2010 [9] for analyzed time period. Level of service is estimated from average control delay calculation per vehicle for each lane group. It means that for variants with signalized access control delay should be in range of 35 – 80 seconds per vehicle and for variant with unsignalized intersection control delay time should be 25 – 50 seconds per vehicle.

In this study level of service at intersection was calculated based on average control delay for intersection (8). Intersection level of service is straightforward related to the average control delay per vehicle.

$$D_{\text{int}} = \frac{\sum D_{a\,pp} V_{a\,pp}}{\sum V_{a\,pp}} \tag{8}$$

Where Dint is the delay time per vehicle for intersection (sec/vehicle), Dapp is the delay time (9) for analysed approach (sec/vehicle) and Vapp is adjusted traffic flow for analysed approach (vehicle per hour).

$$D_{app} = \frac{\sum D_{lanegroup} V_{group}}{\sum V_{group}} \tag{9}$$

Where Dlanegroup is the delay time for lane group on analysed approach (sec/vehicle) and Vgroup is the adjusted traffic flow for lane group (vehicle/h).

The level of service and control delay used in this study for access alternatives are shown in Table 2.

Table 2. Average control delay and level of service

Level of service		Delay (sec/vehicle)
		Signalized intersection
A	Minimal delay	<= 10
B		> 10 – 20
C		> 20 – 35
D	Acceptable delay	> 35 – 55
E		> 55 – 80
F	Demand exceeds capacity	> 80

At time when simulation is stopped by stopping criteria, number of incoming traffic flows to the commercial site (readiness) according to selected access alternative was estimated from simulation model results.

III. Conclusion

Incoming traffic flow readiness evaluation process for the commercial site is analysed. Readiness is considered as one of accessibility parameters. Readiness was observed from simulation model output results taking into account the access design to the commercial site, delay and level of service (D / E level) for considered access alternatives.

To select transport access alternative to the site, isolated intersections and system of two intersections were analysed with the aim to understand how transport intensity and delay can influence in transport access design selection. It was determined that for low transport intensity the better alternative can be unsignalized intersection or roundabout. In vase of increasing transport flow the signalized intersection with left turns from shoulder can be the better alternative. Significant role has the distance between intersection. If distance is less than 300m than intersection should be analyzed as system of intersections. Otherwise modeled results can be overestimated or underestimated based on transport access design. In result five signalized transport accesses were selected for further analysis and modelling, the alternatives differed in number of allowed turns, number of accesses and it was analysed the cases when it is only one or two accesses to the site.

The initial verification of model had shown appropriate results, the number of runs for models varied from five to twelve depending on selected access alternative. Different internal parameters: driver's react time to red and yellow time at intersection, saturated flow rates, percentage of heavy traffic on the links were changed and models were simulated again to view the changes in simulation model behavior. The result have shown that changes in parameters does not lead to unexpected situations results. Interesting result was received for driver's react time to red and yellow time at intersection. It was observed that at intersections where more aggressive drivers are detected, delay time is smaller and level of service is better than at intersections with conservative drivers. The reason is that aggressive drivers have higher speed and smaller react time at intersections, but also increase the number of accidents.

The root mean square was within 5% - 15%, the biggest percentage of RMS showed for the alternative with two signalized accesses with allowed left turns and 4-out lanes. The result of GEH statistics for each access alternative showed that 77% - 86% of road links had GEH <5, but it is unacceptable to pass the test because, for example, according to The British Design Manual for Roads and Bridges to pass test it is necessary at least 85% of the road links should have GEH <5 and at least 90% or road links have GEH <10. In our case only one access alternative passed the test - Two Signalized accesses with allowed left turns and 2-out lanes in T-lane intersection.

Minimum volume ellipsoid and minimum covariance determinant estimator were used for additional simulation models output results validation with aim to detect outliers. In result according to one-sample Hotelling test Minimum volume ellipsoid showed acceptable results.

After outlier detection by MVE, GEH statistics was calculated one more time but without data that were considered as outliers. The result of GEH statistics has shown that all access alternatives have passed test and both acceptance criteria's are completed.

To estimate number of incoming traffic flows to commercial site (readiness) average control delay for intersection and delay time for lane group on analysed approach were calculated during the simulation. At the moment when delay time exceeded the 55 second per vehicle the simulation model stopped and a number of incoming traffic flows to commercial site (readiness) was observed.

The biggest number of incoming traffic flows showed two alternatives: 1) Signalized access with allowed left turns and 2-out lanes and new additional access and 2) Signalized access with allowed left turns and 2-out lanes. The results of the first alternative were expected, because this is alternative with two accesses and more traffic flows can enter through the intersection. The good results of the second alternative can be connected to the fact that additional access near proximity from the site can negatively influence on number of incoming trips.

Further steps should be done in simulation model output result validation by considering different cluster methods to improve the accuracy of simulation models.

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