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Technical Note

Study of a Highly Effective and Affordable Highway Interchange - ITL Interchange

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Abstract

In this paper we present a new solution for the highway interchange, which represents the best compromise between the traffic capacity, the land area used and construction cost. The difference between the known and the new design solution is in the implementation of the opposite directional ramps which are widely separated in the area of the interchange. In the middle, between the directional ramps, some space is created for the left directional ramps. Interchange should be used for four-way highway interchanges or other heavy traffic roads junction in order to increase the capacity and traffic safety at the crossing point. It has no conflict points. ITL Interchange left directional ramps is much shorter than all other known solutions for interchanges. The interchange is built in two levels. These two facts significantly lower the cost of construction. The study compares different types of interchanges. We made a geometric comparison and performance measures. In geometric comparison, the greatest advantages of the ITL interchange are the shortest overall roadway length and the shortest overpasses length. Therefore, such an interchange is advantageous in terms of construction and maintenance costs. When measuring performance, ITL Interchange achieves the best results regardless of the number of vehicles.

Keywords: Highway; ITL Interchange; Left Directional Ramp; Traffic Capacity.

1. Introduction

Modern highway interchanges and other heavy traffic roads interchanges have to ensure the highest possible traffic safety and capacity. As with intersections, left-turning traffic movements are the most challenging to accommodate at interchanges. At interchanges between freeways, or other full-access control facilities, a directional interchange offers the highest level of service by directly serving all movements with minimal or no reductions in speed.

1.1. Types of Interchanges

The most common interchange type is the diamond interchange, named for its diamond shape when viewed from above [4]. The diamond interchange is common because of its economical design and construction, but is limited in capacity. A cloverleaf interchange is typically a two-level, four-way interchange where all turns across opposing traffic are handled by non-directional loop ramps. Assuming right-handed traffic, to go left vehicles first cross over or under the target route, then bear right onto a sharply curved ramp that turns roughly 270 degrees, merging onto the target route from the right, and crossing the route just departed. These loop ramps produce the namesake cloverleaf

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shape. Two major advantages of cloverleaves are that they require only one bridge which makes such junctions inexpensive as long as land is plentiful. The cloverleaf involves weaving maneuvers. When the weaving volume in a particular weaving section exceeds 1,000 veh/h, the quality of service on the main facility deteriorates rapidly, thus generating a need to transfer the weaving section from the through lanes to a collector-distributor road [6].

In the increasingly dense population areas, interchanges must network two major highways, rather than a major highway and a lesser surface street. The Stack interchange accommodates lesser conceptual. The stack is a massive complex of two pairs of left-turning ramps stacked at an imposing height in a network configuration above, below or even between the two interchanging highways. A stack interchange can be far more expensive to construct and take up considerably more space than conventional interchanges, but it can be far safer [5].

Turbine interchange design circles all left-turning traffic around a central bridge in a counterclockwise direction, like a whirlpool, allowing a high volume of traffic to travel between two interstates at highway speed. Since it features smaller bridges with smaller supports and lower roadway profiles than a traditional interchange, a turbine interchange has less impact to traffic during construction, and costs less to build and maintain than other types of conventional interchanges.

A new two-level interchange of a unique design called Pinavia is the latest generation of interchanges. Pinavia is functionally like a conventional four-level stacked interchange: transport flows do not intersect, the driving speed in all directions can be equal to the speeds of the intersecting roads, and the design allows arbitrary capacity in any direction. The Pinavia design makes it possible to utilize the center area of the junction making it unique in its class [2].

1.2. New, Effective and Affordable Highway Interchange

An interchange is the most costly type of intersection. The combined cost of the structure, ramps, through roadways, grading and landscaping of large areas, and possible adjustments in existing roadways and utilities generally exceeds the cost of an at-grade intersection [7]. We present a new solution for the highway interchange, which in most comparisons achieves very good and, in many things, the best results. The characteristic of this interchange is that in the area of the interchange the opposite carriageways of a single highway (roads) are separated to the extent that in the middle there is space for left directional ramps. That's where the name comes from: Inside Turning Left Interchange (ITL Interchange).

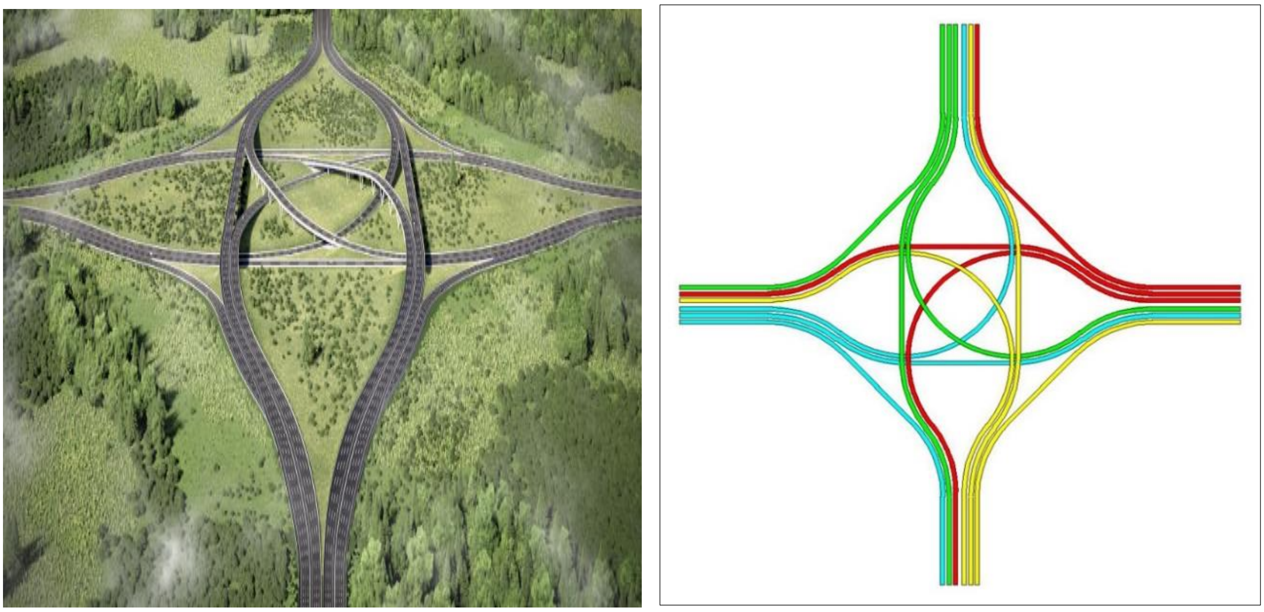


Figure 1. ITL Interchange with driving directions

2. Basic Characteristics of Design ITL Interchange

2.1. Purpose

ITL Interchange should be used for four-way interchanges or other heavy traffic roads junction in order to increase the capacity and traffic safety at the crossing point. ITL Interchange is suitable for interchanges where traffic is approximately evenly distributed in all traffic directions.

ITL Interchange has no conflict points. It is less suitable for roads where most vehicles drive straight ahead and only a few vehicles turn right or left.

ITL Interchange left turning ramps is much shorter than all other known solutions for interchanges. The interchange is built in two levels. These two facts significantly lower the cost of construction.

2.2. Innovation

Innovation is shown in the fact that in the area of the interchange the opposite carriageways of a single highway (roads) are separated to the extent that in the middle there is space left for directional ramps.

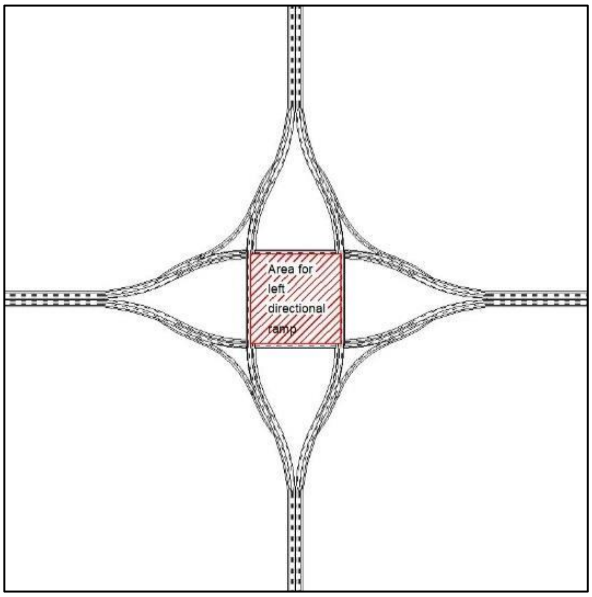


Figure 2. Area for left turning ramps

In the known solutions, the left directional ramp in the first part of the turn is to the right. Then, the longer turn to the left, as the turn angle is at least 140° or more. In the final part, there is again a turn to the right. ITL Interchange has a left directional ramp with only one turn left. The entire horizontal angle of the ramp is 90°. Therefore, the length of the left directional ramp in this case is significantly shorter.

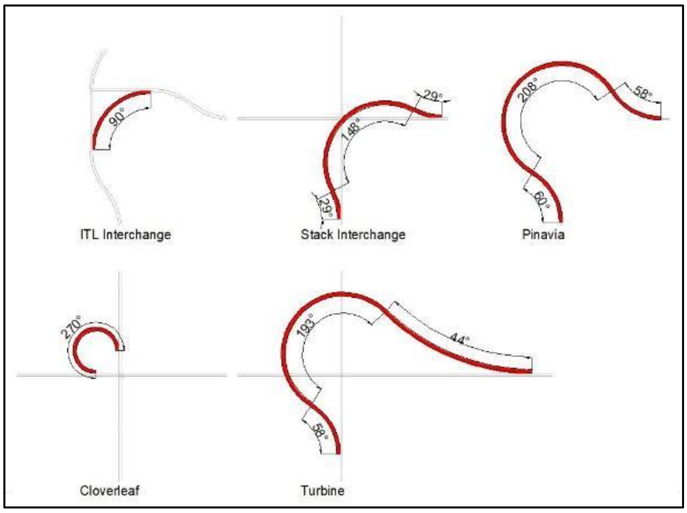


Figure 3. Comparison of the length of the left directional ramps

2.3. Designing the ITL Interchange

2.3.1. Vehicles Sorting Before the Interchange

At a sufficient distance before the interchange on the highway (at least 1500 m), it is necessary to limit the speed and inform the drivers with the vertical and horizontal signalling which lane leads to which traffic direction. This also helps avoid unnecessary weaving within the interchange and prepare drivers for timely sorting.

The ITL Interchange is suitable where traffic is approximately evenly distributed in all directions. The inner lanes lead to left directional ramps. Vehicles that turn to the left do not change the lane. Vehicles driving straight or turning to the right, move to the right-hand lanes before the interchange.

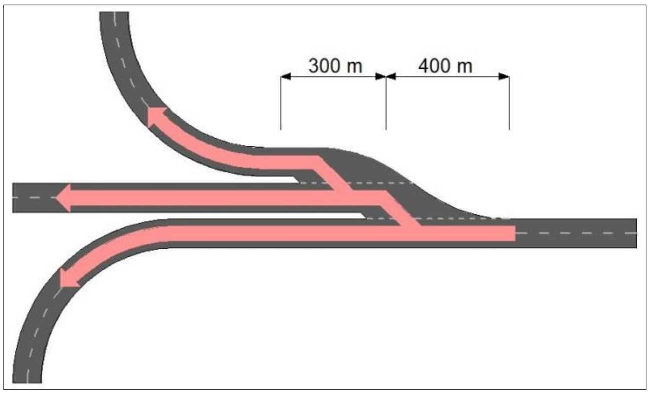


Figure 4. Directional lanes

2.3.2. Level Change of the Slip Road for Turning to the Left

Left directional ramp has to remain on the unchanged level until it crosses both of the left directional ramps at the opposite level. This length is about 2/3 of the entire length of the directional ramp. Therefore, there is a very short distance to pass to come to the opposite altitude level. Sharp vertical convex and concave curves allow significantly lower speeds than allowed by a horizontal turn. In order to mitigate vertical curves, the first part of the left directional ramp at the upper level is additionally raised. On the lower level, the situation is reversed. In the first part, the left directional ramp is additionally deepened.

Thus, at the upper level, the highest point is reached at 1/3 of the total length of the left directional ramp. From this point onward, the ramp can be steadily lowered to reach the opposite level. On the lower level, the situation is reversed. The schemes below show the solutions.

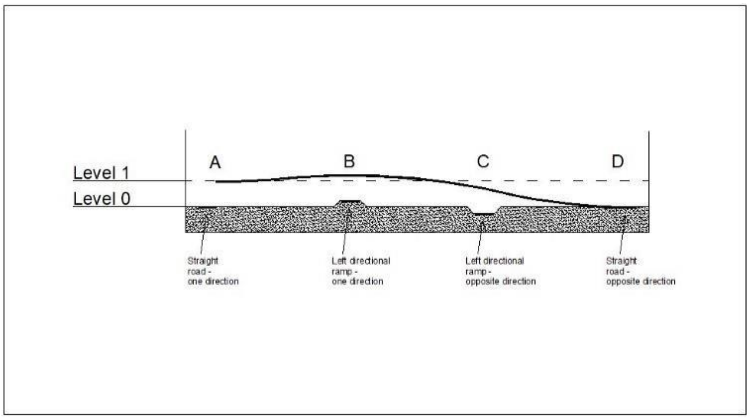


Figure 5. Left directional ramp – Ride downhill

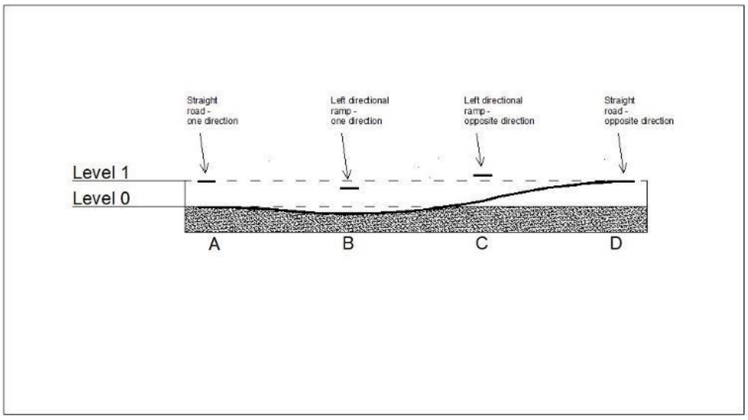


Figure 6. Left directional ramp – Ride uphill

3. Geometry Comparison of Interchanges

Comparison is made for interchanges which allow higher speeds also on the left directional ramps and thus ensure greater traffic capacity. These interchanges also have no conflict points. This group includes: Stack Interchange, Turbine and Pinavia.

There are also other types of interchanges. However, at these interchanges, a crucial speed reduction is required when turning to the left. These interchanges are: Cloverleaf, Contraflow Left, Diverging Windmill ... Due to the low cost of construction, the Cloverleaf is included in the comparison. However, for the same area of the entire interchange as ITL Interchange, the Cloverleaf has a much lower speed limit for turning to the left. The Cloverleaf also has conflicting points, while other interchanges do not.

Comparison is made for interchanges with horizontal radius for the left directional ramp R=250 m. This radius allows driving at a speed of 80 km/h. In case of the Cloverleaf on the same area, horizontal radius is R=100 m for turning to the left.

Parameters:

- Radius of the horizontal circular curve for left directional ramps R=250 m (Cloverleaf R=100 m).
- Maximum transverse inclination 7%.
- Vertical rounding with a convex radius of 2000 m and a concave radius of 1500 m.
- Maximum longitudinal inclination 6%.
- Altitude difference between individual levels 6 m.
- Speed limits 80 km/h.

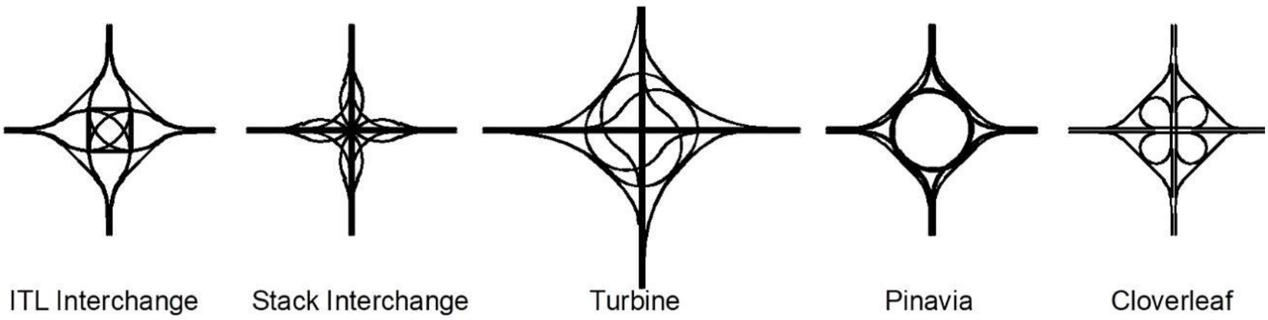


Figure 7. Schemes of interchanges

3.1. Area

The smallest area is needed for the Stack Interchange, 18,5 ha. On the other hand, the largest area is needed for the Turbine. This interchange extends at 58 ha. The area for other interchanges is 33,5 ha.

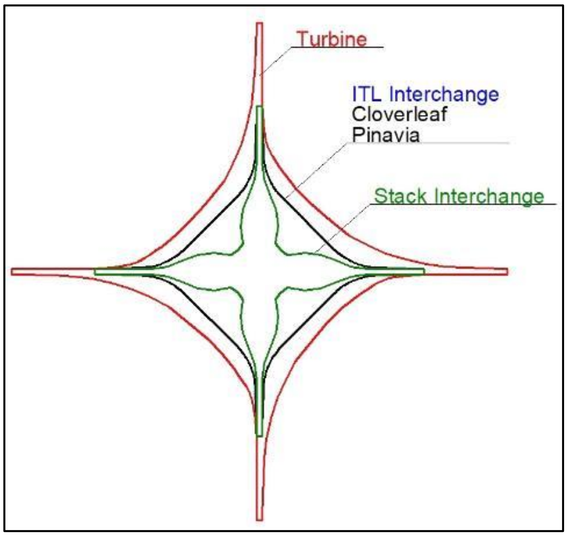


Figure 8. Area comparison

3.2. Lengths of Ramps and Overpasses

Stack Interchange, Turbine and Cloverleaf have a completely straight line when driving through. ITL Interchange has a slightly longer distance due to the separation of carriageways. Pinavia has an even longer distance because lanes run along the circle.

Construction for right directional ramps is similar in all cases. ITL Interchange and Stack Interchange have the shortest length of ramps. The Cloverleaf and Pinavia have an approximately double length, and Turbine, due to its size, has about a triple length according to the most favourable variants. However, construction for left directional ramps totally differs. There are the greatest differences between compared interchanges. Ramps mostly lead over the overpasses. ITL Interchange has an extremely short length of ramps. A little longer distance is in the Cloverleaf, but due to the small radius, there is a lower speed limit. The distance is greater by factor 2 on Stack Interchange and more than by factor 3 on Pinavia and Turbine.

Cloverleaf has the shortest length of overpasses. However, it has lower speed limits for turning to the left and some conflict points. At other compared interchanges, ITL Interchange has the shortest length of overpasses. The distance of overpasses is greater approximately by factor 2.5 on Stack Interchange and Turbine. Pinavia has by far the highest length of overpasses. Compared with ITL Interchange, the factor is more than 5. More technical data for each interchange and comparison with horizontal radius R=250 m. This radius allows driving at a speed of 80 km/h.

Table 1. Technical data and comparison

	ITL Interchange	Stack Interchange	Turbine	Pinavia	Cloverleaf (*A)
Characteristics of interchange					
Arc through (m)	250	0	0	250	0
Arc turn right (m)	250	250	250	250	250
Arc turn left (m)	250	250	250	250	100
Area of interchange (ha) (*B)	**33.5**	**18.5**	**58**	**33.5**	**33.5**
Number of levels	**2**	**4**	**2**	**2**	**2**
Road distance					
Road distance straight (m)	1.360	1.300	1.300	1.420	1.300
Road distance right (m)	330	390	1.070	680	590
Road distance left (m)	395	805	1.295	1.415	460
Road distance total (m)	**8.340**	**9.980**	**14.660**	**14.060**	**9.400**
Overpasses distance					
Overpasses dist. straight (m)	620 /200(*C)	100	100	3.060	100
Overpasses dist. right (m)	0	0	0	0	0
Overpasses dist. left (m)	790	3.220	4.140	4.600	0
Overpasses dist. total (m)	**1.410 / 990 (*C)**	**3.320**	**4.240**	**7.660**	**100**

(A) The cloverleaf in traffic characteristics is not comparable with the other interchanges. The calculation is added as the simplest version of the interchange.

(B) The outer edge of the road is considered.

(C) The road straight on the upper level can also be carried out mostly after the embankments instead of the overpasses. In this case, we have overpasses in the length of 200 m and the embankments in the length of 420 m.

3.3. Summary

The characteristics of interchanges which stand out with their positive or negative characteristics from other intersections.

Advantages:

- Stack Interchange: the smallest area.
- Pinavia: using the area inside the interchange for other purposes.
- ITL Interchange: the shortest length of ramps.

- ITL Interchange: the shortest length of overpasses.
- ITL Interchange: the lowest cost of construction and maintenance.

Disadvantages:

- Turbine: the largest area.
- Pinavia: very large length of ramps and overpasses.
- Stack Interchange: four-level construction.

4. Performance Measures of ITL Interchange and Comparison with other Types

Traffic simulation techniques have been used since early development of traffic theory. Therefore, delay analysis of ITL interchange has been done by microsimulation software, which we usually use for the analysis of complex traffic problems at intersections and interchanges.

Microsimulation software tool is the ideal for setting up a clear and conclusive knowledge basis for decisions for all kinds of traffic engineering questions and can provide the analyst with valuable information on the performance. The microsimulation has been designed for analysing and modelling transport networks of any size, and traffic systems of all types, from individual intersections right up to entire conurbations. PTV Vissim link-connector structure of the network topology allows for highest versatility and – in combination with detailed movement models – extremely precise traffic flow modelling.

Table 2. O/D Matric – origin/destination matric of traffic flows in percentage terms

O/D Matric

$$\rho_1 = \begin{vmatrix} 0.33 & 0.33 & 0.33 & 0 \\ 0.33 & 0.33 & 0 & 0.33 \\ 0.33 & 0 & 0.33 & 0.33 \\ 0 & 0.33 & 0.33 & 0.33 \end{vmatrix}$$

Transportation analysis performance measures (outputs of microscopic model) estimate the performance of different interchange designs; including the ITL. Performance measures in analysis was driven by a goal to determine the capacity of ITL interchange and to estimate the comparison between some of the most common used highway interchanges including some new types like Pinavia.

In this paper we focused on Delay, Average Speed and Distance Travelled. We analysed one traffic distribution test matrices (Table 2): ρ_1 (1/3 of entry traffic crossed the intersection, 1/3 turned left and 1/3 turned right). Performance measures should be sensitive enough to differentiate between analysis scenarios and therefore we used three different load scenarios (2500 veh/h, 3500 veh/h and 4500 veh/h). The fleet composition included in the highway network reflects most common composition on the Highways including passenger cars (90%) and heavy good vehicles (10%). The following assumptions are used:

- Since the ITL interchange presented in this paper only exists on the study stage, no real situation can be observed to calibrate and validate the model according to validation standards (DMRB 12, GEH statistics),
- The vehicle speed at the interchange was modelled according the previous research and recommendations presented in User Manual of Vissim.
- Car Following psycho-physical perception model developed by Wiedemann (1974) was used for all the analysed scenarios,
- The topology of the modelled area used is used with limitation (no additional influence due to acceleration/deceleration),
- The performance of chosen geometry was evaluated according to several measures such as: delay, queue, travel time, distance travelled,
- The Level of service was not calculated, but it can be determined from Average delay.

There is no one-size-fits-all performance measure that can address all the objectives of a design many performance measures focus only one dimension of a problem while ignoring the other. Too many performance measures for a given design may create conflicts and/or confusion during the evaluation process.

4.1. Results

The results of traffic simulation are shown in Table 3. At lower volumes (2500 veh/h) the performance is almost identical for all interchange designs. For middle volume (3500 veh/h) Cloverleaf and Turbine interchange designs are already over congested with Average Delays higher than 140 s/veh. The Average speed drops below 40 km/h in Cloverleaf and 46 km/h in Turbine design. For highest volume traffic scenario (4500 veh/h) only ITL and Pinavia Interchange can throughput the demand with slightly lower delay of ITL; 10.2 s/veh than Pinavia: 13.6 s/veh. Total Delay time of ITL is 25% lower than Pinavia (51 hours vs 68 hours) and the travel distance of ITL is 3.6 % less than Pinavia.

Some measures may not be clearly understandable to the reader of this paper and therefore additional explanation is provided. If we compare Dist. Total (km) in Table 3 for the ITL and Turbine design, there is much less distance travelled for Turbine design, which can lead to misunderstanding that this design has much better performance. In the sum of this measure there are all vehicles that are in the network or have already left it. For Turbine, volume scenario 4500 veh/h, the performance of Average Delay is very high (295.8 s/veh) and therefor many demands are not served and as result much less Total kilometres travelled.

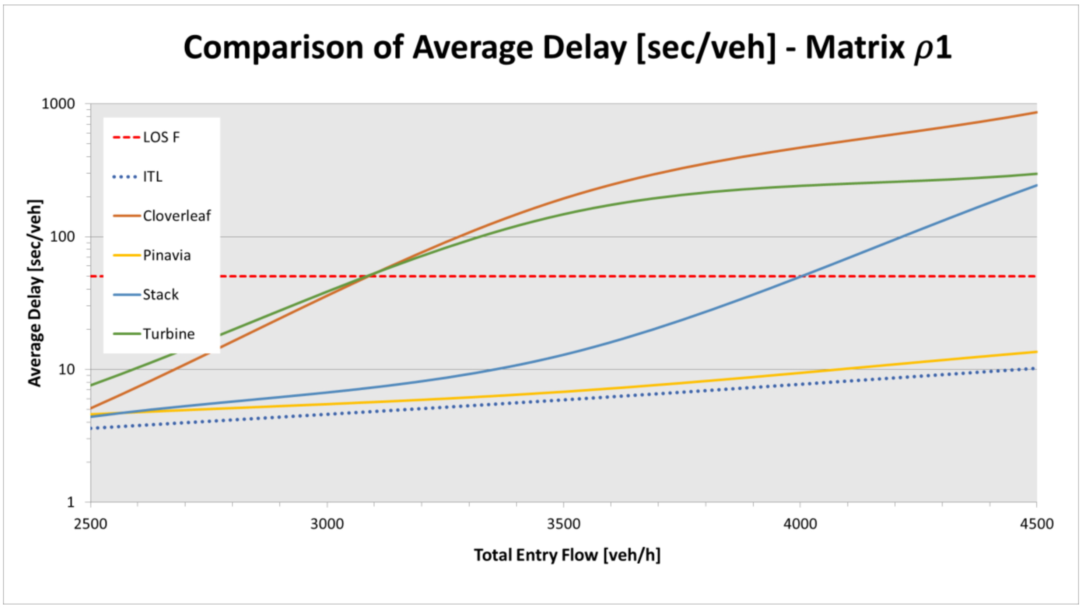


Figure 9. Comparison of Average Delay

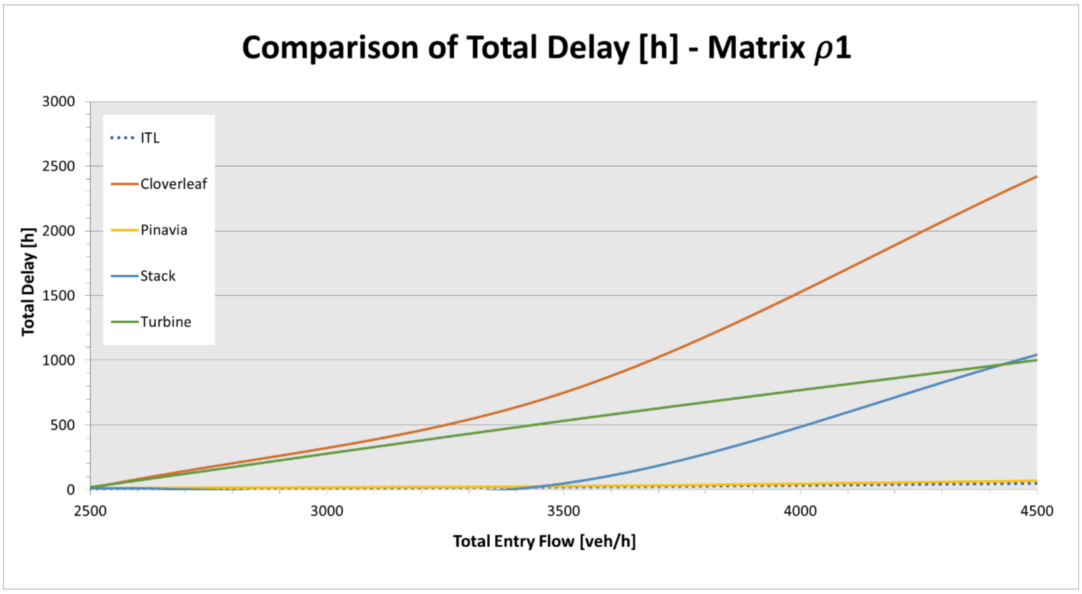


Figure 10. Comparison of Total Delay

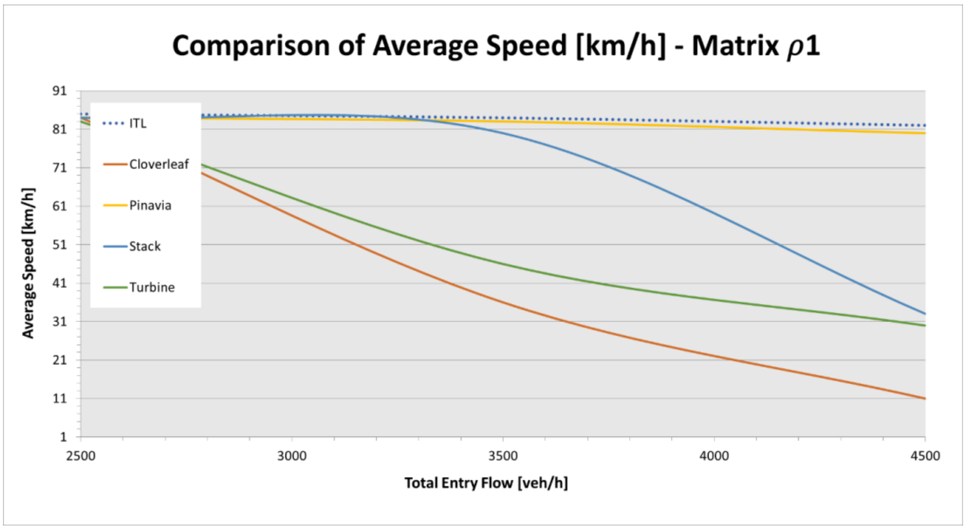


Figure 11. Comparison of Average Speed

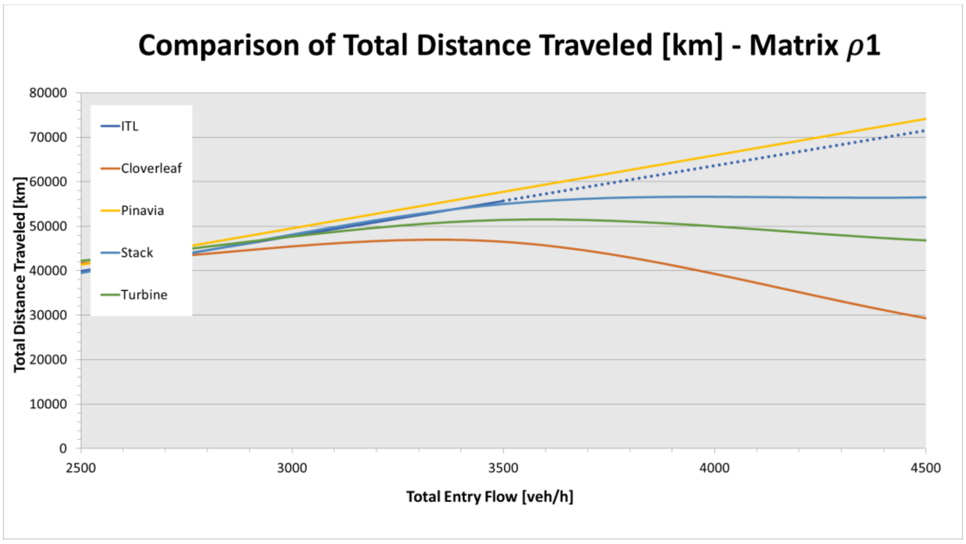
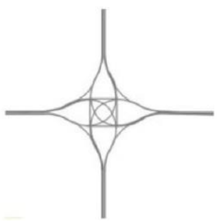
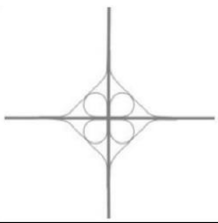


Figure 12. Comparison of Total Distance Travelled

Table 3. ITL Interchange vs. Conventional Interchanges – traffic scenarios and performance results

															
	ITL INTERCHANGE			**CLOVERLEAF**			**PINAVIA**			**STACK**			**TURBINE**		
(Veh/h)	**2500**	**3500**	**4500**	**2500**	**3500**	**4500**	**2500**	**3500**	**4500**	**2500**	**3500**	**4500**	**2500**	**3500**	**4500**
Delay Avg. (s)	3.6	5.9	10.2	5.1	193.3	859	4.6	6.8	13.6	4.4	12.9	243.2	7.6	147	295.8
Speed Avg (km/h)	85	84	82	84	36	11	84	83	80	84	80	33	83	46	30
Dist. Total (km)	39906	55663	71506	41691	46541	29304	41273	57732	74143	39468	54989	56486	42260	51430	46844
Travel Total (km)	471	667	879	496	1289	2760	490	695	927	469	687	1698	510	1129	1545
Delay Total (h)	10	23	51	14	751	2421	13	27	68	12	50	1045	21	534	1003
Delay Total (h)	10	23	51	14	751	2421	13	27	68	12	50	1045	21	534	1003

5. Conclusions

In this paper we analysed new type of ITL Interchange and compared with conventional designs Cloverleaf, Pinavia, Stack, Turbine. ITL Interchange has proven to be a very good or the best choice in all benchmarks.

The geometry comparison concludes:

- The lengths of all ramps at other interchanges are 20-75 % longer than in the ITL Interchange;
- The lengths of all overpasses at other interchanges are from two to five times longer than in the ITL Interchange. In Stack-Interchange, the length of the overpasses is longer by the factor of 2.5, but it has a four-level construction;
- Overpasses incur the highest construction costs. In particular, the ITL Interchange is cheaper to build because it has a significantly lower length of overpasses than other interchanges. Maintenance is much cheaper.

The following conclusions can be made from the Performance analysis:

- For higher traffic volumes (4500 veh/h), the ITL Interchange has better performance and offers much lower delays than conventional types like Clover, Stack and Turbine. Total Delay time of ITL is 25 % lower than Pinavia;
- For lover traffic volumes (2500 veh/h), the ITL Interchange has almost the same Average Delay (3.6 s/veh) than others (from 4.6 s/veh till 7.6 s/veh);
- Average Speed and Total Distance Travelled are much higher for ITL Interchange and it is slightly higher than Pinavia Interchange.

6. Recommendation for Future Research

The safety aspects of the ITL Interchange design need to be studied in detail. A Surrogate safety assessment model (FHWA) is widely used for analysis. The proposed safety model aims at extracting the safety features from VISSIM traffic simulation model by analysing the trajectory of vehicles and estimating their proximity. Another recommendation would be to compare the different load matrix scenario.

7. Conflicts of Interest

The authors declare no conflict of interest.

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