AN APPROACH TO INVESTIGATE RELATIONSHIP BETWEEN SPEED AND SAFETY ON URBAN ARTERIALS

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ABSTRACT

AN APPROACH TO INVESTIGATE RELATIONSHIP BETWEEN SPEED AND SAFETY ON URBAN ARTERIALS

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Traffic safety is an important problem in today's world with increasing number of fatalities and injuries in traffic accidents. For the solution of this problem, determination of accident prone locations on a network and reasons behind is an essential step, which is studied to some extend via different traffic accident analyses in the literature. While major factors affecting accident risk, such as speed, congestion, infrastructural aspects are known, it is still very difficult to figure out the interaction among these factors, due to complexity in the spatial and temporal distribution of the aforementioned factors and traffic network characteristics. While the case of accident analysis on highways is simpler, in case of urban roads, it requires more effort due to more complex traffic networks with quite a number of conflict points and varying flow characteristics. To investigate possible relationships between speed and accident occurrence on urban arterials, a Geographic Information Systems based accident analysis methodology (GIS-TAAM) is developed in this study.

This methodology uses time-dependent average link speeds (calculated from GPS-based data) and accident history of links, and three safety measures in thematic accident maps: i) total number of accident, ii) a severity index based on number of fatality and injury accidents, and iii) an alternative severity index based on total number of fatalities and injuries. The implementation of the proposed methodology and its deliverables are discussed over a pilot study on İnönü Boulevard – Eskişehir Road, Ankara.

Keywords: Accident analysis, Geographical Information Systems, Severity Index, Urban corridors, Speed and safety

ÖZ

KENT İÇİ ANA ARTERLERDE HIZ İLE TRAFİK GÜVENLİĞİ ARASINDAKİ İLİŞKİNİN BELİRLENMESİ İÇİN BİR YAKLAŞIM

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Günümüzde trafik güvenliği, artan ölüm ve yaralanma oranlarıyla önemli bir sorundur. Bir ağdaki kazaya meyilli yerlerin belirlenmesi ve bu kazaların nedenlerinin tespit edilmesi bu sorunun çözülmesi için gerekli bir adımdır ve literatürde farklı kaza analizi yöntemleri ile çalışılmış bir konudur. Kaza riskini etkileyen hız, tıkanıklık, altyapısal durum gibi ana faktörler bilindiği halde, bahsedilen faktörlerin ve trafik ağ özelliklerinin mekansal ve zamansal dağılımındaki karmaşıklıklardan dolayı, işleyen mekanizmayı anlamak hala çok zordur.

Şehirler arası yollar için kullanılan kaza analizi yöntemleri daha basitken, şehir içi yollar söz konusu olduğunda bu ağların daha fazla sayıda çatışma noktası ve değişken akım özellikleri nedeniyle daha fazla çaba gerekir. Bu çalışmada şehir içi ana arterlerde hız ile kaza oluşumu arasındaki ilişkiyi araştırmak için Coğrafi Bilgi Sistemleri tabanlı bir Kaza Analizi Yöntemi (CBS-KAY) geliştirildi. Bu yöntem, (GPS ile ölçülmüş) zamana bağlı ortalama kesim hızları ile kesimin geçmiş kaza oranları ve üç güvenlik ölçütü ile hazırlanan tematik kaza haritalarını kullanır: i) toplam kaza sayısı, ii) ölümlü ve yaralanmalı kaza sayılarına dayalı şiddet endeksi ve iii).ölü ve yaralı sayılarına dayalı şiddet endeksi. Yöntemin uygulanması ve sonuçları Ankara İnönü Bulvarı-Eskişehir Yolu koridoru üzerinde yapılan bir pilot çalışma üzerinden tartışıldı.

Anahtar Kelimeler: Kaza analizi, Coğrafi Bilgi Sistemleri, Şiddet Endeksi, Kent içi koridor, Hız ve güvenlik.,

to
my family

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"Gratitude is when memory is stored in the heart and not in the mind."

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LIST OF ABBREVIATIONS

GDH	General Directorate of Highway
GDS	General Directorate of Security
GIS	Geographical Information Systems
GPS	Global Positioning System
OECD	Organization for Economic Co-operation and Development
SIM	Severity Index Map
SIT	Statistical Institution of Turkey
GIS-TAAM	GIS-based Traffic Accident Analysis Methodology
TAM	Traffic Accident Map
TD-SIM	Time-dependent Severity Index Map
TD-TAM	Time-dependent Traffic Accident Map
TIS	Traffic Information System
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

An ideal transportation system aims to operate safely, effectively and with minimum harm to environment. In today's highway systems, this ideality is being lost mainly due to the imbalance between the travel demand and network supply, which results in high congestion levels, especially on the urban networks (Zhao, 1997). For instance, in the United States, the vehicle travel has increased 70%, while the road capacity has increased slightly more than 1% over the last two decades (Stephanedes, 2000). In such conditions traffic regime is getting more and more complex. As a result of this, the exposure of the population to traffic accidents increases (Zarif, 2000). Thus, the traffic safety problem today becomes "a world wide problem" with over 500 million cars and trucks in use, and more than 1.26 million people dying each year in motor vehicles crashes, and about 50 million are getting injured (Zarif, 2000; WHO, 2004).

A study carried out by Organization for Economic Co-operation and Development (OECD) states that in OECD member countries, more than 125,000 people are killed in road crashes each year and millions more are injured, many of them permanently. The cost of the road safety problem in the OECD area amounts 2% or more of gross domestic product (OECD, 2003). WHO estimates that without any efforts and new initiatives, the total number of fatalities and injuries in road traffic accidents would rise 65 % between years 2000-2020 and in low-income and middle-income countries the fatality rate would increase by 80 % (WHO, 2004).

The trend in Turkey is not any different. While the capacity of the system has not been significantly increased (less than 10% between 1999-2003), the vehicle ownership has been in an increasing trend (more than 140% between 1992-2005). As a result, the traffic safety problem results in 4,500 fatalities and 150,000 injuries annually (GDS, 2005; SIT, 2005).

1.1 Problem Definition

Traffic safety is an important issue that requires special effort to identify accident prone locations as well as their causes. In order to assess the problem, accident analyses methodologies have been developed. The traffic pattern on urban arterials differ from intercity highways in both network and operation terms, thus the accident analysis methodologies should differ. Namely, any design or operational mistakes in the roads would be important in the analysis of urban traffic networks, since the denser patterns possess more conflict points and more complexity distributed spatially. Therefore, the existing accident analysis methodologies developed for the intercity highways should be modified for the urban networks.

There are quite a number of factors causing traffic accidents (human-, infrastructure-, environment-, and vehicle-related), thus affecting traffic safety. The spatial interactions among these factors causing and/or contributing to traffic accidents can be studied effectively using Geographical Information Systems (GIS) environment, which is an integral part of this study. GIS approach is powerful in such an analysis mainly for the following reasons:

> i) GIS enables the spatial analysis and mapping of accidents, where many aspects of urban land use, traffic network characteristics can be displayed in juxtaposition.

ii) Using GIS database options, it is possible to access some descriptive statistics values.

iii) With GIS thematic mapping, a better representation of deliverables (such as accident rate maps, speed distribution maps, etc.) is possible; this makes detection of accident prone locations easier.

The digitization of the network into GIS environment is an important issue, which requires special focus on links defined based on the accident location information as well as the operational and physical attributes of the network at this section.

1.2 Organization of the Thesis

This study includes a brief evaluation of the traffic safety in Turkey in Chapter 2, providing basic statistics showing the current trend in the traffic demand, network capacity and traffic accident rates, and comparisons of the results with the world statistics. In Chapter 3, a literature review on the relationship between speed and safety is presented, followed by the review of the accident analysis methodologies and finally, the use of GIS and GPS in transportation and specifically in accident analysis is summarized. In Chapter 4, a framework for a GIS-based Traffic Accident Analysis Methodology (GIS-TAAM) is presented. A discussion of the deliverables of the methodology is included. In Chapter 5, the analyses of the proposed methodology applied on a pilot corridor (İnönü Boulevard-Eskişehir Road, Ankara) are presented. First, corridor characterization is validated through analysis of average link speeds. In addition to the thematic maps representing total and time-depending accident rates, a descriptive analysis of the traffic safety characteristics of the is included. Chapter 6 presents conclusions and recommendations for future research.

CHAPTER 2

TRAFFIC SAFETY IN TURKEY

The situation of transportation systems in Turkey is not any different than the world trend. The number of vehicles is constantly increasing without much increase in the network capacity. The high capacity roads have increased less than 10 % and the low capacity village roads were increased at most 13.5 % in terms of lengths between years 1999-2005 (see Table 2. 1), while the number of motor vehicles in Turkey is in a continuously increasing trend with a rate of 143 % between years 1992 - 2005 (see Table 2. 2). It should be noted that the decrease in the total length of state highways in Table 2.1 (-0.1%) is mainly due to reclassification of the roads

Table 2. 1 Lengths of Motorways, State Highways, Provincial Roads and Village Roads* (SIT, 2005)

	1999	2000	2001	2002	2003	% increase (1999-2003)
Motorways	1,749	1,773	1,851	1,851	1,881	7.5
State Highways	31,388	31,397	31,376	31,319	31,358	-0.1
Provincial Roads	29,535	29,693	29,929	30,050	30,133	2.0
Village Roads	321,820	354,642	363,248	364,329	365,171	13.5
* : all lengths are in km						

Table 2. 2 Number of Motor Vehicles in Turkey (1992-2005) (SIT, 2005)

Year	Total	Private Car (1)	Minibus	Bus	Pick up Truck (1)	Truck (2)	Motorcycle	Special Purpose Vehicles	Tractor
1992	**4,584,717**	2,181,388	145,312	75,592	308,180	379,410	655,347	10,908	828,580
1993	**5,250,622**	2,619,852	159,900	84,254	354,290	406,398	743,320	12 049	870,559
1994	**5,606,712**	2,861,640	166,424	87,545	374,473	419,374	788,786	12 964	895,506
1995	**5,922,859**	3,058,511	173,051	90,197	397,743	432,216	819,922	13 691	937,528
1996	**6,305,707**	3,274,156	182,694	94,978	442,788	453,796	854,150	15 003	988,142
1997	**6,863,462**	3,570,105	197,057	101,896	529,838	489,071	905,121	16 993	1,053,381
1998	**7,371,241**	3,838,288	211,495	108,361	626,004	519,749	940,935	19 252	1,107,157
1999	**7,758,511**	4,072,326	221,683	112,186	692,935	531,690	975,746	20 319	1,131,626
2000	**8,320,449**	4,422,180	235,885	118,454	794,459	557,295	1,011,284	21 822	1,159,070
2001	**8,521,956**	4,534,803	239,381	119,306	833,175	562,063	1,031,221	22 939	1,179,068
2002	**8,655,170**	4,600,140	241,700	120,097	875,381	567,152	1,046,907	23 666	1,180,127
2003	**8,903,843**	4,700,343	245,394	123,500	973,457	579,010	1,073,415	24 468	1,184,256
2004	**10,236,358**	5,400,714	318,957	152,380	1,260,009	647,295	1,218,710	27,979	1,210,314
2005(3)	**11,145,826**	5,772,745	338,539	163,390	1,475,057	676,929	1,441,066	30,333	1,247,767
% Increase (1992 - 2005)	**143**	**165**	**133**	**116**	**379**	**78**	**120**	**178**	**51**

(1) Including off-road vehicles
(2) Including dump truck, towtruck, tanker, etc.
(3) Including December 2005 data

The traffic safety gets more critical due to the fact that majority of the passenger and freight transportation in Turkey is undertaken by highway systems whereas other modes only have limited shares (see Table 2. 3). The 1983 Transportation Master Plan for Turkey foresaw that the imbalance within the modes of the transportation should have been altered by integrating the modes and decreasing the share of highways. Unfortunately the transportation policies of the last 25 years had not yielded to the expectation.

Table 2. 3 Percentages of Passenger and Freight Transportation in Turkey by Modes of Transportation (SIT, 2006)

	Passsenger (%)				Freight (%)			
	Highway	**Railway**	**Water (*)**	**Air (*)**	**Highway**	**Railway**	**Water (*)**	**Air (*)**
2001	90.47	4.52	4.84	0.17	95.21	3.15	0.02	1.62
2002	91.94	4.40	3.50	0.17	95.37	3.04	0.01	1.58
2003	91.38	5.21	3.24	0.17	95.00	3.40	0.01	1.59
2004	94.15	5.65	-	0.19	95.37	2.87	-	1.76
2005	94.59	5.19	-	0.22	95.28	2.63	-	2.09
2006	94.83	5.17	-	-	97.26	2.74	-	-
(*) Only domestic values								

When the causes of the accidents occurred in Turkey are considered, the human factors stands as the main cause (GDH, 2005). Table 2. 4 presents the detailed distribution of causes of accidents between years 2001 and 2005 based on the on-site filled accident reports. The rate of driver factors contributing to traffic accidents (consistently over 96% in the five year period) is the highest among all the other factors. However, this rate is subject to discussion. Most of the researchers agree that the high rate of driver factors on the contrary to low rate of infrastructural factors is not realistic. This misleading statistics is the result of the following facts:

- In the accident reports the predefined infrastructure related factors do not cover all the possible cases, but include very rare cases, such bridge collapse
- Police officers preparing the report do not always posses the knowledge to detect the possible infrastructure defects causing an accident.
- It is a common practice to penalize humans, more specifically drivers, as the active causes of an accident, instead of a full analysis with more precise allocation of fault.

Nevertheless, it is a commonly accepted fact that the majority of the accidents in Turkey occur due to driver errors.

Table 2. 4 Causes of Traffic Accidents for Turkey, 2001-2005 (GDH, 2005)

YEAR	DRIVER (%)	PEDESTRIAN (%)	PASSENGER (%)	VEHICLE (%)	ROADWAY (%)	OTHER (%)
2001	96.82	2.38	0.16	0.32	0.32	-
2002	96.99	2.48	0.12	0.25	0.16	-
2003	97.29	2.16	0.13	0.25	0.17	-
2004	97.46	2.08	0.1	0.21	0.15	-
2005	97.68	1.98	0.05	0.15	0.14	-

The statistics on traffic accidents are kept by two law enforcement units based on their jurisdictions: police department and the gendarmerie outside the police jurisdiction (according to Law No. 2918; The Law of Highway Traffic). Currently, the police handle traffic safety control over 114,000 km of road in mainly urban regions while gendarmerie deal control over 313,000 km of road. In case of an accident, the responsible agency is obliged to fill in the accident report. Currently there are two types of accident reports in effect; one for property damage only accidents and one for injury and fatal accidents. In these reports, mainly information about the involved people and vehicles, the weather and infrastructure at the instance of accidents, and the results of the accidents are recorded.

All these reports prepared by the officials are kept at the local stations for legal and insurance purposes but, for accidents with injuries or fatalities, a copy of the report is sent to General Directorate of Security (GDS) where the digital accident database is composed and kept. The Traffic Information System (TIS) is activated by GDS in March 2003 for the aim of establishing a standard system with different interfaces for different end-users providing proper traffic related data to the related agencies and people. As a subsystem of TIS, all the police teams among the country are equipped with tablet computers with wireless internet connections enabling queries among the system as well as GPS receivers enabling the record of coordinates of accidents. Since the activation of the system, all the accidents occurred throughout the country are recorded in the TIS database with the GPS coordinates (Işıldar, 2005).

The digital data is processed and the cumulative statistical reports are sent to Statistics Institution of Turkey (SIT), the responsible agency for publishing them yearly. All the accident data from Turkey is collected and tabulated by SIT (2005) showing about 4,500 fatalities and 150,000 injuries every year in Turkey. A detailed statistics is presented in Table 2.5. The significance of the traffic accidents for the society does not stem only from directly these deaths and injuries but, also from the consequent problems, some of which include mental disorders of victims and their families, failure in business and education, etc. Besides, the economical burden of the accidents to Turkey is estimated as 5 billion YTL per year. Although the number of accidents occurred have been in an increasing manner, the number of fatalities decreased up to 2003 then started to increase.

The cumulative values here are not good indicators of the situation. They should be normalized considering the population, vehicle ownership, number of licensed drivers and vehicle-kilometers traveled. For this purpose, Table 2.6 is prepared (SIT, 2004; GDS, 2002). The rates of fatalities and injuries are in a decreasing trend for Turkey; however they are still greater than the rates for developed countries (see Table 2.7).

Table 2. 5 Number of Accidents Occurred in Turkey and Their Results, 2001- 2005 (GDH, 2005)

			2001	2002	2003	2004	2005
Number of Accidents	Police	Urban	363,528	362,979	373,531	436,187	502,682
		Rural	45,879	44,124	48,771	58,664	67,737
		Total	409,407	407,103	422,302	494,851	570,419
	Gendermarie		33,553	32,855	33,365	42,533	50,764
	TOTAL		**442,960**	**439,958**	**455,667**	**537,384**	**621,183**
Number of Fatalities	Police	Urban	1,309	1,215	973	1,128	1,159
		Rural	1,645	1,685	1,845	1,954	2,056
		Total	2,954	2,900	2,818	3,082	3,215
	Gendermarie		1,432	1,269	1,148	1,346	1,310
	TOTAL		**4,386**	**4,169**	**3,966**	**4,428**	**4,525**
Number of Injuries	Police	Urban	62,690	62,202	59,355	67,693	77,843
		Rural	31,807	32,023	35,969	41,988	46,142
		Total	94,497	94,225	95,324	109,681	123,985
	Gendermarie		21,705	21,820	21,944	26,548	30,109
	TOTAL		**116,202**	**116,045**	**117,268**	**136,229**	**154,094**
Amount of Property Damage (YTL)	Police	Urban	163,535,154	199,439,042	326,826,637	46,527,450	606,380,239
		Rural	70,635,371	82,622,865	141,508,999	205,663,878	272,889,529
		Total	234,170,525	282,061,907	468,335,636	652,191,328	879,269,768
	Gendermarie		37,239,241	40,350,323	66,873,083	95,729,840	126,876,873
	TOTAL		**271,409,766**	**322,412,230**	**535,208,719**	**747,921,168**	**1,006,146,641**

Table 2. 6 Fatality and Injury Rates for Turkey, (1980-2005) (GDS, 2002; SIT, 2005)

	Number of					Fatality per 100,000			Injury per 100,000		
Year	Fatalities	Injuries	Population	Licenced Drivers	Vehicles	Population	Licenced Drivers	Vehicles	Population	Licenced Drivers	Vehicles
1980	4,199	24,608	44,439,000	2,788,439	1,684,019	9.45	150.59	249.34	55.37	882.50	1461.27
1981	4,441	29,744	45,540,000	2,909,716	1,785,758	9.75	152.63	248.69	65.31	1022.23	1665.62
1982	4,884	35,976	46,688,000	3,030,907	1,887,878	10.46	161.14	258.70	77.06	1186.97	1905.63
1983	5,201	44,769	47,864,000	3,164,629	2,018,608	10.87	164.35	257.65	93.53	1414.67	2217.82
1984	5,731	50,521	49,070,000	3,365,784	2,186,515	11.68	170.27	262.11	102.96	1501.02	2310.57
1985	5,680	51,586	50,307,000	3,750,794	2,375,141	11.29	151.43	239.14	102.54	1375.34	2171.91
1986	7,315	71,264	51,433,000	4,195,915	2,653,715	14.22	174.34	275.65	138.56	1698.41	2685.44
1987	7,530	80,321	52,561,000	5,168,831	2,987,215	14.33	145.68	252.07	152.81	1553.95	2688.83
1988	6,846	79,174	53,715,000	5,336,257	3,313,005	12.75	128.29	206.64	147.40	1483.70	2389.79
1989	6,332	80,013	54,894,000	6,119,046	3,655,090	11.53	103.48	173.24	145.76	1307.61	2189.08
1990	6,286	87,693	56,098,000	6,951,291	4,091,888	11.21	90.43	153.62	156.32	1261.54	2143.09
1991	6,231	90,520	57,193,000	7,321,386	4,487,259	10.89	85.11	138.86	158.27	1236.38	2017.27
1992	6,214	94,824	58,248,000	8,152,827	4,584,717	10.67	76.22	135.54	162.79	1163.08	2068.26
1993	6,457	104,330	59,323,000	8,860,359	5,250,622	10.88	72.88	122.98	175.87	1177.49	1987.00
1994	5,942	104,717	60,417,000	9,426,727	5,606,712	9.83	63.03	105.98	173.32	1110.85	1867.71
1995	6,004	114,319	61,532,000	9,982,417	5,922,859	9.76	60.15	101.37	185.79	1145.20	1930.13
1996	5,428	104,599	62,667,000	11,096,626	6,305,707	8.66	48.92	86.08	166.91	942.62	1658.80
1997	5,181	106,146	63,823,000	12,351,842	6,863,462	8.12	41.95	75.49	166.31	859.35	1546.54
1998	4,935	114,552	65,001,000	13,256,967	7,371,241	7.59	37.23	66.95	176.23	864.09	1554.04
1999	4,596	109,899	66,200,000	14,026,799	7,758,511	6.94	32.77	59.24	166.01	783.49	1416.50
2000	3,941	115,877	67,421,000	15,066,282	8,320,449	5.85	26.16	47.37	171.87	769.11	1392.68
2001	2,954	94,497	68,365,000	15,426,272	8,521,956	4.32	19.15	34.66	138.22	612.57	1108.87
2002	2,900	94,225	69,302,000	15,802,680	8,655,170	4.18	18.35	33.51	135.96	596.26	1088.66
2003(*)	2,818	95,324	70,231,000		8,903,843	4.01		31.65	135.73		1070.59
2004(*)	3,082	109,681	71,152,000	no data	10,236,358	4.33	no data	30.11	154.15	no data	1071.48
2005(*)	3,215	123,985	72,065,000		11,145,826	4.46		28.84	172.05		1112.39

Table 2. 7 Fatality Rates for Some Countries (International Road Traffic and Accident Database, 2005)

Country	Number of Accidents	Number of Fatalities	Number of Vehicles	Population (1000)	per 1000 population	per 100 000 Vehicles	per 100 000 population
Austria	43,426	931	5,114	8,118	630	18	11
Canada	156,904	2,766	18,869	31,630	597	15	9
Czech Republic	27,320	1,447	4,490	10,203	441	32	14
Finland	6,907	379	2,657	5,206	510	14	7
France	90,220	6,058	36,198	59,625	608	17	10
Germany	354,534	6,613	53,656	82,537	650	12	8
Iceland	787	23	207	290	714	11	8
Japan	947,993	8,877	80,970	127,619	635	11	7
Korea	240,832	7,212	17,519	47,925	366	41	15
Netherlands	31,635	1,028	8,387	16,192	518	12	6
New Zealand	10,615	461	2,801	4,009	697	16	11
Norway	7,921	280	2,752	4,577	601	10	6
Poland	51,078	5,640	15,899	38,191	416	35	15
Portugal	41,495	1,546	5,197	10,475	496	30	15
Slovenia	11,910	242	1,065	1,996	534	23	12
Spain	99,987	5,399	25,170	42,196	597	21	13
Sweden	18,365	529	4,998	8,941	559	11	6
Switzerland	23,840	546	4,888	7,318	668	11	7
Turkey	**83,788**	**4,525**	**11,146**	**72,065**	**155**	**41**	**6**
United Kingdom	220,079	3,658	31,950	59,554	537	11	6

CHAPTER 3

ACCIDENT ANALYSIS STUDIES

Road traffic is a consequence of the interaction between road users (drivers, passenger and pedestrians), infrastructure and vehicles. Traffic accidents occur when there are conflicts between these elements, thus the factors affecting safety are closely related to these elements. Among them, human related ones are often referred to as the prime factor as discussed in the previous chapter. Among human related factors that affect safety, speed is pronounced as one of the most important that it is cited as a related factor in 30% of fatal crashes and 12% of all crashes (Aljanahi et al., 1999; Aarts et al., 2006)

3.1 Speed and Safety

The adverse effect of excessive speed on traffic safety is proved by the following two statements: a) Physically the higher the speed of a vehicle, the higher the kinetic energy to be dissipated in case of an accident, thus the more severe the result of the accident will be and b) the higher the speed of a vehicle, the more time required for drivers for safe stopping, but unfortunately lower time is allowed usually, due to driver’s limitations (Kloedon et al., 1997; Feng, 2001).

3.1.1 Speed and Safety Relations

The earliest study in the literature on the speed and traffic safety subject is Solomon’s (1964) commonly cited work in which a U-shaped curve was developed between crash involvement rate and deviation from average travel speed. As a result of the study, he concluded that crash rates were lowest for speeds close to mean speed of the traffic. Cirillo (1968) confirmed these results. Some of the later studies objected their results suggesting that they have overestimated the effect of slow speeds since the accidents occurred at slow speed ranges are most probably occur due to maneuvers of the vehicles thus related to these maneuvers rather than slow speeds (Stuster, J., 1998). None of the more recent studies found evidence that slower vehicles have an increased crash liability (Aarts et al., 2006).

In the literature there exist quite a number of studies that seek analytical relationships in between accident occurrences and the speeds. In a significant number of these studies, absolute speeds (speeds of individual vehicles or links) are considered (Aljanahi, et al., 1999; Navon, 2003). When the speeds of individual vehicles were considered, either the speed of the vehicle at the instance of accident was estimated or the measured vehicular speeds were associated with the accident history of the driver (Kloedon et.al, 1997; Solomon, 1964). In case of link speeds, either the accident rates of the links are associated with their average speeds or the effect of a development on the rates of accidents were investigated through before-after studies. Besides absolute speed, speed variation is another parameter significant in accident analyses. Some studies in the literature are based on association of the vehicular speed differences with accident rates where some other on link-based speed differences (Frith et al., 2001; Solomon, 1964).

Since the speed definition varies among studies, the relationships differ in nature. But generally higher accident rates are expected in higher speed ranges. In most of the studies, exponential relations are offered (Kloedon et. al, 1997; Fildes, 1991).

3.1.2 Speeding Behavior

Despite that a clear relationship between speeds and traffic accidents exists, speed violation is a common behavior that even more than 90% of all motorists are estimated to exceed the speed limits during their driving careers (Moroney & Dewar, 1987; Zaal, 1997). Rumar (1989) explains the speeding behavior by mobility being the main goal for the road users, yet safety only secondary. The persistent speeding behavior of drivers suggests that accidents are perceived as rare events, thus drivers fail to perceive the relationship between accident occurrence and speed (Zaal, 1997; Elliot, 1992) explains. Further more speeding is perceived to be rewarding to drivers by saving time and giving the individuals a feeling of excitement (Fuller, 1990). Hillman and Plowden (1986) claims that conviction of speeding has a small probability of occurrence and this tolerant attitude would encourage speeding.

This high rate of commitment highlights the significance of factors that may influence the driver's speed choice. These are summarized as follows (Navon, 2003; Kloeden, et al., 1993; Feng, 2001):

- Environmental Factors: The time of day, weather conditions, etc. affects the speed choice of a driver.
- Driver Characteristics: The age, alcohol consumption, experience, gender, having risk taking behavior of a driver is effective in the speed choice.
- Infrastructure Related Factors: The physical characteristics of the roadway (the curvature, grade, etc.) and the operational design parameters (signalization, intersection, lightening, etc.) are referred to as effective in the speed choice.

- Speed Limit: The speed limit is also an important factor in the speed choice of a driver. A number of studies are available on the effects speed limit change on traffic safety.

3.2 Accident Analysis Methods

The significance of the traffic safety is already summarized in the previous sections. It is obvious that analytical approaches should be developed for the assessment and solution of such a large scale safety problem, which is a matter of public concern. For this purpose, accident analysis methodologies are developed.

The traffic safety measures are important at this point. The 'safety' in terms of traffic is usually quantified by the rate, frequency, severity indices. Most of the countries keep an accident database storing certain accident data such as the number of cars involved, number of fatalities and injuries, accident type, characteristics of the drivers and vehicles, environmental conditions at the instance of accident, etc. of accidents. But the content of such databases vary among countries, so do the accident analyses. Nevertheless, the first step in an accident analysis is the determination of accident prone locations, so called 'black spots'. Right after the black spot analysis, the following steps are listed in a general accident analysis: a) observation of the problems, b) identification of possible precautions, c) estimation of the effects, d) prioritization, e) application, f) monitoring and evaluation (Sjolinder, 2001).

3.2.1 Black Spot Analysis

Black spot analysis aims to determine the accident prone locations. The cumulative attributes of the accidents occurred at the same segment, intersection or location on a highway are used to confirm a black spot. The attributes may change according to the methodology but the commonly referred ones are the accident, fatality and injury rates.

In the literature, the following methods are referred for this confirmation: 1) Frequency Method, 2) Accident Rate Method, 3) Frequency Rate Method, 4) Rate- Quality Control Method, 5) Severity Index Method, 6) Inventory of Road Characteristics, 7) Proneness Index (Khisty et al., 1998). In a comprehensive accident analysis methodology, traffic flow and density parameters should also be associated with the accident rates for normalization.

3.2.2 Accident Analysis Method in Turkey

In Turkey, the rate-quality control method is accepted by the General Directorate of Highways (GDH). In practice, this method offers to compare the i) accident rate, ii) frequency and iii) severity index of 1 km segment of a highway with the statistically determined upper limits. When all of these three values exceed the upper limits, the segment is defined as a black spot. In the analyses, exposure based and population based rates are preferable for comparison purposes (Roess et al., 2004).

There exist two different definitions of severity index. In the first one (SI_A), the accidents are categorized into three as 'Property Damage Only (PDO)', 'Injury (I)' and 'Fatal (F)' and the severity of the accident is calculated by multiplying the number of accidents in each category using predefined coefficients for that category. In the second severity index (SI_B) calculation, selected coefficients are applied directly to number of injuries and fatalities in all the accidents in a segment.

The SI_A computed by GDH in Turkey is as follows (Sjolinder, 2001):

$$SI_A = PDO + 3 * I + 9 * F \quad \text{(1)}$$

where:

PDO: number of property damage only accidents.

I: number of injury accidents.

F: number of fatal accidents.

Another definition of severity index considers the number of fatalities, injuries and damaged vehicles instead of number of accidents which can be calculated as follows (Sjolinder, 2001):

$$SI_B = PDV + 3 * In + 9 * Fa \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where:

PDV: number of damaged vehicles.

In: number of people injured in accidents.

Fa: number of people died in accidents

The calculations with PDO accidents are better in terms of black spot confirmation, but since 2001 the data for PDO accidents are not stored in the database of GDS in Turkey. In the light of this new application, the formulas in Equations 1 and 2 can be modified simply leaving out the PDO and PDV terms, respectively. This results in severity indices where a relative fatality to injury ratio of (9:3) is obtained (Sjolinder, 2001).

3.3 GIS/GPS Use in Transportation

Geographical Information Systems (GIS) can be defined as computer-based systems consisting of hardware, software, people, and data that enable capturing, storing, updating manipulating, analyzing, and displaying geospatial data (Aronoff, 1991). Nowadays GIS are preferable in many different disciplines with their database and analysis tools as well as mapping tools. With this capability of mapping geo-referenced data, today GIS are extensively used in geography, archeology, city planning, disaster management, facilities management and transportation.

Global Positioning System (GPS) is a positioning system based on getting instantaneous location, time and speed information from the satellites (Unsal, 2006). The commercial GPS receivers used today enable: i) navigation through software specially developed, ii) storage, display and transfer of track data. GPS track data gathered can be easily transferred to a GIS environment and further analyses can be done at this environment. This is because the basic GPS position information is provided in the form of latitude and longitude on the surface of the Earth, which is compatible with common GIS location specifications (Taylor, 2001).

3.3.1 GIS/GPS Applications in Transportation

With their capabilities in geo-referenced data manipulation, GIS are frequently used for transportation (GIS-T). Transportation analysts and decision makers are using GIS tools in infrastructure planning, design and management, public transit planning and operations, traffic analysis and control, transportation safety analysis, environmental impacts assessment, hazards mitigation, and configuring and managing complex logistics systems (Miller, 2001).

In transportation studies, GPS receivers are used to collect travel time and speed data. With the integration of these data with GIS, fleet management and monitoring, and transportation network mapping are possible (Demiroluk, 2007; Unsal, 2006; Mintsis, 2004). Another recent application area of GPS in transportation is the collection of coordinates of accidents. In Turkey the GPS coordinates of the accidents are recorded since March 2003 (Işıldar, 2005).

3.3.2 GIS/GPS Use in Accident Analyses

GIS is an effective tool in traffic safety studies enabling accident analyses as well as displaying the accident-prone locations with thematic maps. It is possible to carry out accident analysis with the collected GPS coordinates of the accidents in a GIS environment. Another possible analysis may be the association of speed data collected by GPS to accidents.

So far, there are three recent GIS-based studies in Turkey. Though none of these studies include association of speed to accident rate or consideration of volume normalization, it is important to summarize them here for the sake of completeness of literature review.

First study includes development of a model correlating the geometric and environmental features of the highways to accident rates in Turkey (Şener, 2005). In this study, the national accident data is cross-referenced highway characteristics (lane number, divided/undivided road, etc.) and environmental factors (weather, daytime versus nighttime, etc.) at the location of the accident from accident reports database. A logistic regression analysis is performed to find weights of selected factors in accident risk. These nation-wide values are compared with the ones calculated for the state highways and motorways of the city of Ankara. GIS environment is used only for visual display of the accidents.

The second study is the GIS-based analysis of traffic accidents occurred in Ankara between years 2002-2004 (Soylemezoglu, 2006). In this study, the accident database of city of Ankara is digitized into GIS environment and some queries are performed in order to determine high accident rate locations and the causes of the accidents. In addition to this, a detailed analysis is available in the study for Atatürk Boulevard which has the highest accident rate for the study period. In this part of the study, the spatial distribution of the accidents by type (rear-end, head-on collision, etc.) on this corridor are mapped.

Last study is the accident analysis of a ten-year period (1996-2006) intercity roads of Afyonkarahisar and its neighboring cities, in GIS environment (Erdogan et al., 2007). In this study, black spots on the study roads are detected through a Poisson model defined and the reasons behind the accidents were investigated through field surveys.

CHAPTER 4

A GIS-BASED TRAFFIC ACCIDENT ANALYSIS METHODOLOGY (GIS-TAAM)

Today, the population and car ownership in many metropolitan cities are increasing, so are the demand and traffic congestion in the transportation systems. When the capacities of the arterials become insufficient during peak hours, the municipalities traditionally try to increase the capacities by adding extra lanes if possible, which however results in higher operating speeds during off-peak periods. As a result, sudden and big speed changes are observed, when vehicles slow down at merging, diverging and crossing points on arterials. Thus, lane addition results in not only speeding and sudden speed changes during off-peak hours but also very different operating speeds on the same route in a day. In addition to this, when the transportation demands for suburban settlements of metropolitan cities are met by the main arterials, the suburban parts of the main arterials experience less congestion but higher operating speeds compared to urbanized parts.

All these conditions about urban arterials make the effort to develop a more specific traffic accident analysis methodology worthwhile. Such a methodology should be developed by customizing the ones for the intercity highways to address the following two urban traffic safety situations:

- In urban networks the distance between two successive intersections varies and there are many operational and physical features within very short distances.
- The accident reports in urban regions of Turkey refer to major buildings or benchmarks for the accident location data, whereas in intercity highways simply the station km information is recorded.

In this chapter, a proposed framework of an accident analysis methodology for urban corridors is presented. Such a methodology has to cope with the complexity of the urban traffic conditions, such as dense network and time-dependent traffic nature. Thus, a discussion on the data requirements and GIS component of the proposed methodology is provided in the following sections.

4.1 A Framework for a GIS-TAAM

Although the accident analysis methodology may differ depending on the classification of the road (highway, urban), the goal is the same: assessment and solution of traffic safety problem. Initially, one or more accident rate measures discussed in Chapter 3 are calculated for pre-defined segments of the roadways (links, station kilometers, intersections, etc.). This is generally followed by the determination and verification of "black spots" in the network. Later, the operational and physical attributes of these segments are associated to these rates and black spot locations to detect any relationship in between. To develop a traffic accident methodology associating speeds of the links to accident rates, it requires; i) speed measurement, ii) traffic accident statistics, iii) association of speed and accident rates. A framework of such a general methodology developed in GIS environment for urban corridors is presented in Figure 4.1.

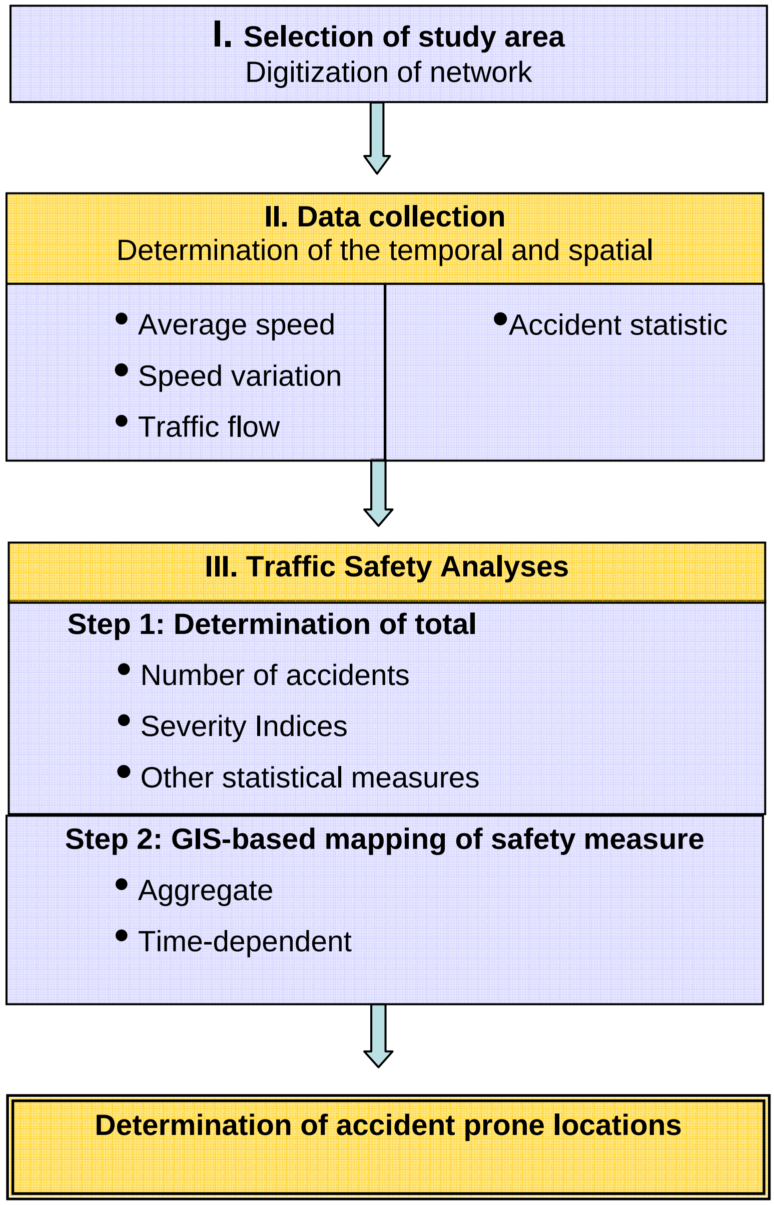


Figure 4. 1 Framework of the proposed GIS-TAAM

4.1.1 Corridor Characterization

Segmentation of the corridor is the first and an important step of this process. Especially, urban road segments where accidents are catalogued in reference to buildings, or locations, etc, traffic accident reports should be studied to detect common benchmark definitions to be used in corridor link definitions. Additionally, the operational and infrastructure features should be considered when defining the links; in other words; all the operational and physical changes (such as the intersection locations, the speed variances, the conflict points, etc.) and possible black spots on the area that would be effective in accident occurrence should be identified and digitized. It is better to divide the study corridor into sections, if different urbanization levels and/or land use patterns exist along it. This is required due to the fact that traffic regimes differ under different traffic demand derived from land use and urbanization levels. For example, travel demand of suburban regions is met by the main arterials, which creates less congestion, thus higher operating speeds, in the suburban parts of the arterials, compared to highly urbanized central parts.

4.1.2 Data Requirements

The required data for an accident analysis study that associates speed and accident rates are i) network data, ii) accident data, and iii) speed data.. Additionally, traffic characteristics such as flow and density can be also used in association with speed and accident data. As a simple example, the accident numbers can be normalized based on the average flow at the location. Also, it is well know that traffic speed is a function of flow and density, itself. While a more detailed analysis using such additional data is recommended, this study only focuses on a methodology capturing the direct relation between speed and accidents, ignoring the secondary or indirect interactions. Also, it should be noted that for the proposed study to produce conclusive results, the speed and accident observations should be proper and relevant, with enough archival data. The details of the required database for the proposed methodology are discussed below:

Network Data

The network should be digitized according to its operational and physical attributes. This requires defining the nodes and links, locating the operational changes, collecting the information related to infrastructure (such as direction of flow, number of lanes, etc.), identifying neighboring buildings and areas, etc. For an accident analysis, it is better to define the links and nodes considering the location definitions in the accident reports, in addition to the operational and physical aspects. In case of urban regions, these location definitions are mainly based on common buildings and benchmarks in the neighborhood. However, in the low-urbanized parts, the station kilometer of the location is preferred.

Accident Data

For the proposed methodology, the attributes of interest of the accidents can be listed as: a) time at the instance of accident, b) results of the accident (in terms of fatalities and injuries), c) exact location of the accident.

In Turkey, the time, and the number of fatalities and injuries are recorded in the accident reports. The locations of the accidents are also recorded with verbal definitions; for urban areas reference to some benchmarks is observed In addition to this, with the activation of TIS, the traffic policemen are GPS-equipped thus recording the GPS coordinates of the accidents as well. When available, these coordinates of the accidents occurred on the study area can be used to establish the exact locations of the accidents. If GPS data is not available, the accident definitions recorded in the reports can be used for a manual match with the traffic network.

Speed Data

The proposed methodology requires association of average link speeds to accident rates, therefore a speed archive should be available for average link speeds observed on the links. At this point, two issues are significant for urban corridors:

a) The point speed measurements commonly used on intercity highways are difficult, expensive and not reliable on urban roads.

b) On urban corridors, the speed is i) time-dependent (temporal), and ii) geographically distributed (spatial). In other words; not only different links may vary in speeds significantly but even speed of a single link may vary based on the time of the day. Namely, on the main arterials during peak periods of morning and evening, speeds are slower than the speeds in noon off-peak and night. To capture the variation of average link speeds during a day, link speeds should be observed and archived in a time-based manner.

One of the most cost-efficient methods to obtain such kind of a speed data for urban regions is measurements with GPS-equipped probe vehicles. A detailed discussion of types and shortcomings of such methods, as well as data archive requirements are discussed by Demiroluk (2007). Demiroluk's statistical algorithm mainly focuses on characterization of links and traffic regimes on them to detect bottleneck probabilities, based on average and distribution of link speeds. This method uses an algorithm to calculate link speeds from GPS data called Track Data Analyst (TDA), developed by Unsal (2006).

Briefly stated, TDA first matches GPS track data with the digitized network, then detects the entrance (t_{in}) and exit (t_{out}) times for the probe vehicle for each link. If it is not possible to match a track data to nodes, the t_{in} and t_{out} values are estimated through the last/first track data on the previous/next link and the first/last data on the link. The difference between either measured or estimated t_{in} and t_{out} values for each link gives the travel time on the link, which is used to calculate the average speed using link length. After multiple lapses over the link, statistical averaging of these link speeds is also performed. To capture the realistic characteristics of the corridor, the determination of the link speeds should be carried out this analysis in a time-dependent manner. For this purpose, Demiroluk defined a Time-dependent Corridor Characteristics Database, which should be considered for an accident analysis studying the impact of speed, as well.

As previously stated, in this methodology the average link speeds calculated through the analyses of GPS-equipped probe vehicle measurements are associated to archival accident rates. There is no reference to the actual speeds of the vehicles at the instance of accidents.

4.2 The GIS Component

When dealing with a phenomenon that has temporal and spatial variation, such as the speeds and accidents on urban corridors, GIS is an essential part of the proposed methodology. GIS component here is effective at different levels. Initially, the corridor is digitized into a GIS environment. A simple GIS application would be the mapping of accident data in association with the corridor links that would show the spatial distribution of the accidents. When supported with additional layers of land use or road characteristics, etc, the GIS mapping of accidents can easily display any safety characteristics along the selected corridor.

As a separate analysis, average link speeds for different time windows can be thematically mapped via GIS for the observation of speed variance along the corridor. After this, the accident rates of the links can be calculated by the association of the accidents to the links, in a time-dependent or aggregate manner. It is possible to map time-dependent average speeds of each link from a separate GIS analysis as a different layer for the developed time-based accident rate maps or to map the aggregate accident rates on the corridor as the next step.

Thematic GIS maps described above, which are some of the deliverables of the GIS-TAAM, can be grouped into two as follows:

a) Aggregate Maps:

- Traffic Accident Map (TAM): Aggregate number of accidents occurred on each link can be thematically mapped.
- Severity Index Maps (SIM): Severity Index values for each link can be calculated and thematically mapped.

    a) SIM_A: Can be calculated as defined in Equation 1.

    b) SIM_B: Can be calculated as defined in Equation 2.

b) Time-dependent Maps:

- Time-dependent Accident Map (TD-TAM): Different maps for different time windows can be prepared with simultaneous mapping of average link speeds and number of accidents for each time window.
- Time-dependent Severity Index Maps (TD-SIM): Different maps for different time windows can be prepared with simultaneous mapping of average link speeds and severity index values of each period. Similar to aggregate maps, different severity index definitions can be mapped.

    a) SIM_A: Can be calculated as defined in Equation 1.

    b) SIM_B: Can be calculated as defined in Equation 2.

Possible outcomes and analyses through these maps can be listed as follows:

- Determination of accident-prone locations.
- Relationship between average link speeds of links and number (or severity and equivalency) of accidents.
- Temporal and spatial distribution of accident probability.
- Prioritization of the accident prone locations.
- Determination of locations with high fatality rates.

Among these maps, it is important to understand and interpret the chosen analysis measure correctly. For the aggregate maps, while a TAM would give the distribution of accidents along the corridor, mostly enabling to detect "black spots" in terms of number of accidents. A SIM_A would further highlight locations where more accidents with fatality are recorded. Different than a SIM_A, a SIM_B would rather show locations where more people got injured/died. Also, it is possible to confirm or evaluate the appropriateness of standard coefficients used to convert number of fatalities to injuries in the severity index calculations. However, it should be noted that if there are extreme cases such as one accident involving a public transit vehicle with very high number of fatality/injury, an SIM_B would be affected from it and give more importance to that location; but it would be more just to look not only to the SIM_B but also the frequency of such high fatality/injury rate accidents.

Similar to aggregate maps, the time-based maps enable comparison of number of accidents to number of fatalities and injuries in a time-based manner. In addition to these, these maps can be used to interpret the speed variance among the urban and suburban parts of the corridors for the same time window or speed variance of the same link for different time windows. The effects of these variances among accident occurrence, and fatality and injury rates can also be observed via TD-SIMs.

4.3 Descriptive Statistics

In addition to thematic maps created by GIS-based analyses, it is important to gather and examine some statistics for link based accident rates and severity indices. These statistics can be gathered by any statistical software as well as a spreadsheet program, or simply by query options of the GIS software. The percentage of links within speed intervals for different periods, the percentage of links with high accident rate in addition to high observed speeds, the percentage of links having accidents, etc. can be significant statistical data in the evaluation of the safety of the study corridor. This way, a numerical representation of any relationship between selected safety measures and network characteristics can be drawn or tested. While standard test or reports of statistical analyses have not been developed within in the scope this work, some example analyses are performed for the case study discussed in the next chapter using the pilot study data.

CHAPTER 5

CASE STUDY: TRAFFIC ON İNÖNÜ BOULEVARD - ESKİŞEHIR ROAD CORRIDOR

As a pilot study, the traffic safety and flow-speed characteristics of an urban arterial corridor in Ankara are analyzed by the GIS-TAAM and link-based statistical measures described in the previous chapter. This chapter includes a description of the corridor, brief discussion on the network digitization, speed data collection via GPS-equipped probe vehicles, and available accident data for the study. Later, the thematic maps of the corridor derived based on GIS-TAAM are presented with a discussion on the safety characteristics of different parts of the corridor. Finally, the GIS analyses are supported by descriptive statistics, whenever possible.

5.1 Description of the Corridor

The study area is selected as the İnönü Boulevard - Eskişehir Road corridor, one of the main arterials of Ankara. The corridor extends from Kızılay Intersection to Beltway Exit with a length of slightly more than 20 km (see Figure 5.1). Since the direction is an important factor on the time--dependent traffic characteristics, the two directions will be studied separately. Kızılay to Eskişehir direction is denoted as “outbound” direction and Eskişehir to Kızılay

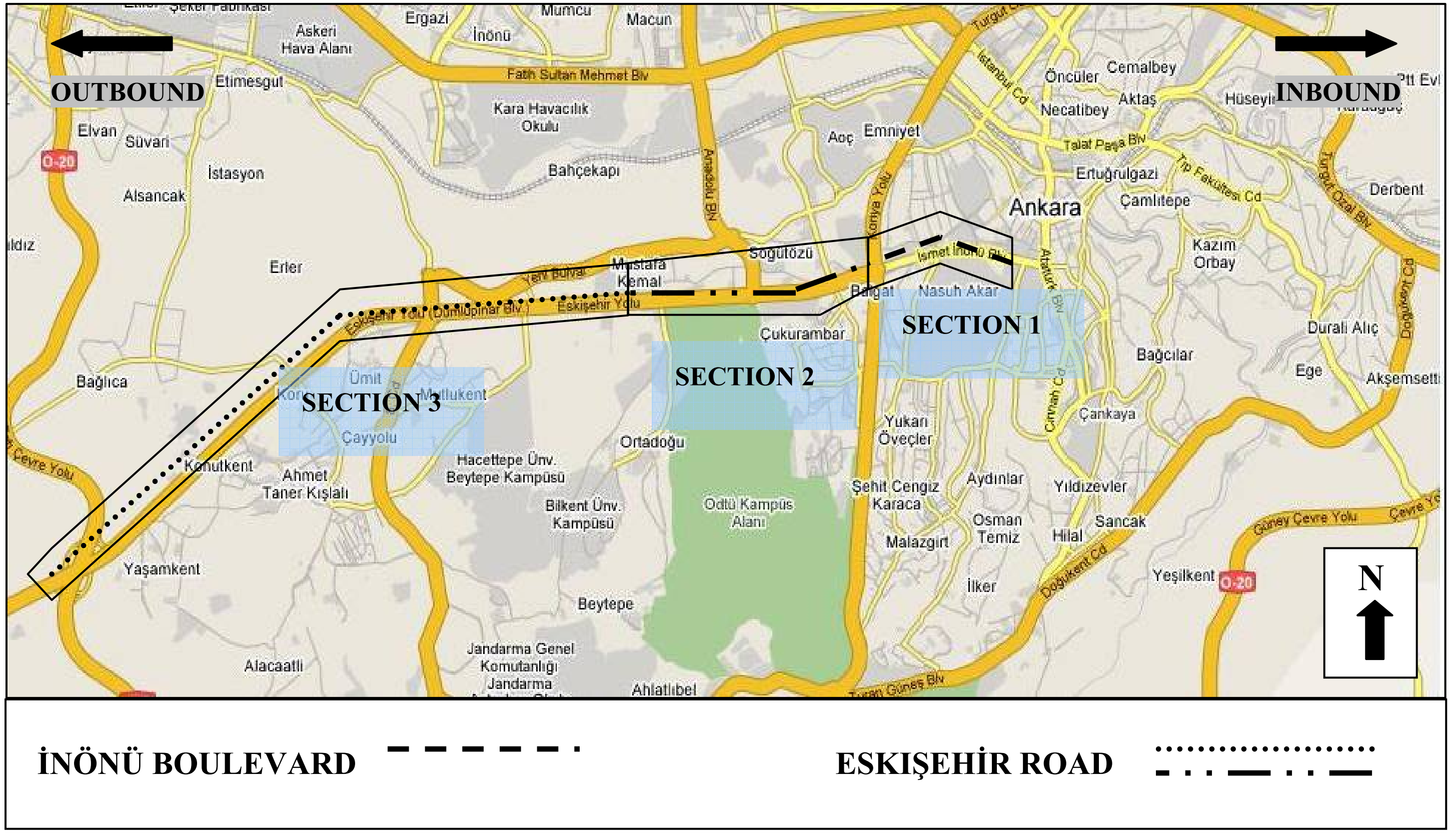


Figure 5. 1 Map of İnönü Boulevard – Eskişehir Road Corridor (Map of Ankara City Center, 2008)

direction is denoted as “inbound” hereafter. The whole corridor is a divided road having either three or four lanes per direction along the route.

As the corridor is a relatively long arterial stretching from city center to the beltway and possesses different traffic characteristics at different locations, it is divided into three sections according to flow characterizations and urbanization level alongside as follows:

- **Section-1:** This section is the 3.5 km long highly urbanized portion of the corridor extending from Kızılay Intersection (at a central business district and the House of Parliament) to Konya Road Intersection. It has many office buildings for the military, ministries, etc. and is interrupted with a number of intersections connecting highly populated residential regions of the city (Bahçelievler, Balgat, Anıttepe, Maltepe, Kızılay), thus showing urban arterial characteristics (See Figure 5.2). Along this section, there exist three lanes per direction and the current traffic operational design includes two grade-separated intersections, one causing one-lane segments at critical merge/diverge points. Heavy vehicles are not allowed to travel at this part of the corridor. During the speed measurements, there existed a work-zone in the inbound direction at Bahçelievler region; therefore the inbound traffic is rerouted as shown in the network.

- **Section-2:** This is a 4.2 km long segment extending from Konya Road Intersection to Bilkent University Intersection and serving the traffic of/to major shopping centers, and two big university campuses (Middle East Technical University and Bilkent University with populations of approximately 25,000 and 10,000, respectively), as well as traffic from outer suburban neighborhood located in Section 3. There is relatively less residential population along this segment but it is mainly a

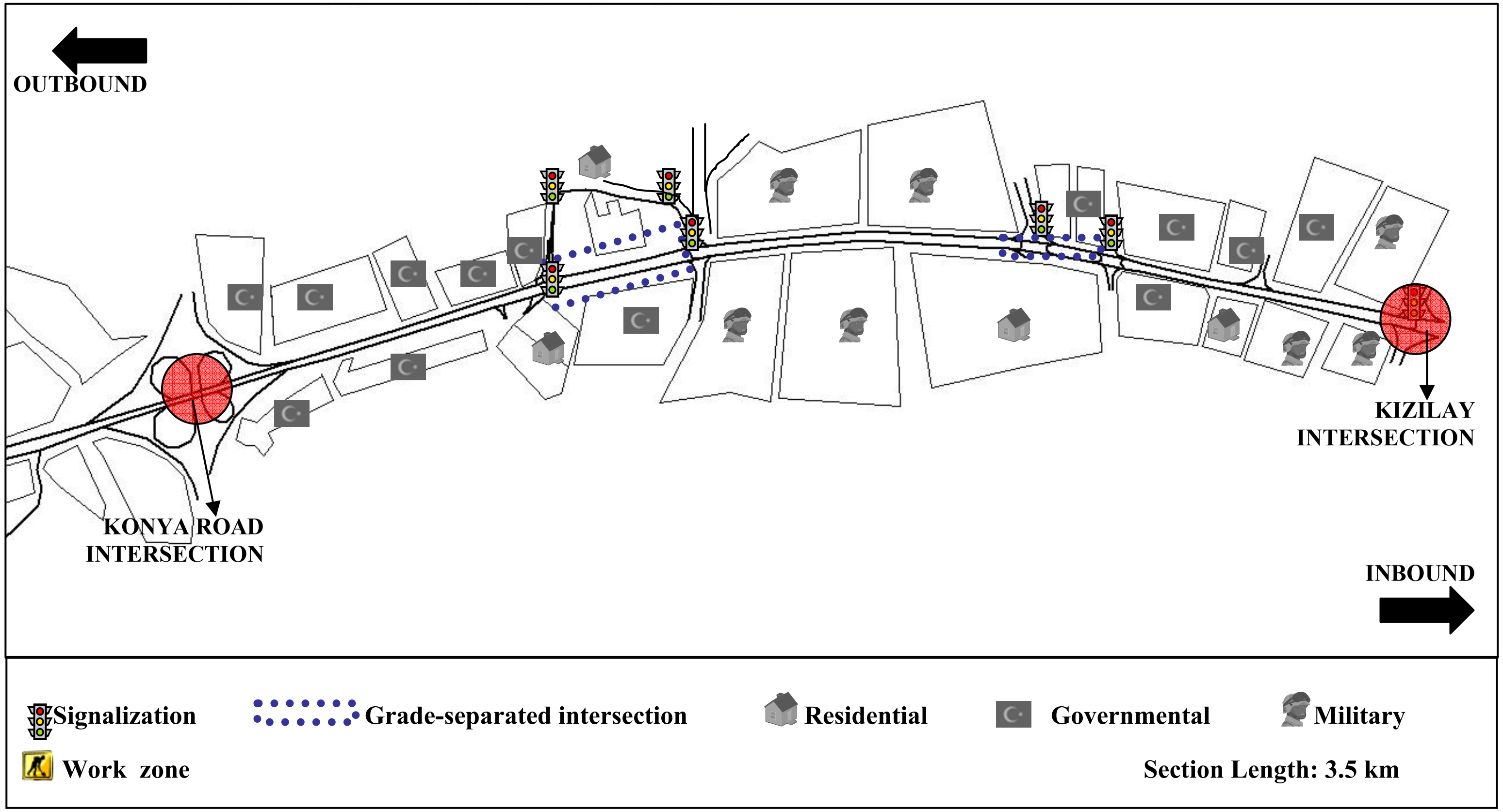


Figure 5. 2 Map of Section-1 with Adjacent Land-Use

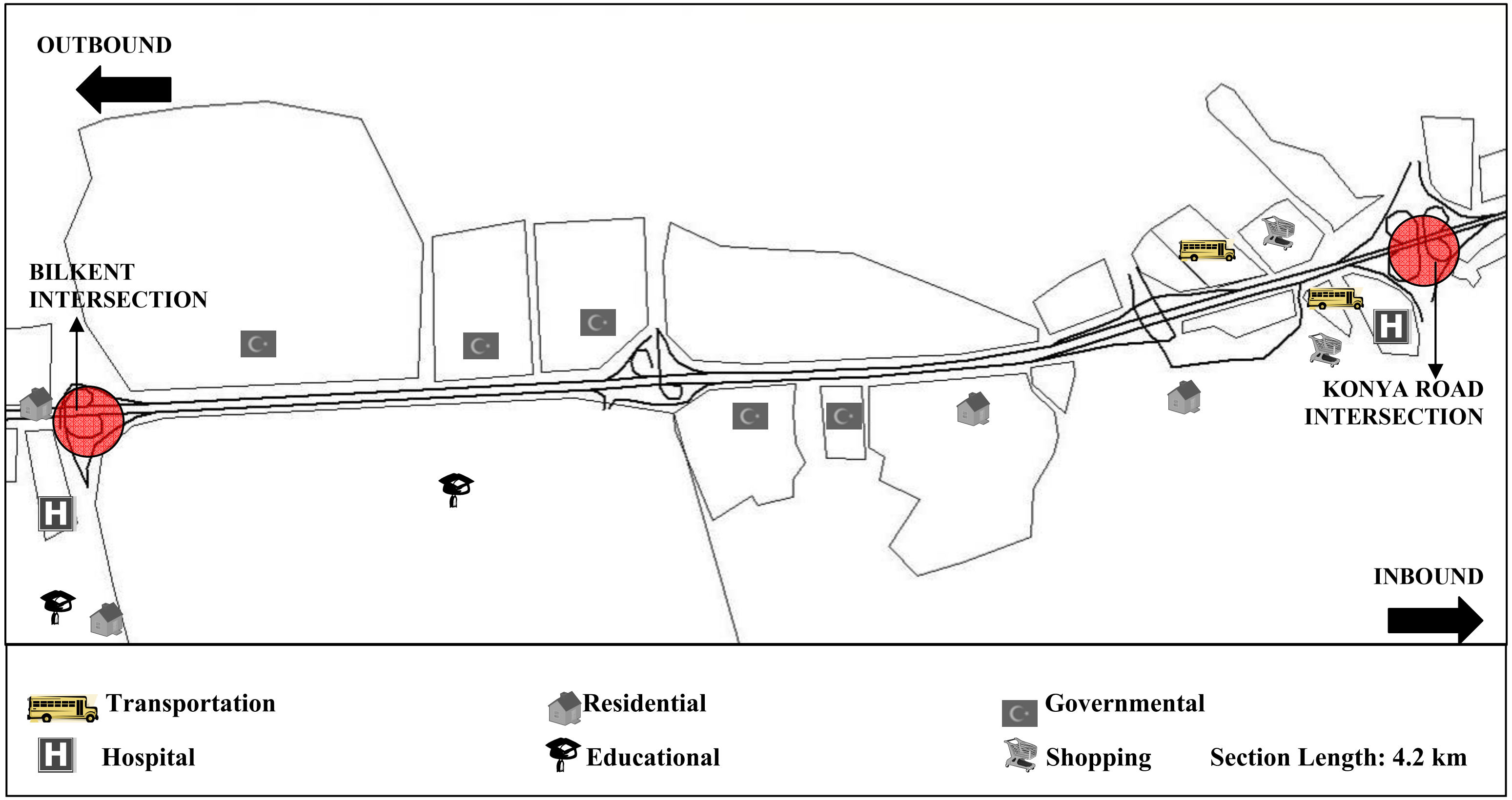


Figure 5. 3 Map of Section-2 with Adjacent Land-Use

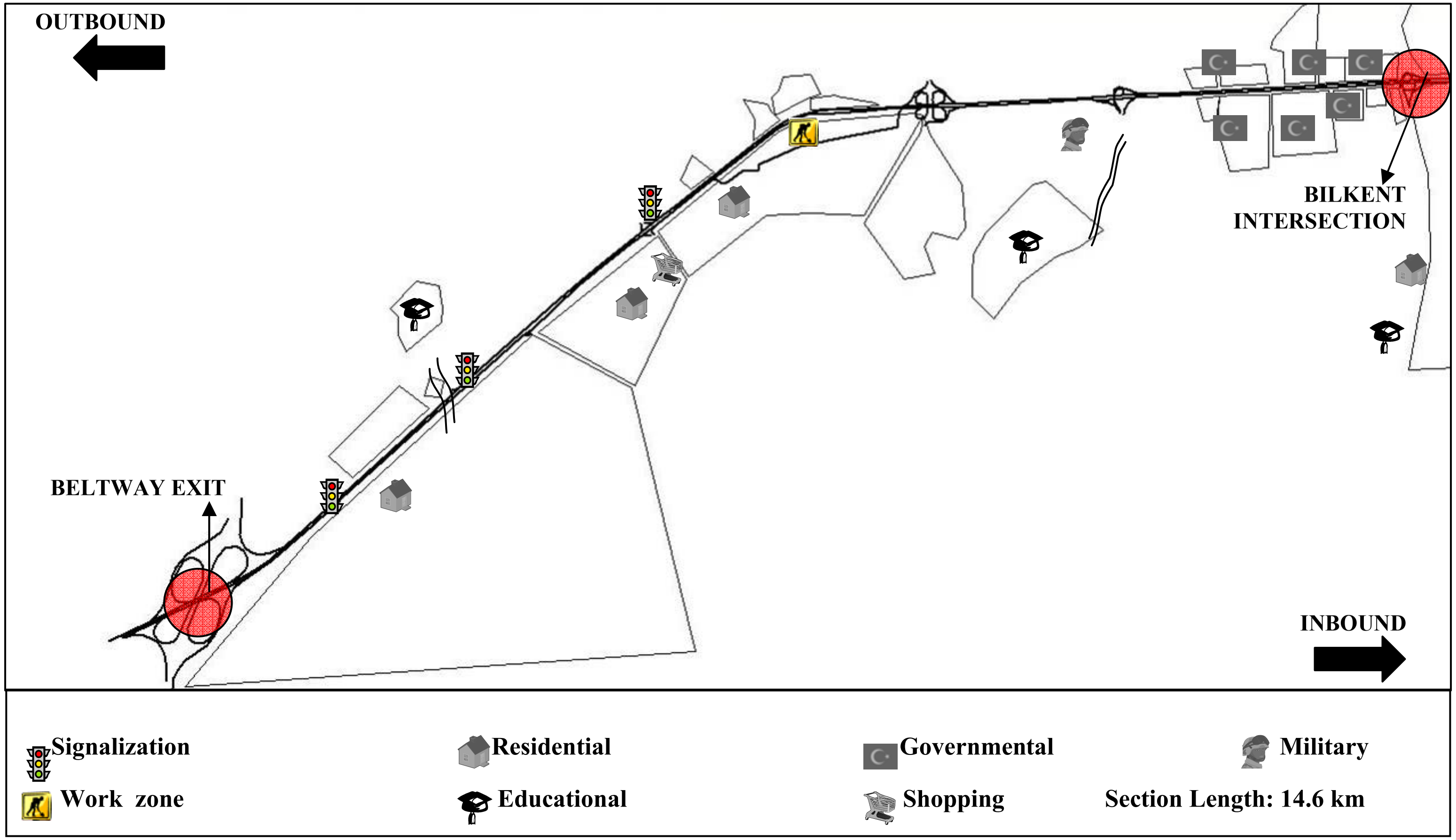


Figure 5. 4 Map of Section-3 with Adjacent Land-Use

transitional part of many public transit routes serving the suburbia (see Figure 5.3).

Section-3: The last section extends 14.6 km from Bilkent University Intersection to Beltway Exit (See Figure 5.3). The regions served by thissection of the corridor are; i) recently urbanized regions such as Ümitköy, Çayyolu and Konutkent carrying the suburbia structure, ii) military and governmental areas with limited access and large unused areas, iii) two other university campuses (Hacettepe Univesity and Başkent University with populations of 30,000 and 10,000 respectively). Between Ümitköy and Konutkent there exist a work-zone in the inbound direction hence the traffic is rerouted at this portion of the section.

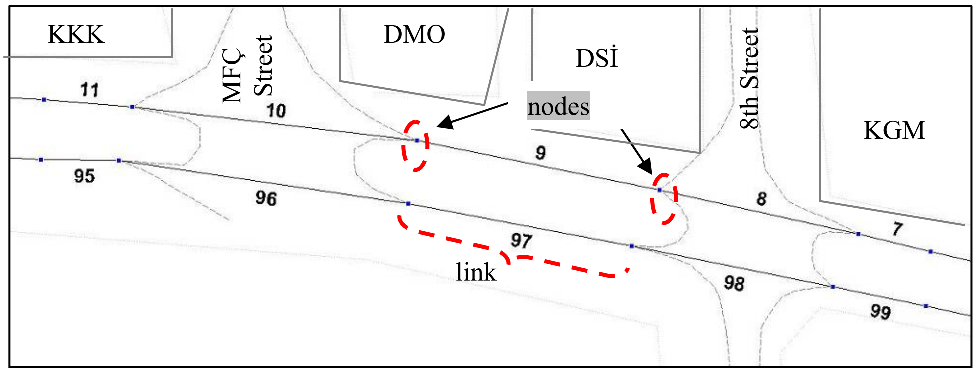
5.2 Data Requirements

As described in GIS-TAAM, in the network creation part, the whole corridor is digitized into a GIS environment via MapInfo software by defining 104 links (53 in Section-1, 16 in Section-2 and 35 in Section-3), mainly based on the accident report reference points, such as major buildings, and operational and design criterion such as intersections, grade-separation start and end nodes, traffic lights (see Appendix A). All the statistical and GIS analyses mentioned hereafter are based on these predefined links.

Then, the accident database of GDS was used to calculate the accident rates on the individual links. Average link speeds were estimated through speed data collected via probe vehicles using TDA software developed by Ünsal (2005). A detailed discussion of these data is provided in the following sections.

5.2.1 Network Data

The important part of the network digitization is the definition of links and nodes. In this study, nodes are defined as locations where there are operational changes (changes in number of lanes, etc.), physical changes (entrance of grade-separated intersections, etc.), or operational features (signalization, etc.) are observed. Some other nodes are defined to denote certain lengths or location definitions used in the accident reports. A link lies in between two successive nodes. As there is no length-based limit in defining nodes, links between nodes are of different lengths. Any accident defined (from accident report) or located on a link (from GPS data) is mapped at the middle of the link. Although the intersections are commonly denoted by nodes in traffic networks, in this study, it is preferred to define them as short links in order to represent accidents recorded to happen at an intersection. A part of the network with the corresponding nodes and links is depicted in Figure 5.5.



Link 7: Karayolları Genel Müdürlüğü (KGM) Intersection (Int.)
Link 8: 8th Street Int.
Link 9: In front of Devlet Su İşleri (DSİ) and Devlet Malzeme Ofisi (DMO) buildings
Link 10: Mareşal Fevzi. Çakmak (MFÇ) Int.
Link 11: Kara Kuvvetleri Komutanlığı (KKK) Int.

Figure 5. 5 A Snapshot of the Digitized Network with Links and Nodes

5.2.2 Accident Data

The fatal and injury accidents occurred on İnönü Boulevard - Eskişehir Road corridor between years 2003 and 2005 were used in this study. Through queries among the digital database of the GDS, several attributes of these accidents that would be related to the study (time at the instance of accident, fatalities and injuries, location of accidents, GPS coordinates, etc.) are summed up for statistical and GIS analyses.

Initially the GPS coordinates of the accidents are mapped, verified, and corrected (when necessary) with the verbal definitions of the locations of the accidents. For the accidents having no GPS coordinate data (the accidents occurred before March 2003), only the verbal definitions are used to manually assign the accidents to links. As a result, each accident is assigned to a link on the network The accident statistics for year 2006 are also available but not included into the analyses for this study because the data for Section-2 and 3 do not include the verbal accident definitions. Since a verification and correction of the available GPS data was not possible, this year was not covered in this study.

For time-dependent analysis, the accident data is divided into subgroups based on the four time windows defined in a day: morning period (07:00 - 11:00), noon (11:00 - 15:00), evening (15:00 - 20:00), and night (20:00 - 07:00). During the study period (2003 – 2005), a total of 431 fatal and injury accidents occurred on the corridor, yearly distributions of which are available in Table 5.1. According to this table, the annual number of accidents on the corridor has been increasing. Furthermore, most of the accidents occurred during night in the 3 year period. It should be noted night time is a 11-hour period, where as the periods have durations of only 4 or 5 hours. It is also important to remember that the number of accidents occurred is not considered as a good or conclusive measure for traffic safety. Instead, the number of fatalities and injuries should also be included in the analyses as well as the number of vehicles traveling through the corridor in each time period. For this purpose; the severity indices of these accidents will be calculated in the following parts of the analyses.

Table 5. 1 Yearly statistics of Fatal and Injury Accidents on İnönü Boulevard - Eskişehir Road Corridor (2003 - 2005)

	Morning	Noon	Evening	Night	Total
2003	13	20	27	30	90
2004	26	33	35	48	142
2005	40	40	55	64	199
Total	79	93	117	142	**431**

5.2.3 Speed Data

The speed data collection is performed in accordance with the previously defined time windows by tracking with GPS-equipped probe vehicles for a representative one hour interval within these periods. The track logs for 08:30 - 09:30, 12:30 - 13:30, 18:30 - 19:30, and 23:30 - 00:30 respectively for morning, noon, evening and night are collected on a number of days. During data collection, basically Magellan GPS receivers (Explorer 400 and Explorer XL) are connected to the laptops and several laps were completed by one or two probe vehicles simultaneously. The probe vehicles simply followed the middle lanes conforming to operating speed of this lane at the time of measurement. Consequently, average speeds of each link are estimated through TDA software in a time-dependent manner (as for morning, noon, evening and night). This average link speeds are assumed to be constant within the link but also representative values for these time windows. For the sake of simple display, the average speeds of the links are grouped into four intervals as follows: 0-25 km/hr, 25-40 km/hr, 40-60 km/hr, and >60 km/hr. These values are selected based on the traffic regime limits for this corridor suggested by Demiroluk (2007), such as 0-25 km/hr mostly captures slow traffic regime during peak hours or high demand, and >60 km/hr represents high level of service running at free flow conditions (especially when the legal operational speed limit is defined as 50 km/hr for most of the corridor)

An important note here is that these average link speeds should be considered only as representative values calculated just for demonstration of the methodology since they are estimated through the analyses of a limited number of track logs. When there are more speed data measurements done, the average link speeds will be calculated more reliably, contribution positively to the reliability of the analyses and outcomes from the methodology.

5.3 Corridor Characterization

The analyses of track data by TDA estimated average speeds for individual links defined on the corridor for different time windows. Different speed characteristics are observed for previously defined three sections along the corridor. The observations for inbound and outbound directions are summarized in Table 5.2 and speed profiles of the Section-1, Section-2 and Section-3 are mapped in Figures 5.6, 5.7 and 5.8, respectively. In accordance with the table and figures, the speed characteristics for each section can be gathered as below:

Table 5. 2 Number of Links within Speed Intervals

STAGE 1		OUTBOUND				INBOUND			
		Morning	Noon	Evening	Night	Morning	Noon	Evening	Night
SPEED (km/h)	0-25	5	3	7	2	11	6	13	6
	25-40	13	8	11	8	9	10	9	5
	40-60	4	11	4	10	4	7	1	12
	>60	3	3	3	5	3	4	4	4
STAGE 2		**OUTBOUND**				**INBOUND**			
		Morning	Noon	Evening	Night	Morning	Noon	Evening	Night
SPEED (km/h)	0-25	0	0	0	0	0	0	0	0
	25-40	1	0	0	0	1	0	0	0
	40-60	1	3	1	0	1	3	1	0
	>60	6	5	7	8	6	5	7	8
STAGE 3		**OUTBOUND**				**INBOUND**			
		Morning	Noon	Evening	Night	Morning	Noon	Evening	Night
SPEED (km/h)	0-25	1	0	1	0	0	0	1	0
	25-40	0	0	0	0	0	1	0	2
	40-60	0	2	1	0	2	2	3	2
	>60	12	11	11	13	14	13	12	12

Speed Characteristics for Section-1:

- In the outbound direction, while most of the links are traveled at speeds between 0-40 km/hr during morning and evening periods, in the noon

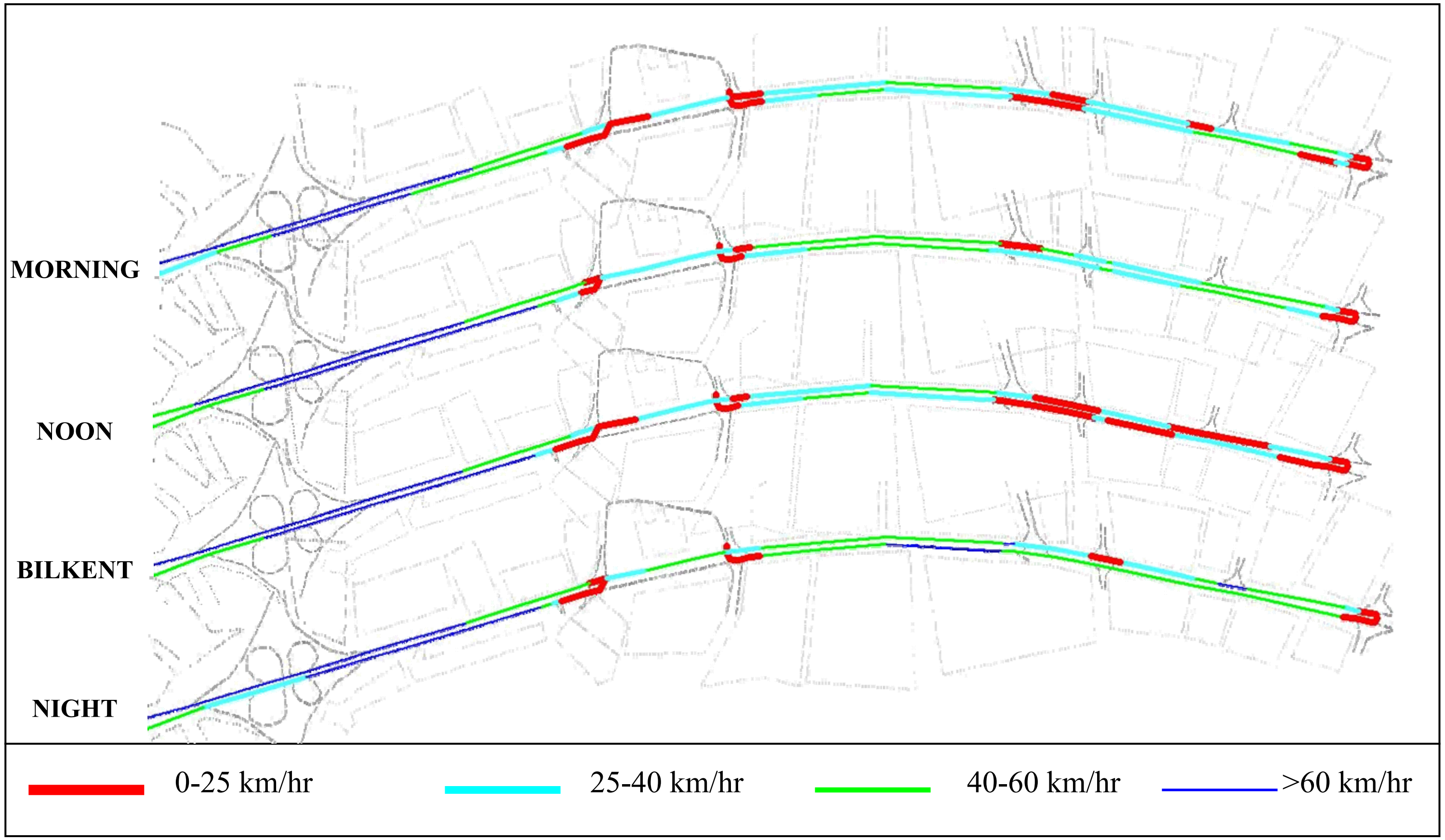


Figure 5. 6 Average Speed Profile along Section-1

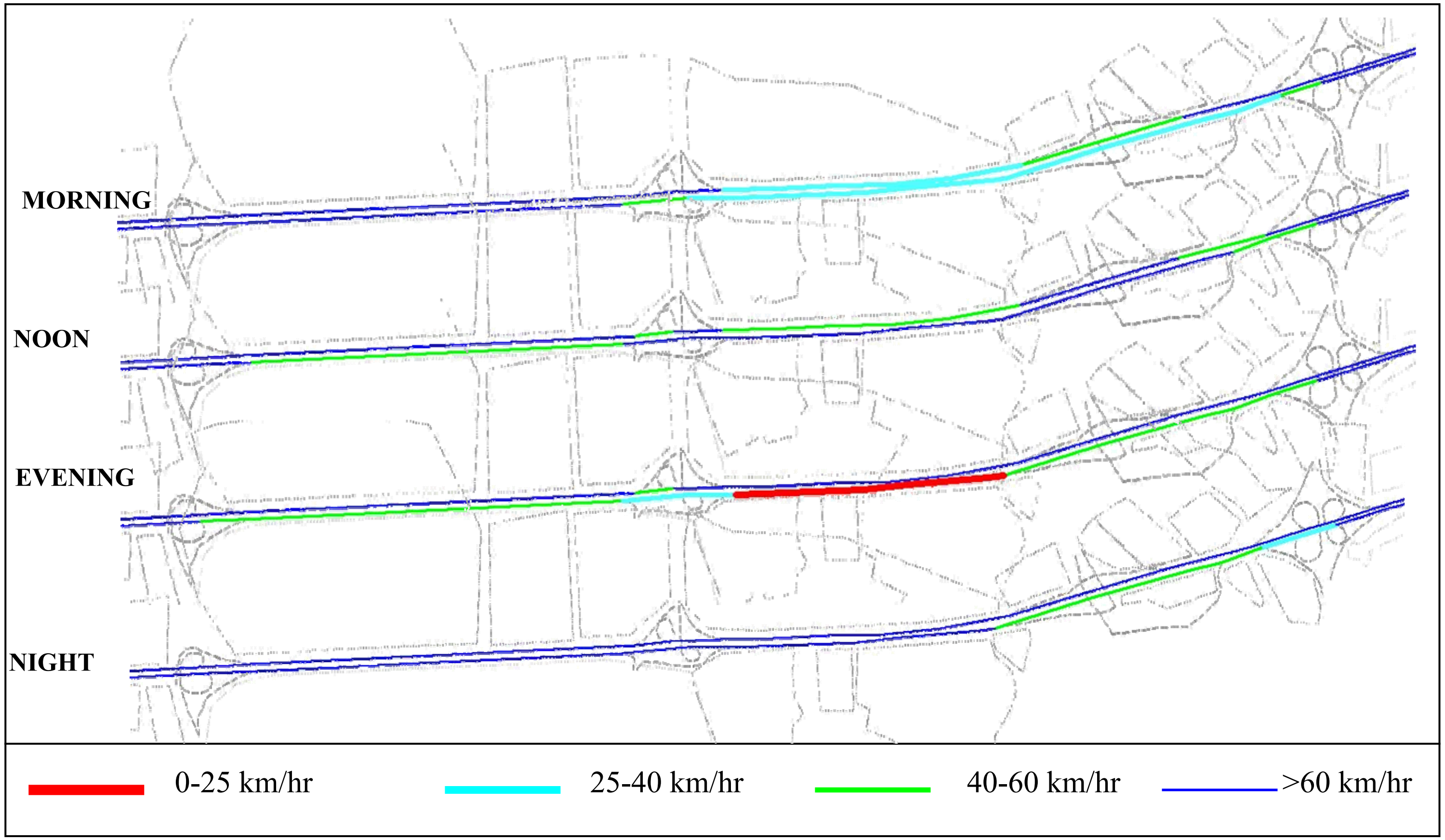


Figure 5. 7 Average Speed Profile along Section-2

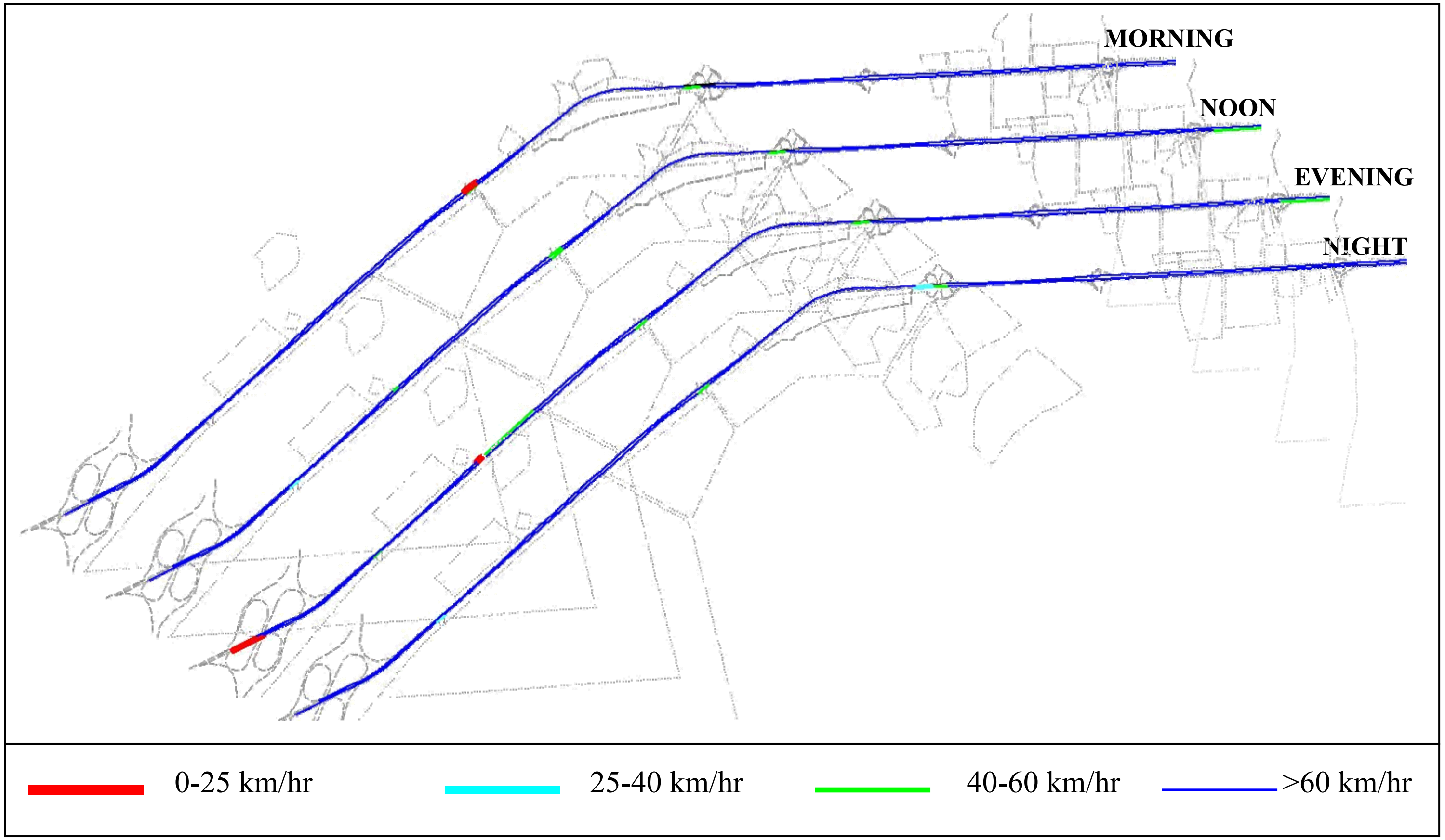


Figure 5. 8 Average Speed Profile along Section-3

off-peak and night periods most of the links have average speeds of 40-60 km/hr.

- In the inbound direction, in addition to morning and evening periods, average link speeds less than 40 km/hr are also observed on most of the links during noon off-peak
- Slow traffic regime (<25 km/hr) is observed in the morning for 5 links on which the evening trend is similar. In the evening, additionally two links are within this interval.
- In the morning and evening periods, a smooth variation of speed can be observed among the links where in the noon off-peak and night, sudden speed changes exist.

Speed Characteristics for Section-2:

- Most of the links are operated at speeds higher than 40 km/hr.
- Especially during night and noon off-peak periods, the observed operating speeds are higher than 60 km/hr for both directions.
- The inbound direction experiences the slowest traffic regime during evening peak.

Speed Characteristics for Section-3:

- Operating speeds higher than 60 km/hr are observed on almost all of the links in both directions.

These observed speed characteristics confirm to the prior section definitions: Section-1 experiences a slower traffic regime than the others due to being a highly urbanized region with a large number of conflict points. This section shows even slower regimes with highly congested parts in the morning and evening peaks. In Section-2, a transitional pattern is observed with slower operating speeds during peak hours in accordance with its transitional land use, urban to suburban. High operating speeds observed in Section-3 due to limited traffic conflict points and relatively high capacity links makes this section a transition segment with “almost highway” characteristics.

5.4 GIS-TAAM Analyses

Each traffic accident occurred on the corridor is associated to a link according to the recorded GPS coordinates and accident location definitions as described in the methodology chapter. In the development of the proposed GIS-TAAM, Section 1 is used as the test corridor for which a detailed report including various thematic maps TAMs, SIM_As and TD-TAMs is presented previously (Ardıç Eminağa and Tüydeş, 2007). In this dissertation, such thematic maps are prepared for two other sections, as well.

In thematic mapping, two approaches are followed: aggregate and time-dependent. With the aggregate analysis, the high accident rate locations are detected where with the time-dependent analysis, the timely distribution of and the effect of average link speeds on accident rates are observed. While both aggregate and time-dependent maps are prepared for all three sections, only some of these maps are presented in the following sections and the rest is available in the appendices.

5.4.1 Aggregate Analyses

In the aggregate analysis, all injury and fatal accidents (a total of 431) occurred within the study period (2003-2005) are associated to links. The TAMs and SIMs are prepared for each section (see Figures 5.9 through 5.11 for Section-1 through Section-3, respectively). The high accident prone locations are detected with different accident rate measures as follows:

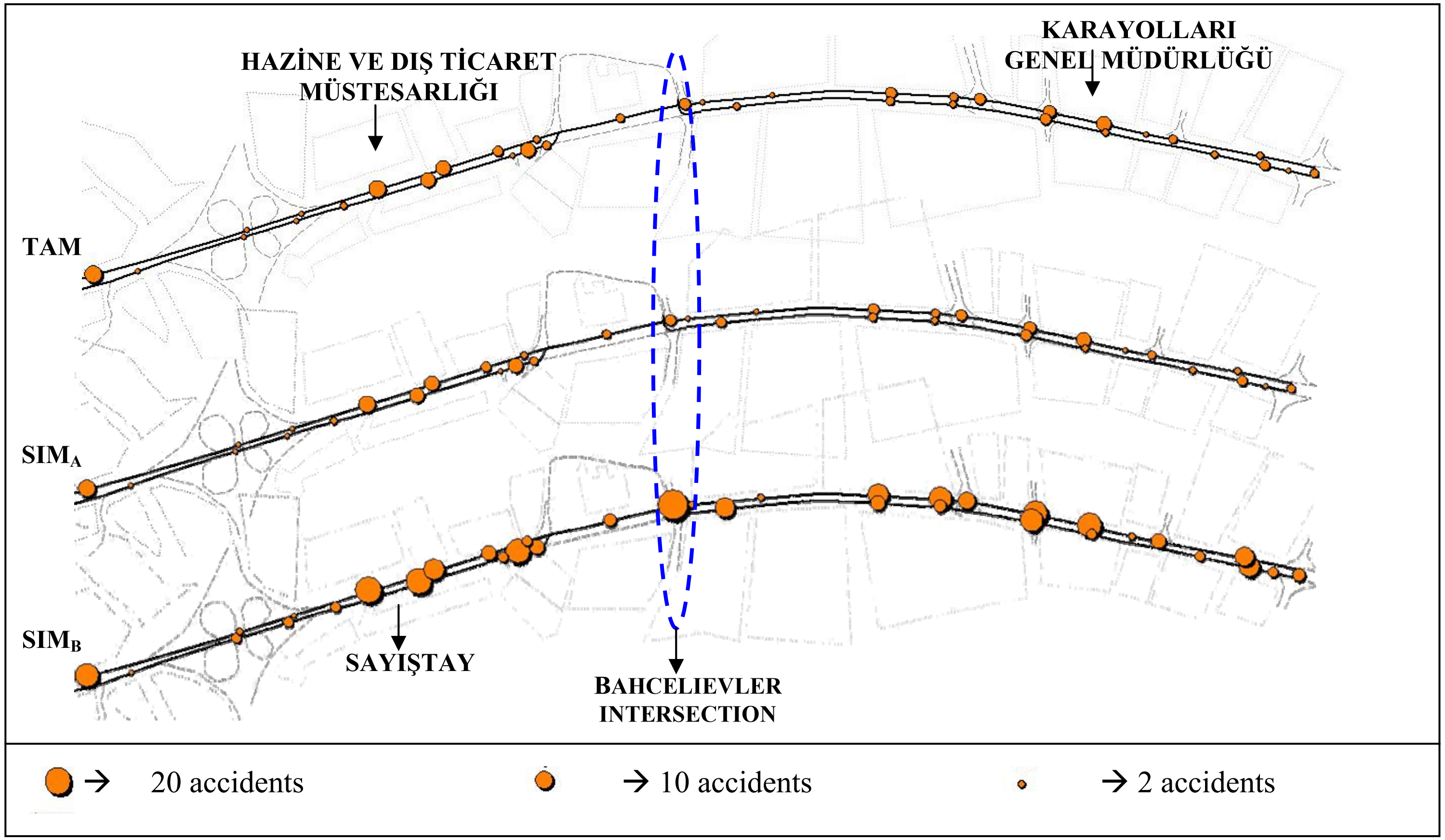


Figure 5. 9 Aggregate Maps for Section-1

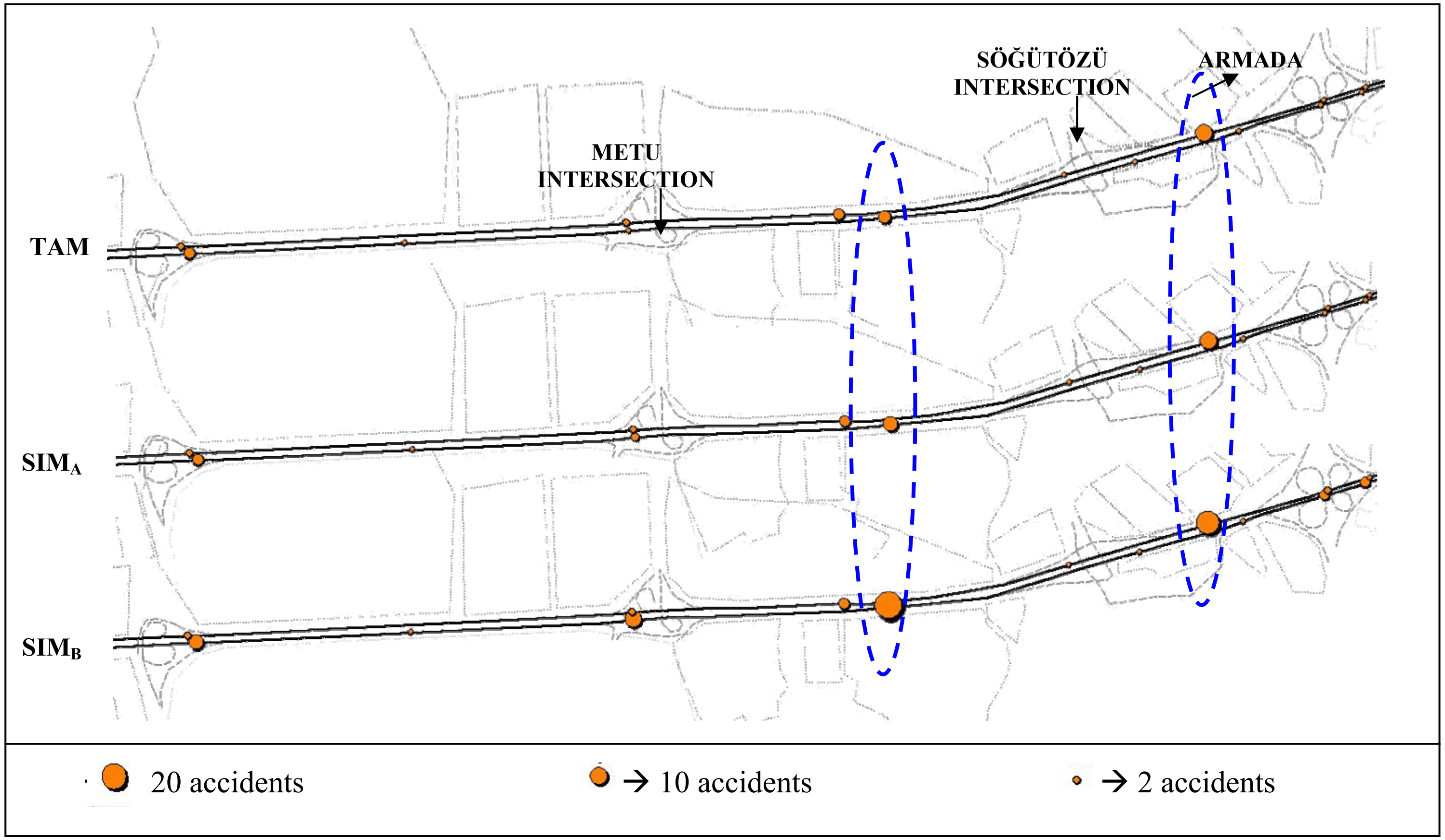


Figure 5. 10 Aggregate Maps for Section-2

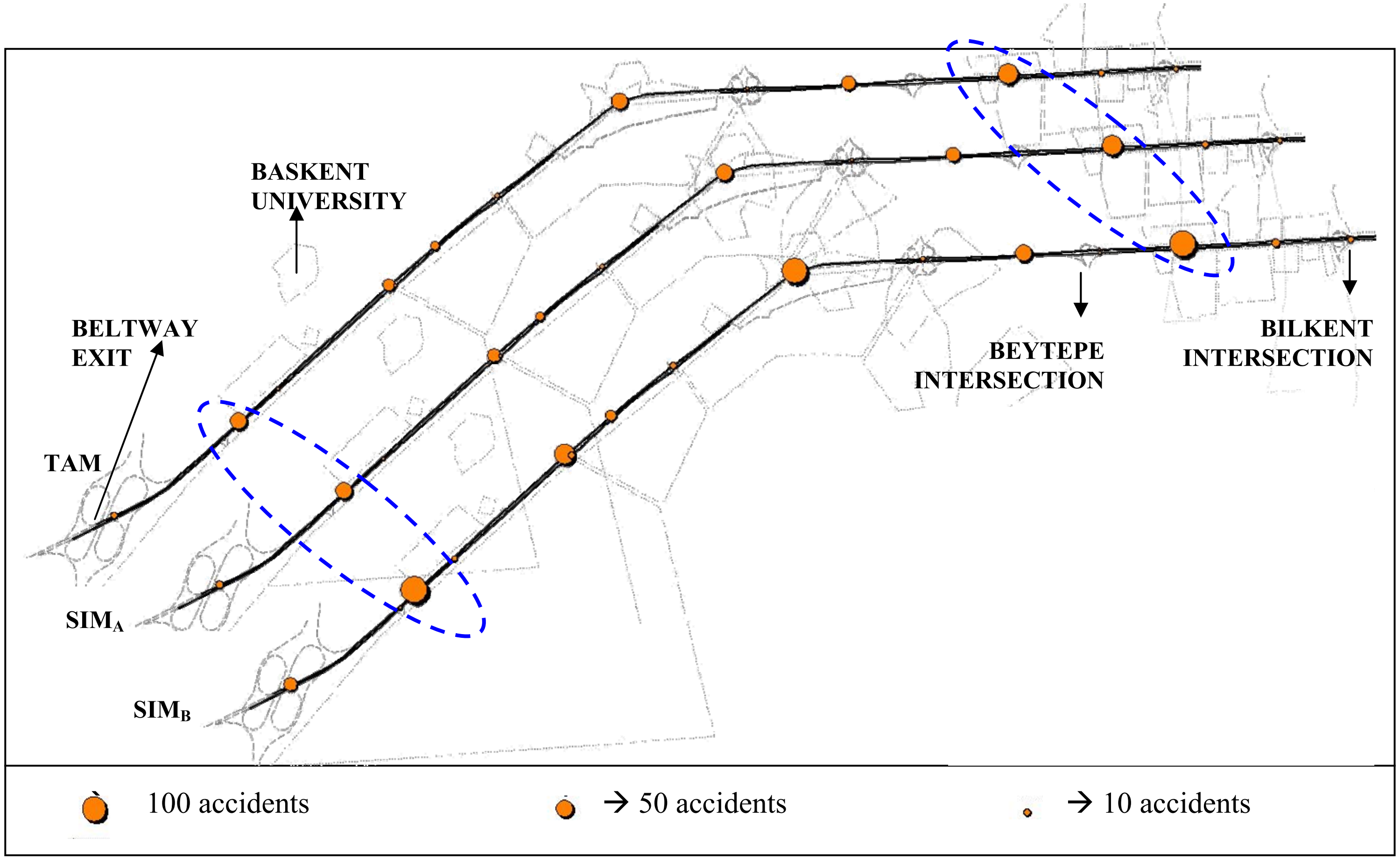


Figure 5. 11 Aggregate Maps for Section-3

Section-1: A total of 111 injury and 1 fatal accidents occurred in this section during the study period are mapped aggregately in Figure 5.9. When the TAM is examined, the links with high number of accidents are detected as; the links in front of Hazine ve Dış Ticaret Müsteşarlığı, Sayıştay, Karayolları Genel Müdürlüğü. In terms of SIM_A, the accident-prone links are similar to results of TAM analysis. But, when the SIM_B is examined, it can be inferred that some other links are also critical. For example, the Bahçelievler Intersection is not one of the most critical links according to TAM and SIM_A, but gets importance with the consideration of number of injuries and fatalities, indicating that there are not many injury and fatality accidents there but accidents with high number of fatalities and injuries.

Section-2: A total of 33 injury and 2 fatal accidents occurred in this section during the study period. Aggregate maps prepared accordingly are presented in Figure 5.10. According to TAM, the highest number of accidents occurred on the link in front of Armada. This link stays as one of the most critical for SIM_A and SIM_B also. But, according to SIM_B, the most critical link is between METU and Soğütözü Intersections.

Section-3: A total of 275 injury and 9 fatal accidents occurred in this section during the study period. Aggregate maps prepared accordingly are presented in Figure 5.11. When we look at the links between Başkent University to Beltway Exit and Bilkent Intersection to Beytepe Intersection, according to TAM and SIM_A, the latter is more critical where according to SIM_B the former is as critical as the latter. This reveals that the number of accidents occurred between Başkent University and Beltway Exit are greater than the ones between Bilkent Intersection and Beytepe Intersection. On the contrary, in case of number of fatalities, the situation is vice versa.

In an overview of these results, the accident prone links are observed to differ in accordance with the selected accident rate. Namely, in the pilot study, the SIM_As confirmed the accident prone parts detected by TAMs. This is mainly due to a small number of fatal accidents have occurred on the corridor But high deviations are observed when the SIM_Bs are considered because there exist a number of accidents with large number of people injured, possibly due to involvement of high occupancy vehicles.

5.4.2 Time-dependent Accident Analysis

To map the link speeds with accidents the three measures (accident numbers, and two severity indices) are calculated for each time period (morning, noon off-peak, evening and night) for each section of the corridor. As a result, 36 time-dependent Maps (TD-) can be obtained for all sections. As an example, 4 maps related to Section-1 for morning, noon, evening and night time periods are presented in juxtaposition in Figure 5.12, while the rest are available in Appendices B, C and D. The conclusions through the examination of them are as follows:

TD-Maps for Section-1 (See Figures 5.12, B.1 and B.2):

- The number of accidents occurred is almost uniformly distributed among the time windows (See Figure 5.12).
- In the morning the portion from Bahçelievler Intersection to Konya Road Intersection that serves as a transition from slow to normal traffic regime, is the most accident prone location (See Figure 5.12). The same portion is critical in the reverse direction in the evening period
- In the noon off-peak and night, the speed is more uniformly distributed as is the accident proneness (See Figure 5.12).

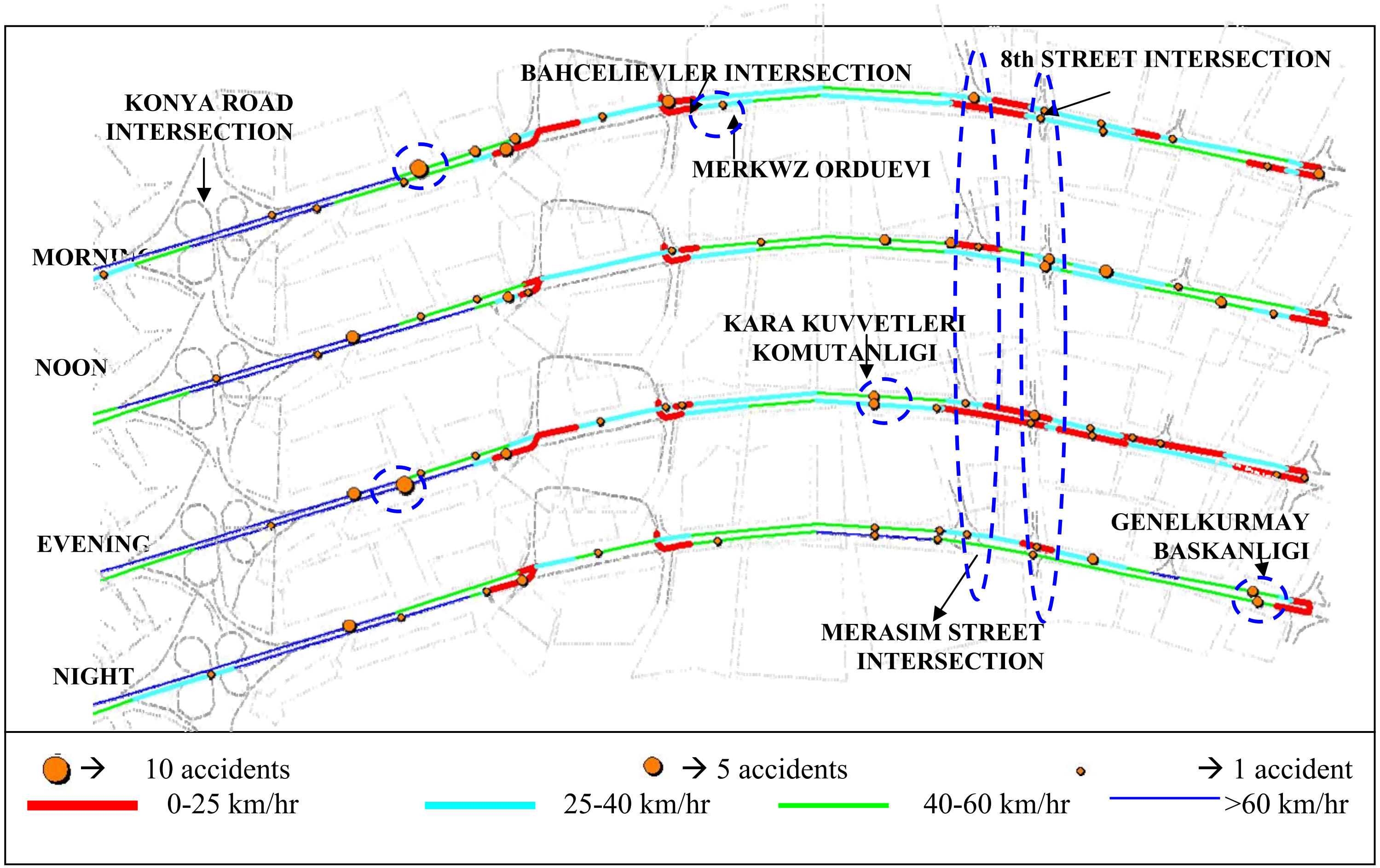


Figure 5. 12 TD-TAMs for Section-1

- The vicinities of the intersections are critical in all time windows, especially during morning peak when sudden slow downs (seen as slow regime segments with speeds <20km/hr before the intersections) between consecutive links are observed due to congestion (See Figure 5.12).

- On some of the links, the accidents are observed in all time windows as 8th Street and Merasim Street Intersections where on some of them, accidents occurred in only one specific time window as the case for the link in front of Genelkurmay Başkanlığı, having accidents only in night time period (See Figure 5.12). while there is no conclusive evidence for speed being a major reason for these accidents, it should be noted that the network at this point has two grade-separated parts in each direction (inbound and outbound) and speeds are measured only on the street level parts, while the accidents may have occurred in either part under the influence of other factors. Also, during the accident analysis period (2003-2005), there had been work zones in the vicinity of this location which might have contributed especially during night time.

- The SIM_A (see Appendix B) map is almost the same as the TAM, due to lack of high numbers of fatal accidents. When compared with the TAM, it is seen that the only difference is observed at the link in front of Merkez Orduevi in morning time period (see Figure B.1), which must be due to occurrence of fatal accident(s).

- When the severity index based on number of injuries and fatalities, SIM_B, (see Appendix B) is analyzed, some of the links detected critical in TAM or SIM_A loss their significance, as there may be locations with fewer number of accidents but higher number of fatalities/injuries in the accidents. For instance, in the evening period, link at Bahçelievler Intersection is the most accident prone in SIM_B (see Figure B.2) while it is not in the TAM and SIM_A (see Figures 5.12 and B.1). However, it should be noted that this severity index is subject to impact from extreme situations such as a high occupancy vehicle (a transit bus or a minibus) involved in an injury or fatality accident.

- For the links in front of and across to Kara Kuvvetleri Komutanlığı, the number of accidents occurred are the same (See Figure 5.12) where they significantly differ in terms of SIM_B (See Figure B.2) for the evening period. This is due to the higher number of injured people in the accidents occurred on the link in front of the Kara Kuvvetleri Komutanlığı building than across to it in this period.

- When SIM_B is considered (see Figure B.2), the evening period is more critical than the other periods. Morning period follows it.

TD-Maps for Section-2 (See Appendix C):

- In the night time, when average link speeds are higher than the other periods, more traffic accidents occurred (see Figure C.1) When the SIM_A in Figure C.2 is examined, the night time is still the most critical where in terms of SIM_B in Figure C.3 the evening time becomes critical.

- The most critical location in this section according to total number of accidents is the link in front of Armada in the outbound direction in the night time, where in the evening time the link at Bilkent intersection in the inbound direction becomes critical (see Figure C.1).

- On the link between METU and Söğütözü intersections in the inbound direction, no accidents have occurred during morning period. The slow speed regime (<25 km/hr) measured on this link during evening time may be due to some extreme events on the measurement days (see Figure C.1). In the night time, lower number of accidents has occurred on this link than on the link in front of Armada (see Figure C.1) where their severity index values are nearly the same (see Figures C.2 and C.3). This is mainly due to the fact that the numbers of fatalities and/or injuries on the link between Söğütözü and METU intersections are higher than the link in front of Armada in the night time.

TD-Maps for Section-3 (See Appendix D):

- In the night time, when average link speeds are higher than the other periods, more traffic accidents occurred (see Figure D.1) When the SIM_A in Figure D.2 is examined, the night time is still the most critical where in terms of SIM_B in Figure D.3 the evening time becomes critical.
- For this section regardless of the time window, high average link speeds are measured. As this segment is known to be in the suburban region, it is expected there are fewer number of factors or conflict points disturbing traffic regime. Also, knowing the lower traffic volumes and longer link lengths in this section, one has to consider normalization with respect to flow and/or length before judging on the speed versus accident relationship.
- Most of the accidents have occurred on the links in the inbound direction regardless of the time.
- The link between Bilkent and Beytepe intersections in the inbound direction has high number of accidents regardless of the time window (see Figure D.1). This link is still critical in terms of SI_A for all time windows (see Figure D.2) where in terms of SI_B (see Figure D.3), the evening time is significantly more critical.
- The link between Ümitköy and Koru Sitesi intersections in the inbound direction is more critical in terms of number of accidents occurred (see Figure D.1).

- The link between Beltway Exit and Başkent University intersections is one of the most critical links in terms of number of accidents and SI_A especially for the night period (see Figure D.1). When the SI_B is considered, the evening period becomes more critical than the night period (see Figure D.3)

5.4.3 Descriptive Statistics

While it is good to visualize geographic and temporal distribution of accidents and even with average speed values, it is still beneficial to look at some statistical values behind these GIS maps. For this purpose, a basic descriptive statistics analysis is performed as presented in Table 5.3. Some insights that can be highlighted from this table are as follows:

- In Section-1, the 25-40 km/hr speed range is critical for the morning and noon periods where for morning 0-25 km/hr range and for noon 40-60 km/hr range are critical in terms of equivalency factor. In the morning and evening time windows, slow-regime is observed on the majority of the links where in the noon and nighttime higher speeds are available.
- In Section-2, in all time windows the average speed on the majority of the links are greater than 40 km/hr and the 0-25 km/hr speed can only be observed in the evening on a single link which is subject to high number of injuries and deaths. On the contrary, for noon-off peak and nighttime, the accident number, rate and both of the severity indices are greater for high-speed range (>60 km/hr). In the morning, only 4 of a total of 35 accidents occurred, 3 of which in the 35-40 km/hr speed range.
- In Section-3, nearly all of the links are operated in the high-speed range in all time windows, thus all accidents occurred on links with high speed range. 102 of the 279 accidents occurred in the night time when on 28 of the 32 links high-speed regime is observed.

Table 5. 3 Time-dependent Accident Statistics

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		SPEED (km/h)														
		SECTION 1					SECTION 2					SECTION 3				
		0-25	25-40	40-60	>60	TOTAL	0-25	25-40	40-60	>60	TOTAL	0-25	25-40	40-60	>60	TOTAL
MORNING	No. of Accidents	**9**	**11**	**8**	**2**	30	---	3	0	1	**4**	1	---	0	44	**45**
	Severity Index	9	13	8	2	32	---	3	0	1	4	1	---	0	46	47
	Equivalency Factor	**38**	**31**	18	3	90	---	3	0	1	4	1	---	0	73	74
	No. of Links	17	22	8	6	53	---	5	3	8	16	1	---	2	29	32
	No. of Links with Accidents	4	9	3	2	18	---	2	0	1	3	1	---	0	8	9
	% Links with Accidents	24	41	38	33	34	---	40	0	13	19	**100**	---	0	28	28
NOON	No. of Accidents	**2**	**11**	**10**	**5**	28	---	---	2	5	**7**	---	0	0	57	**57**
	Severity Index	2	11	10	5	28	---	---	2	5	7	---	0	0	59	59
	Equivalency Factor	4	26	30	10	70	---	---	2	6	8	---	0	0	105	105
	No. of Links	10	18	18	7	53	---	---	5	11	16	---	1	5	26	32
	No. of Links with Accidents	2	6	7	3	18	---	---	2	4	6	---	0	0	10	10
	% Links with Accidents	20	33	39	43	34	---	---	40	36	38	---	0	0	38	31
EVENING	No. of Accidents	**11**	**7**	**4**	**9**	31	2	0	5	3	**10**	1	---	1	73	**75**
	Severity Index	11	7	4	9	31	2	0	5	3	10	1	---	1	81	83
	Equivalency Factor	34	20	8	19	81	10	0	7	3	20	1	---	3	181	185
	No. of Links	21	20	5	7	53	1	3	7	5	16	2	---	4	26	32
	No. of Links with Accidents	9	6	3	3	21	1	0	3	2	6	1	---	1	11	13
	% Links with Accidents	43	30	60	43	40	**100**	0	43	40	38	50	---	25	42	41
NIGHT	No. of Accidents	3	5	9	6	23	---	0	0	14	**14**	---	0	0	102	**102**
	Severity Index	3	5	9	6	23	---	0	0	18	18	---	0	0	108	108
	Equivalency Factor	8	14	**32**	**26**	80	---	0	0	38	38	---	0	0	198	198
	No. of Links	9	13	22	9	53	---	1	2	13	16	---	2	2	28	32
	No. of Links with Accidents	2	4	7	4	17	---	0	0	7	7	---	0	0	11	11
	% Links with Accidents	22	31	32	44	32	---	0	0	54	44	---	0	0	39	34
TOTAL	No. of Accidents	**25**	**34**	**31**	**22**	**112**	**2**	**3**	**7**	**23**	**35**	**2**	**0**	**1**	**276**	**279**
	Severity Index	**25**	**36**	**31**	**22**	**114**	**2**	**3**	**7**	**27**	**39**	**2**	**0**	**1**	**294**	**297**
	Equivalency Factor	**84**	**91**	**88**	**58**	**321**	**10**	**3**	**9**	**48**	**70**	**2**	**0**	**3**	**557**	**562**

- The 'SIM_A / Number of Accidents' rate for each part is around 1, proving that the majority of the accidents are injury accidents rather than fatality accidents.

- When the 'SIM_B / Number of Accidents' rates are examined, the results show that the rate for Section 1 is around 3 while for the other two parts this rate is around 2, suggesting that for Section 1 the number of fatalities and injuries are higher. This high rate of Section 1 is actually the result of the higher urbanization level, denser population, and higher traffic volume observed on this section.

- When 'Number of Accidents / Length of Section' rates for the sections are examined, Section-1 stands as the most critical with a rate around 32 accidents/km, followed by Section-3 of 19 accidents/km. Section-2 is the least critical with a rate of 8 accidents/km, far less than the other two. However, as discussed before, a simple accident/km measure is not a reliable one when urban corridors with many conflict points are in question. Also, normalization with respect to flow rates should be included in a length-based normalized measure, as the total number of accidents is also a function of number of vehicles on the road.

5.5 Summary of Outcomes

The GIS-based TAAM proposed in Chapter 4 is implemented in a pilot study on İnönü Boulevard – Eskişehir Road corridor. The corridor starts at a central business district and extends to urban/suburban transitional part followed by an suburban/rural region. On this account, the corridor is divided into three sections in the analyses. In an attempt to verify this division, the time-dependent average link speeds are computed through TDA analysis of probe-vehicle GPS track data and thematically mapped. As a separate analysis, the link statistics based on speed intervals are prepared. The cross examination of these analyses revealed that the proposed methodology has the potential to detect speed variation, thus the different characteristics of flow in the urban corridors.

The accidents occurred on the study corridor between years 2003 and 2005 are included in the analysis. Three different safety measures are used in the analyses: number of accidents and two severity indices (SIM_A and the SIM_B). An aggregate analysis is performed with this data resulting in aggregate thematic maps, TAMs, and SIMs, developed for the predefined three sections. Then the time-dependent average link speeds are mapped with the time-dependent accident rates in juxtaposition producing the TD-TAMs, TD-SIM_As and TD-SIM_Bs. The examination of these maps reveals that the proposed method the potential to capture and display different aspects of traffic and safety characteristics of the study corridor such as:

- Section average speeds in different time periods.
- Change in section characteristics based on land use and urbanization along the section.
- Critical locations with higher number of accidents, as well as, locations exposed to higher number of injuries and fatalities (sometimes two of these coincides).
- Time-dependent accident proneness of links based on three selected safety measures.
- Additional statistical measures such “total number of accidents/section length” for each section.
- Time periods during which accident risk is higher.

CHAPTER 6

CONCLUSIONS AND RESEARCH RECOMMENDATIONS

Traffic safety problem is getting more and more important with the increasing rates of injuries and fatalities all over the world. For the assessment and solution of this problem, a special effort is needed as there are many factors affecting traffic safety. However, the factors associated with urban traffic safety and safety on freeways differs. Thus, in this study a method for traffic accident analysis for urban corridors is presented. As the temporal and spatial variation of not only accidents but the factors affecting them is an integral part of the problem, the proposed algorithm has a GIS component.

The proposed GIS-based traffic accident analysis method (GIS-TAAM) requires modification of the methodologies used for intercity highways for application to urban areas, mainly due to the following reasons:

- The traffic characteristics on urban corridors are time-dependent and spatially distributed. Namely, congestion resulting in slow speed regimes gives rise to bottleneck locations. After the release of these, sudden changes are observed in the traffic regimes as opposed to more constant traffic regimes along highways.
- In urban networks the distance between two successive intersections varies and there exist a number of operational and physical features in between within very short distances. Additionally, the traffic network

patterns in the urban regions are denser and more complex, resulting in shorter link lengths and more conflict points.

- The accident reports in urban regions generally refer to major buildings or benchmarks for the accident location data whereas in intercity highways simply the station km information is recorded.

In this chapter, highlights of the proposed methods and e next section the notable issues of this study are discussed followed by recommendations for further research.

6.1 Conclusions

The proposed methodology suggests the association of link-based time-dependent or permanent characteristics (operational or physical) to accident rates. For this study the following traffic safety measures are covered: the number of accidents and two severity indices (SIM_A and the SIM_B). All these three measures are studied i) as the whole data as an aggregate measure and ii) in terms time periods based on the time of the accidents to be associated with the average speed values during selected time intervals(time-dependent). Consequent to the support of some link-based statistical measures to these maps, the traffic safety characteristics of the study corridor are provided.

GIS component strengthens the proposed methodology with its capabilities not only in spatial analyses but also by providing the following tools and aspects:

- With the advances in the technology, today it is possible to collect and store the exact location of the accidents as in the form of latitude and longitude coordinates with GPS receivers. This enables mapping these locations in a GIS environment.

- With thematic mapping, GIS enhances the visuality and thus understanding.

- As far as multiple factors are concerned, GIS provides presentation of different aspects by its layering options.

- It is possible to convert any accident database or simply construct a new database into GIS environment in order to carry out queries and obtain statistical measures. Once the database is prepared, it is easy to add other factors or to remove the existing ones.

The proposed GIS-TAAM has the potential to represent many aspects of traffic safety as follows:

- Not only observation of spatial distribution of the number of accidents is provided, but also the distribution for the severity indices. It is possible to carry out the analysis for any other safety measure, easily as well.

- The deliverables of the GIS-TAAM includes aggregate or time-dependent thematic total accident maps (TAMs) and severity index maps (SIMs).

- The GIS-TAAM provides multi-criteria analyses options with mapping different variables in juxtaposition.

- Although it is not possible to carry out a regression analysis in this study, the representation provides a clear idea of the traffic safety characteristics of the corridor.

The proposed GIS-TAAM is tested in a pilot study (İnönü Boulevard – Eskişehir Road corridor) by the association of different accident rates to links and time-dependent average link speeds in a GIS environment. It is also shown that using the speed information, the corridor characterization is possible.

6.2 Recommendations for Further Research

In this study, the safety measures are selected as total number of accidents and severity indices that depend on either again number of fatality and injury accidents or number of fatalities and injuries, with some conversion factors. However, these values have not been compared or associated with the average traffic volume and/or the link length. As the number of vehicles in the traffic increase, the total number of accidents is expected to be higher, so are the aforementioned severity indices. The same direct proportionality holds between the accident numbers and link lengths. Thus, in a future analysis, normalized versions of the selected safety measures should be calculated and would provide better information for black spot detection.

Another notable concern is that in this study the operational and physical features of the network are not considered. After detecting the high accident rate locations, these (signalization, conflict point, bottleneck location, etc.) can also be associated to the rates in both aggregate and time-dependent manners.

One important note is that the speeds calculated in this study are only representative values. It is not claimed that these speeds calculated from limited measurements are directly related to the speeds causing or avoiding accidents. But when an archival speed data is available with more observations, even capturing averages for each hour, or specific day of the week, or seasonal patterns, the methodology has the potential to derive more conclusive results.

In addition to these, this methodology can be used in before-after studies as well, as long as the data is available. It is also possible to investigate the effects of any other factor affecting safety rather than speed with this methodology. Another possibility is to replace the traffic safety measures in the analysis with other measures. With these capabilities, the methodology provides a flexible base for the analysis.

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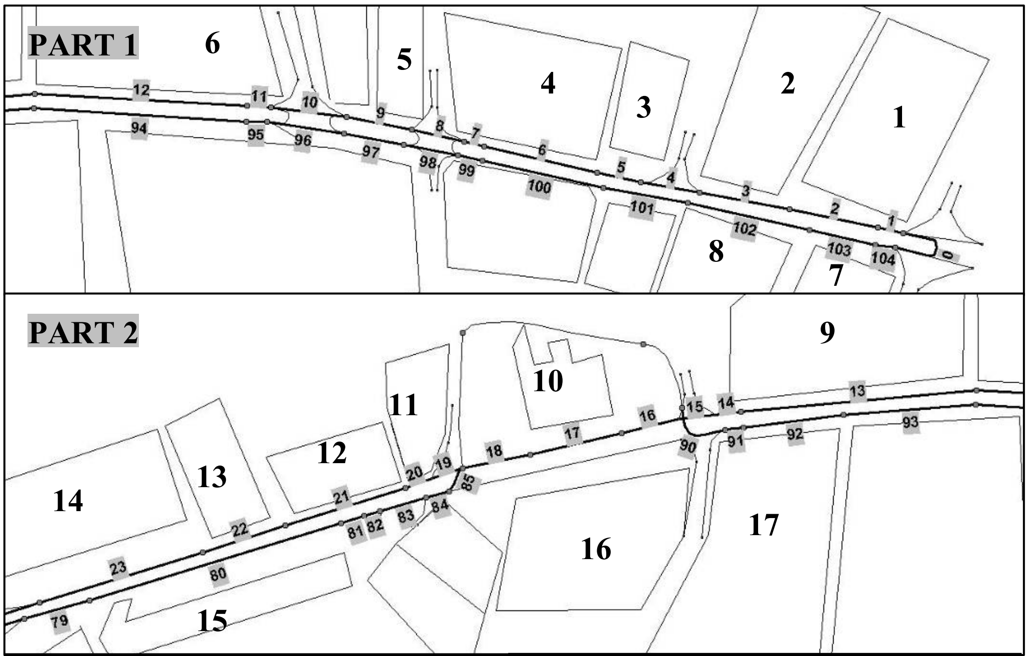
APPENDICES

APPENDIX A

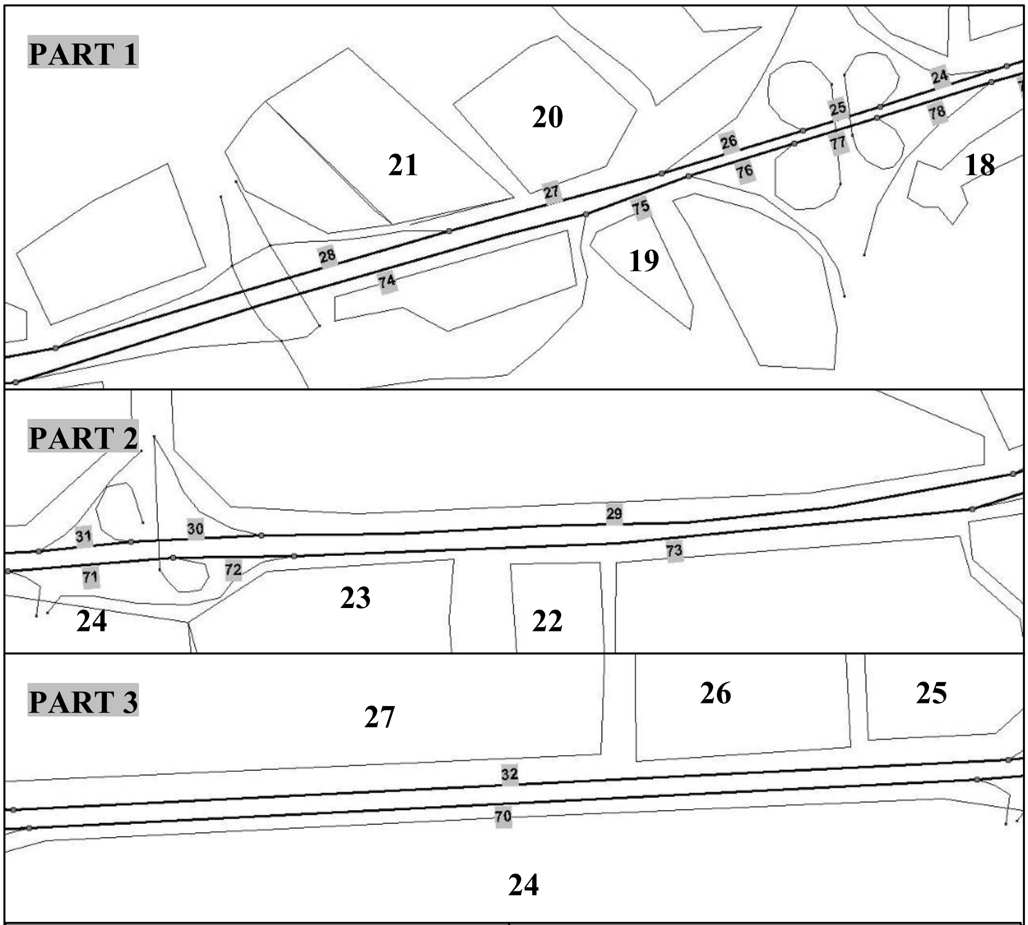
NETWORK DETAILS



Building/region Id	Name	Building/region Id	Name
1	Genelkurmay Başkanlığı	9	Kara Kuvvetlerı Komutanlığı
2	Milli Savunma Bakanlığı	10	Milli Kütüphane
3	Devlet İstatistik Enstitüsü	11	Ulaştırma Bakanlığı
4	Karayolları Genel Müdürlüğü	12	Turizm Bakanlığı
5	Devlet Su İşleri	13	Çalışma ve Sosyal Güvenlik Bakanlığı
6	Devlet Malzeme Ofisi	14	Hazine ve Dış Ticaret Müsteşarlığı
7	Deniz Kuvvetleri Komutanlığı	15	Sayıştay
8	Hava Kuvvetleri Komutanlığı	16	Enerji ve Tabii Kaynaklar Bakanlığı
		17	Merkez Ordu evi

→ Building / region id   # → Link id

Figure A. 1 Network Details for Section-1



Building/region Id	Name	Building/region id	Name
18	Dış İşleri Bakanlığı	23	Şap Enstitüsü
19	Ulusoy Turizm	24	Orta Doğu Teknik Üniversitesi
20	Varan Turizm	25	Bayındırlık ve İskan Müdürlüğü
21	Armada	26	Sanayi ve Ticaret Bakanlığı
22	Maden Tetkik Arama	27	Elektrik İşleri Etüt İdare Genel Müdürlüğü

→ Building / region id   # → Link id

Figure A. 2 Network Details for Section-2

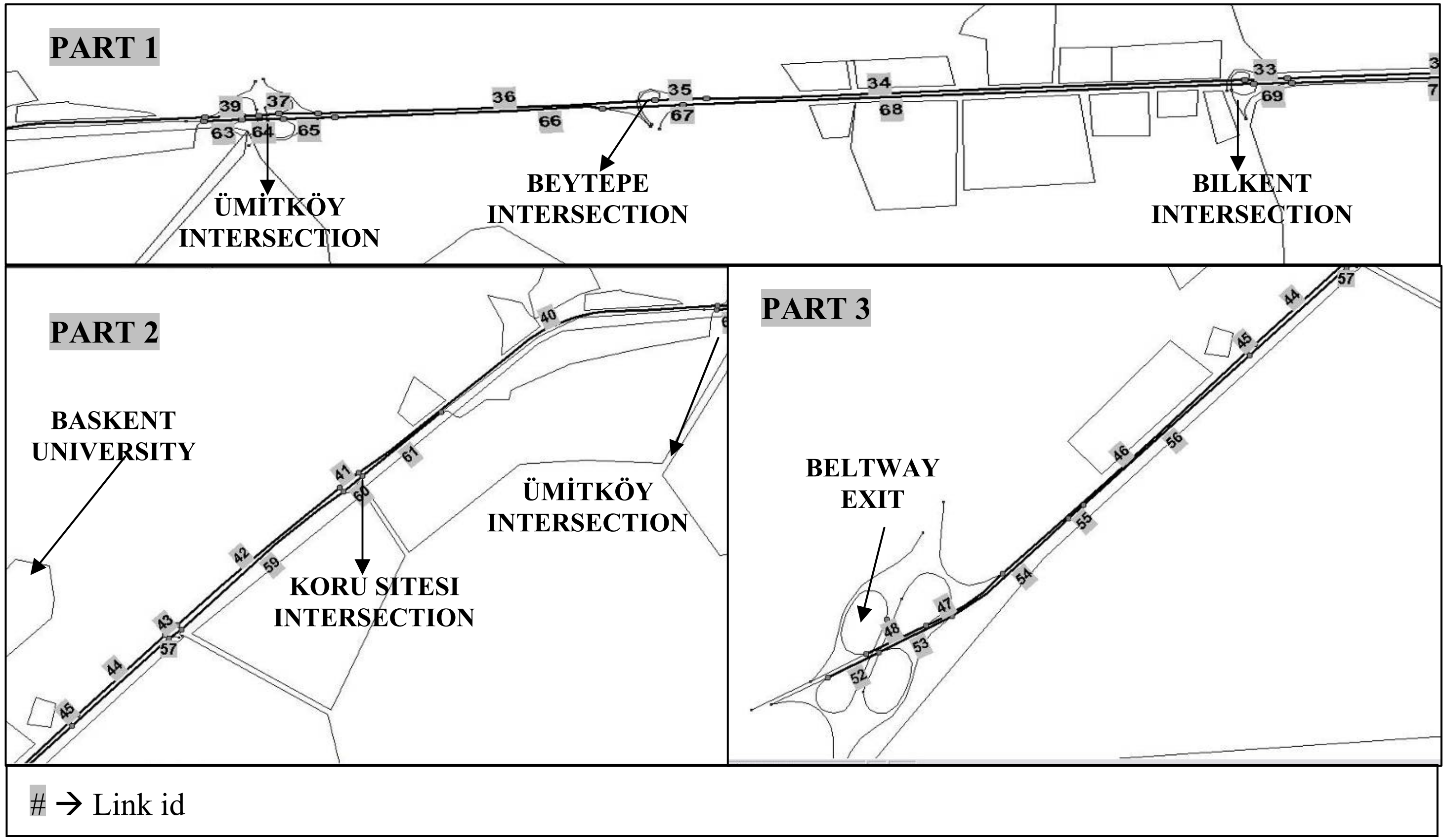


Figure A. 3 Network Details for Section-3

Table A.1.a Time-dependent Average Link Speed and Accident Data for Links (Morning and Noon)

		MORNING					NOON				
			Fatal Accidents		Injury Accidents			Fatal Accidents		Injury Accidents	
			Number of		Number of			Number of		Number of	
LinkId	Length (m)	Speed (km/hr)	Accidents	Deaths	Accidents	Injured	Speed (km/hr)	Accidents	Deaths	Accidents	Injured
0	131.00	6.40	0	0	2	4	7.10	0	0	0	0
1	39.79	29.10	0	0	0	0	36.00	0	0	0	0
2	133.82	43.40	0	0	0	0	45.30	0	0	0	0
3	136.49	36.00	0	0	0	0	46.90	0	0	0	0
4	88.61	29.50	0	0	1	2	49.00	0	0	1	4
5	66.47	21.60	0	0	0	0	38.70	0	0	0	0
6	173.50	31.90	0	0	1	2	35.20	0	0	3	8
7	29.83	33.20	0	0	0	0	44.70	0	0	0	0
8	80.73	28.20	0	0	1	4	36.40	0	0	2	4
9	98.49	16.10	0	0	0	0	45.40	0	0	0	0
10	114.26	26.60	0	0	2	4	19.50	0	0	1	2
11	35.04	39.90	0	0	0	0	50.50	0	0	2	8
12	316.97	44.10	0	0	0	0	54.70	0	0	2	8
13	353.09	36.00	0	0	0	0	51.80	0	0	1	2
14	40.09	20.80	0	0	0	0	24.70	0	0	0	0
15	54.06	22.80	0	0	3	22	25.20	0	0	1	2
16	88.06	25.50	0	0	0	0	33.00	0	0	0	0
17	140.67	29.20	0	0	1	2	39.00	0	0	0	0
18	102.11	21.00	0	0	0	0	26.00	0	0	0	0
19	49.75	32.10	0	0	0	0	15.90	0	0	0	0
20	40.88	34.50	0	0	2	4	41.70	0	0	0	0
21	189.39	41.60	0	0	2	4	50.30	0	0	1	2
22	129.45	57.20	0	0	5	10	58.90	0	0	1	2
23	255.04	75.00	0	0	0	0	78.80	0	0	3	6
24	198.60	79.20	0	0	1	1	83.60	0	0	0	0
25	120.91	75.80	0	0	0	0	82.00	0	0	1	2
26	221.36	78.60	0	0	0	0	83.40	0	0	0	0
27	329.13	64.67	0	0	1	1	48.64	0	0	2	2
28	615.03	57.95	0	0	0	0	69.26	0	0	0	0
29	1100.59	26.98	0	0	2	2	59.67	0	0	1	1
30	189.47	60.28	0	0	0	0	72.00	0	0	0	0
31	135.28	61.52	0	0	0	0	51.40	0	0	0	0
32	1449.74	64.30	0	0	0	0	82.84	0	0	0	0
33	196.30	83.76	0	0	0	0	88.34	0	0	0	0
34	2521.07	78.24	0	0	17	26	80.37	0	0	12	12
35	239.92	86.37	0	0	0	0	79.17	0	0	1	2
36	1574.22	84.58	0	0	4	4	69.97	0	0	8	10
37	185.13	95.21	0	0	0	0	74.05	0	0	0	0
40	2735.98	66.10	0	0	5	7	67.00	1	1	7	12
41	161.86	8.70	0	0	1	1	44.51	0	0	0	0
42	1414.62	94.31	0	0	2	2	85.26	0	0	3	4
43	106.78	76.88	1	2	0	0	86.49	0	0	8	14
44	785.99	91.28	0	0	0	0	69.03	0	0	0	0
45	81.65	73.49	0	0	0	0	51.44	0	0	0	0
46	2191.42	75.13	0	0	8	11	76.78	0	1	10	32
47	623.74	80.20	0	0	0	0	80.61	0	0	0	0
48	442.03	75.78	0	0	3	7	74.38	0	0	3	9
49	881.66	61.04	0	0	0	0	58.80	0	0	0	0
50	487.69	76.33	0	0	0	0	73.15	0	0	0	0

Table A.1.a Time-dependent Average Link Speed and Accident Data for Links (Morning and Noon) (continued)

		MORNING					NOON				
			Fatal Accidents		Injury Accidents			Fatal Accidents		Injury Accidents	
			Number of		Number of			Number of		Number of	
LinkId	Length (m)	Speed (km/hr)	Accidents	Deaths	Accidents	Injured	Speed (km/hr)	Accidents	Deaths	Accidents	Injured
51	590.89	64.46	0	0	0	0	65.47	0	0	0	0
52	381.66	72.31	0	0	0	0	85.87	0	0	0	0
53	544.35	75,98	0	0	0	0	85.20	0	0	0	0
54	1015.02	68,78	0	0	0	0	76.16	0	0	0	0
55	134.46	69.15	0	0	0	0	30.14	0	0	0	0
56	1492.31	91.06	0	0	0	0	75.40	0	0	2	3
57	871.16	84.76	0	0	0	0	69.95	0	0	0	0
58	100.11	76,3	0	0	0	0	72.08	0	0	2	4
59	1421.39	78.72	0	0	0	0	89.77	0	0	0	0
60	161.41	40,91	0	0	0	0	41.50	0	0	0	0
61	676.34	70,78	0	0	0	0	65.81	0	0	0	0
63	177.39	58.05	0	0	0	0	55.64	0	0	0	0
64	196.16	70.62	0	0	0	0	78.46	0	0	0	0
65	237.07	85.35	0	0	0	0	86.21	0	0	0	0
66	1254.01	80.61	0	0	0	0	82.08	0	0	0	0
67	376.71	79.77	0	0	0	0	78.05	0	0	0	0
68	2667.57	78.72	0	0	4	4	85.57	0	0	0	0
69	182.03	72.81	0	0	0	0	87.77	0	0	1	2
70	1381.32	62.32	0	0	0	0	59.45	0	0	1	1
71	242.63	50.28	0	0	0	0	62.39	0	0	0	0
72	175.53	36.14	0	0	0	0	74.60	0	0	0	0
73	990.23	35.22	0	0	0	0	72.87	0	0	1	1
74	889.49	37.63	0	0	0	0	68.94	0	0	1	1
75	163.80	35.17	0	0	1	1	45.36	0	0	0	0
76	166.03	56.00	0	0	0	0	54.10	0	0	0	0
77	128.74	60.90	0	0	0	0	63.00	0	0	0	0
78	180.27	65.20	0	0	0	0	67.20	0	0	0	0
79	101.84	65.50	0	0	1	2	69.60	0	0	1	2
80	392.28	51.80	0	0	1	4	67.40	0	0	0	0
81	36.86	32.70	0	0	0	0	47.90	0	0	0	0
82	24.79	25.40	0	0	0	0	52.90	0	0	0	0
83	71.30	11.50	0	0	3	10	30.00	0	0	2	4
84	35.89	10.30	0	0	0	0	20.30	0	0	1	2
85	41.04	18.40	0	0	0	0	18.30	0	0	0	0
88	276.86	20.30	0	0	0	0	24.60	0	0	0	0
89	121.46	16.20	0	0	0	0	21.40	0	0	0	0
90	94.94	12.80	0	0	0	0	13.70	0	0	0	0
91	25.93	23.00	0	0	0	0	26.70	0	0	0	0
92	150.66	33.60	1	1	0	0	37.80	0	0	0	0
93	198.02	46.20	0	0	0	0	56.80	0	0	0	0
94	316.89	31.60	0	0	0	0	54.50	0	0	0	0
95	30.93	31.30	0	0	0	0	35.90	0	0	0	0
96	116.60	21.90	0	0	0	0	34.50	0	0	0	0
97	90.40	22.10	0	0	0	0	37.30	0	0	0	0
98	81.69	25.70	0	0	1	2	28.30	0	0	2	4
99	37.70	38.80	0	0	0	0	42.10	0	0	0	0
100	184.78	27.00	0	0	1	2	31.90	0	0	0	0
101	127.22	42.10	0	0	0	0	43.40	0	0	0	0
102	185.42	46.20	0	0	0	0	48.50	0	0	2	4
103	101.56	10.20	0	0	1	2	33.30	0	0	1	4
104	29.78	25.10	0	0	0	0	24.80	0	0	0	0

Table A.1.b Time-dependent Average Link Speed and Accident Data for Links (Evening and Night)

		MORNING					NOON				
			Fatal Accidents		Injury Accidents			Fatal Accidents		Injury Accidents	
			Number of		Number of			Number of		Number of	
LinkId	Length (m)	Speed (km/hr)	Accidents	Deaths	Accidents	Injured	Speed (km/hr)	Accidents	Deaths	Accidents	Injured
0	131.00	4.60	0	0	1	2	6.21	0	0	0	0
1	39.79	28.70	0	0	0	0	35.81	0	0	0	0
2	133.82	33.30	0	0	0	0	43.80	0	0	2	12
3	136.49	24.00	0	0	0	0	54.60	0	0	0	0
4	88.61	15.70	0	0	1	2	63.80	0	0	0	0
5	66.47	13.90	0	0	1	2	59.82	0	0	0	0
6	173.50	28.60	0	0	1	4	36.74	0	0	2	4
7	29.83	27.80	0	0	0	0	26.85	0	0	0	0
8	80.73	17.30	0	0	2	8	10.76	0	0	1	2
9	98.49	16.80	0	0	0	0	29.55	0	0	0	0
10	114.26	25.80	0	0	1	2	31.64	0	0	1	2
11	35.04	42.90	0	0	0	0	63.07	0	0	1	8
12	316.97	49.50	0	0	2	4	57.06	0	0	1	2
13	353.09	35.30	0	0	0	0	57.78	0	0	0	0
14	40.09	24.70	0	0	1	2	28.86	0	0	0	0
15	54.06	29.20	0	0	1	2	38.92	0	0	0	0
16	88.06	29.10	0	0	0	0	45.29	0	0	0	0
17	140.67	27.60	0	0	1	2	46.04	0	0	1	2
18	102.11	24.50	0	0	0	0	28.28	0	0	0	0
19	49.75	26.50	0	0	0	0	0.00	0	0	0	0
20	40.88	39.70	0	0	0	0	49.05	0	0	0	0
21	189.39	41.90	0	0	1	2	48.70	0	0	0	0
22	129.45	52.20	0	0	1	2	58.25	0	0	0	0
23	255.04	63.80	0	0	3	5	76.51	0	0	3	10
24	198.60	67.40	0	0	0	0	89.37	0	0	0	0
25	120.91	67.30	0	0	0	0	108.81	0	0	0	0
26	221.36	71.80	0	0	0	0	61.30	0	0	0	0
27	329.13	69.70	0	0	2	2	91.14	0	0	5	12
28	615.03	73.80	0	0	1	1	88.56	0	0	0	0
29	1100.59	73.37	0	0	0	0	92.14	0	0	2	2
30	189.47	68.21	0	0	0	0	85.26	0	0	0	0
31	135.28	54.11	0	0	1	1	81.17	0	0	1	1
32	1449.74	81.63	0	0	0	0	77.90	0	0	0	0
33	196.30	83.43	0	0	1	1	79.50	0	0	1	1
34	2521.07	79.97	0	0	20	37	77.57	0	0	21	33
35	239.92	82.45	0	0	0	0	86.37	0	0	0	0
36	1574.22	83.96	1	2	7	10	96.05	1	1	14	17
37	185.13	89.26	0	0	0	0	90,76	0	0	1	2
40	2735.98	62.54	2	5	13	38	71.89	0	0	16	28
41	161.86	68.11	0	0	3	8	83.24	0	0	1	1
42	1414.62	87.83	0	0	5	5	80.84	0	0	6	13
43	106.78	70.48	0	0	4	8	76.88	0	0	17	37
44	785.99	55.93	0	0	0	0	76.47	0	0	0	0
45	81.65	16.22	0	0	1	1	97.98	0	0	0	0
46	2191.42	62.58	0	0	10	25	88.64	1	1	19	46
47	623.74	80.20	0	0	0	0	93.56	0	0	0	0
48	442.03	74.05	1	2	3	8	75.78	0	0	0	0
49	881.66	60.51	0	0	0	0	60.11	0	0	0	0
50	487.69	76.48	0	0	0	0	70.23	0	0	0	0

Table A.1.b Time-dependent Average Link Speed and Accident Data for Links (Evening and Night) (continued)

		MORNING					NOON				
			Fatal Accidents		Injury Accidents			Fatal Accidents		Injury Accidents	
			Number of		Number of			Number of		Number of	
LinkId	Length (m)	Speed (km/hr)	Accidents	Deaths	Accidents	Injured	Speed (km/hr)	Accidents	Deaths	Accidents	Injured
51	590.89	70.99	0	0	0	0	66.48	0	0	0	0
52	381.66	11.63	0	0	0	0	76.33	0	0	0	0
53	544.35	90.76	0	0	0	0	93.32	0	0	0	0
54	1015.02	73,61	0	0	0	0	65.25	0	0	0	0
55	134.46	40.34	0	0	1	3	28.47	0	0	0	0
56	1492.31	67.32	0	0	1	4	85.27	0	0	0	0
57	871.16	76.90	0	0	0	0	61.49	0	0	0	0
58	100.11	90.10	0	0	0	0	91,2	0	0	1	6
59	1421.39	83.89	0	0	0	0	66.45	0	0	0	0
60	161.41	44.39	0	0	0	0	50,55	0	0	0	0
61	676.34	77.47	0	0	0	0	73,82	0	0	0	0
63	177.39	58.05	0	0	0	0	39.91	0	0	0	0
64	196.16	74.54	0	0	0	0	54.32	0	0	0	0
65	237.07	81.47	0	0	0	0	77.59	0	0	0	0
66	1254.01	73.90	0	0	0	0	70.54	0	0	0	0
67	376.71	79.04	0	0	1	1	75.34	0	0	1	2
68	2667.57	81.91	0	0	2	4	80.70	1	1	2	3
69	182.03	48.74	0	0	3	5	72.81	0	0	1	1
70	1381.32	48.66	0	0	0	0	82.88	0	0	0	0
71	242.63	38.13	0	0	0	0	79.41	1	1	0	0
72	175.53	34.69	0	0	0	0	90.27	0	0	0	0
73	990.23	23.93	0	0	2	10	62.54	1	1	2	9
74	889.49	59.30	0	0	0	0	53.37	0	0	0	0
75	163.80	45.36	0	0	0	0	45.36	0	0	0	0
76	166.03	52.30	0	0	0	0	37.36	0	0	0	0
77	128.74	61.60	0	0	0	0	35.65	0	0	1	4
78	180.27	65.90	0	0	1	4	72.11	0	0	0	0
79	101.84	71.70	0	0	0	0	91.66	0	0	0	0
80	392.28	62.50	0	0	5	10	67.25	0	0	1	6
81	36.86	39.90	0	0	0	0	44.23	0	0	0	0
82	24.79	36.90	0	0	0	0	29.75	0	0	1	4
83	71.30	20.50	0	0	2	4	18.33	0	0	0	0
84	35.89	16.10	0	0	0	0	5.38	0	0	2	6
85	41.04	20.80	0	0	0	0	21.69	0	0	0	0
88	276.86	20.60	0	0	0	0	32.15	0	0	0	0
89	121.46	17.60	0	0	0	0	25.72	0	0	0	0
90	94.94	13.80	0	0	0	0	10.36	0	0	0	0
91	25.93	28.70	0	0	0	0	24.90	0	0	0	0
92	150.66	39.00	0	0	0	0	45.20	0	0	1	4
93	198.02	53.40	0	0	0	0	59.41	0	0	0	0
94	316.89	36.40	0	0	2	6	60.04	0	0	1	2
95	30.93	31.80	0	0	1	4	55.68	0	0	1	2
96	116.60	23.50	0	0	0	0	52.47	0	0	0	0
97	90.40	12.10	0	0	0	0	54.24	0	0	0	0
98	81.69	19.30	0	0	1	8	49.01	0	0	1	2
99	37.70	29.50	0	0	0	0	45.25	0	0	0	0
100	184.78	23.00	0	0	1	2	44.35	0	0	0	0
101	127.22	33.90	0	0	0	0	45.80	0	0	0	0
102	185.42	27.20	0	0	0	0	55.63	0	0	0	0
103	101.56	7.60	0	0	0	0	40.62	0	0	2	8
104	29.78	21.30	0	0	1	4	2.02	0	0	0	0

APPENDIX B

TD-MAPS FOR SECTION 1

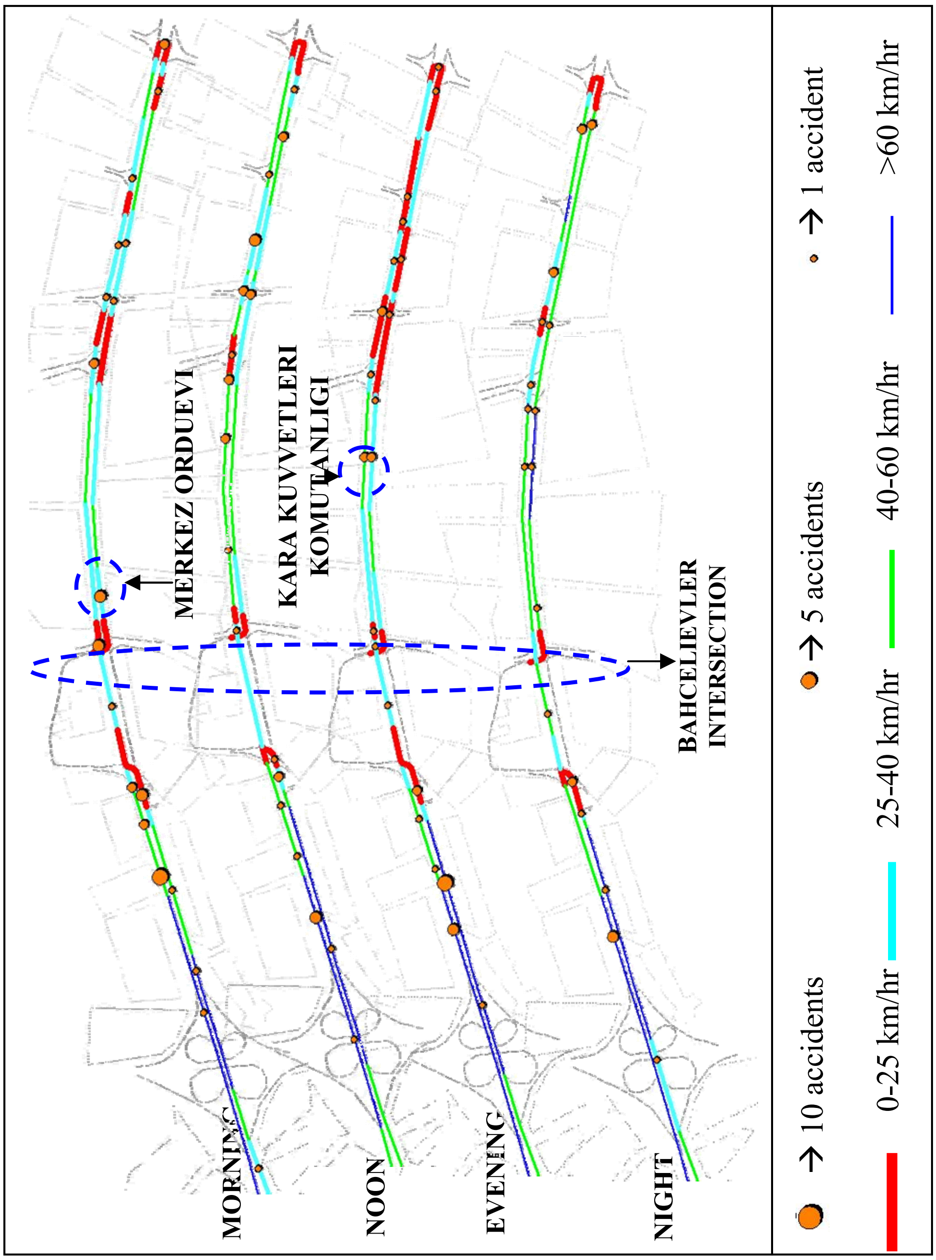


Figure B. 1 TD-SIM$_A$ s for Section-1

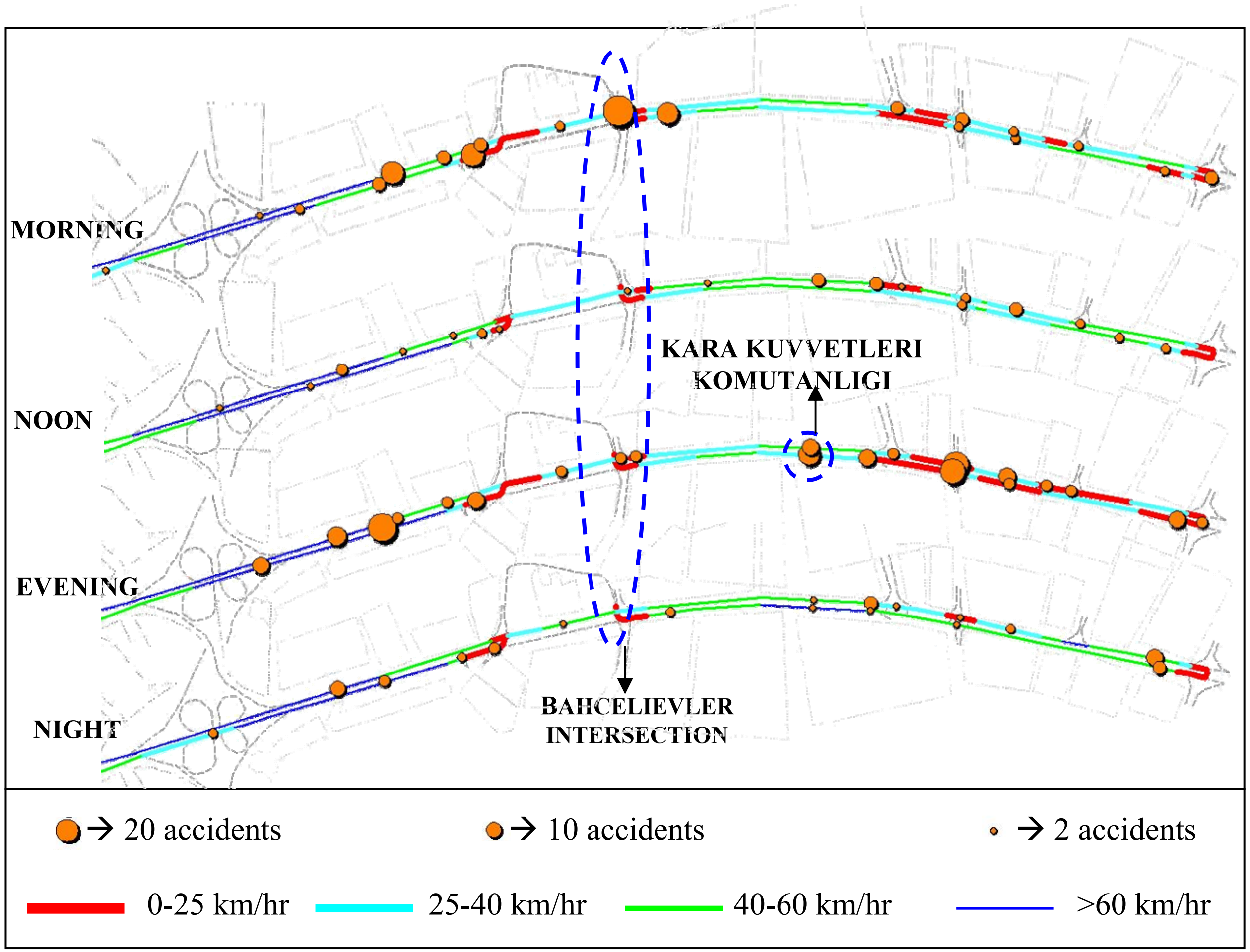


Figure B. 2 TD-SIM$_{Bs}$ for Section-1

APPENDIX C

TD-MAPS FOR SECTION 2

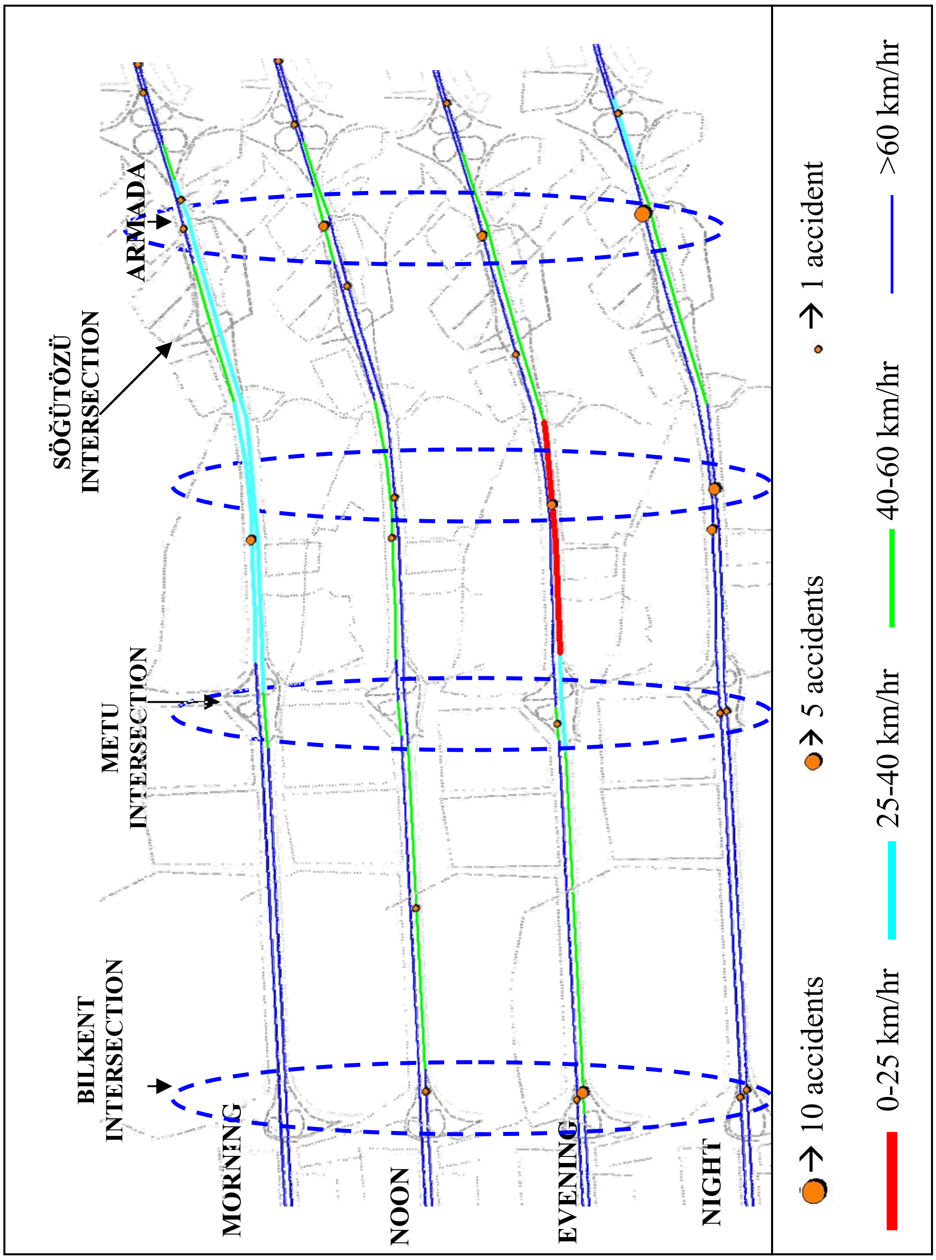


Figure C. 1 TD-TAMs for Section-2

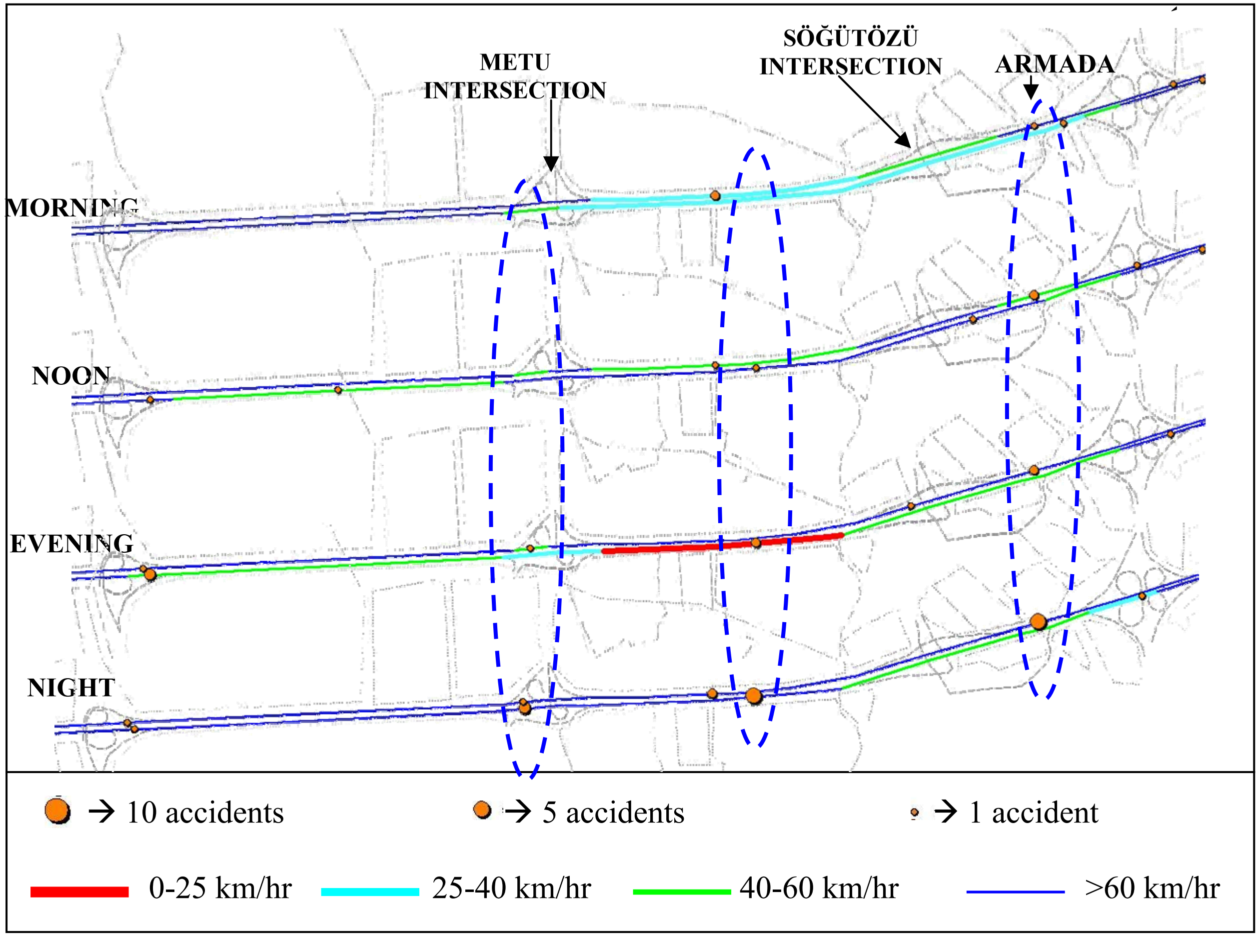


Figure C. 2 TD-SIM$_A$s for Section-2

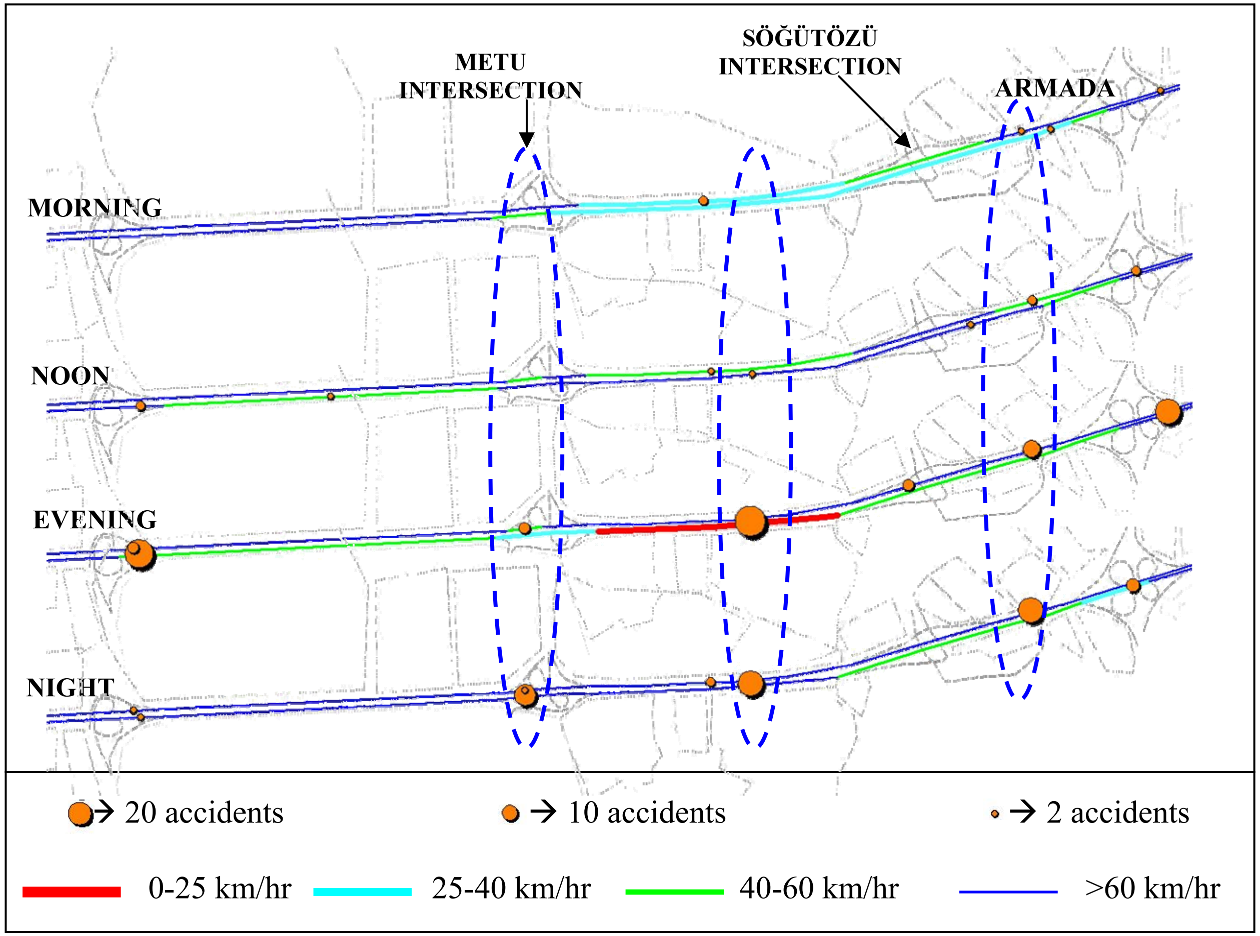


Figure C. 3 TD-SIM$_B$ s for Section-2

APPENDIX D

TD-MAPS FOR SECTION 3

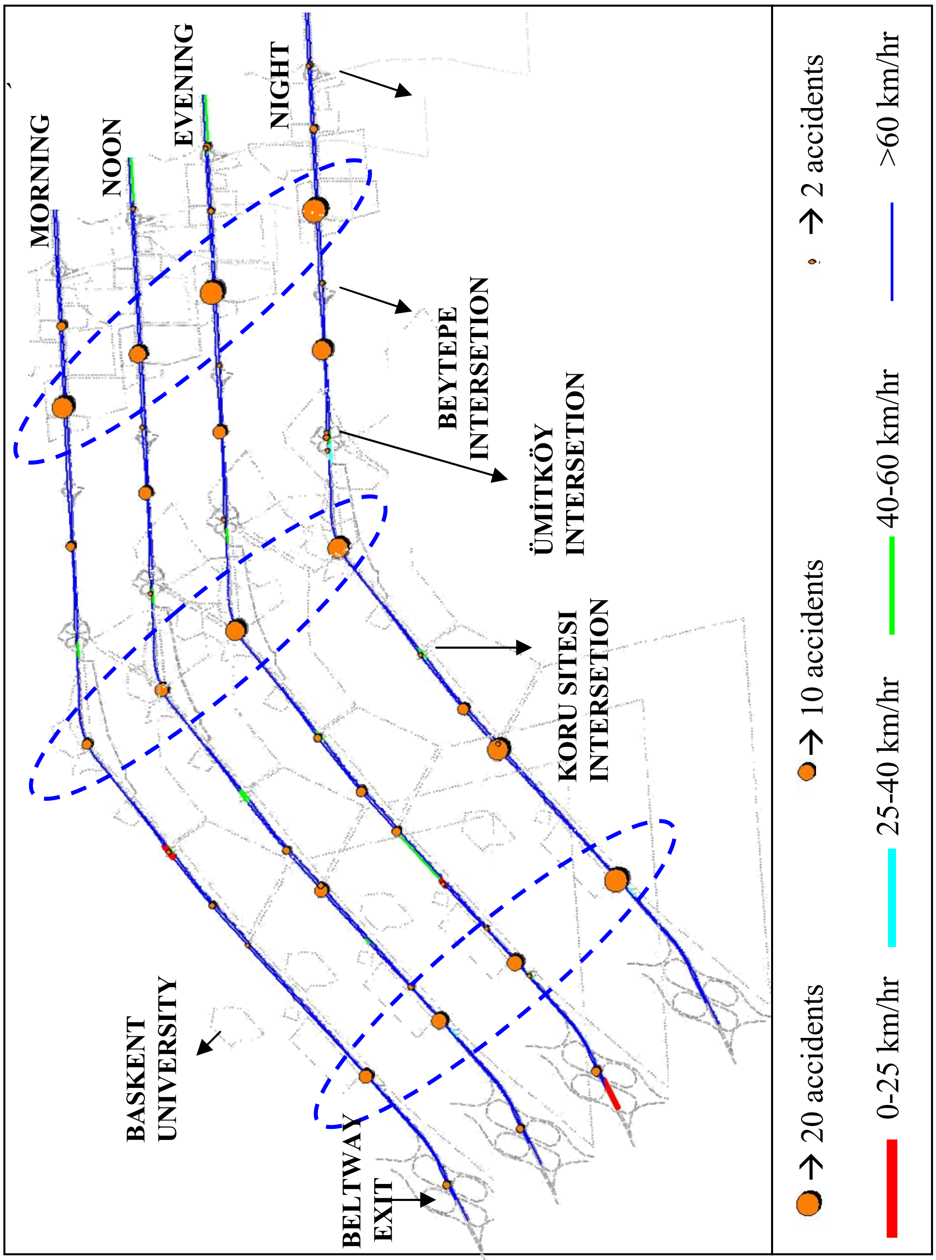


Figure D. 1 TD-TAMs for Section-3

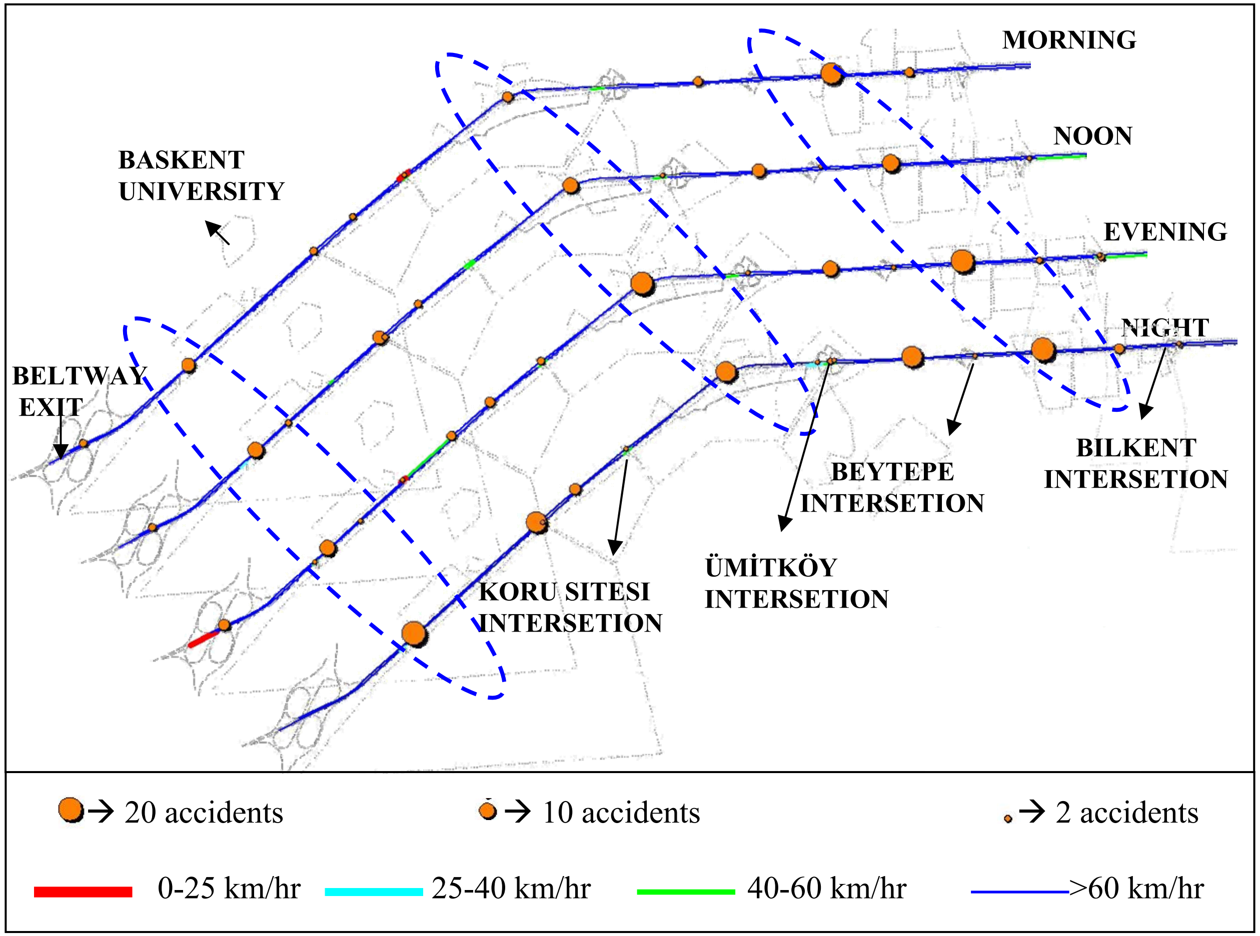


Figure D. 2 TD-SIM$_A$s for Section-3

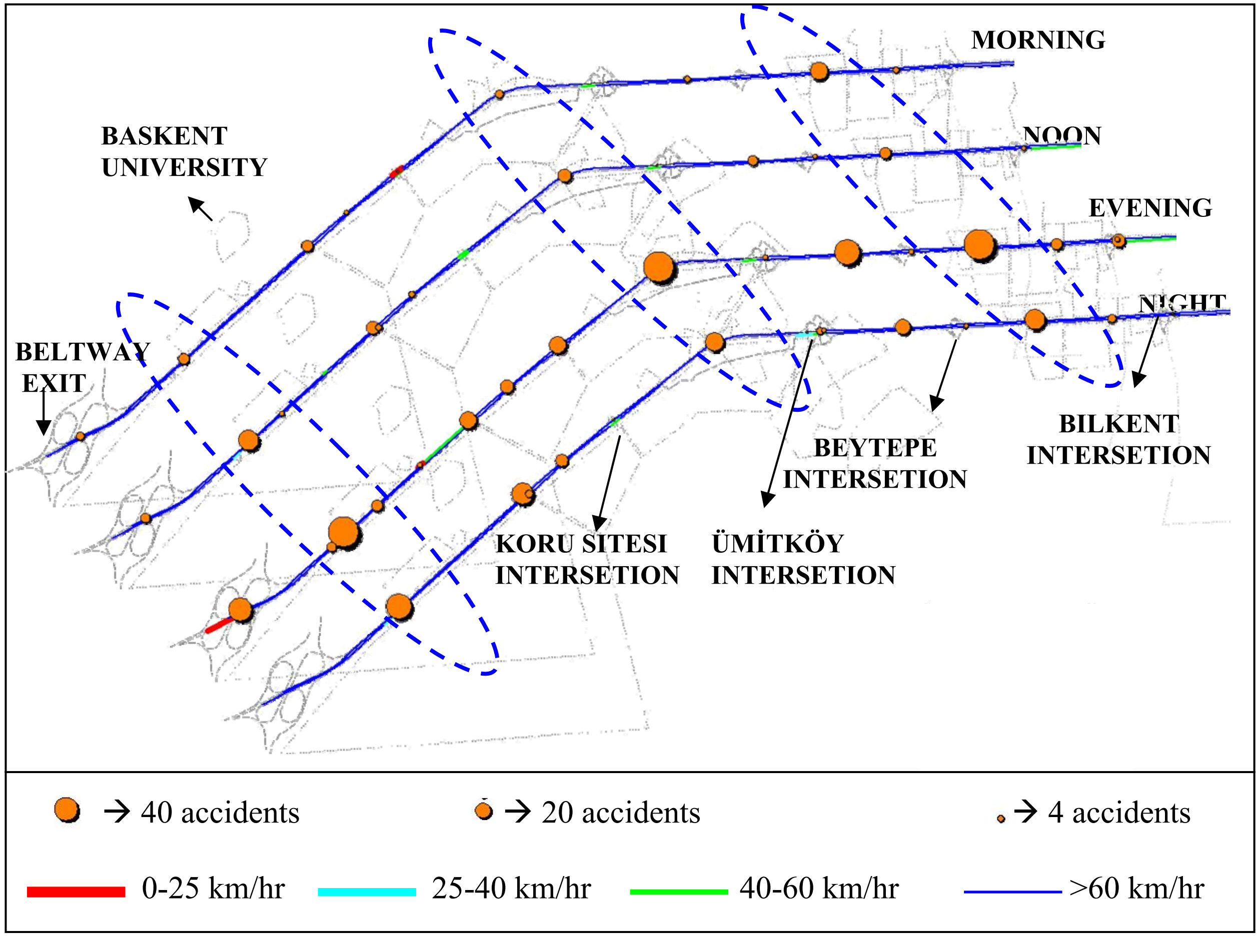


Figure D. 3 TD-SIM$_B$ s for Section-3