



**VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF ENVIRONMENTAL ENGINEERING
DEPARTMENT OF ROADS**

Deividas Saročka

**SANKRYŽŲ MAGISTRALINIUOSE KELIUOSE TYRIMAS,
ANALIZĖ IR REKOMENDACIJOS JOMS PROJEKTUOTI**

**RESEARCH, ANALYSIS AND RECOMMENDATIONS FOR DESIGN
OF INTERSECTIONS ON MAIN ROADS**

Master thesis

Innovative Road and Bridge Engineering, state code 628H20001

Road and Bridge Engineering specialization

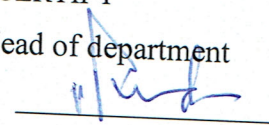
Field of study of Civil Engineering

Vilnius, 2019

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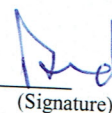
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OBJECTIVES FOR MASTER THESIS

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Approved on 11, November 2018 by Dean's decree No. 193 ap

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THE OBJECTIVES:

To review the structure of Lithuanian road network and Main Road Intersections. To analyse classification of Main Road Intersections on Lithuanian state roads and standard regulations for their design. To formulate the objectives and tasks of research paper. To compare design regulations for intersections of developed countries like USA, Germany, The Netherlands and Lithuania. To analyse design documentation of several, selected intersections and design practices in Lithuania. To analyse traffic volume, road geometric elements taking attention to the road function, design speed and level of services.

To propose the most favourable international experience for implementation in Lithuania. To deliver general conclusions and recommendations for a practical application of new design standards recommendations for Main Road Intersections.

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Antrosios pakopos studijų **Inovatyvios kelių ir tiltų inžinerijos** programos magistro baigiamasis darbas 3 (keliai)

Pavadinimas **Sankryžų magistraliniuose keliuose tyrimas, analizė ir rekomendacijos jų projektavimui**

Autorius **Deividas Saročka**

Vadovas **Virgaudas Puodžiukas**

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Anotacija

Baigiamojo magistro darbo tikslas - apžvelgti Lietuvos kelių tinklo ir magistralinių kelių sankryžų schemas, išanalizuoti eismo intensyvumą, kelio geometrinius elementus, atkreipiant dėmesį į kelio funkcinę paskirtį, projektinį greitį, aptarnavimo lygį. Palyginti lietuviškų magistralinių kelių sankryžų projektavimo taisykles su kitomis gerai išsivysčiusiomis šalimis, tokiomis kaip JAV, Vokietija, Latvija ir Olandija. Baigiamojo darbo pagrindinis tikslas - išnagrinėti Lietuvos magistralinių kelių sankryžų projektavimo reglamentuojančius dokumentus, užsienio šalių patirtį ir rekomendacijas dėl sankryžų projektavimo magistraliniuose keliuose. Tyrimui naudojama HCM 2010 metodika, kurioje naudojami magistralinio kelio sankryžų eismo kokybės rodiklio (LOS) skaičiavimai ir analizuojamas kelių saugumas. Baigiamajame magistro darbe analizuojami rezultatai, pateikiamos išvados ir rekomendacijos vieno bei skirtingų lygių sankryžų projektavimui magistraliniuose keliuose.

Darbo apimtis - 66 p. teksto be priedų, 27 paveikslėliai, 24 lentelės, 25 literatūros šaltiniai.

Atskirai pridedami priedai.

Prasminiai žodžiai: eismo kokybės rodiklis, magistraliniai keliai, skirtingų lygių sankryžos, vieno lygio sankryžos, eismo intensyvumas, funkcinė paskirtis

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Department of Roads

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Master Degree Studies **Innovative Road and Bridge Engineering** study programme Master Graduation Thesis 3 (Roads)

Title **Research, Analysis and Recommendations for Design of Intersections on Main Roads**

Author **Deividas Saročka**

Academic supervisor **Virgaudas Puodžiukas**

Thesis language: English

Annotation

The objective of the final master's thesis is to review the structure on Main Road Intersections of Lithuania road network, to analyze traffic volume, road geometric elements taking attention to the road function, design speed, level of service. To compare Lithuanian design regulations for Main roads intersections design with other well-developed countries like USA, Germany, Latvia, and Netherlands. The main aim of the final thesis is to examine the documents regulating the design of Lithuanian Main road intersections, the experience of foreign countries and to provide recommendations for the design of intersections on Main roads (Motorways and Highways). The HCM 2010 methodology is used for the study, which uses the level of service (LOS) calculations for Main road intersections, and analyzes road safety. At the end of the master thesis is given an analysis of the results, conclusions, and recommendations for the application of one level and grade-separated intersections on the Main roads by their function.

Thesis consist of: 66 p. text without appendixes, 27 pictures, 24 tables, 25 bibliographical entries. Appendixes included.

Keywords: level of service, main roads, grade separated intersections, one level intersections, traffic volume, functional level

(the document of Declaration of Authorship in the Final Degree Paper)

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**DECLARATION OF AUTHORSHIP
IN THE FINAL DEGREE PAPER**

January 2, 2019

I declare that my Final Degree Paper entitled „Research, Analysis and Recommendations for Design of Intersections on Main Roads“ is entirely my own work. The title was confirmed on November 29, 2018 by Faculty Dean's order No. 193ap. I have clearly signalled the presence of quoted or paraphrased material and referenced all sources.

I have acknowledged appropriately any assistance I have received by the following professionals/advisers:
Assoc Prof Dr Virgaudas Puodžiukas.

The academic supervisor of my Final Degree Paper is Assoc Prof Dr Virgaudas Puodžiukas.

No contribution of any other person was obtained, nor did I buy my Final Degree Paper.


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INTRODUCTION

Lithuania is a transit country. Sustainable and safe roads make a serious effect to the country's economy and road users' safety. The largest traffic flows are distributed on Main roads of the Lithuania; therefore, it is very important to have the good quality roads. The Main roads in Lithuania consist of Motorways and Highways, together they make up about 8 percent of the total length of the Lithuanian National roads. To ensure smooth and safe automobile traffic on the highest traffic volume roads, it is important to have sufficiently safe and proper intersections (for high traffic volume) on Main roads. This means driving on these roads must ensure the safety and sustainability at the design speed, which allows you to move from point A to point B as quickly and safely as possible.

Mobility, accessibility and uninterrupted traffic flow must be ensured on Main roads. In my master's thesis I would have studied whether Lithuanian Main road intersections meet their functional level, checked the suitability of the intersections at the current situation and are presented recommendations on how to improve the quality of the design of the Main road's intersections.

The aim of the thesis is to: determine whether selected Main road intersections performs their functional level - the level of mobility and make recommendations for their further development.

Thesis tasks:

1. Study normative documents in the Republic of Lithuania;
2. To study foreign normative documents and scientific articles which describes the design of the intersections on Main roads;
3. To prepare recommendations of intersections types on Main roads
4. Carry out analysis of research results
5. To compare the experience of foreign countries with the legal acts of the Republic of Lithuania and the results of the data analysis of the research.
6. Provide recommendations for the design of intersections on Main roads.

1. LITERATURE ANALYSIS

In my master thesis is studied a lot of various laws, documents, and scientific articles that is described not only in Lithuania but also in a well-developed country like US, Germany, Netherlands, Latvia and etc. The main purpose of the literature analysis is to understand the differences between Lithuanian and other countries road design principles.

1.1. LITHUANIAN LITERATURE ANALYSIS

1.1.1. The Law of Traffic Safety on Automobile Roads of the Republic of Lithuania.¹

The Law of Traffic Safety on Automobile Roads of the Republic of Lithuania establishes requirements for roads, their design, construction and maintenance, traffic control measures and the related responsibilities of road owners. The provisions of this Law are combined with the legal acts of the European Union. In this Law are described the main concepts of roads distribution in Lithuania. Automobile – a motor vehicle intended for use on the road, its purpose is to transport cargo/passengers or other motor vehicles. Highway on the Main road – is a road designed and built specifically for the traffic of motor vehicles which is not intended to enter or leave the near territories and which basically have two separate running lanes of opposite directions separated from each other by means of a separating band for driving vehicles. Motorway – is a road which runs only through the grade separated, roundabouts or regulated junctions. Both Highways and Motorways are the Main Roads of Lithuania.

In other words, this Law describing the main principles of the Lithuanian roads and about their groups and categories. And in this document written that Main roads (Highways and Motorways) of Lithuania run only through the grade separated junctions.

1.1.2. Road Technical Regulations “Automobile Roads”²

This is the main document of roads design in Lithuania, which describes the construction, reconstruction, and repair design requirements. The grade separated intersections in this document described as an engineering structure for organizing uninterrupted traffic in various directions. In this document is written about roads classification according their categories, function and traffic volume.

¹ Lietuvos Respublikos saugaus eismo automobilių keliais įstatymas [1].

² Kelių techninis reglamentas KTR 1.01.2008 „Automobilių keliai“ [2].

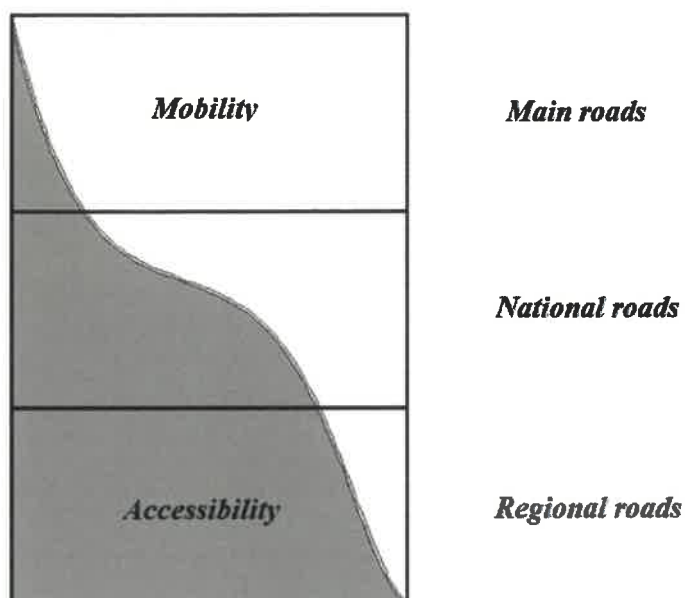
According this document, roads by function are divided into National Significance and Local roads. National Significance roads are divided into Main, National and Regional roads. Main roads are designed for convenient traffic between the main cities of the country. Also, Main roads are allocated for transit traffic. National roads are connecting Main roads and centers of administrative units of the Republic of Lithuania. Regional roads connecting larger rural areas, Main and Regional roads and allow to reach smallest rural and economical areas. According road parameters and Average Annual Daily Traffic, roads are dividing into I-V and AM categories. All roads classification according this document are shown in 1 table.

Table 1. Roads classification according road categories and function (KTR 1.01.2008) [2]

Road function classification		Road category	Average annual daily traffic volume automobiles/day	Design speed, km/h	Number of lanes (S – distinctive bar)	Types of cross-section	Types of intersections
1	2	3	4	5	6	7	8
Road Network of National Significance	Main roads (Motorways and Highways)	AM	> 45000	130/110	3+S+3	1	Grade separation
		AM	12000–55000	130/110	2+S+2	2	
		I	12000–55000	110/100	2+S+2	3	Grade separation, one level
		II	to 15000 (20000)	90	2	5	
		IIa	to 18000 (23000)	100	2+1	6	
		III	to 15000 (20000)	90	2	7	
	National roads (Highways)	Ia	12000–30000	90	2+S+2	4	One level and grade separation
		IIa	to 18000 (23000)	90	2+1	6	
		III	to 15000 (20000)	90	2	7	
		(IV)	to 10000 (12000)	90	2	8	
	Regional roads (Highways)	IV	to 10000 (12000)	90	2	8	One level
		V	to 3000, to 1000 ¹⁾	70	2	9, 10	
		Va	to 1500	70/50	1	11	
Local roads		I _v	1000–2000	50/40	2	12, 13	One level
		II _v	500–1000	40/30	1	14, 15	One level
		III _v	to 500	30/20	1	16	One level

It is important to mention that, to determine road category, design alignment elements and the cross-sections of the road, we must take into account the service life of the road for 20 years. In some cases, when we have justification from the economic and technical point of view, service life periods can be set for 10, 15 or 30 years.

The purpose of Road functional classification is to ensure the proper balance between mobility and accessibility (Picture 1). Main roads – emphasis on travel mobility, National roads- balance between mobility and accessibility and Regional roads – emphasis on accessibility.



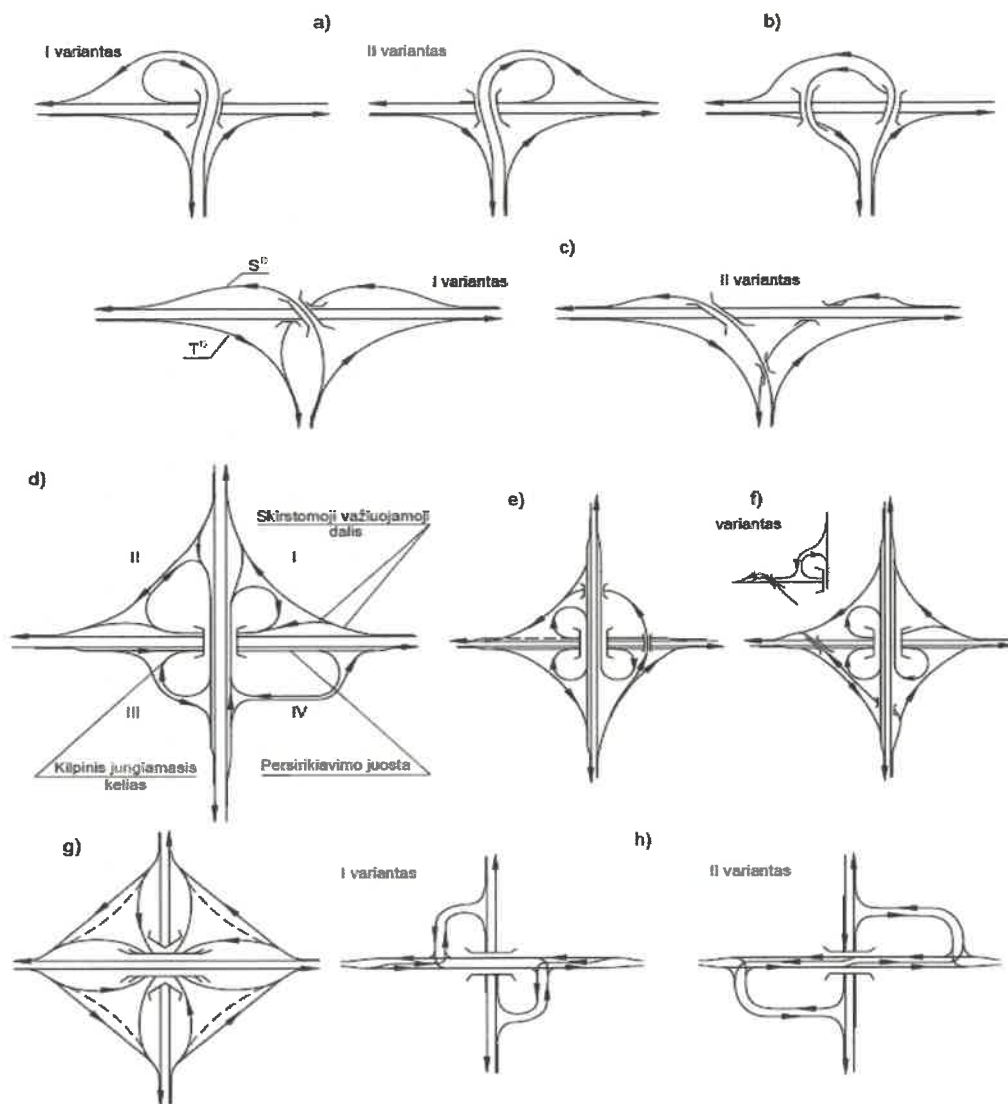
Picture 1 Road functional classification

In this document road classification are described clearly and understandable. It is clear which road categories have Main roads. But it is written that, on Main roads we can use not only grade separated intersections but also and one level intersections. This is an uncertainty in the document, that in National Main roads we can design and use one level intersections. Road users may not understand to what kind of road they are driving and what the functional level of the road is.

1.1.3. Construction Recommendations R36-01. Intersections of the Automobile Roads³

The Construction Recommendations R36-01 written for grade separated and one level intersections. First part of recommendations talking about one level intersections and second part of recommendations talking about grade separated intersections design. In this document written, that all types of one level intersections can be design on II-V categories roads. Either there written that we can use one level intersection on I category roads. Grade separated intersections are using in AM and I category roads in all cases. In II and III category roads grade separated intersections are using exceptionally. Intersections of traffic flows at one level are not allowed on AM and I categories of roads. When preparing grade separated intersection, we must take into account design traffic flow and future intersection development. In this document are shown main types of grade separated interchanges (1 picture).

³ Statybos rekomendacijos R36-01. Automobilių kelių sankryžos. [3]



Picture 2. The main types of grade separated interchanges. (R36-01) [3]

Cheapest type of interchange when one of the roads are Main road are scheme a, and the cheapest and most effective intersection when we have both Main roads are scheme d (cloverleaf intersection). Safe driving on connecting roads in interchanges require enough visibility, geometrical parameters and relevant design speed in accordance with this document. At grade separated interchanges we must use safest and the most economical types of intersections. Either we need take into account environmental impact.

In other word, this document also takes a biggest attention to calculated future Average Annual Daily Traffic (AADT), their composition and future development of intersection. In most stages of the design we are using AADT. As well as it is important to mention, that in this document are some confusion, when we need to design one level and when we need to design grade separated intersections in I category roads. There is not clear thought about I category roads intersections types and it is hard to understand when we must use grade separated intersections on that category.

1.2. FOREIGN LITERATURE ANALYSIS

Foreign literature analysis deals with normative documents, various scientific articles and publications. Evaluated intersections of grade separated level, their types are distinguished in foreign literature. The theory of road classification according to their functional level is also analyzed in foreign countries regulations and articles.

1.2.1. Highway Capacity Manual (HCM 2010)⁴

"Highway capacity manual" (HCM 2010) is the main US document expressing research findings on capacity and quality of service. Presenting methods for analyzing the operations of Main roads facilities. This document describes the level of service (LOS) index, which is related to the functional level of the road. Either in this document are described Freeway (Motorway in Lithuania) capacity calculation methods for the Main road performance monitoring.

This manual presents methods for road capacity and level of service analysis for a broad range of transportation facilities. Road capacity analysis tries to give a clear understanding of how much traffic a given transportation facility can accommodate. Level of service attempts to answer how good the present traffic situation on a given facility is. Thus, it gives a qualitative measure of traffic, whereas road capacity analysis gives a quantitative measure of a facility. Road capacity and level of service varies with the type of facility, prevailing traffic and road conditions etc.

Most important classification of transportation facilities from the engineering perspective is based on the continuity of flow, which is uninterrupted flow and interrupted flow. Uninterrupted flow is the flow of traffic in which there is no obstructions to the movement of vehicles along road. HCM defines the levels of service of Freeway (US) sections based on density, as described in table 2.

Table 2 LOS for a basic freeway (US) segment (HCM 2010) [4]

LOS	K (veh/km/lane)	FFS (km/h)	v/c
A	0-7	120	0.35
B	7-11	120	0.55
C	11-16	114	0.77
D	16-22	99	0.92
E	22-28	85	1.0
F	>28	<85	>1.0

⁴ HCM 2010 : Highway Capacity Manual. Washington, D.C. :Transportation Research Board, 2010. [4]

In the table 2 are given some terms like: LOS (Level of Service) – is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience. K (vehicles density) is a rate of traffic over distance. Either Highway Capacity Manual (HCM) using travel speed and volume by capacity ratio (v/c ratio) to distinguish between various levels of service. The value of v/c ratio can vary between 0 and 1. Depending upon the travel speed and v/c ratio, HCM has defined six levels of service, level A to level F based on a graph between operating speed and v/c ratio. [4]

Main road capacity and level of service are two important terms applied to traffic operation and are given suitable definitions by Highway Capacity Manual. Road capacity represents the ability of the system to handle traffic whereas level of service looks at the system from the driver's perspective. The fundamental diagrams of traffic flow can be used in the illustration of level of service. Level of service ranges from level A to F, representing the free flow conditions and F representing the worst traffic conditions like less speed, high density etc. Those measures help designers to choose best types of grade separated junctions and design them not only by existing traffic flow (daily annual traffic flow), but also takes into account other measures like traffic interruptions, comfort, freedom to maneuver, convenience and etc.

1.2.2. Guidelines for the Design of Motorways (RAA; R1)⁵

The Germany Guidelines for the Design of Motorways (Richtlinien für die Anlage von Autobahnen, RAA R1)) are concerned with Main roads design. As definite by the RAA R1, a Main road is a dual-carriageway, multi-lane, completely grade separated road with no entree to adjacent land. The term 'Main road' also shelters Main road like roads and municipal Motorways. These regulations apply to such roads irrespective of signing in accordance with the German Road Traffic Regulations (Straßenverkehrs-Ordnung, StVO) and road's dedication in accordance with road law. [5]

⁵ Richtlinien für die Anlage von Autobahnen [5]

Table 3 Road categories (RAA R1) [5]

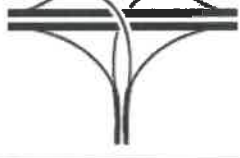
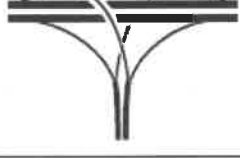
Category group		Motorways	Rural roads	Trunk roads in non built-up areas	Trunk roads in built-up areas	Local roads
Link function level		AS	LS	VS	HS	ES
continental	0	AS 0		–	–	–
sub-continental	I	AS I	LS I		–	–
inter-regional	II	AS II	LS II	VS II		–
regional	III	–	LS III	VS III	HS III	
sub-regional	IV	–	LS IV	–	HS IV	ES IV
local	V	–	LS V	–	–	ES V

Legende:

AS I	Designation of the category as it occurs
	problematic
–	does not occur or is not justifiable

RAA R1 document purpose is to establish uniform standards for Main roads of the same type. Either, that document design principles are based on the function of the network, which is indicated by road category (Table 3). To ensure the consistency of Motorways with equal network functions and traffic significance, Motorways are separated up into Motorway design classes (EKAs). Motorways that belong to the categories AS 0 and AS I both inside and outside built-up areas (long-distance motorways) and motorways that belong to category AS II outside built-up areas (inter-regional motorways) are designed in accordance with EKA 1. In order to ensure that the significance of the link (link function level) is adequately taken into consideration, EKA 1 is divided up into EKA 1 A (AS 0 and I) and EKA 1 B (AS II). In these guidelines written, that in some cases roads and grade separation structure solutions are not easily understood by drivers who are not familiar with the area and it is not always possible to explain them clearly on road maps about existing situation. So, it is very important to ensure that all road structures comply with the functional requirements of the road.

In other words, one of the main ideas of the RAA is to form a basis for the design of trustworthy Main roads that meet functional requirements. These guidelines also present about road network spatial planning, that one of the objectives is: functional level, quality of supply, relief function, link function and connectivity. It says, that road functional level makes a noticeable influence appropriate definition of the road categories and link function level. It is important to mention, that according Main roads functional level those roads must be completely grade separated

Design class of the through motorway		EKA 1	EKA 1	EKA 1	EKA 2	EKA 2	EKA 3
Design class of the connected motorway ('third arm')		EKA 1	EKA 2	EKA 3	EKA 2	EKA 3	EKA 3
'Left-facing' trumpet (Fig. 38)		+	+	+	+	+	+
'Right-facing' trumpet (mirror image of Fig. 38)		-	-	•	•	•	•
'Pear' (Fig. 39)		•	•	•	•	+	+
T-interchange with one structure (Fig. 40)		+	+	+	+	+	+
T-interchange with three structures (Fig. 41)		+	+	+	+	+	+
Y-interchange, without uniform definition of mainline carriageways (Fig. 42)		-	-	-	-	-	+

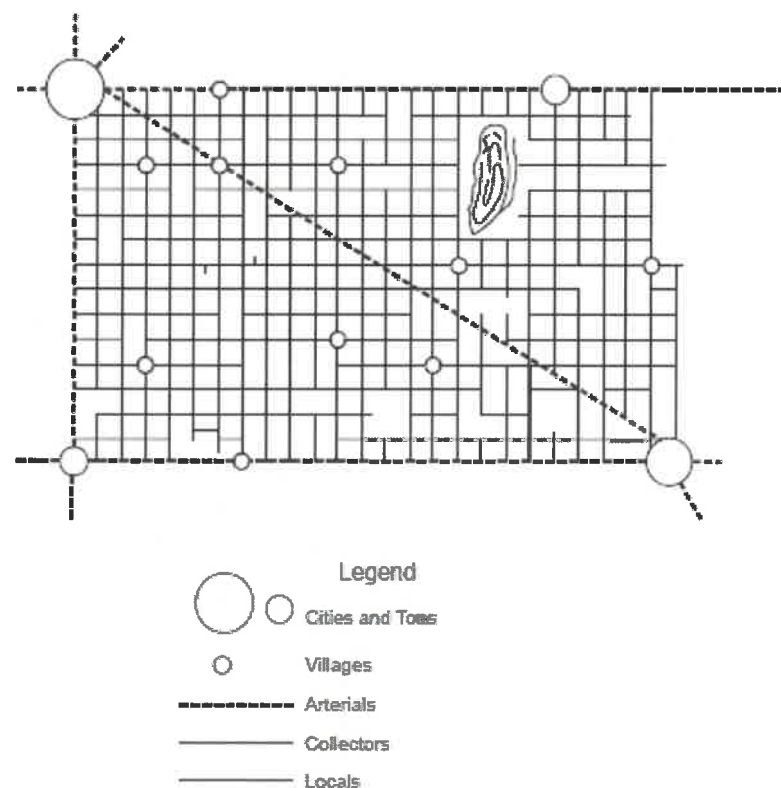
Legend: + suitable • of limited suitability - unsuitable

Picture 3 Example of the three-way interchange's application according to Motorway design class (RAA R1) [5]

1.2.3. A Policy on Geometric Design of Highways and Streets (2011 6th Edition)⁶

The State highway departments, working through the American Association of State Highway and Transportation Officials (AASHTO) develop design standard - A Policy on Geometric Design of Highways and Streets (The Green Book 2011), which provides guidance based on established practices that are supplemented by recent research. This document is also intended as a comprehensive reference manual to assist in administrative, planning, and educational efforts pertaining to design formulation. The intent of this policy is to provide guidance to the designer by referencing a recommended range of values for critical dimensions.

This standard also takes a high attention to road functional level. There written, that functional classification of the roads must be applied to Main roads according to the character of service they are intended to provide. This classification recognizes that local roads do not serve travel independently. Rather, most travel involves movement through road networks and can be classified by its relationship to such networks in logical and consistent categories. Functional classification of American roads is shown schematically in the Picture 3. [6]



Picture 4 Schematic illustration of a functionally classified Main road Network (A Policy on Geometric Design of Highways and Streets 2011) [6]

⁶ American Association of State Highway and Transportation Officials. 2011. A Policy Geometric Design of Highways and Streets. Washington, DC. [6]

The functional criteria for road systems have been expressed herein primarily in qualitative rather than quantitative terms. Main roads systems developed by using these criteria are generally expected, in all states of America except Alaska and Hawaii, to fall within the percentage ranges shown in Table 4.

Table 4 Guidelines on Extent of Rural Functional Systems (A Policy on Geometric Design of Highways and Streets 2011) [6]

Systems	Percentage of Total Rural Road Length
Principal arterial system	2–4%
Principal arterial plus minor arterial system	6–12%
Collector road	20–25%
Local road system	65–75%

Furthermore, The Green Book also takes a high attention to intersections design. While inspecting existing Main road intersections it is very important to know existing traffic flow at intersection on peak periods of the day. Important design considerations for at-grade intersections divided into two major categories - the geometric design of the intersection (including a road capacity analysis) and the location and functional level of the road consideration.

Thus, this Policy on Geometric Design of Highways gives clearly understanding, that the main principle of roads design is road functional level. It is important to understand when we must use one functional system, and when another. So, to ensure homogenous and uninterrupted traffic flow on Main roads we need take into account road functional level.

1.2.4. Sustainable Safe Road Design (A practical manual)⁷

This manual has been created during the project “Safe Road Design”, funded by the World Bank and in cooperation with the Dutch Ministry of Transport, Public Works and Water Management as part of their ‘Partners for Roads’ program. The consultancy services are provided by: DHV Environment and Transportation, The Netherlands. This manual is not guideline on road design for one specific country. This document is based not only on Dutch standards, but also by Estonia, Lithuania, Bulgaria, Latvia, Poland, Romania and Turkey given standards example. Sustainable Safe

⁷ World Bank, The Dutch Ministry of Transport, Public Works and Water Management. 2005. Sustainable safe road design. A practical manual. Amersfoort. [7]

Road Design manual its international manual with best practices from many European countries, so for further Main roads and their intersections analysis this document is very useful.

Sustainable Safe Road Design manual takes a high attention to road system functionality. There are written, that roads, within road network, have different functions. Long-distance traffic does not belong on roads with an access function, and local traffic does not belong on roads with a through function. Through function should not offer direct access to homes, schools, offices, factories, sports facilities, etc. For example, sustainable safe road network has three traffic functions:

- a) Flow function- uninterrupted traffic; meets through, national, main roads.
- b) Distributor function- for the collection and distribution of traffic; meets distributor, regional roads.
- c) Access function- provide entrance; meets access, local roads

In this manual are written, that road users must know what traffic behavior is expected related to road category, and what to expect from other road users. Emphasizing the recognizability of each category increases predictability. The mechanism that ensures the right level of predictability consists of two steps: road users must be able to recognize road category by a small number of design elements; road users should know which possible traffic situations are associated with the present road category. Main roads in this manual are divided in two types: type I Motorways and type II Highways (table 5). [7] There written, that Main roads must have physical separation, complete marking and split-level interchanges.

Table 5 Examples of Main roads outside built-up area (made by author)

Type I: Motorway	Type II: Highway
	
A1 road in Lithuania (Image created by lakd ⁸)	A14 road in Lithuania (Image created by lakd)

⁸ LAKD – Lietuvos automobilių kelių direkcija (Lithuanian Road Administration)

On a detailed road design level, the sections of roads have a different function. (Table 6). Intersections are for traffic exchange (allowing changes in direction) whilst road sections facilitate traffic flow.

Table 6 Purpose of road links and intersections on different road categories (Safe Road Design Manual 2005) [7]

Road type	Road elements	
	Road link	Intersection
Main road	Flow	Flow
Distributor road	Flow	Exchange
Access road	Exchange	Exchange

In other words, in this manual written, that Main roads with a flow function (Motorways and Highways) do not have intersections at one level, but have fully grade separated intersections with free-flowing links. Every road must be categorized, which means that every road must be given a certain function. Thereafter, the proper design should be defined on basis of the road category and road functional level. Determining a function to a road, it is important to build up a logical road network based on the three categories of roads: flow function, distribution function and access function.

1.3. CONCLUSIONS OF THE LITERATURE ANALYSIS

Having analyzed literature of the Main road intersections and the main principles of roads classifications, the following remarks is made:

1. According to the experience of foreign countries, roads must have their own functional levels: flow function, distributor function, access function.
2. In most foreign countries design literature is written that Main road intersections according to safety and functional level must be grade separated, but in Lithuania normative documents Main road intersections can be not only grade separated, but also it is possible to use one-level intersection type.
3. The Lithuanian roads network categorization is the close to the American roads network categorization, therefore for further analysis is applying HCM 2010 methodologies to establish road capacity and level of service indicators.

2. THEORETICAL JUSTIFICATION

This master's thesis presents the theoretical justification of the chosen research methodology. The basis of the research methodology is the United States scientists Highway Capacity Manual (HCM 2010), which analyzes Main roads capacity and level of service (LOS). The theoretical justification presents the main aspects, essence and application of the methodology.

2.1. THE ESSENCE OF THE METHODOLOGY

The Road Capacity and Level of Service analysis used by the US researchers at Highway Capacity Manual 2010 is used in the final master's thesis. The following research studies allow us to assess the potential of a road or its elements to serve existing traffic flows in existing or design conditions, as well as to assess the quality of traffic. Level of service (LOS) is a term closely related to capacity. When capacity gives a quantitative measure of traffic, level of service (LOS) give a qualitative measure. A designed traffic flow is the maximum number of vehicles, passengers, which can be accommodated by a given facility or system under given conditions at a given level of service.

For a given road or facility, road capacity could be constant. But actual flow will be different for different days and different times in a day itself. The intention of LOS is to relate the traffic service quality to a given flow rate of traffic. It is a term that designates a range of operating conditions on a particular type of facility.

The main thesis of the methodology is the analysis of road capacity and level of service applied to separate road elements, for example: straight sections of the Main roads, grade separated intersections, bypasses and etc. Most important classification of transportation facilities from the engineering perspective is based on the continuity of flow that is uninterrupted flow and interrupted flow. Uninterrupted flow is the flow of traffic in which there is no obstructions to the traffic flow of vehicles along the road. Motorway (Freeway in US) is one example for this type of facility. In a Motorway, when a vehicle enters a Motorway, there is no need for the vehicle to stop anywhere till it leaves the Motorway. There are three sections in a Motorway - basic unit, weaving section and ramps (on/off). Vehicles will be entering the Motorway through ramps. Ramps used for entering the Motorway is called on-ramps and those used for exiting the Motorway are called off-ramps. Motorways generally have 4, 6, or 8 lane alignments. [4]

Thus, to assess whether the implementation of grade separated intersections projects on National roads importance corresponds to their functional level and does not delay traffic conditions, it is possible to carry out analysis of Capacity and Level of Service (LOS) for an individual element – the Grade Separated Intersection.

2.1.1. Factors affecting Road Capacity and Level of Service

Understanding the risk factors affecting road condition, capacity, LOS, accidents and etc. is an important area in road safety and functionality research. Many of the procedures provide a formula or simple tabular or graphic presentations for a set of specified standard conditions, which must be adjusted to account for prevailing conditions that do not match. The standard conditions so defined are termed base conditions.

Base conditions in US are written in HCM 2010. Base conditions assume good weather, good pavement conditions, and users familiar with the facility, and no impediments to traffic flow.

Base conditions for uninterrupted-flow facilities include the following: (HCM 2010)

- Lane widths of 3.6 m,
- Clearance of 1.8 m between the edge of the travel lanes and the nearest obstructions or objects at the roadside and in the median,
- Free-flow speed of 100 km/h for multilane Main roads,
- Automobiles in the traffic stream,
- Level terrain,
- No no-passing zones on two-lane Main roads, and
- No impediments to through traffic due to traffic control or turning vehicles.

Base conditions for intersection approaches include the following:

- Lane widths of 3.6 m,
- Level grade,
- No curb parking on the approaches,
- Automobiles in the traffic stream,
- No local transit buses stopping in the travel lanes,
- Intersection located in a noncentral business district area, and
- No pedestrians.

In most road capacity analyses, prevailing conditions differ from the base conditions, and computations of capacity, service flow rate, and level of service must include adjustments. Prevailing conditions are generally categorized as roadway, traffic, or control. [4]

Traffic capacity is directly dependent on traffic control measures and their impact on traffic flow. Different adjustment tools, such as vertical and horizontal road markings at Main roads intersection, have different effects on traffic capacity. When introducing such regulatory measures, it is necessary to assess the flows of vehicles, their distribution, and the dominant direction, that the highest possible level of service index would be maintained. Therefore, the analysis should take into account the traffic conditions in the road element under consideration.

In other words, road capacity and level of service (LOS) depends on a wide range of factors. In assessing the influence of grade separations of intersection on these parameters, the geometrical parameters of the roadway elements, the composition of vehicles, and their distribution at intersections in different directions and traffic control measures at the intersection must be taken into account.

2.1.2. Fields of application

In the course of analysis, research, calculations, we always get a result, but it is necessary to understand the potential use of the result and its benefits. The methodology under consideration determines the use of results in the following areas: planning, designing and analysis of existing elements (implemented objects). This part defines the fields of application of the results and determines which of them is relevant to the topic of the research work.

Application of a more realistic approach for assessing road's performance indicators would result in better estimates which could suggest the most appropriate decision to be made (for situations where upgrading is needed); especially, in terms of finance, materials and human resources.

An analysis of existing road elements is dedicated to determine the current problems and their origin. The result is not only the confirmation of the current problem, but the decision is made how the problem can be solved. The most commonly offered are some improvement options, and one of them should be recommended. Road traffic analysis can be analyzed for each of the alternatives, to predict the changes in traffic indicators, to select the recommended plan. Therefore, HCM methods are used to improve existing infrastructure, helping to make one of the best solutions from many alternatives.

HCM methodology can also be used when planning a road network. The analysis in this area is very similar to the implemented projects - the aim is to improve the existing infrastructure. The main difference is that planning requires fewer details for input data and uses a larger number of key values. The result is not only a solution to the need for improvements, but it is possible to determine where and for what. Thus, using the analysis of general data, it is possible to obtain generalized solutions for certain areas of the road network.

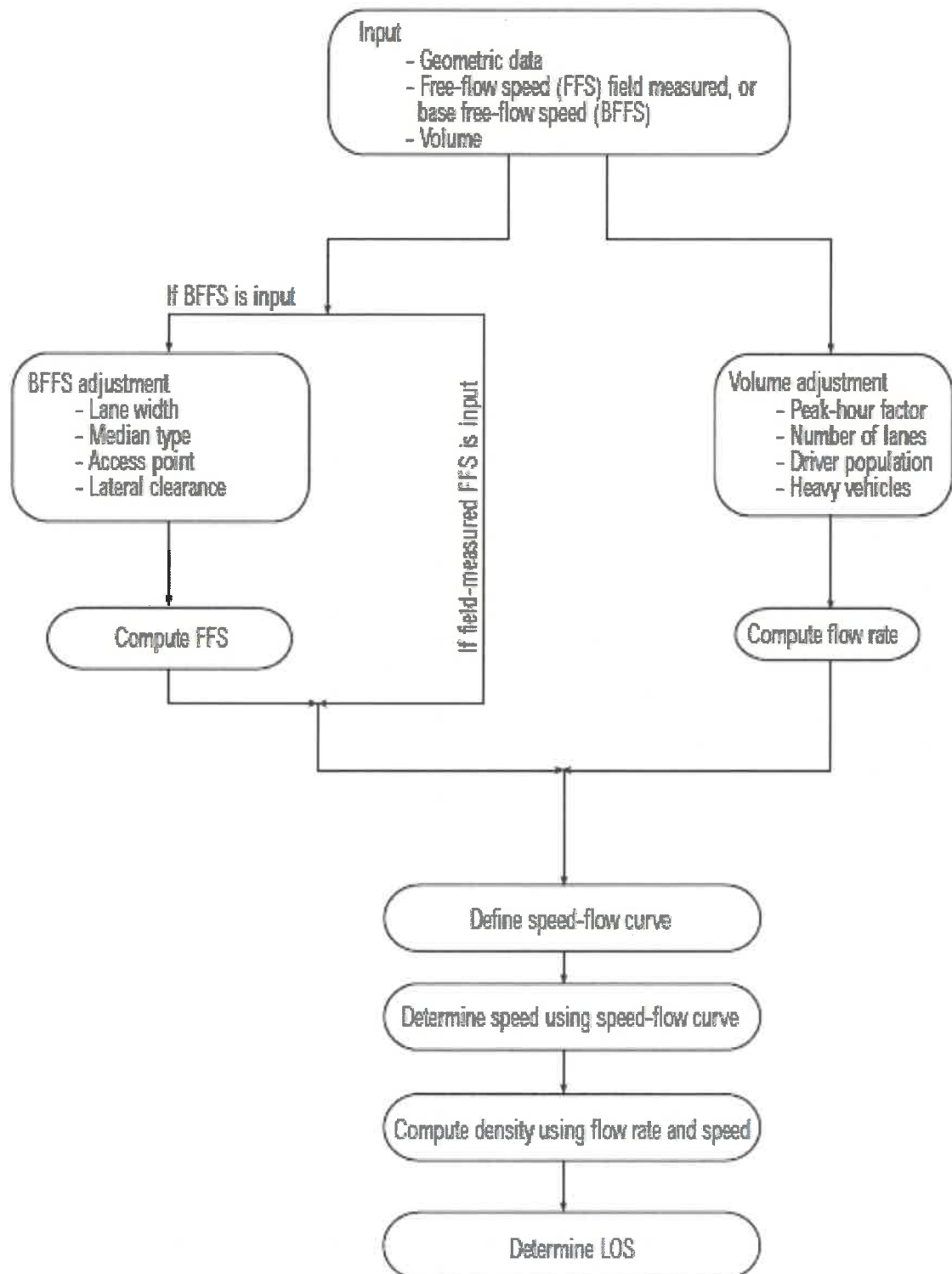
Under ideal conditions, HCM analysis should be applied at all stages: planning, design, monitoring, thus ensuring the best traffic conditions across the road network. The HCM 2010 methodology on work topics applies to implemented grade separated intersections projects to determine the capacity and level of service indicator. During the analysis, the possible result is the identification of existing problems, for example, why are forming traffic jams on investigating area.

2.1.3. The essence of the methodology and the conclusions

1. With HCM methodology we can estimate the performance of a grade separated level intersection from the perspective of the vehicle.
2. HCM methodologies are easy to apply to various road elements, it is easy to determine the parameters of problem points and traffic quality.
3. Analysis - complex and applied at different stages: planning, design, monitoring.
4. The LOS measure is divided into six letter grades, "A" through "F" with "A" representing excellent operating conditions with traffic flowing freely and "F" representing extremely congested conditions.

2.2. THE APPLICATION OF THE METHODOLOGY FOR SELECTING THE GEOMETRY OF INTERSECTION OF THE MAIN ROAD

When deciding the type of the intersections of the Main roads, the crucial factor is whether the traffic is interrupted or uninterrupted. For interrupted-flow facilities, the control of the time for movement of specific traffic flows is critical to capacity and level of service. The most critical type of control is the traffic signal. Basically, on Main roads are using uninterrupted traffic flow that road users can travel freely. To ensure uninterrupted traffic flow (without traffic signals) we must use ramps, grade separations and grade separated intersections. Uninterrupted-flow facilities that allow access solely through a system of on-ramps and off-ramps from grade separations or service roads are considered Freeways (US) and should be evaluated using the methodology presented in picture 4.

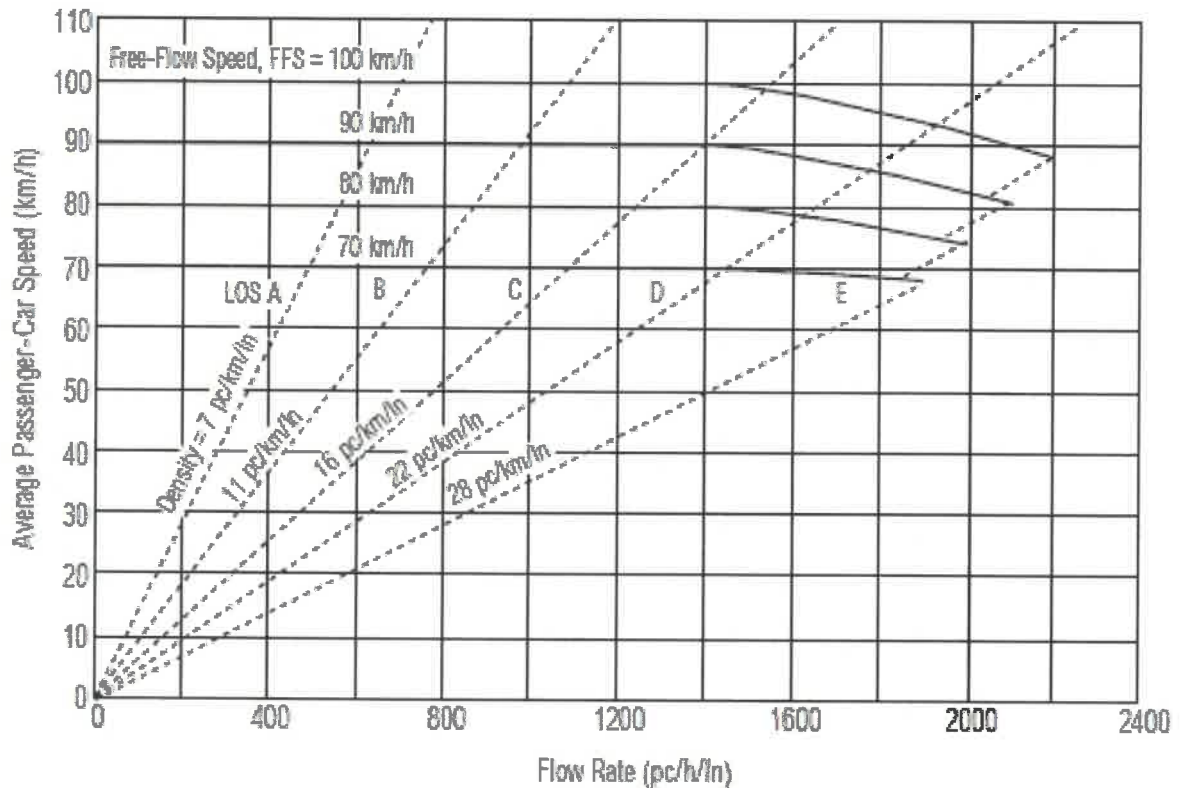


Picture 5 Multilane Highway methodology [4]

The procedures in this methodology determine the reduction of travel speed that occurs for less-than-base conditions. Under base conditions, the full speed and capacity of a Main road are achieved. These conditions include good weather, good visibility, and no incidents or accidents. In general, when segmenting a Main road for analysis, the minimum length of a study segment should be 760 m. Also, the limits of study segments should be no closer than 0, 4 km to a signalized intersection.

2.2.1. Level of Service (LOS)

Speed is a major concern of drivers, freedom to maneuver within the traffic stream and the proximity to other vehicles are also important. The LOS criteria are based on the typical speed-flow and density-flow relationships shown in Picture 6.



Picture 6 Speed-flow curves with LOS criteria [4]

Picture 6 also shows LOS boundaries as sloped lines, each corresponding to a constant value of density. The fundamental diagrams of traffic flow can be used in the representation of level of service. Level of service ranges from level A to F (table 2), representing the free flow conditions and F representing the worst traffic conditions like less speed, high density etc.

The objective of design analysis for flow rate up is to estimate an equivalent flow rate expressed in passenger cars per hour per lane (pc/h/ln) given a set of traffic, roadway, and FFS conditions. The desired LOS is entered on the worksheet. Then, the FFS of the segment is established using both the base FFS and the four adjustment factors or an FFS measured in the field. Once this segment speed-flow curve is established, the analyst can determine what flow rate is achievable with the given LOS. This would be considered the maximum flow rate achievable or allowable for the given level. [4]

2.2.2. Components of the methodology

To investigate more types of solutions for existing Main road intersections and to get more accurate results in my master thesis, I am using 3 different types of intersection analysis methodologies based on HCM scientists' scoring models. All models are using similar calculations models based on HCM methodologies.

2.2.2.1. One-level Signalized intersections traffic model's methodology

This methodology provides framework for the evaluation of road networks. This framework is using to determine the road's level of service (LOS). This analyst is able to investigate the effect of signalized intersection procedure for the through-traffic lane group. By redefining the lane arrangement, the analyst can influence which traffic flow is in the through-traffic lane group as well as the capacity of the lane group.

Necessary calculations of the methodology:

- Road class

The first step in the analysis is to determine road class. Road class are identifying by their functional and design categories.

- Free-Flow Speed (FFS)

Free-Flow Speed are determined by urban street or road class. (Table 3.)

Table 7. Urban Street or road LOS by class (HCM 2010) [4]

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	90 to 70 km/h	70 to 55 km/h	55 to 50 km/h	55 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	Average Travel Speed (km/h)			
A	> 72	> 59	> 50	> 41
B	> 56–72	> 46–59	> 39–50	> 32–41
C	> 40–56	> 33–46	> 28–39	> 23–32
D	> 32–40	> 26–33	> 22–28	> 18–23
E	> 26–32	> 21–26	> 17–22	> 14–18
F	≤ 26	≤ 21	≤ 17	≤ 14

- Volume (veh/h)

Determined by live data at the peak-hour in the analyzed intersection.

- Segments, sections and length of segments (>400 m)

Determined from the existing intersection data.

- Control delay

The control delay for the through mobility is the appropriate delay to use in an urban street evaluation. In general, the analyst should have this information because the intersections should have been evaluated individually as a part of the overall analysis. To calculate control delay are using these equations:

$$d = d_1(PF) + d_2 + d_3$$

$$d_1 = \frac{0.5C \left(1 - \frac{g}{C}\right)^2}{1 - \left[\min(1, X) \frac{g}{C}\right]}$$

$$d_2 = 900T \left[(X - 1) + \sqrt{(X - 1)^2 + \frac{8kIX}{cT}} \right]$$

d- control delay (s/veh);
d₁- uniform delay (s/veh);
d₂- incremental delay delay (s/veh);
d₃- initial queue delay delay (s/veh);
PF- progression adjustment factor;
X- volume to capacity (v/c) ratio for the lane group (also termed degree of saturation);
C- cycle length (s);
c- capacity of lane group (veh/h);
g- effective green time for lane group (s);
T- duration of analysis period (h);
k- incremental delay adjustment for the actuated control;
l- incremental delay adjustment for the filtering or metering by upstream signals.

- Progression adjustment factor

$$PF = \frac{(1 - P)f_{PA}}{\left(1 - \frac{g}{C}\right)}$$

PF- progression adjustment factor;
P- proportion of all vehicles arriving during green;
g/C- effective green-time ratio;
f_{PA}- supplemental adjustment factor for platoon arrival during the green.

The value of P may be measured in the field or estimated from the time-space diagram.

- Travel speed

Travel speed calculation equation is used on each segment and on the entire section.

$$S_A = \frac{3600L}{T_R + d}$$

S_A - average travel speed of through vehicles in the segment (km/h);

L - segments length (km);

T_R - total of running time on all segments in defined sections (s);

d - control delay for through movements at the signalized intersections (s).

• Road Capacity

The through road capacity of an intersection in the urban street is computed using this equation:

$$c = N * s * \frac{g}{C}$$

c - capacity of the through lane (veh/h);

N - number of through lanes at the intersection;

s - adjusted saturation flow per through lane (veh/h);

g/C - effective green time per cycle for the through movement at the intersection.

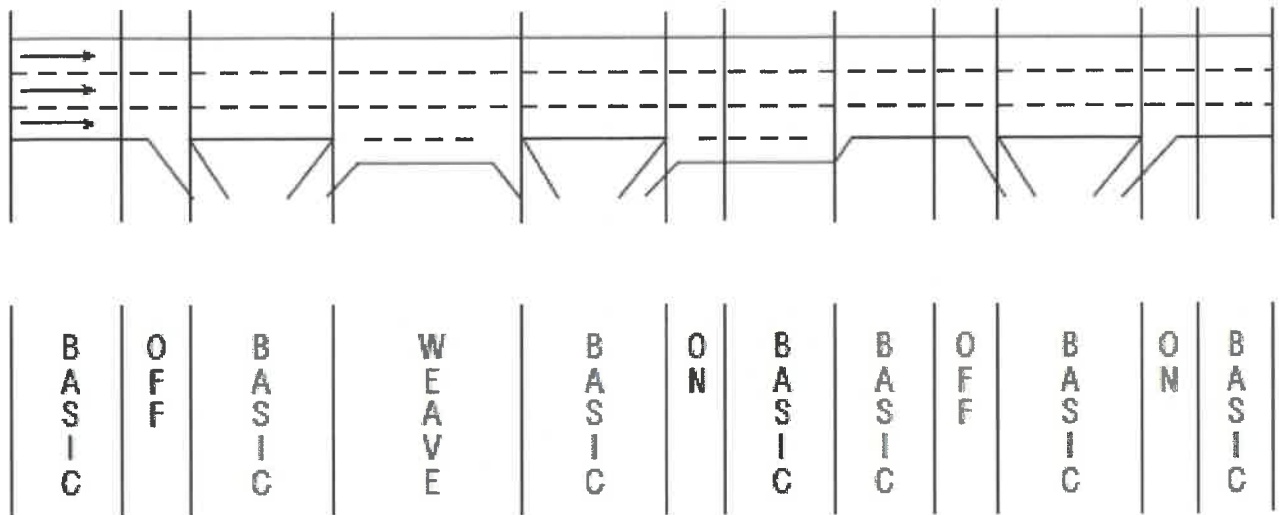
The capacity of road is defined for a single direction of travel as the capacity of the through movement at its lowest point. The capacity is determined by the number of lanes, the saturation flow rate per lane, and the green time per cycle for through movement at the intersection. [4]

Either, it is important to mention, that if we can't collect all necessary data from existing intersection, we can use basic values given in HCM 2010 manual.

2.2.2.2. Basic Motorways segments, ramp segments, and weaving segments methodology

A Motorway (Freeway in US) facility is analyzed by traffic flow direction, and the independent analysis of both directions constitutes the analysis of a two-direction Motorway facility. This methodology integrates the basic Motorway segment, ramp segment, and weaving segment procedures into a Motorway facility analysis. The methodology adjusts vehicle speeds appropriately to account for effects in adjacent segments. The methodology can analyze Motorway traffic management strategies only in cases for which 15 min time intervals are appropriate and for which reliable data for capacity and demand estimates exist.

Main idea of the methodology:



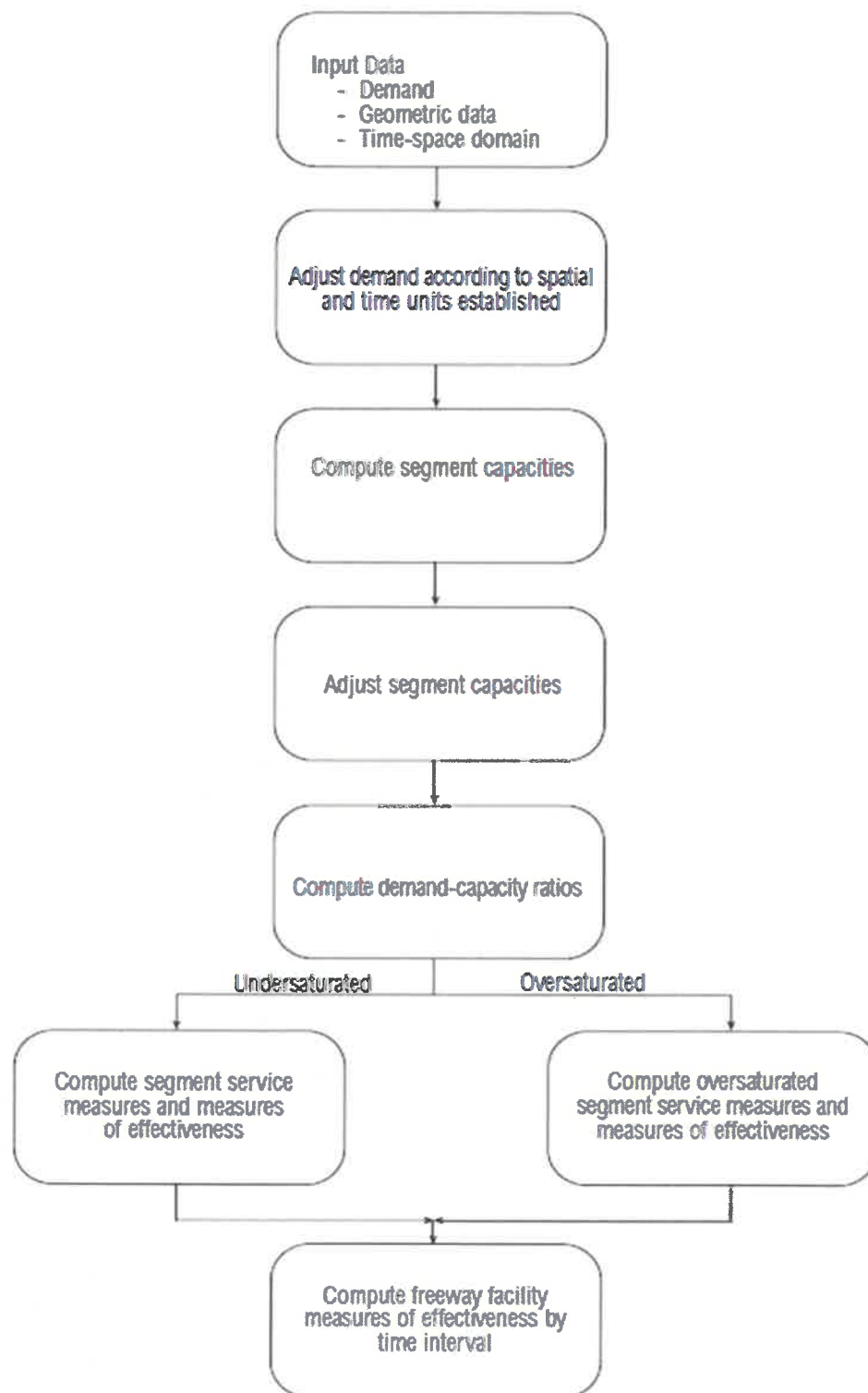
Picture 7 Freeway (US) Segments along Main road Facility (HCM 2010) [4]

In the picture shown above the horizontal scale is divided into Motorway (Freeway in US) segments. A Motorway segment boundary occurs wherever there is a change in traffic demand. For example, on-ramp or off ramp, lane drop or lane addition.

The procedure is to sum the Motorway entrance demands along the entire Motorway facility and to compare it with the sum of the Motorway exit counts along the entire directional Motorway facility for each time interval. The ratio of the total Motorway entrance demands to the Motorway exit counts in each time interval is called the time interval scale factor. Theoretically, the scale factor should approach 1.00 when the Motorway exit counts are, in fact, Motorway exit demands. [4]

Therefore, when the entrance and exit demands are determined, the traffic demands for each Motorway section In each time interval can be calculated.

Main principle of the methodology for Motorway weaving, on-ramp and off-ramp segments are shown in 7 picture.



Picture 8 Main principles of the methodology [4]

- Road Capacity

Segments capacity estimates are determined for basic, weaving, and ramp segments (on-ramp and off-ramp), respectively. All estimates of segment capacity should be carefully reviewed and compared with local knowledge and available traffic information for the study site.

- On-Ramp flow

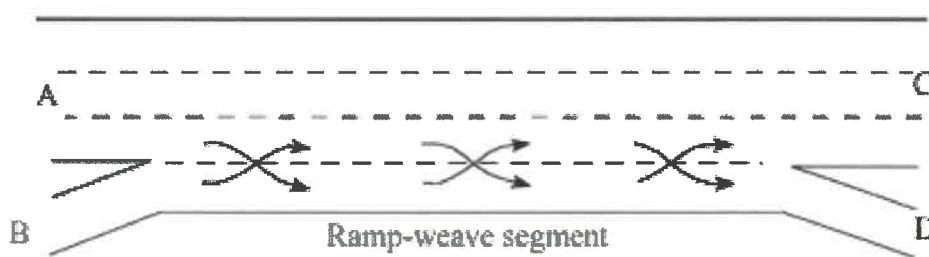
The on-ramp flow is the minimum of the on-ramp input and output. Ramp input in a time interval is the ramp demand plus any unserved ramp vehicles from a previous time interval. On-ramp output is limited by the ramp roadway capacity and the ramp-metering rate.

- Off-Ramp flow

The off-ramp flow is determined by calculating a diverge percentage based on the segment and off-ramp demands. The diverge percentage varies only by time interval and remains constant for vehicles that are associated with a particular time interval. The methodology ensures that all off ramp vehicles prevented from exiting during the presence of a bottleneck are appropriately discharged in later time intervals.

- Weaving segments

Weaving is defined as the crossing of two or more traffic streams traveling in the same general direction along a significant length of the roadway without the aid of traffic control devices. Weaving segments are formed when a merge area is closely followed by a diverge area, or when a one-lane onramp is closely followed by a one-lane off-ramp and the two are joined by an auxiliary lane. (Picture 9) [4]



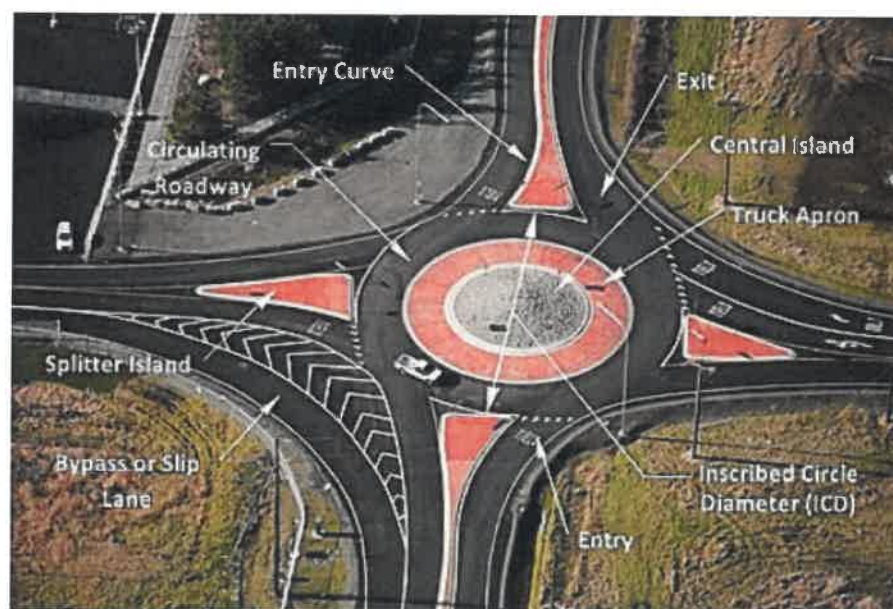
Picture 9 Weaving segments types [4]

In interchanges, such as between the on- and off-ramps of cloverleaf interchanges, there are typical weaving segments. Based on the number of lane changes required of each weaving movement, the HCM (2010) identifies three categories of weaving configurations: Type A, Type B and Type C. Among them, the characteristic of a Type A weaving segment is that each weaving vehicle must make one lane change at least to successfully complete a weaving maneuver. Type A weaving segment can be identified into ramp-weave segment and major-weave segment.

In other words, the traffic operation of weaving, on-ramp and off-ramp segments is very complex, the capacity of those segments has been always the difficulty of studies. Although the HCM (2010) has estimated the capacity of weaving segments based on field data, these weaving segments appear on Motorway and their capacity values are not suitable for urban expressway weaving segments. It points out and verifies that the capacity of weaving segments has not only a relationship with volume ratio and length of weaving segments but also with the source and distribution of weaving flow and non-weaving flow. Subsequently, using the calibrated simulation model, capacity values of urban expressway weaving segments have been estimated, in which capacity values of weaving segments shorter than 150m that the Highway Capacity Manual (HCM) 2010 doesn't consider are included. Through comparing with field data of maximum traffic flow, it is verified that capacity values estimated by the simulation method are reliable.

2.2.2.3. Methodology for roundabouts

Roundabout throughput calculations are performed using a gap tolerance model. This model is based on the fact that roundabouts are moving in the corresponding traffic. For this reason, geometric parameters of the junction, traffic control measures and different behavior of the driver in different road elements need to be evaluated (Akçelik 2007). Since the HCM 2010, due to the lack of US roundabouts, only analyzes the lanes of one lane with inlets of one lane and only provides an opportunity for calculating the throughput, further analyzes the newer version of HCM 2010, in which the methodology for roundabout analysis has been complemented by the National Highway Research Program. For further roundabouts calculations are using this methodology model.



Picture 10 Roundabout design elements (WSDOT Design Manual) [8]

2.2.3. Software for calculations

The calculations of the road capacity and LOS in terms of the formulas given in HCM 2010 and HCM 2010 may not be easy. It is a complex mathematical model that needs to be applied to a segment of the main road's intersections. Various software can be used to facilitate calculations. The PTV Vistro 7⁹ software package is chosen for the job theme because of its compatibility with the HCM 2010 and HCM 2010 computing models.

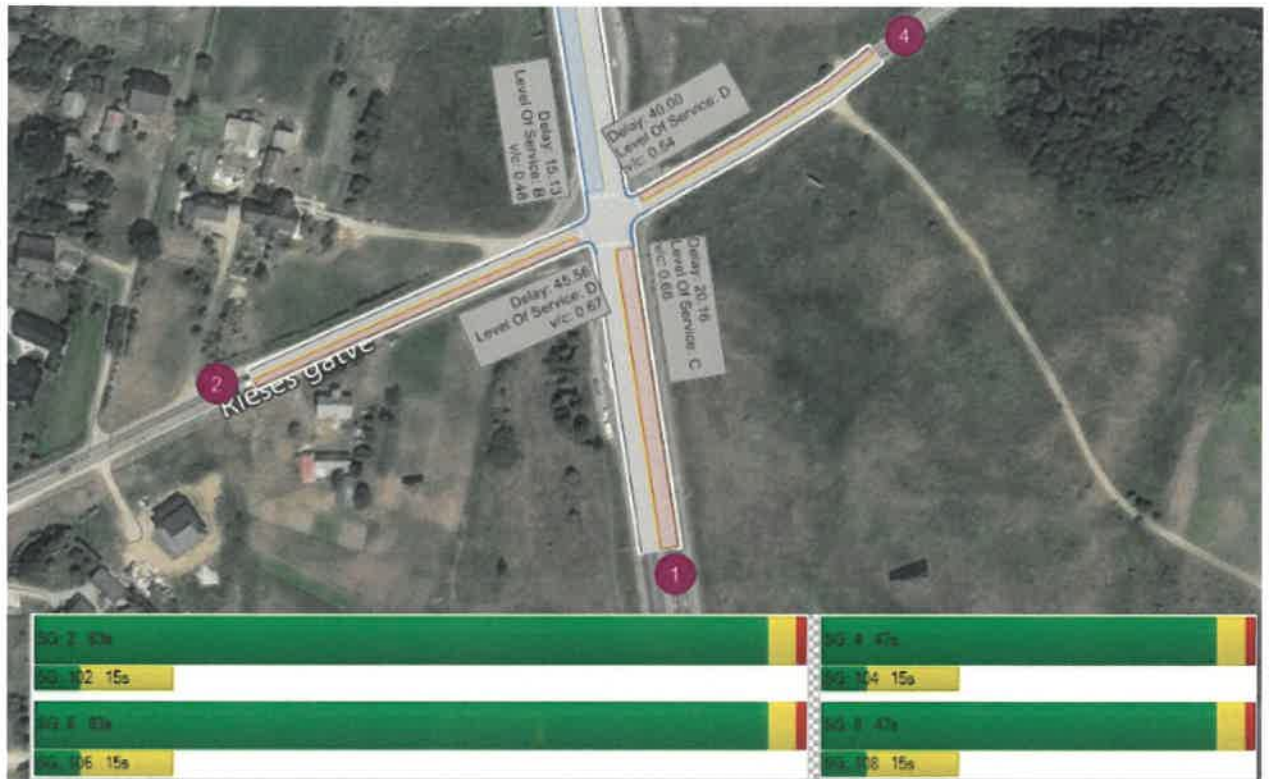
PTV Vistro 7 is a traffic software developed by PTV Germany to analyze traffic performance of roads and intersections. In analyzing signalized intersection performance, PTV Vistro 7 software uses several methods, one of which Highway Capacity Manual (HCM) 2010 method. The HCM 2010 method is a traffic modelling method based on empirical United States of America traffic conditions. The first version of the software was released in 1992, but has been continuously refined with user comments and new methodologies from HCM.

The PTV Vistro 7 program was selected for its simplicity and the ability to model the junction in ideal conditions in accordance with the HCM methodology with only the traffic volume and geometry of the intersection. In the case of a one-level signalized intersection (Picture 9), program having only traffic intensities and ideal (HCM 2010 methodology) conditions, simulate the most effective traffic flow and most effective possible cycles. Also, program calculates LOS and road capacity according to the most effective use of the possible traffic collision crossing. This allows accurately, without secondary data, analyze the suitability of the selected intersection type for existing traffic flow and compare it with other types of intersections. For another type of intersection, accurately without the passive data-distorting accuracy of the result.

Thus, using the possibility to make calculations faster and more qualitative (without probability of errors), PTV Vistro 7 software is used at final thesis.

⁹ PTV Vistro 7 [online] 2018. Available from internet:

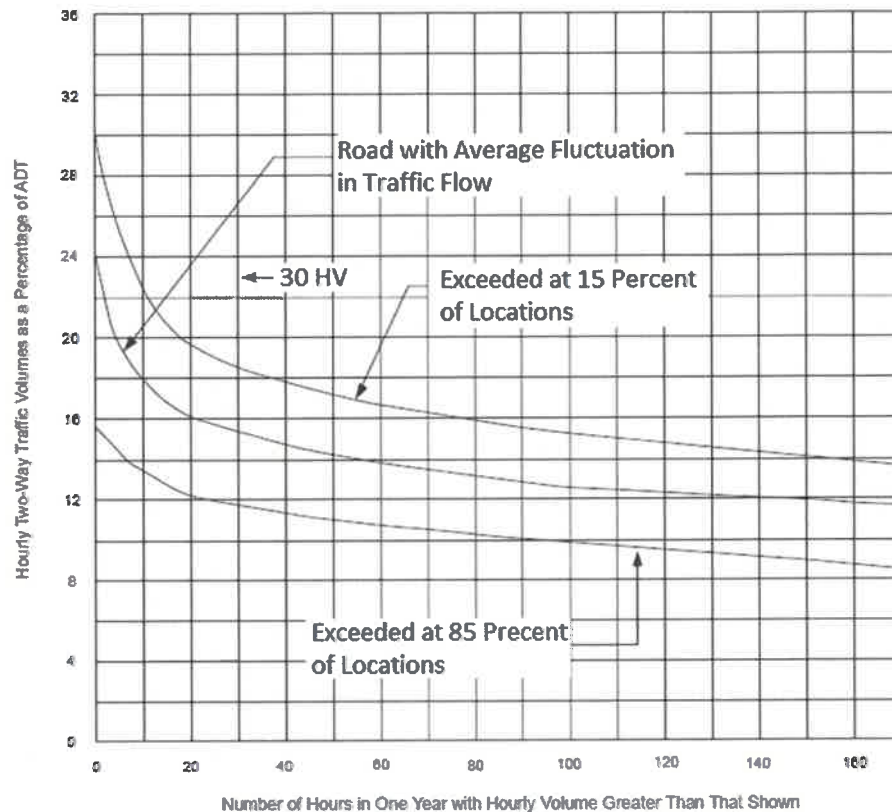
<https://www.ptvgroup.com/en/solutions/products/ptv-vistro/>



Picture 11 Example of the PTV Vistro 7 Signalized intersection calculations

2.2.4. Peak-Hour Traffic

According to A Policy on Geometric Design of Highways and Streets 2011 [6] traffic volumes for an interval of time shorter than a day more appropriately reflect the operating conditions that should be used for design. The brief, but frequently repeated, rush-hour periods are significant in this regard. In nearly all cases, a practical and adequate time period is one hour. A key design decision involves determining which of these hourly traffic volumes should be used as the basis for design. One guide in determining the hourly traffic volume that is best suited for use in design is a curve showing variation in hourly traffic volumes during the year. Picture 11 shows the relationship between the highest hourly volumes and ADT on rural arterials.



Picture 12 Relations between Peak-Hour and Average Daily Traffic Volumes on Main Roads (A Policy on Geometric Design of Highways and Streets) [6]

Based on a review of these curves, it is recommended that the hourly traffic volume that should generally be used in design is the 30th highest hourly volume of the year, abbreviated as 30 HV. The reasonableness of 30 HV as a design control is indicated by the changes that result from choosing a somewhat higher or lower volume. The curve in Picture 11 steepens quickly to the left of the point showing the 30th highest hour volume and indicates only a few more hours with higher volumes. The curve flattens to the right of the 30th highest hour and indicates many hours in which the volume is not much less than the 30 HV. On Highways with average fluctuation in traffic flow, the 30 HV is typically about 15 percent of the ADT. [6]

The 30th highest hourly volume of the year value reflects a rational traffic conditions at all year time period, because these traffic conditions arise very often. So, for further LOS and road capacity calculations to get more accurate results it is better to use 30 HV.

2.3. CONCLUSIONS OF THE THEORETICAL JUSTIFICATION

1. The HCM methodology analysis of road capacity and LOS is easy to applicate to individual Main road elements and segments.
2. The main idea of HCM methodology is to give a clear understanding of how much traffic a given transportation facility can carry out.
3. Depending upon the travel speed and v/c ratio, HCM has defined six levels of service, level A to level F based on a graph between operating speed and v/c ratio. The value of v/c ratio can vary between 0 and 1.
4. During the analysis of the Main road intersections is taking into account geometric parameters of the Main road intersection, vehicle traffic flow, and its capacity at the different intersection segments in different directions according to the type of intersection.
5. The most critical type of control on Main roads intersection is the traffic signal. Basically, on Main roads are using uninterrupted traffic flow (grade separated intersections), that road users can travel freely.
6. When entrance and exit demands of the intersection are determined, the traffic demands for each Main road section in each time interval can be calculated.
7. Analysis is complex and applies at different design stages: planning, monitoring and design.

3. ANALYSIS

In the final master's thesis "Research, Analysis and Recommendations for Design of Intersections on Main Roads" the analysis of the road capacity and level of service (LOS) indicator of intersections located on Main roads was made. The analysis is made to determine the quality of the existing intersections on Main roads of Lithuania, which contains the functional level of the intersection.

The objective of the analysis is to determine whether the parameters of the road capacity and LOS indicators of the intersections located on main roads, correspond to the parameters of the roads in which they are located according to their functional level.

The tasks of the analysis:

1. To analyze traffic flow distribution at the intersections.
2. To make geometric analysis of the intersections.
3. To analyze determination of road capacity and LOS indicators.
4. To determine the Delay time of the vehicles.
6. Submit the results of the analysis.

The objects of the analysis:

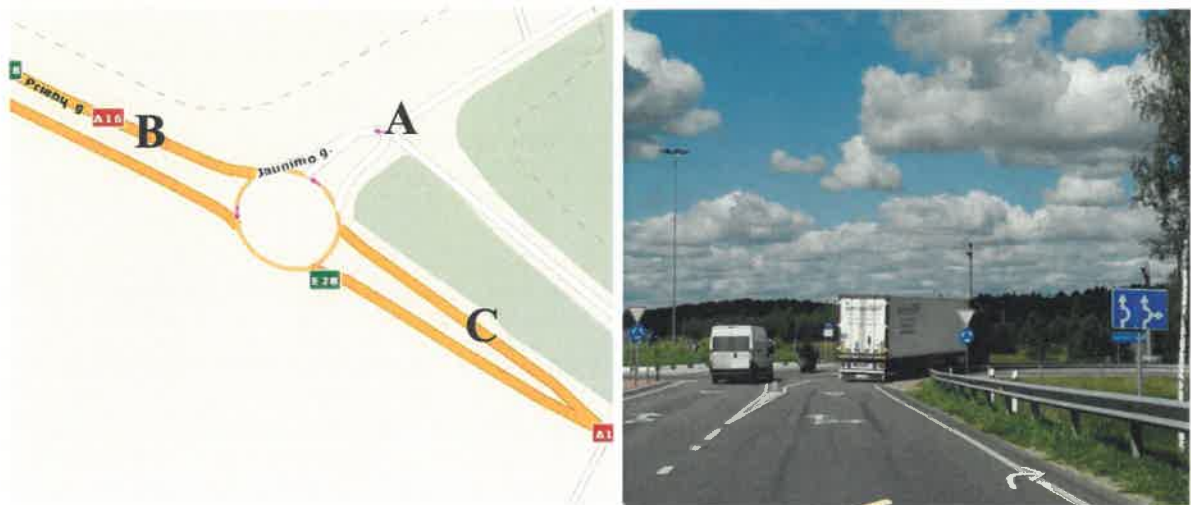
1. Birštonas roundabout – a three-leg intersection on Main road A16 Vilnius-Birštonas-Marijampolė and Local Jaunimo street of Birštonas;
2. The intersection of Riešės is a four-leg intersection, it crosses the main road A14 Vilnius-Utena and the road No 5210.
3. The intersection of Šmurai is a four-leg intersection, it crosses the main road A5 Kaunas-Marijampolė - Kalvarija and the road No 189.
4. The intersection of 5237 and A2 roads is a four-leg intersection, it crosses the main road A2 Vilnius – Ukmergė - Panevėžys and the road No 5237.
5. The intersection of 4520 and A12 roads is a four-leg intersection, it crosses the main road A12 Riga-Šiauliai-Kaliningrad and the road No 4520.

3.1. INITIAL DATA

The intersections are selected as analysis objects according to the task of the final master's thesis. In total, 5 objects are being investigated. Intersections are characterized by the fact that there are different categories of roads with different Average Annual Daily Traffic Volume and different design 30 HV, intersecting not only National roads, but also urban streets and lower traffic flow roads.

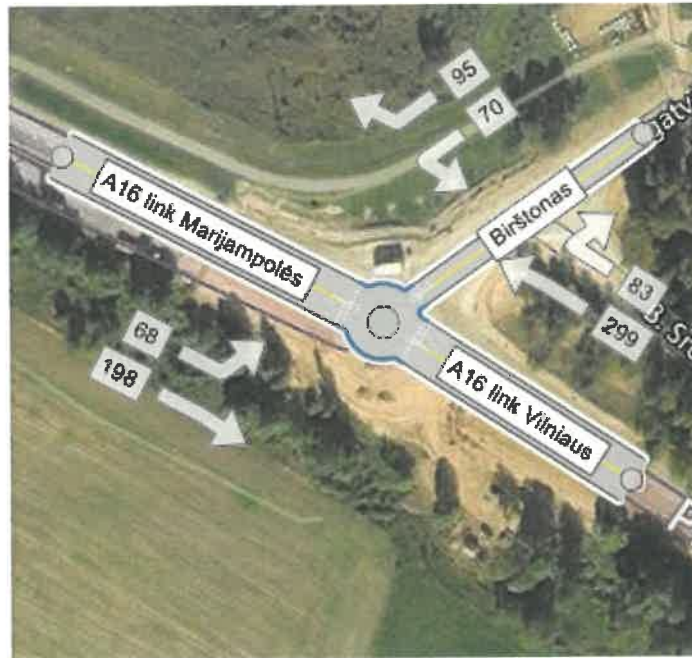
3.1.1. Birštonas roundabout

The roundabout of Birštonas is a three-leg intersection, it crosses the main road A16 Vilnius-Prienai-Marijampolė and the street Jaunimo. Picture 13 shows the position of the intersection, and connecting roads are marked with letters: direction A – street Jaunimo in the direction of Birštonas, direction B – Main road A16 to Marijampolė and direction C – Main road A16 to Vilnius.



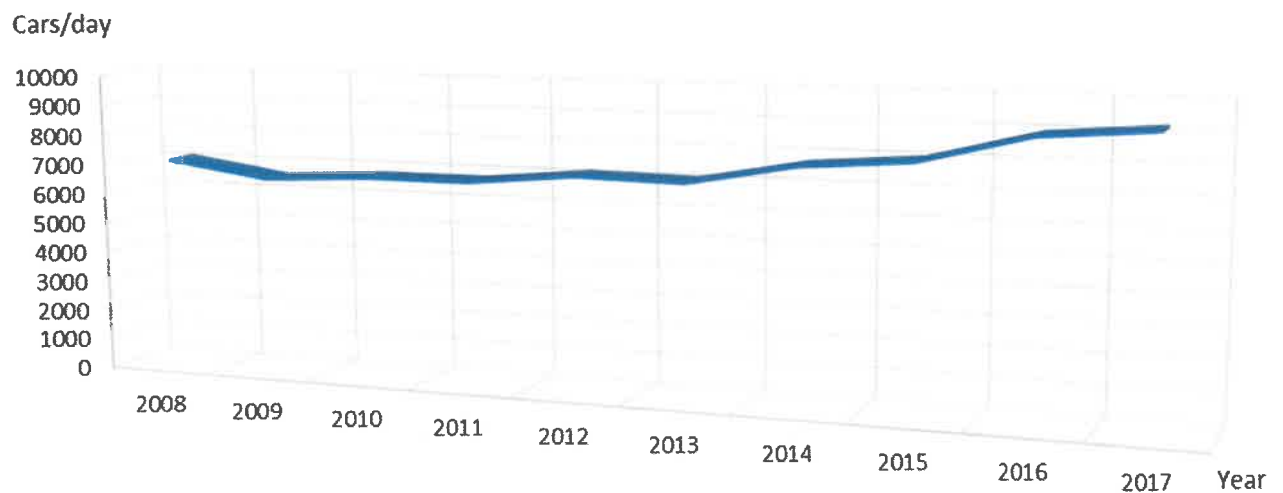
Picture 13 Birštonas roundabout (made by author)

Measurements of hourly traffic volume at intersections was made on 2018-11-09 (Friday). Measured from 18:00 to 19:00 Traffic volume data are presented in Picture 14. This data shows the traffic flow distribution on all intersection segments.



Picture 14. Measured hourly traffic volume distribution at Birštonas intersection (made by author)

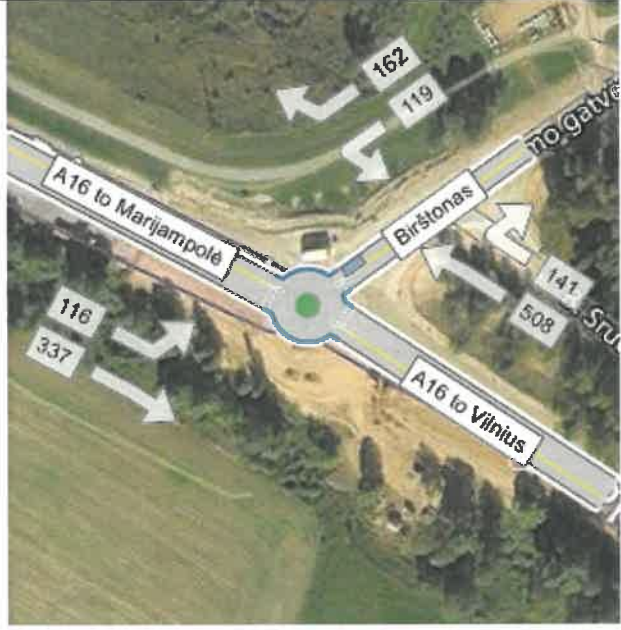
Average Annual Daily Traffic Volume (AADT) studies is conducted year by year by the Lithuanian Road Administration (LAKD). AADT from 2008 till 2017 year of the Main road A16 from 89,32 km to 94,95 km is taken from official website [www.eismoinfo.lt] and is shown in Picture 15. For further calculations is taken 2017 year value of AADT.



Picture 15 Average Annual Daily Traffic Volume changing in 10 years period of A16 road near the Birštonas intersection (made by author)

According to The Green Book [6] methodology the 30 HV is typically about 15 percent of the AADT. In the picture 15 we see, that AADT growing year by year, therefore we need take into account service life period (20 years in Lithuania) and calculate growing (3% in a year) of traffic flow according to Lithuania normative KTR 1.01:2008 [2] methodology. 30 HV calculation results is presented in Table 8.

Table 8. 30 HV calculations of Birštonas intersection (made by author)

Existing calculated 30 HV	30 HV calculations of 20 years' service life
	

The geometric parameters of the intersection are collected from existing Lithuanian normative, measured in the object and is shown in the Table 9.

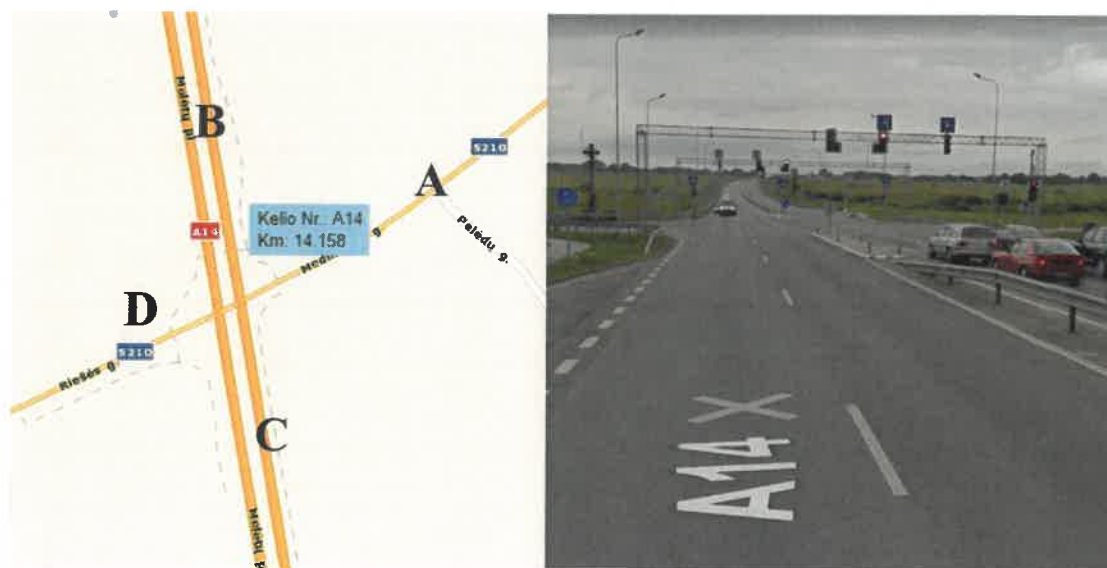
Table 9 Major geometric parameters of the Birštonas intersection. (Made by author)

<i>Geometric parameter</i>	<i>Value</i>
Main road width	3,50
Connecting roads width	3,25
Type of intersection	Roundabout (one level)
Category of the Main road (according Average Annual Daily Traffic Volume)	III
Speed limit (design speed) on the Main road	90 km/h

Analyzing the existing Birštonas intersection shows that the prevailing direction at the intersection is the road A16. It is also seen from Picture 15, that that due to Birštonas as a resort town, the attendance of tourism is increasing. Therefore traffic flow is also growing year by year at this intersection.

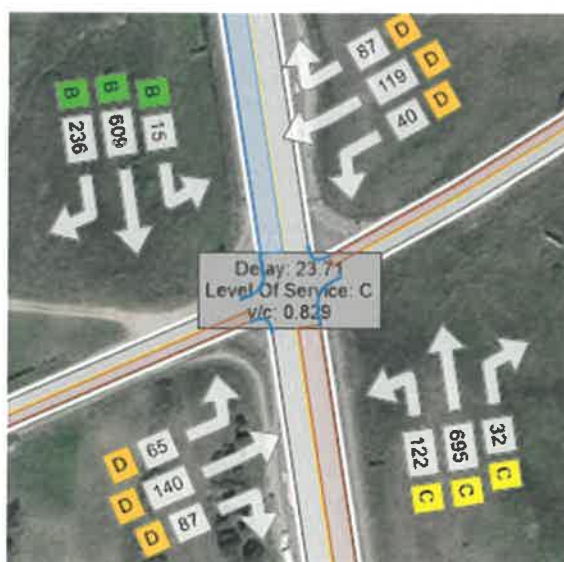
3.1.2. Riešės signalized intersection

The intersection of Riešės is a four-leg intersection, it crosses the main road A14 Vilnius-Utena and the road No 5210. Picture 16 shows the position of the intersection, and connecting roads are marked with letters: direction A – street Medikiškių (Road No 5210) in the direction to Mažieji gulbinai, direction B – Main road A14 to Utena, direction C – Main road A14 to Vilnius, direction D – street Riešės in direction to Didžioji Riešė.



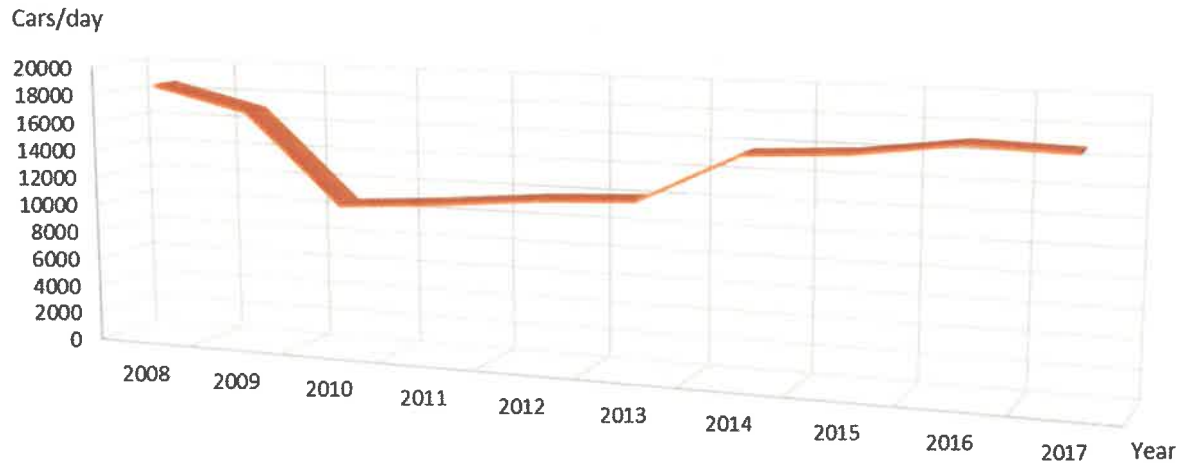
Picture 16 Riešės intersection (made by author)

Measurements of hourly traffic volume at intersections was made on 2018-10-30 (Friday). Measured from 18:00 to 19:00 Traffic volume data are presented in Picture 17. This data shows the traffic flow distribution on all intersection segments.



Picture 17 Measured hourly traffic volume at Riešė intersection (made by author)

Average Annual Daily Traffic Volume (AADTV) studies is conducted year by year by the Lithuanian Road Administration (LAKD). AADTV from 2008 till 2017 year of the Main road A14 at 14,15 km is taken from official website [www.eismoinfo.lt] and is shown in Picture 18. For further calculations is taken 2017 year value of AADT.



Picture 18 Average Annual Daily Traffic Volume changing in 10 years period of A14 road near the Riešės intersection (made by author)

According to The Green Book [6] methodology the 30 HV is typically about 15 percent of the AADT. In the picture 18 we see, that AADT growing year by year, therefore we need take into account service life period (20 years in Lithuania) and calculate growing (3% in a year) of traffic flow according to Lithuania normative KTR 1.01:2008 [2] methodology. 30 HV calculation results is presented in Table 10.

Table 10. 30 HV calculations of Riešės intersection (made by author)

Existing calculated 30 HV	30 HV calculations of 20 years' service life

The geometric parameters of the intersection are collected from existing Lithuanian normative, measured in the object and is shown in the Table 11.

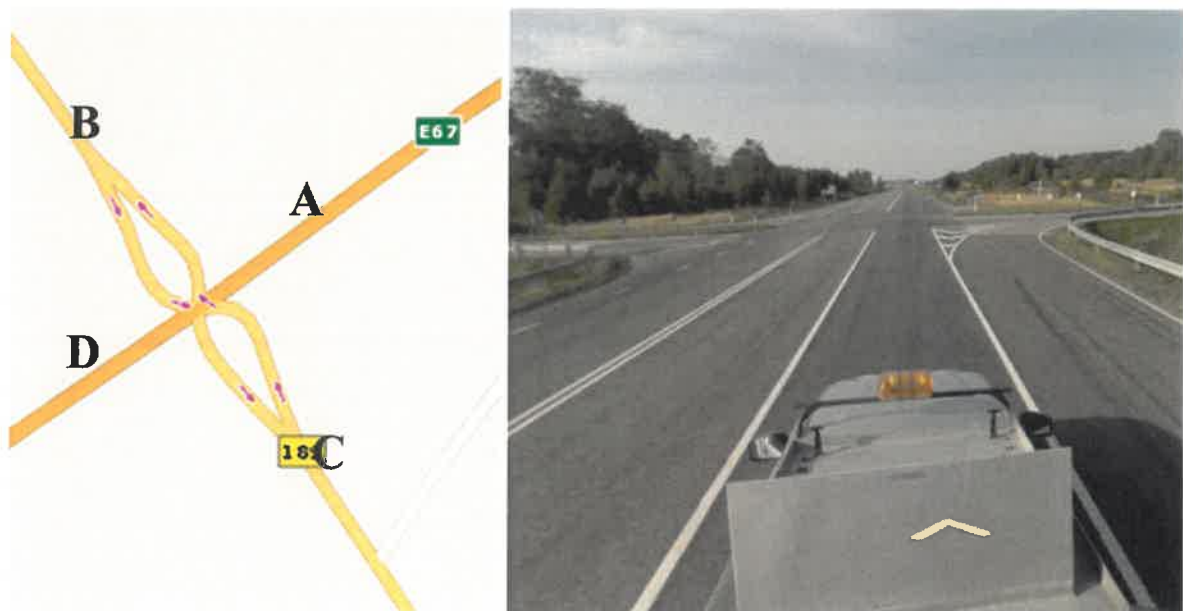
Table 11 Major geometric parameters of the Riešės intersection. (Made by author)

<i>Geometric parameter</i>	<i>Value</i>
Main road width	3,50
Connecting roads width	3,50
Type of intersection	Signalized intersection (one level)
Category of the Main road (according Average Annual Daily Traffic Volume)	I
Speed limit (design speed) on the Main road	90 km/h

Analyzing the existing Riešės intersection shows that the prevailing direction at the intersection is the road A14. It is also seen from Picture 18, that the traffic flow is growing from 2010 year more or less steadily.

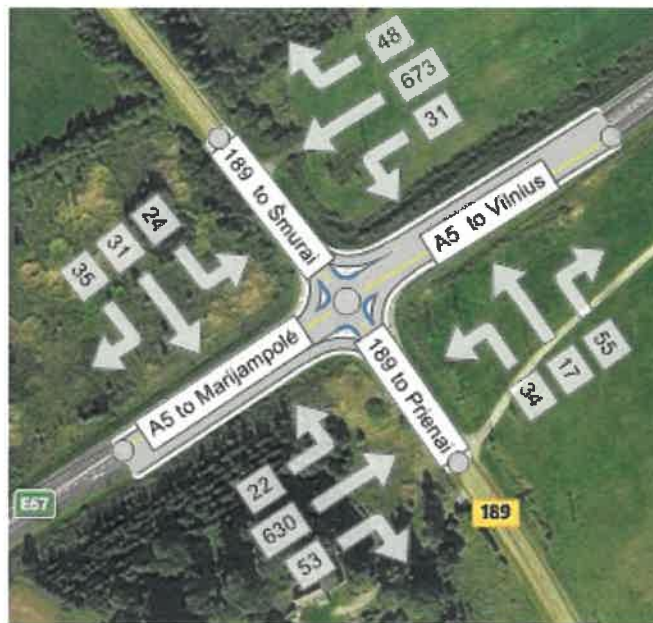
3.1.3. Šmurai unsignalized four-leg intersection

The intersection of Šmurai is a four-leg intersection, it crosses the main road A5 Kaunas-Marijampolė - Kalvarija and the road No 189. Picture 19 shows the position of the intersection, and connecting roads are marked with letters: direction A – Main road A5 to Vilnius, direction D – Main road A5 to Marijampolė, direction C –road No 189 to Prienai, direction B – road No 189 in the direction to Šmurai.



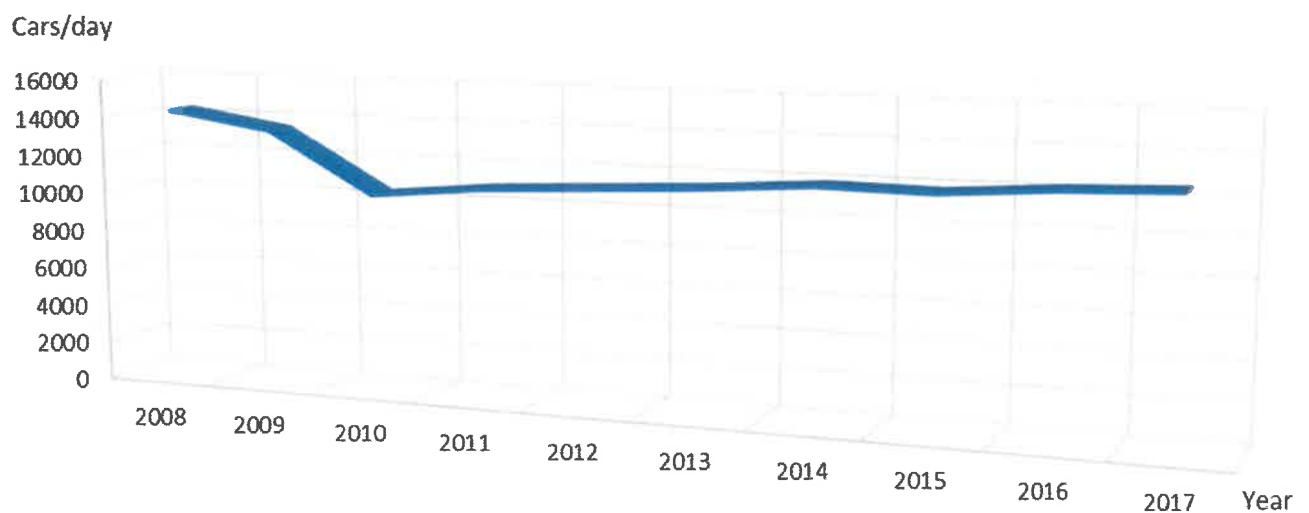
Picture 19 Šmurai intersection (made by author)

Measurements of hourly traffic volume at intersections was made on 2018-11-09 (Friday). Measured from 16:00 to 17:00 Traffic volume data are presented in Picture 20. This data shows the traffic flow distribution on all intersection segments.



Picture 20 Measured hourly traffic volume at Šmurai intersection (made by author)

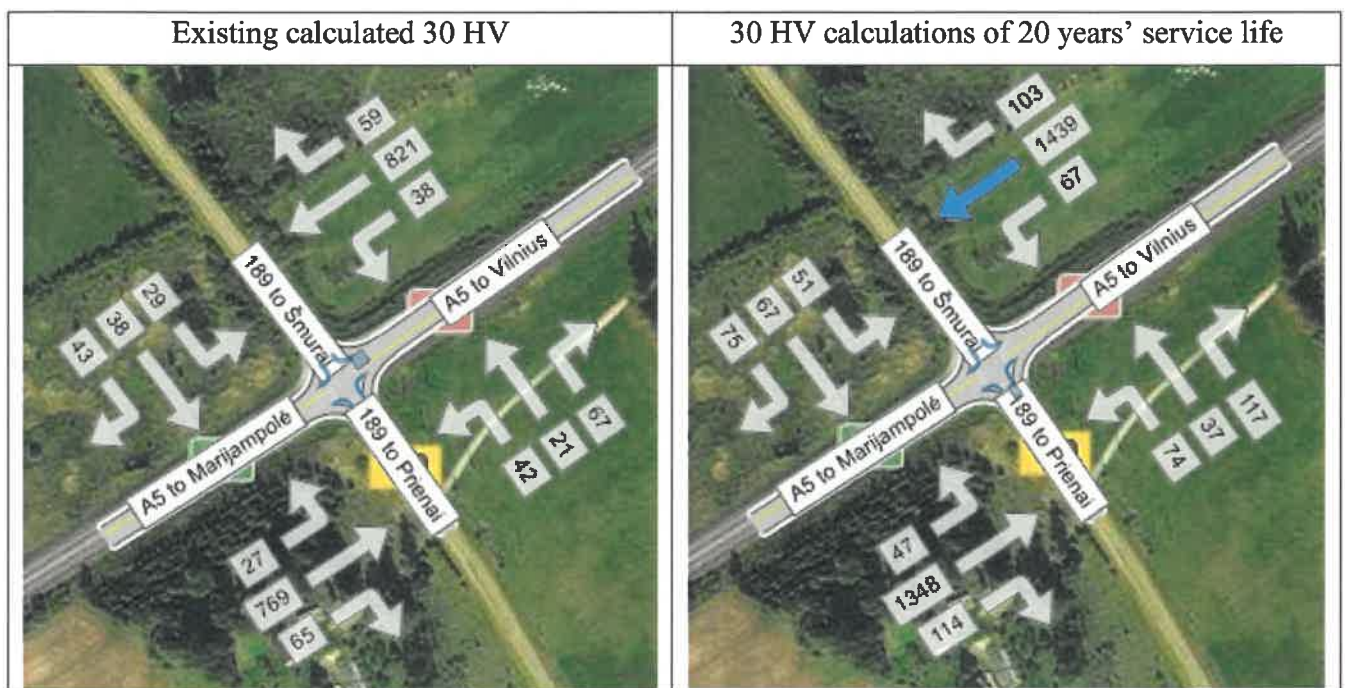
Average Annual Daily Traffic Volume (AADTV) studies is conducted year by year by the Lithuanian Road Administration (LAKD). AADTV from 2008 till 2017 year of the Main road A5 at 31,7 km is taken from official website [www.eismoinfo.lt] and is shown in Picture 21. For further calculations is taken 2017 year value of AADTV.



Picture 21 Average Annual Daily Traffic Volume changing in 10 years period of A5 road near the Šmurai intersection (made by author)

According to The Green Book [6] methodology the 30 HV is typically about 15 percent of the AADT. In the picture 21 we see, that AADT growing year by year, therefore we need take into account service life period (20 years in Lithuania) and calculate growing (3% in a year) of traffic flow according to Lithuania normative KTR 1.01:2008 [2] methodology. 30 HV calculation results is presented in Table 12.

Table 12. 30 HV calculations of the Šmurai intersection (made by author)



The geometric parameters of the intersection are collected from existing Lithuanian normative, measured in the object and is shown in the Table 13.

Table 13 Major geometric parameters of the Šmurai intersection. (Made by author)

<i>Geometric parameter</i>	<i>Value</i>
Main road width	3,50
Connecting roads width	3,25
Type of intersection	Unsignalized intersection (one level)
Category of the Main road (according Average Annual Daily Traffic Volume)	II
Speed limit (design speed) on the Main road	90 km/h

Analyzing the existing Šmurai intersection shows that the prevailing direction at the intersection is the road A5. It is also seen from Picture 21, that the traffic flow from 2008 till 2010 decreases, but from 2010 till 2017 traffic flow slowly increasing year by year.

3.1.4. Vilnius street (5237 road) and Main road A2 grade separated intersection

The intersection of 5237 and A2 roads is a four-leg intersection, it crosses the main road A2 Vilnius – Ukmergė - Panevėžys and the road No 5237. Picture 22 shows the position of the intersection, and connecting roads are marked with letters: direction A – Galinės street to Riešė, direction B – Main road A2 to Ukmergė, direction C – Main road A2 to Vilnius, direction D – road No 5237 (Vilnius street) in the direction to Sudervė.



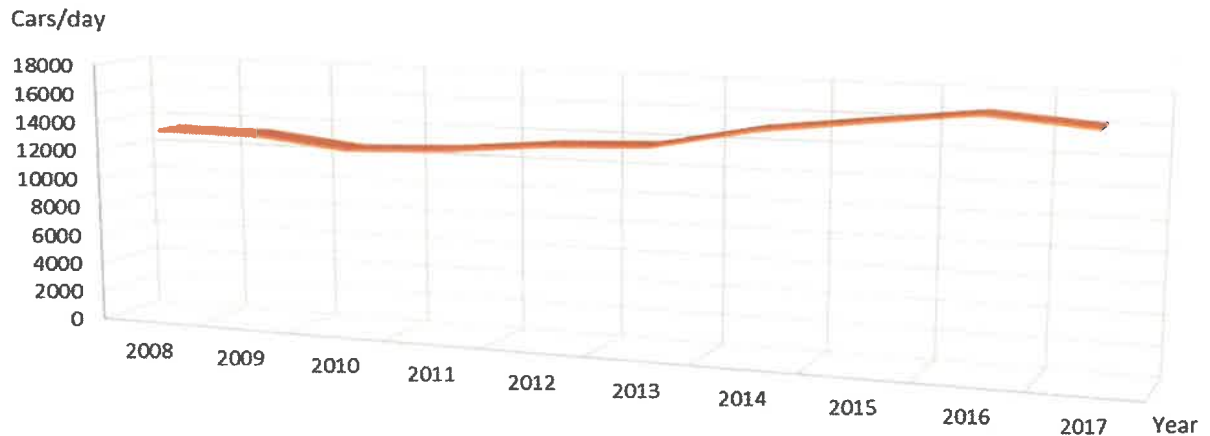
Picture 22 Road No 5237 and the Main road A2 grade separated intersection (made by author)

Measurements of hourly traffic volume at intersections was made on 2018-11-16 (Friday). Measured from 18:00 to 19:00 Traffic volume data are presented in Picture 23. This data shows the traffic flow distribution on all intersection segments.



Picture 23 Measured hourly traffic volume at Road No 5237 and the Main road A2 intersection (made by author)

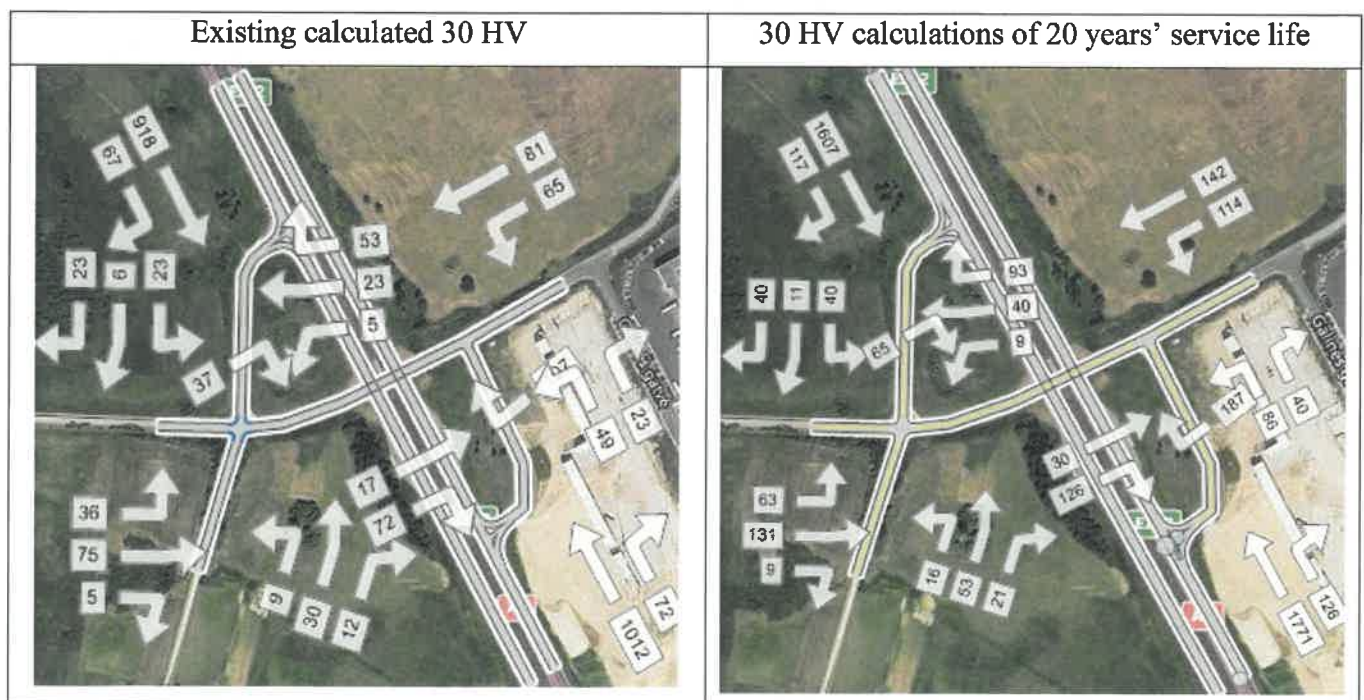
Average Annual Daily Traffic Volume (AADTV) studies is conducted year by year by the Lithuanian Road Administration (LAKD). AADTV from 2008 till 2017 year of the Main road A2 at 16,3 km is taken from official website [www.eismoinfo.lt] and is shown in Picture 24. For further calculations is taken 2017 year value of AADT.



Picture 24 Average Annual Daily Traffic Volume changing in 10 years period of A2 road and 5237 road intersection (made by author)

According to The Green Book [6] methodology the 30 HV is typically about 15 percent of the AADT. In the picture 24 we see, that AADT growing year by year, therefore we need take into account service life period (20 years in Lithuania) and calculate growing (3% in a year) of traffic flow according to Lithuania normative KTR 1.01:2008 [2] methodology. 30 HV calculation results is presented in Table 14.

Table 14. 30 HV calculations of the A2 road and 5237 road intersection (made by author)



The geometric parameters of the intersection are collected from existing Lithuanian normative, measured in the object and is shown in the Table 15.

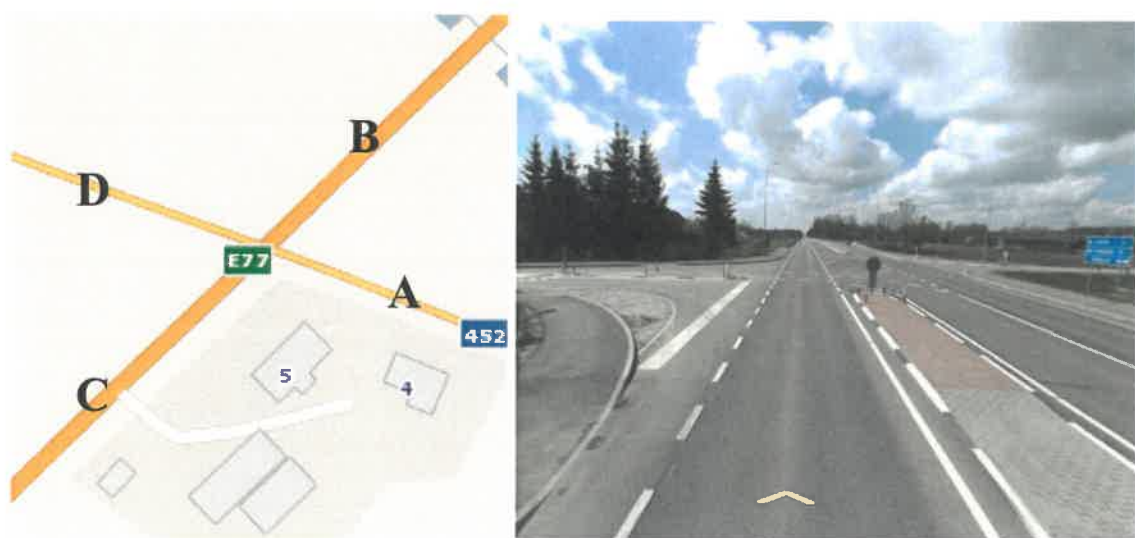
Table 15 Major geometric parameters of the Road No 5237 and the Main road A2 intersection. (Made by author)

<i>Geometric parameter</i>	<i>Value</i>
Main road width	3,75
Connecting roads width	3,25
Type of intersection	Unsignalized two level intersection
Category of the Main road (according Average Annual Daily Traffic Volume)	AM
Current speed of the Main road	130 km/h

Analyzing the existing Road No 5237 and the Main road A2 intersection shows that the prevailing direction at the intersection is the road A2. It is also seen from Picture 24, that the traffic flow from 2008 till 2017 increases year by year.

3.1.5. Santakos street (4520 road) and Main road A12 unsignalized four-leg intersection

The intersection of 4520 and A12 roads is a four-leg intersection, it crosses the main road A12 Riga-Šiauliai-Kaliningrad and the road No 4520. Picture 24 shows the position of the intersection, and connecting roads are marked with letters: direction A – Santakos street to Batakiiai, direction B – Main road A12 to Šiauliai, direction C – Main road A12 to Kaliningrad, direction D – road No 4520 (Santakos street) in the direction to Lomiai.



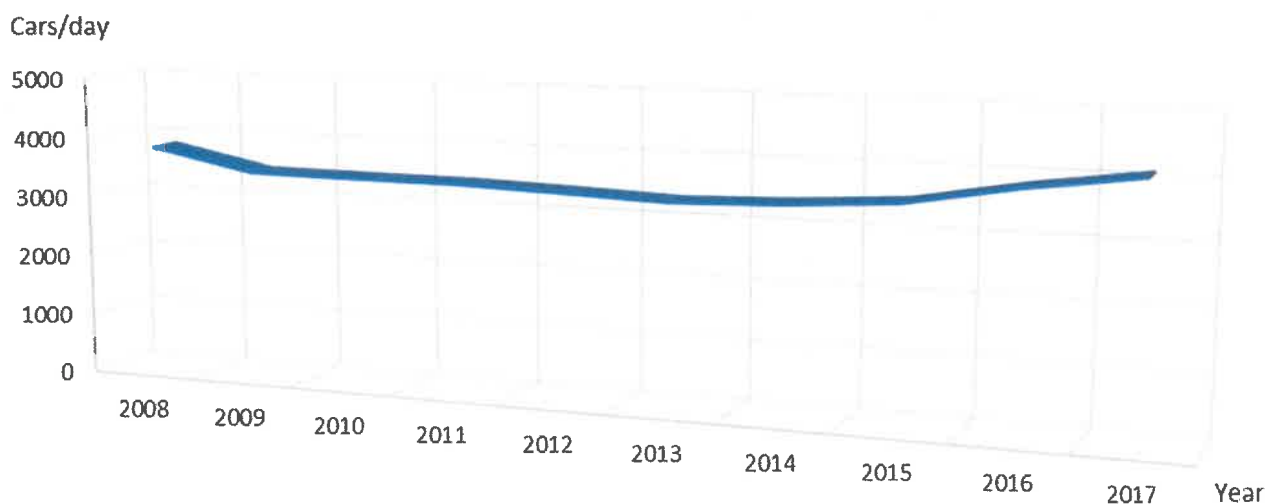
Picture 25 Road No 4520 and the Main road A12 unsignalized four-leg intersection (made by author)

Measurements of hourly traffic volume at intersections was made on 2018-12-07 (Friday). Measured from 17:00 to 18:00 Traffic volume data are presented in Picture 26. This data shows the traffic flow distribution on all intersection segments.



Picture 26 Measured hourly traffic volume at Road No 4520 and the Main road A12 intersection (made by author)

Average Annual Daily Traffic Volume (AADTV) studies is conducted year by year by the Lithuanian Road Administration (LAKD). AADTV from 2008 till 2017 year of the Main road A12 at 139,5 km is taken from official website [www.eismoinfo.lt] and is shown in Picture 27. For further calculations is taken 2017 year value of AADTV.



Picture 27 Average Annual Daily Traffic Volume changing in 10 years period of A12 road and 4520 road intersection (made by author)

According to The Green Book [6] methodology the 30 HV is typically about 15 percent of the AADT. In the picture 27 we see, that AADT growing, therefore we need take into account service life period (20 years in Lithuania) and calculate growing (3% in a year) of traffic flow according to Lithuania normative KTR 1.01:2008 [2] methodology. 30 HV calculation results is presented in Table 16.

Table 16. 30 HV calculations of the road No 5237 and the Main road A2 intersection (made by author)

Existing calculated 30 HV	30 HV calculations of 20 years' service life

The geometric parameters of the intersection are collected from existing Lithuanian normative, measured in the object and is shown in the Table 17.

Table 17 Major geometric parameters of the Road No 5237 and the Main road A2 intersection. (Made by author)

Geometric parameter	Value
Main road width	3,50
Connecting roads width	3,25
Type of intersection	Unsignalized four-leg intersection
Category of the Main road (according Average Annual Daily Traffic Volume)	III
Current speed of the Main road	90

Analyzing the existing Road No 4520 and the Main road A12 intersection shows that the prevailing direction at the intersection is the road A12. It is also seen from Picture 27 that the traffic flow from 2008 till 2017 increases not so much in all 10 years period.

3.2. Investigation of the collected data

Investigations of are performed to determine the proportion of heavy vehicles in traffic, to supplement the missing traffic data and to determine the directional distribution of vehicles at the intersections. The investigations according the HCM 2010 model take 15 or 30 minutes, and then these data are expressed in hourly expressions. Value of 30 EI, it is determined during the analysis. The results of field studies are shown in 3.1. part and in the table 18. The intensity of traffic, where unit of measurement automobiles per hour is indicated, is indicated by the percentage of heavy vehicles in traffic.

Table 18 Investigated intersections average percentage of heavy vehicles (made by author)

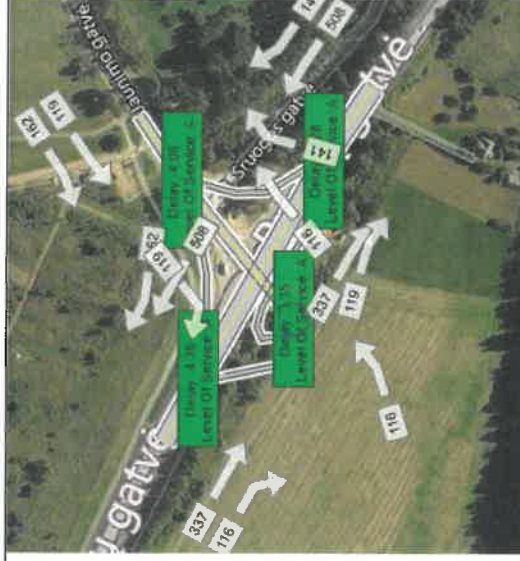
<i>Intersection</i>	<i>Percentage of heavy vehicles, %</i>
Birštonas roundabout	6,6
Riešės intersection	3,6
Šmurai intersection	40,5
The intersection of 5237 and A2 roads	8,3
The intersection of 4520 and A12 roads	8,6

3.3. Calculations of Level of Service and intersection Delay Time

Based on the initial data with the PTV Vistro 7 software, calculations of capacity and LOS are performed for each intersection to be analyzed. The results of LOS are presented together with the results of the delay time. All listed results are presented schematically.

3.3.1. Birštonas roundabout

Table 19 Birštonas roundabout analysis according determined 30HV with PTV Vistro 7 software (made by author)

Type of intersection	Existing type of intersection (turbo-roundabout)	1 version (signalized three-leg intersection)	2 version (grade separated intersection)
Scheme			
Main road LOS	A (B*)	B (B*)	A (A*)
Main road Delay Time	6,20s (14,15s*)	12,00s (18,09s*)	4,39s (6,47s*)
Intersection LOS	A (C*)	B (D*)	A (A*)
Intersection Delay Time	6,28s (19,24s*)	13,36s (51,04s*)	4,39s (6,47s*)
Highest cost and environmental impact of intersection			+
Best type of intersection to current situation	+		

* Calculated value with 30 HV of 20 year's service life. (Calculation was made with PTV Vistro 7)

3.3.2. Riešės intersection

Table 20 Riešės intersection analysis according determined 30HV with PTV Vistro 7 software

Type of intersection	Existing type of intersection (signalized four-leg intersection)	1 version (turbo-roundabout)	2 version (grade separated intersection with two roundabouts)
Scheme			
Main road LOS	E (D*)	C (F*)	A (A*)
Main road Delay Time	60,25s (244,41s*)	17,18s (255,86s*)	6,72 s (9,83s*)
Intersection LOS	D (F*)	E (F*)	A (B*)
Intersection Delay Time	40,65s (361,90s*)	35,73s (643,12s*)	8,08s (13,18s*)
Highest cost and environmental impact of intersection			+
Best type of intersection to current situation			+

* Calculated value with 30 HV of 20 years' service life. (Calculation was made with PTV Vistro 7)

3.3.3. Šmurai intersection

Table 21 Šmurai intersection analysis according determined 30HV with PTV Vistro 7 software

Type of intersection	Existing type of intersection (unsignalized four-leg intersection)	1 version (turbo-roundabout)	2 version (grade separated intersection with two roundabouts)
Scheme			
Main road LOS	A (A*)	E (F*)	A (A*)
Main road Delay Time	0,43s (0,65s*)	44,20s (391,99s*)	5,12 s (7,96s*)
Intersection LOS	F (F*)	E (F*)	A (B*)
Intersection Delay Time	887,23s (>1000s*)	39,31s (398,81s*)	5,53 s (11,54s*)
Highest cost and environmental impact of intersection			+
Best type of intersection to current situation			+

* Calculated value with 30 HV of 20 years' service life. (Calculation was made with PTV Vistro 7)

3.3.4. The intersection of 5237 and A2 roads

Table 22 The intersection of 5237 and A2 roads analysis according determined 30HV with PTV Vistro 7 software

Type of intersection	Existing type of intersection (grade separated intersection)	1 version (turbo-roundabout)	2 version (signalized four-leg intersection)
Scheme			
Main road LOS	A (A*)	B (E*)	B (D*)
Main road Delay Time	6,62s (8,98s*)	13,42s (57,63s*)	14,10s (38,55s*)
Intersection LOS	B (B*)	C (F*)	C (F*)
Intersection Delay Time	10,73s (13,94s*)	24,17s (702,5s*)	20,76 s (598,36s*)
Highest cost and environmental impact of intersection	+		
Best type of intersection to current situation	+		

* Calculated value with 30 HV of 20 years' service life. (Calculation was made with PTV Vistro 7)

3.3.5. The intersection of 4520 and A12 roads

Table 23 The intersection of 4520 and A12 roads analysis according determined 30HV with PTV Vistro 7 software

Type of intersection	Existing type of intersection (unsignalized four-leg intersection)	1 version (turbo-roundabout)	2 version (signalized four-leg intersection)
<i>Scheme</i>			
<i>Main road LOS</i>	A(A*)	A(A*)	A(B*)
<i>Main road Delay Time</i>	0,42s (0,46 s*)	4,61s (6,82s*)	8,37s (10,69s*)
<i>Intersection LOS</i>	C(F*)	A(A*)	B(C*)
<i>Intersection Delay Time</i>	16,56s (50,13s*)	4,51s (6,61s*)	19,70s (22,62s*)
<i>Highest cost and environmental impact of intersection</i>		+	
<i>Best type of intersection to current situation</i>		+	

* Calculated value with 30 HV of 20 years' service life. (Calculation was made with PTV Vistro 7)

3.4. Conclusions

1. From the initial data, it can be observed that almost all traffic volumes growing year by year in the Main roads of National Significance, therefore it is important to have appropriate Main roads intersections.
2. In this analysis I take existing parameters of the intersection. Where it is not possible to have existing data of intersection, I take values from HCM 2010(ideal conditions).
3. The percentage of heavy vehicles was taken into account in the calculations.
4. For better analysis of existing situation and for possibility to find better solution on chosen Main road intersections I made calculations for additional two types of intersections.
5. Only Birštonas intersection have LOS A. Intersections of 5237 and A2 roads have LOS B, 4520 and A12 roads have LOS C. Riešės intersection have LOS D and Šmurai intersection have LOS F.
6. It is important to mention, that in analyzed intersections different legs have different LOS. Main roads in analyzed intersections have higher LOS than other intersecting roads.
7. To ensure better overall intersection LOS index, I tried to reduce Delay Time in all analyzed intersections legs as much as possible.

4. RESULTS ANALYSIS

In the final master's thesis a Main road intersections on the following roads was investigated: Birštonas roundabout – a three-leg intersection on Main road A16 Vilnius-Birštonas-Marijampolė and Local Jaunimo street of Birštonas; The intersection of Riešės is a four-leg intersection, it crosses the main road A14 Vilnius-Utena and the road No 5210; The intersection of Šmurai is a four-leg intersection, it crosses the main road A5 Kaunas-Marijampolė - Kalvarija and the road No 189; The intersection of 5237 and A2 roads is a four-leg intersection, it crosses the main road A2 Vilnius – Ukmergė - Panevėžys and the road No 5237; The intersection of 4520 and A12 roads is a four-leg intersection, it crosses the main road A12 Riga-Šiauliai-Kaliningrad and the road No 4520. Road function classification and road category is described in table 1. Link function level given in table 3. Recommended LOS is calculated from HCM 2010 methodology according to road parameters by road category given in KTR 2008 and compared with “Valstybinės reikšmės kelių suskirstymo pagal paskirtį ir plėtros schemos iki 2040 m projektas” 2015 [14] article.

Table 24 Road functional level and LOS (made by author)

<i>Road No.</i>	<i>Road function classification</i>	<i>Link function level</i>	<i>Road category</i>	<i>Recommended min. LOS</i>	<i>Calculated existing LOS</i>	<i>Calculated LOS of 20 years' service life</i>	<i>Best type of intersection (from 3.3.)</i>
<i>Birštonas roundabout</i>							
A16	Main road	Inter-regional	III	B	A	B	Existing (turbo-roundabout)
Jaunimo street	Regional road	Local	V	D	A	C	
<i>Riešės four-leg intersection</i>							
A14	Main road	Sub-continental	I	B	E	D	2 version (grade separated)
5210	Regional road	Local	V	D	D	F	
<i>Šmurai four-leg intersection</i>							
A5	Main road	Sub-continental	II	B	A	A	2 version (grade separated)
189	National road	Regional	IV	C	F	F	
<i>The four-leg intersection of 5237 and A2 roads</i>							
A2	Main road	Sub-continental	AM	B	A	A	Existing (grade separated)
5237	Regional road	Local	IV	D	B	B	
<i>The four-leg intersection of 4520 and A12 roads</i>							
A12	Main road	Inter-regional	III	B	A	A	1 version (turbo-roundabout)
4520	Regional road	Local	V	D	C	F	

Table 24 shows that for the Main roads which ones have III road category it is enough to have one-level intersections, but for higher categories Main roads we need to design grade separated intersections. In the study of functional level of the Lithuania road network and make recognizable roads we need take into account not only function of the road but also LOS index, delay time, environmental impact, price of the project and etc. Therefore to ensure smooth automobiles traffic and make recognizable roads.

The implementation of the concept of recognizable roads is an important political guideline for the state of Lithuania to become an advanced road safety country. The purpose of this concept is a clear, homogeneous road environment in which the driver, the road user, has no unexpected factor. It is implemented by categorizing the road network into categories according their functional level and LOS index, rather than by AADT.

According to the results of the study, it was found that at the two intersections examined, the primary junction type was not correctly selected, the traffic flow of the vehicles, the share of heavy vehicles in traffic, the functional level of the road and others were not taken into account. Three intersections are designed appropriately - the intersections corresponds to the level of service (LOS) index according to the functional level of the road and ensures road safety.

5. CONCLUSIONS

1. It has been determined that the LOS of a Main road intersections does not meet the exception for a road with an intersection, according to its functional level, in cases where the deceleration of the design speed of a higher category main road is unavoidable due to the condition of the road, terrain conditions or other circumstances. Therefore it is necessary to regulate the LOS determination calculations of the road design normative documents.

2. The LOS determination study at Main roads intersections at the planning or design stages and on the basis of this study work should be done, then the implementation of the concept of recognizable roads in Lithuania can be achieved.

3. After studying the normative documents valid in the Republic of Lithuania, it has been determined that roads are not classified according to their functional level, Main roads intersections are classified in normative documents, methodological instructions, even laws, but none of these documents accurately determines which category or functional level of the road can be used for this type of intersection (one-level, grade separated intersections). The classification of the road network according to its functional level is defined only in other countries scientific works.

4. Based on the experience of foreign countries, it is reasonable that roads should have their own functions: transit, connecting and access roads. Due to their uninterrupted traffic flow on transit roads, only grade separated intersection recommended to be designed, and one level intersections in the foreign countries under consideration (the Netherlands, the United States, Germany) are recommended to be designed only on lower functional level roads (connecting, access roads).

5. Analysis of scientific articles on the theme of final thesis shows that road classification by functional level is one of the principles of a recognizable road concept that ensures road safety, reduces the possibility of accidents, and enables the road user to predict factors that may be present in the road environment, i.e. y. recognize it according to its characteristic elements.

6. The determining the capacity and level of service index is carried out according to the US methodology HCM 2010, which is also used by other European Union countries, because the methodology is easily applied to individual road elements. At the study used 30 HV hour. The study was performed in this order: measured existing traffic volume distribution in all directions, geometric parameters were analyzed, were calculated 30 HV value, other calculations was performed by software PTV Vistro 7. It was determined that Birštonas roundabout LOS A, Riešės four-leg

intersection LOS C, Šmurai intersection LOS F, The intersection of 5237 and A2 roads LOS B and the intersection of 4520 and A12 roads LOS B.

6. RECOMMENDATIONS

Evaluating the results of the research work, the experience of foreign countries and in order to improve road safety on the roads of national significance in Lithuania, implementing the theory of self-explaining roads, it is recommended:

1. Refuse III category roads from Main roads classification and put to the National roads classification. KTR 1.01: 2008 (1 Table)

1. Refuse possibility to design one level intersections on Main roads. On Main roads (Motorways and Highways) should be designed only grade separated intersections. KTR 1.01: 2008 (1 Table)

2. Write sentence in KTR 1.01: 2008: "When choosing intersection type, designer must take into account road functional level and calculate level of service (LOS) index."

3. For the calculation of the level of service index for better results 30 HV should be used, therefore the owner of roads in the Lithuanian Road Administration under the Ministry of Transport and Communications has to ensure the availability of these data.

4. To evaluate the possibilities of the Lithuanian Road Administration under the Ministry of Transport and Communications to implement the concept of self-explaining roads in the Lithuanian road network.

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