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Concept Design and Evaluation of Traffic Management in Beijing

Luyi Weng

September 2010



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Concept Design and Evaluation of Traffic Management in Beijing

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Colophon

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Preface

This report is the final product of my MSc. thesis, and it is also regarded as a milestone of my two-year master study in Technical University of Delft in the Netherlands.

This graduation work is executed on behalf of Rijkswaterstaat (RWS). It is my great pleasure to do such a thesis project related to my home country. And I enjoy both the experience of practical site investigation in Beijing and theoretical thesis work at ITS Edulab. This precious opportunity enables me to find a way to integrate theory with practical aspects and learn many things besides technical skills.

I would like to extend my heartfelt thanks to all my committee members. Thanks for providing me with helps when I encounter difficulties in research and offer my persistent encouragement me when I was kind of depressing during the process.

I would also like to express my warm gratitude to Prof. Chen and the students in her study group in Technical University of Beijing. They gave me the feeling of family during my stay in Beijing, which is both familiar and unfamiliar to me. Without their help, I cannot successfully conduct a 1.5 month local investigation in Beijing.

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Thanks to Transport, Infrastructure and Logistics department of faculty of Civil Engineering and Geo-Science and TU Delft for providing me such integrated knowledge during the past two years.

Finally, I would like to thank my family and friends overseas. Thanks Jessie and Lugia for their spirit support. I dedicated this thesis to my parents. I cannot have the opportunity to study and graduate in the Netherlands without supporting from them; I can feel your love always.

Luyi Weng (Louise)
Delft, September 2010.

Notation

Abbreviations:

BRT	Bus Rapid Transit
DACCORD	Development and Application of Co-ordinated Control of Corridors
DSP	DYNASMART
DTM	Dynamic traffic management
ITS	Intelligent Transport System
MFD	Macroscopic Fundamental Diagram
MOE	Method of Evaluation
PPA	Praktijkproef Verkeersmanagement Amsterdam (Dutch)
TAZ	Traffic analysis zone
VMS	Variable message signs

Variables:

Flow theory:

q	flow rate/intensity
k	density
u	instantaneous speed
k_c	critical density

DSP algorithm:

$K_{i,t}$	density in section I during the t time step
$NV_{i,t}$	number of vehicles on link during the t time step
L_i	length of I link
Nol_i	number of lanes of link i
$V_{i,t}$	mean speed in section I during the t time step
V_f	free flow speed
V_i	speed intercept
V_o	minimum speed
K_b	density breakpoint
K_j	jam density
α	capture the sensitivity of speed to density
$d_{m,t}$	distance of the vehicle can advance during the t time step
Δt	simulation time interval
$R_{i,m,t}$	distance to beginning of next downstream link

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1. Introduction

1.1 Introduction

Along with rapid developments in economy, society and level of urbanization, the need for mobility is correspondingly soaring. This leads to increase in the frequency of traffic jams and growing lengths of the queues in the traffic network, which result in delays, higher travel cost and negative impact on the environment. The gap between travel demand and infrastructure supply is always the main concern faced by the authority in most countries, which is especially true for developing countries. Instead of new infrastructure supply, consensus has reached that traffic management on the efficient use of existing infrastructure ought to play an essential role.

A better utilization of the existing infrastructure nowadays is of main concern in various countries. Traffic management methods which aim to improve the traffic performance on bottleneck area have been focused as an essential way in dealing with traffic congestion in a lot of cities, and practice has shown obvious benefit. Innovation of more dynamic traffic management (DTM) measures further take effect in recent years.

Traditionally, traffic management is local: locally there is a problem and it is solved with a local traffic management measure, mostly without considering the effects on the rest of transportation system (Taale et al, 2004). However, as more and more instruments are deployed, chances are that conflicts will arise when different control tools are applied in the same area, and between neighbouring regions (van Katwijk & van Koningsbruggen, 2002). It is realized that uncoordinated management measures has limitations. Hence, a network-wide traffic management has called for attention. Various studies have been conducted on the issues in different countries and show optimistic effects.

Recently, commissioned by the Dutch Ministry of Transport, Public Works and Water Management, a pilot project Integrated Traffic Management Amsterdam (Dutch: Praktijkproef Verkeersmanagement Amsterdam, PPA) as one of the most ambitious DTM projects in the world has finished its concept proof and ex-ante evaluation phase. Results based on expert opinions and macroscopic model simulation (RBV model) show that further improvement can be obtained with integrated traffic management approach compared to mere local measures (by 1.3%), and the pay-back period is estimated four times faster than infrastructure projects (Hoogendoorn & Hoogendoorn-Lanser, 2009).

With the encouraging result, DVS considers extending the test to other countries and further investigate the potential of traffic management in dealing with congestion.

As far as DVS considered, Beijing, the capital city of China is of potential. In this study, Beijing will be investigated for traffic management on a local level and integrated level.

1.2 Problem identification

As a developing city, the traffic components in Beijing are totally different from what it is in most other developed cities, some major differences at first sight can be concluded as follows:

- Much higher traffic demand
- Larger urban area
- More complicated highways/urban expressways structure

Under such pre-condition, driving behaviour, traffic problems are not likely the same, thus measures applicable in other foreign cities may not all be the key to Beijing, and so do the integrated management structure and the corresponding effect. At the beginning phase of developing the blueprint of traffic management in Beijing, it is worthwhile to make this study.

The problem definition is formulated as follows:

.....
Problem definition

Different kinds of traffic management measures have been practiced and researched showing their potential in dealing with congestion. While the traffic background in Beijing is very different from other cities, the traffic problems thus are not likely to be the same. Accordingly, the effect of measures experienced in foreign cities is doubted to be applicable in Beijing.

1.3 Research objective and question

Based on the problem definition the following research objective is placed:

.....
Research Objective

The objective of the research is to investigate traffic characteristics in Beijing, conceptually design traffic management measures and schemes specific to Beijing situation, predict and evaluate the potential of traffic management in improving the traffic in Beijing.

To be able to meet the research objectives, the project aims to answer two main questions and a subset of step wise secondary questions followed by respectively:

.....
Research question 1

What measures can be of potential in dealing with the congestion problems in Beijing?

- Why traffic management is a promising alternative to deal with increasing traffic congestion?
- How traffic network is composed in Beijing situation?
- What typical features and flow characteristics lie in Beijing traffic?
- What kind of traffic management measures might be adequately applicable to Beijing situation in dealing with traffic congestion?

.....
Research question 2

What is the potential of traffic management measures in Beijing situation?

- What is the tool choice and how is the validation of the tool?
- What is the potential effect of the designed local measures?
- How can DTM measures be responsively integrated for a non-recurrent situation? And what effect can be expected?

.....
Research question 3

How should traffic in Beijing be dealt with to accompany the economic growth in the future?

1.4 Research approach

In order to answer the research questions and sub-questions be raised in section 1.3. The research is conducted essentially with three approaches.

Part 1: Background and conceptual design

The first part aims to answer the first research question. The need for traffic management is investigated with traffic theories and policy aspect discussed utilizing TRAIL framework. The general traffic management approaches are to review with literature and research fact sheets.

Afterwards, based on the fact sheets and field survey, the traffic system background in Beijing is described and given analysis. Traffic feature and problems are afterwards pointed out. The tailored local measures are then designed based on the findings, a theoretical effect is presented.

Part 2: Case study and modelling

A case study is carried out to further investigate the practical potential of traffic management. The effects of measures are accessed by model simulation approach. Software is chosen based on the simulation objective and software availability.

The study area network model is then set up and calibration conducted to some extent. The results obtained by the initial model are used then as a benchmark to observe the improvement offered by the different control measures adopted. Afterwards, possible measure responsive integration approach is considered for a non-recurrent situation under different scenarios. The modelling performance are compared and discussed on several selected criteria.

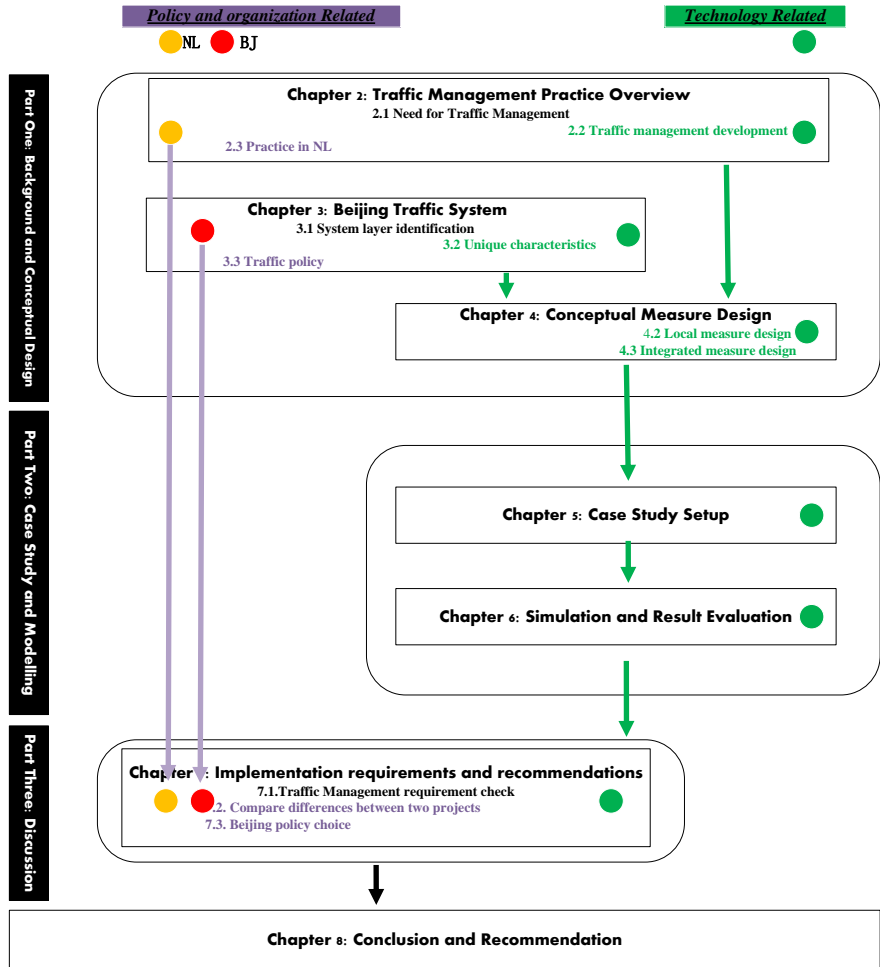
Part 3: Discussion

Based on the findings of above parts, a discussion will be conducted on the detailed traffic management implementation requirement on technical and organizational perspective. A reflection on the reference Dutch case will be compared. And recommendations are provided for Beijing government on the traffic issues.

1.5 Reading guide

Figure 1.1 provides the report outline.

Figure 1.1 Report structure



Generally, the report is divided into three parts as mentioned in the previous section. Two clues can be found in the report being technical aspect and policy aspect. The policy and organization perspective on Dutch and Beijing are respectively developed in separated chapters, orange and red dots indicate their location in the report.

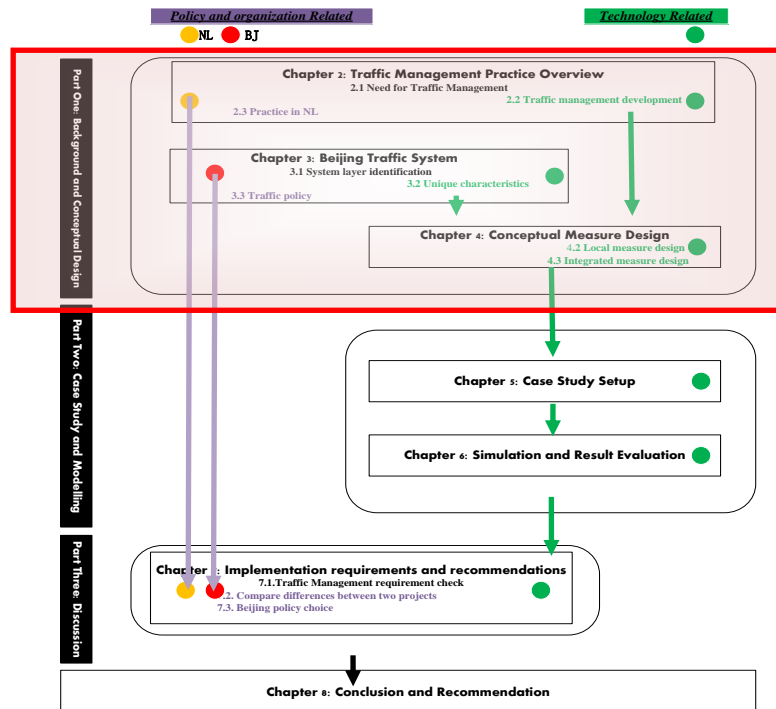
Part One: Background and Concept Design

The first part is conducted to get basic knowledge on traffic management issues and have an overview of the Beijing situation.

The need for traffic management is first presented from traffic theories and policy aspect respectively. The general traffic management approaches are reviewed with literature and research fact sheets. Local traffic management and integrated traffic management are studied.

In the ensuing of this part, the situation in Beijing is investigated. Based on the fact sheets and field survey, the traffic system background in Beijing is described and elaborated in detail. Traffic feature and problems are afterwards pointed out.

Finally, central to this part, the tailored local measures are designed based on the findings, a theoretical effect is presented. And an integrated traffic management approach is also proposed.



2. Traffic Management Overview

In this chapter, a general research on the traffic management is presented. The chapter's central question is:

Research question of Chapter 2

Why traffic management is a promising alternative to deal with increasing traffic congestion?

The need for traffic management is first investigated from both theoretical aspect and traffic policy aspect. The conventional fundamental diagram illustrating local traffic dynamics is looked into and a new concept of macroscopic fundamental diagram (MFD) from a network point of view as well. The merits and defects of different policy choices are discussed based on TRAIL model framework. Afterwards, an overview of the development and recent researches of traffic management measures development are outlined. And specifically, the Dutch's practice of traffic management is investigated.

2.1 Need for traffic management

Traffic management, by definition, is the monitoring and control of traffic. It is the software reinvestment----- utilization on the existing hardware-----physical road infrastructure. The need for traffic management can be explicated from two perspectives: either by basic traffic flow theory which explains the optimal traffic state from technical aspect, or shown by current policy inclination with more of social and economic benefit applicability.

2.1.1 Theoretical Perspective

(1). Generate flow model

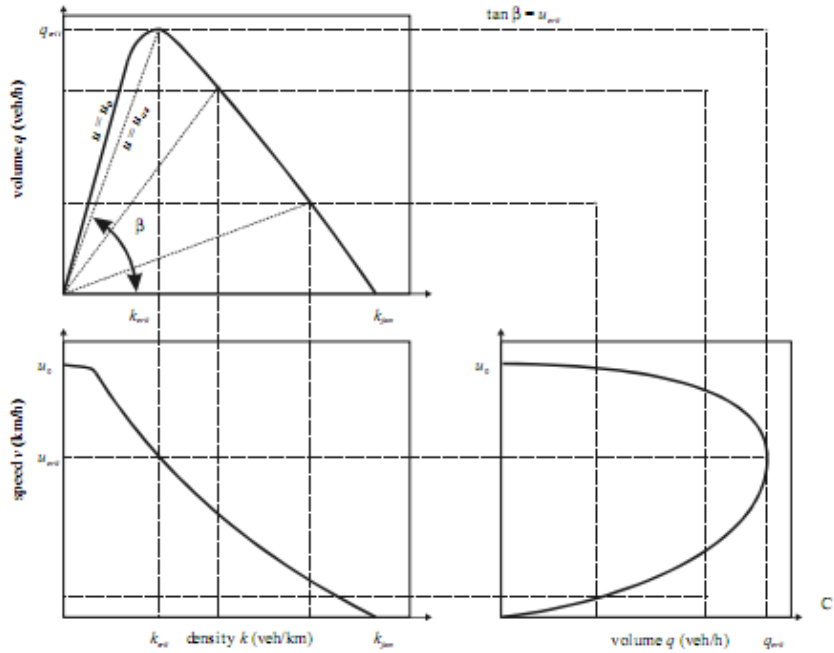
Considering the traffic dynamics from a macroscopic point of view, the basic variables of a traffic flow are flow rate/intensity (q), density (k), and speed (u). Traditional traffic theories believe traffic flow streams on long homogeneous roads exhibit reproducible relations among these factors, holding the equilibrium situation:

$$q=ku$$

Equation 2.1

Such relationship between the above factors of a road section is indicated by fundamental diagrams. Derived by different researches, lots of theoretical model are generated, e.g. Greenshield, Smulders, DeRomphs, Daganzo's, etc. Though models are different in shape, the generally accepted fundamental diagram as shown in Figure 2.1 similarly implicates causality amongst these factors.

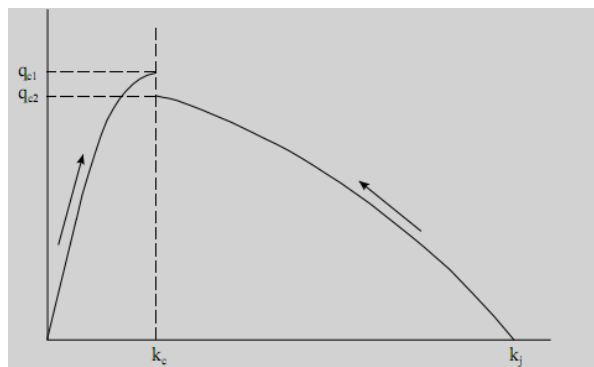
Figure 2.1: Illustration of Fundamental Diagram



For a predefined condition (road network, road usage regulation, general driving behaviour and vehicle composition, weather and lighting condition, etc.), the fundamental diagram indicates the flow regimes evolution as traffic demand increases. When density is below critical density (K_c), the traffic flow maintains a free and stable status. As density keeps growing with the increase in demand flow until exceeds the capacity density, the total flow can be served would decrease, traffic would enter the congestion and unstable state.

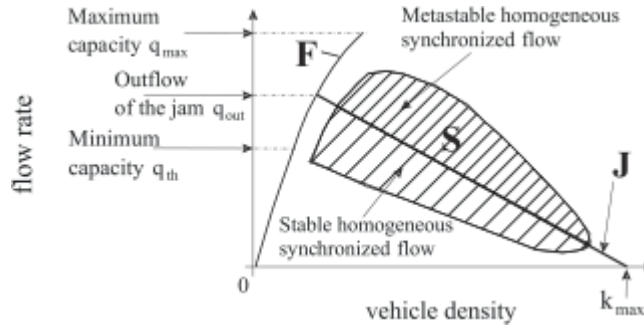
Further, Edie in his research indicated the possibility of a discontinuity in the diagram around the capacity point (Edie, 1965). Wu (Wu, 2000) has also developed a model for the diagram with a capacity drop, which illustrated the fact that vehicles allow longer time headways when they accelerate from a queue than during the traffic conditions just before traffic breakdown. Thus, in the light of the capacity drop two capacities do exist: free flow capacity and queue discharge capacity. Free flow capacity can be observed when density approaching the critical value in absence of queues upstream. The queue discharge flow is the maximum flow rate observed at the downstream location as long as congestion exists. Differences between the two capacities are in the range of -1% to -15% (Hoogendoorn, 2008).

Figure 2.2: Wu's Fundamental Diagram with Capacity Drop



Kerner further developed the density-flow relationship possesses some empirical spatiotemporal features of vehicular traffic feature which reflects traffic occur in space and time (Kerner, 2004). The congestion phase in conventional fundamental diagram was divided to two distinct phases: synchronized flow (S) and wide moving jam (J), bringing the total number of phases to three, as shown below. Thus, Kerner's theory was named as "three-phase traffic" theory.

Figure 2.3: Three-phase Traffic Theory

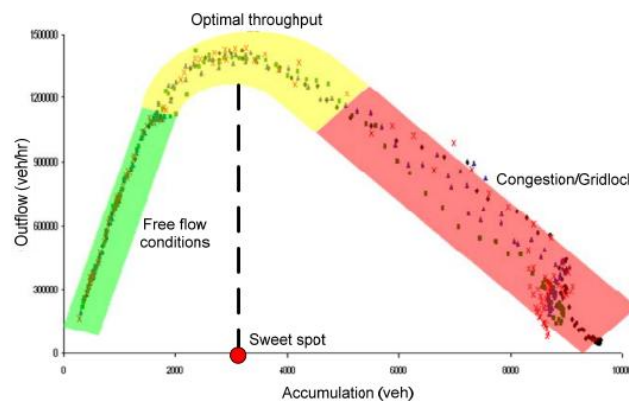


Based on the above discussed theoretical model on link level, we can see that the optimal use of infrastructure, in other words, the way to perform the maximum capacity flow is to keep the density below the critical point. On the other hand, the fact of capacity drop offers a substantially possible opportunity of monitoring and controlling the traffic from breakdown by means of traffic management. And the fact that deteriorated traffic performance under synchronized flow and wide moving jam phase make it worth for traffic management to take the role so as to improve the efficient use of infrastructure.

(2). Network Fundamental Diagram

Apart from the aforementioned conventional link fundamental diagram which shows the potential need of traffic management, the recent studies demonstrated similar theory exist in a larger network traffic performance as well. The concept, known as macroscopic fundamental diagram (MFD) was proposed by Geroliminis and Daganzo (Geroliminis and Daganzo, 2007). Instead of density and flow, MFD addresses the relationship between the accumulations of vehicles on the road in the network at any time with the rate at which trips reach their destinations. Simulation results and field test showed the following figure.

Figure 2.4: Network Fundamental Diagram



Similarly, for a defined network (road network, vehicle composition and distribution, lighting and weather condition, traffic control measures), three phases are demonstrated. The outflow keeps free and smooth

under low travel production. With the increase of the number of vehicles, the outflow gradually rises up until reaches the so called "sweet point", the point where network output capacity can be found. When inflow exceeds this critical point, the network is then subjected to severe loads, network production would degenerate and the flow results in a congestion state, indicated by the red part.

Therefore, the MFD can thus be understood as an expansion of link fundamental diagram to network level. Two main causes for the production deterioration of overloaded networks are spill-back of queues/ grid-lock effects, and the capacity drop (Hoogendoorn et al, 2010). When queues on links spill to intersections and spread over the network, vehicle-vehicle blockage extends to link-link blockage, which further causes system gridlocks. And likewise, a drop of flow between the onset and the resolving of congestion can be observed on a network level shown by MFD as well (Xiaoyu Qian, 2009). These reasons provide opportunities and directions in which network traffic flow operation can enable an improvement,

Hereby, the findings of similar network traffic performance as on link level suggest that traffic management should as well be looked into from a macro-perspective network perspective. Thus the interaction and corporation among traffic management measures should be taken into consideration.

2.1.2 Policy Perspective

Traffic congestion is a problem posing threatens to all countries accompanied by the economic growth and development. The immediate consequences of it range from individual traveller delays to reduced throughput of vehicles. Further consequences include reduced safety, reduced economic competitiveness and increased environmental pollution, which threaten to the quality of life and development of economy in society. Worldwide, various policy choices are implemented aiming to fill up the gap between demand and supply in urban mobility needs, which can be classified in different categories.

The Dutch government accepted a new policy on traffic and transport in 2001. Three packages of strategy (3B in abbreviation) as the main points are proposed: Bouwen (Building), Beprijzen (Pricing or more general term as demand management), and Benutten (Utilization). This instrument classification provides a good policy framework in most countries nowadays and would be as an example classification hereafter in this study. The following discussion is based on the traffic components indicated by the TRAIL layer model (Schoemaker et al, 1999, see Figure 2.5 and Appendix A).

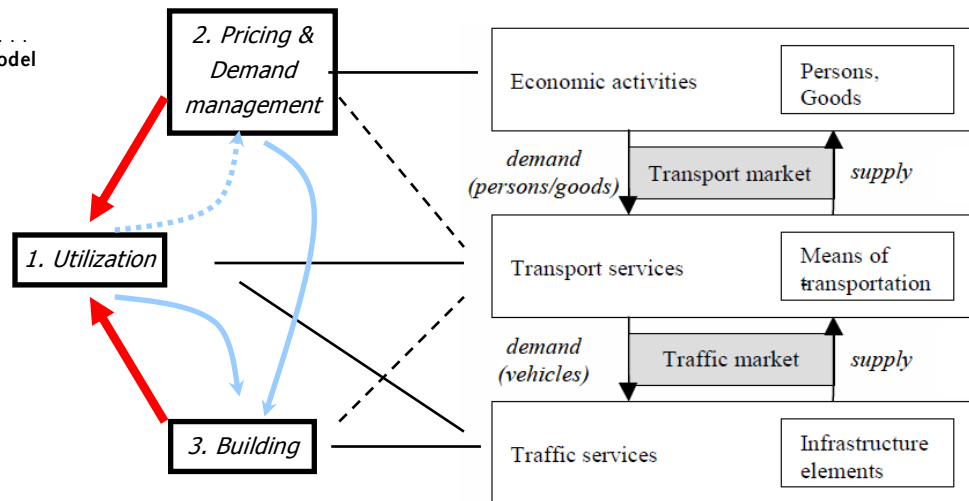
Building, as a traditional supply measure does create more mobility capability. In short term, it is the most direct and effective way to add on supply in meeting the demand. It obviously influences the traffic services, and consequently leads to more transport services. While building new infrastructures often require for heavy investment and likely to induce more traffic. Additionally, the physical land recourse limitation dooms continuous construction not to be the only answer in the long run.

Pricing and other demand management measures, address congestion with certain restriction, can somehow effectively mitigate the

aggravating congestion problem at the expense of economic activities interference on location and time. However, the public acceptance is usually an obstacle issue in practice.

Utilization refers to the promotion of active traffic management measures on more efficient use of existing infrastructure without severe impact on economic activities, and in such a way influences the actual supply from traffic services and transport services as well. Compared with building approach, utilization methods cost less money and time to realize. And less political difficulties lie in this approach than passive demand restrictions. Moreover, the less usage of land resource marks a more sustainable development towards future.

Figure 2.5: 3B policy and TRAIL model



The above figure concludes the influence of three policy approaches on different layers in the TRAIL model. In the figure, solid lines in black indicate direct influence, and dashed ones refer to secondary influence. On the left side of the figure, a “policy loop” from the government perspective is suggested. For a normal city with a certain level of complete structured network (in regards to geographical accessibility), in the context of limited resource and budget, maximize the effectiveness and efficiency of current facility by utilization instruments might be the priority choice to combat with congestion. In such a way potential capacity are explored. When these active management measures meet the bottleneck, pricing and demand restriction could be further considered for interference from demand orientation while challenged by political risky. In ultimate case, the government turns back to building new infrastructure to add physical capacity directly from supply aspect. While in the meantime, utilization would still be worthwhile to pay attention to for optimize usage.

Hereafter, the term “traffic management” in this study will all refer to the management methods aim to improve the utilization of existing traffic infrastructure.

More and more isolated traffic management means are widely applied to improve road network performance on different level. However, the increasing amount of control systems is causing a number of operational problems (van Katwijk et al., 2002), comprising:

- traffic services, for example highway and urban roads, are operated under different operators

-
- control conflicts between traffic control centers in neighboring regions under different regional operator
 - the increasing number of operator tools/systems, requiring better integration
 - control conflicts when different control tools are applied in the same area
 - different objective and care of the operators

In this sense, either from technical level or operational level, more cooperation between measures and operators is suggested and required.

2.2 Traffic Management Development

Traffic management has long existed to organize and regulate the traffic in one form or another. In the early days, measures are more for safety objective to avoid confliction. Examples can be found from simple lane separation to later the fixed-time control traffic lights appear at intersections. As traffic becomes heavier, except from safety issues, more countries have design more static traffic measures concerning for improvement of the general traffic performance on existing infrastructure. For instance, the introduction of dedicated lane, buffering design, etc. Moreover, thanks to the development of emerging information and communication technologies, Intelligent Transport System (ITS) has grown apace in recent years on freeway control in some countries. The measures are no longer static but dynamically active to current traffic situation. These instruments in favor of ITS are called Dynamic Traffic Management (DTM). Some of representative ones are ramp metering and actuated signal control. The above mentioned measures are mostly operated individually aiming at limited affect regions, thus are considered as "point" measure or "local" measures. In Appendix B, some local measures developed for freeway in practice or under assessment are concluded.

Locally there is a problem and it is solved with a local traffic management measure, however, mostly without considering the effects on the rest of transportation system (Taale et al, 2004). As more and more instruments are deployed, chances are that conflicts will arise when different control tools are applied in the same area, and between neighbouring regions (van Katwijk & van Koningsbruggen, 2002). In this sense, the measures are actually not playing its full potential. As discussed in the previous section, either from the theoretical perspective or policy perspective, an upgraded interaction can be mutual productive but also likely to be counterproductive. Co-operation among individual measures is called for attention in an attempt to further benefit from traffic management. Thereby, the extension from local/ (point) control to arterial (link) and network (corridor) level control is the issue and nowadays being a heat topic in discussion.

In the DACCORD framework (DACCORD D06.1, 1997), the co-operation of more than one local measure is distinguished into two concepts: coordination and integration. The difference between integrated and coordinated control is that integrated control refers to the cooperation of different type control measures as opposed to coordinated control which refers to the cooperation of the same type control measures.

A lot of algorithm studies on coordination of DTM measures are put forward, and some practical applications can be found in reality. Coordination of traffic lights is one of the most common applications of coordinated traffic control and practice examples can be found in many researches and in practice. SCOOT (Hunt et al, 1982), TRANSYT (Robertson, 1969) are some of the example link coordination systems. A more recent application of coordination is coordinated ramp metering. HERO (Heuristic Ramp metering coOrdination) coordination algorithm which employs an extended version of the feedback regulator ALINEA at the local level, the simulation results of which shown good effect of possible speed increase of 35% to 59% (Papamichail, 2008). And the pilot practical application on the Monash Freeway in Melbourne, Australia does outperform uncoordinated local ramp metering (Papamichail, 2010).

While with regard to “integrated management”, the detail control algorithm is still rather vague. Although the concept is not new, many studies remain on theoretical level. Under 4th European Framework Program, a large scale major European project called DACCORD (Development and Application of Co-ordinated Control of Corridors) was carried out dealing with dynamic traffic management and control on inter-urban motorways based on three test sites (Paris, Italy, and the Netherlands), and further develop open system architecture for interurban traffic management. Research has shown potential effects. And recently in Netherlands, a pilot project “Integrated Traffic Management Amsterdam” (Dutch: Praktijkproef Verkeersmanagement Amsterdam, acronym as PPA) as one of the most ambitious DTM projects in the world has finished its concept proof phase based on a hieratical multi-level control approach. Ex-ante evaluation has also shown cost-benefit result, the detailed approach will be followed in next section (Rijkswaterstaat, 2009). However, so far, the knowledge about integrated management effect is still limited to theoretical estimation. Not yet practical field test has yet been conducted.

2.3 Practice in Netherlands

In Netherlands, the planned construction projects are set aside and the introduction of road pricing are postponed many times. Instead a shift from building new infrastructure towards a better usage of existing infrastructure can be observed since early 1980s’ and receiving increasing attention. Traffic management becomes an important pillar and continuously being emphasized in successive policy documents till now. Table 2.1 gives an overview of the traffic management measures taken in the Netherlands in the past two decades. In the document “Policy Framework for Utilization” (Ministry of Transport and Water Management, 2008), it was estimated that with these measures, congestion (measured in vehicle hours delay) has decreased by 25% during the years 1996-2005 (Taale, 2009).

Table 2.1: Traffic Measures in Netherlands

Measure	#Site	Kilometers
Motorway traffic management system		1179
Monitoring		2628
Speed measures (80 km/hr zones)	5	20
Ramp metering	99	
Overtaking prohibition trucks	82	1100

Peak lanes (using hard shoulder)	25	135
Bus lanes, truck lanes, tidal flow lanes	12	24
Services for busses	88	
Traffic signal control	257	
Camera systems	1494	
Variable message signs	258	

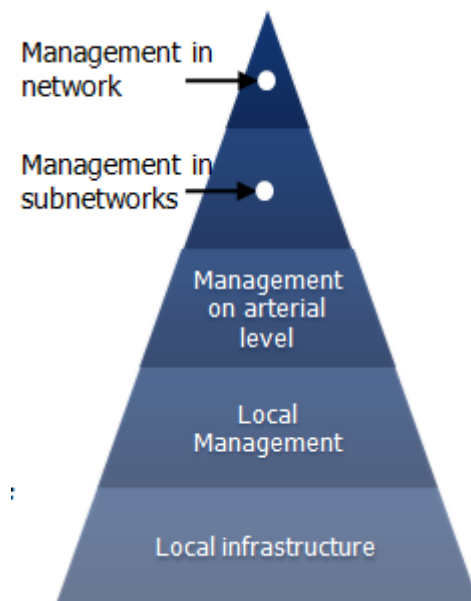
Recently, commissioned by the Dutch Ministry of Transport, Public Works and Water Management, a pilot project Integrated Traffic Management Amsterdam (Dutch: Praktijkproef Verkeersmanagement Amsterdam, PPA) as one of the most ambitious DTM projects in the world has finished its concept proof and ex-ante evaluation phase. The project aims at network wide coordination of the different DTM measures in the region of Amsterdam. The project was done following GGB (Gebiedsgerichte uitwerking) approach (Rijkswaterstaat, 2002). Integrated measures as well as control approach were initially developed.

Three main principles lies in the control approach are interpreted as follows:

1. Solve problems locally if possible, increase level of coordination amongst measures if required. Deployment of (combination of) measures depends of characteristics of problem occurring in network:
 - local problems are dealt with locally
 - more severe problems call for more coordination
2. From sweet to sour. Deploy soft measures (informing) when possible, hard measures (controlling) when needed.
3. Graceful degradation of network performance. If congestion cannot be prevented or solved, the network performance is allowed to deteriorate in accordance with the priorities and functions of different roads (Hoogendoorn et al, 2010).

These principles are supposed to be applied “hand in hand” under the proposed control architecture based on a distributed hierarchal approach as shown in Figure 2.6.

Figure 2.6: Hieratical multi-level control approach



The lowest level of control represents the static infrastructure measures. Confronting traffic dynamics, responsive isolated traffic management measures are further called on. If problems at the local level become too severe, congestion on local spill over to the urban network, coordinated arterial management will start. Likely, when the system is detected unsolvable still, a more macro management approach on sub-network level and network level should be looked into, which entails further clustering of the coordination.

Results based on expert opinions and macroscopic model simulation (RBV model) show that further improvement can be obtained with integrated traffic management approach compared to mere local measures (by 1.3%), and the pay-back period is estimated four times faster than infrastructure projects (Hoogendoorn & Hoogendoorn-Lanser, 2009).

Encouraging results shown in the Amsterdam project, although not yet practically proven, enlightens general management concept to other cities. However, different background in various aspects, from basic traffic components to political organization, would likely lead to different results.

2.4 Conclusion

In this chapter, an overview on the traffic management issues is reviewed. It is concluded from either theoretical point of view, or a policy perspective, traffic management and the co-operation of management on a higher level are efficient towards a better utilization of the traffic network and thus alleviate the congestion traffic situation. And then, a practical review is carried out on the existing measures and concept approaches regarding traffic management. A lot of measures have been demonstrated to take effect in real life in different countries. And the DTM measures and integrated traffic management proposed indicate, nowadays, the trend towards a more responsive management approach.

3. Beijing Traffic Characteristics

Beijing, the capital city of China, is experiencing astonishing development in the past decades. Accompanied by economic development is the increasing “disturbing” traffic problem. Beijing is severely challenged by urban mobility, encounters the most serious traffic congestion among major Chinese cities. Traffic in Beijing has long been a headache of residents and the government, “A Giant Car Park” was a nickname given to this bustling metropolis. According to the 2009 Foton Chinese Index for Mobility (FCIM) released by Horizon Research Consultancy Group (Horizon Group), Beijing imposes the highest economic cost from congestion among seven Chinese cities of similar size and economic level. Research showed that the monthly economic cost of traffic congestion for one single Beijing resident reached 335.6 Yuan, topping those of other cities (CCTV news, 2009). The capital is definitely also being “capital” in terms of congestion.

Facing such severe problems, it is expected the introduction of traffic management and further integrated methods would improve the situation. However, before methods could be used, the different traffic background should be first investigated to warrant that the problem source matches with the method objective. Otherwise, it is not likely applicable.

To this end, this chapter serves to answer the following questions:

Research question of Chapter 3

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|--|
| <ul style="list-style-type: none">● How traffic network is composed in Beijing situation?● What typical features and flow characteristics lie in Beijing traffic? |
|--|

To illustrate the traffic system in Beijing, the TRAIL model mentioned in the last chapter (Schoemaker et al, 1999, see Appendix A) is used as a framework again to analyze the road transport layer components respectively. Fact figures are collected and compared in the process. After a general picture is presented, unique traffic features on physical layout and traffic flow performance are pointed out, which should be considered when developing traffic management methods to be tailored to. And finally, a policy aspect is described to sketch the current development and look into future opportunities.

3.1 Beijing Traffic System

3.1.1 Traffic service: Road Network

At the bottom of the TRAIL model, infrastructure is the basic supply of the whole system, of which road network builds up the skeleton of a city.

From a macroscopic view, Beijing network shows its distinctive grid network structure. Most streets in the city, especially the inner city are strictly North-South direct or towards West-East in parallel. This is mostly the result of the way the built-up areas are organized in the old days. And for historical reservation reasons, the roads remain this way

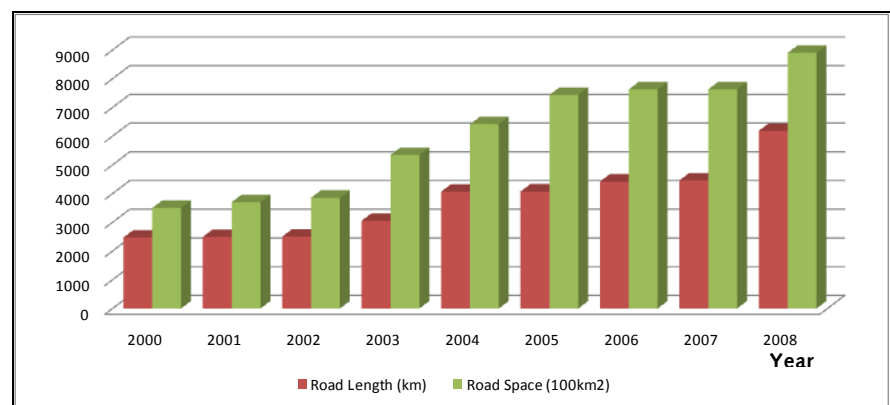
as it was. Grid network in itself has defect on inefficient land use and low accessibility (more detours) compared to circular and radian network allocation (Bolt, 1982). Especially in Beijing case where many close area (residential zone) with dead end roads are there to exist.

Figure 3.1: Beijing Road Network
Google map



The government has paid much effort in extending road network to facilitate the ever increasing demand in the past decades. As depicted in Figure 3.2, road infrastructure has grown significantly over the last decade. The total length in kilometer in 2008 has more than doubled that of 2000 in the urban area (inside and including Ring 5 expressway), the road space as well. The density of road space in 2008 was 4.52km per 100km² (Beijing Transport Annual Report, 2009).

Figure 3.2: Road Network Growth
(Source: Beijing Roadway Administration Bureau)



According to road grade and function classification, Beijing urban roads are divided to 4 main types: urban expressway, major road, secondary road and other feeder roads.

The road network for the central districts expands from five expressway loops, a traffic structure unique in the world. Urban expressways gradually built up in current years are regarded as the skeleton holding the whole network. As shown in Figure 3.3, five ring roads are all

centered about the city centre and connected with each other through radiate expressways at different points.

Table 3.1: Traffic Measures in Netherlands

#Ring	Lanes per Direction	Ring Length (km)	Direct Distance to Centre (km)	Speed limit (km/h)
2nd Ring	3	33	2-3	80
3rd Ring	3	48	3-6	80
4th Ring	4	65.3	8	80
5th Ring	3	98.58	10-15	100
6th Ring	4	200	15-20	100

Mainlines on urban expressways, shown in red in Figure 3.3, are isolated high volume rapid transit corridor specific for uninterrupted vehicle flow. The designed free flow speed limitation is 80-100 kilometers per hour. Similar to general freeway, urban expressways are enclosed type all way through, free of traffic lights at intersections, and linked with parallel roads through entrance and exit ramps. Urban expressway plays an essential role in carrying long and median distance trips. The initial desired functions of expressway lie in improving the mobility and accessibility between centre city and suburban region, connecting different function areas, and facilitating cross town and inter-district traffic in the city.

Figure 3.3: Ring road and Major Road Network



Major road are shown in blue in the above figure. They are also high capacity lanes (usually 3-4 lanes per direction), but with interrupted flow due to traffic lights at intersections. Most major roads are structured as kind of three breadth roads, with separated parallel lanes on the outmost side (for both vehicles and bicycles). It aims to alleviate the influence from roadside stopping vehicle on mainline and separate the right turning vehicle in advance. Major roads handle most trips between regions in the urban areas, and share the burden on parallel expressway. The designed speed is 50-60km/h.

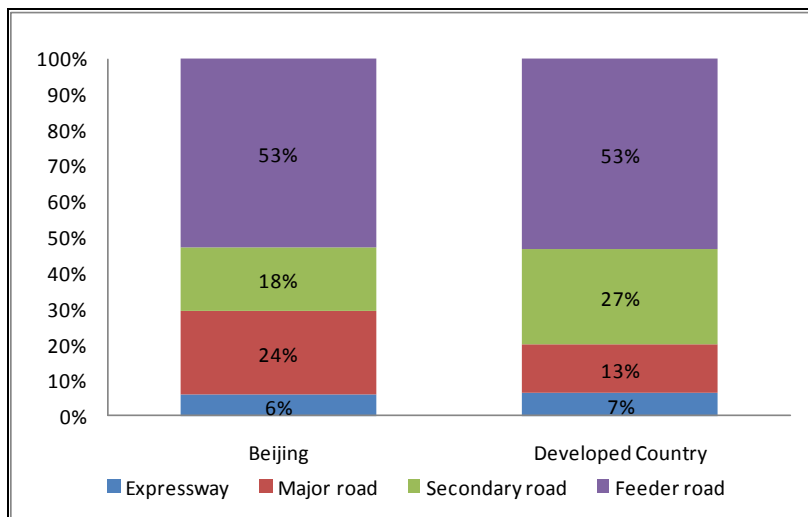
Figure 3.4: Example of three breadth main road



Secondary roads and feeder roads are to serve the traffic mostly within the region, playing a role of distribution and collect traffic for higher grade roads. Speed is limited to 30-40km/h.

The concluding remark of traffic service concerns the road type structure. Up to the end of 2008, the total length of expressway was 247 km, major road accumulated to 755 km, while secondary road summed up to only 644km. The ratio of these grades of roads, from high to low (expressway/highway: major road: secondary road: feeder road) is 1:4:3:9. While in developed countries, the pyramid like fraction of 1:2:4:8 is preferred (Beijing Municipal Commission of Transport, 2009). Comparing the ratio, it can be observed that lack of secondary roads and feeder road is one of the main defects in current Beijing road network system structure. Adding on the network geographic structure, this leads to a severe problem of the so called “micro-circulation”, meaning the low accessibility of lower grade roads in subarea. And on the other hand, the fact adds on the traffic dependence thus pressure on higher grade roads.

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Figure 3.5: Road type structure compare

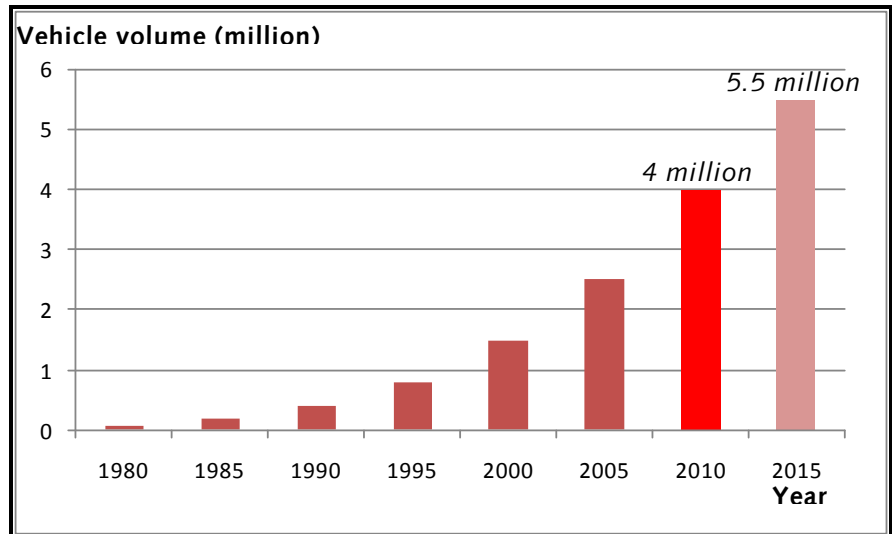


3.1.2 Transport Service: Vehicle

In this study, transport service in consideration includes only vehicles on general vehicles, no subway, bike or other modes are considered. Accompanied by economic development, urban sprawl, growing automobile industry, the number of vehicles is increasing with

astonishing speed. At the end of 2009, car ownership hit 4 million (Beijing Traffic Management Bureau, 2009) which approximately triples the number ten years ago. It is estimated that if no policy measure is to intervene, the increasing rate (about 10% per year) is expected to be kept conservative in the coming years. At this rate, at least 5.5 million vehicles ownership could be anticipated in 5 years.

Figure 3.6: Vehicle Growth



3.1.3 Economic Activity

More than 22 million people are living in the capital city. With inevitable urban sprawl and suburbanization accompanied by economic prosperous, residents are moving further far from center region, while main functional area remain unchanged. In essence, such imperfectly functioned urban sprawl, different from developed cities, is making the central urban area more crowded due to more mobility needs. Accordingly, commuters are experiencing even longer travel distance and more severe congestion (Weng, 2008). According to 2009 Beijing Transport Annual Report, the daily commute traffic accounts for 31.51% in all travel types, peak hour appears at 7:00-8:30 period. And the average time spent for commute is 52 minutes. Regarding the traffic geographical distribution, 34% of traffic is observed inside 2nd Ring, and the route of 50% drivers passed through the 4th Ring, the ring road which is often regarded as the boundary of centre urban and suburban traffic (Chen, 2009). In this sense, the traffic shows significant center oriented feature.

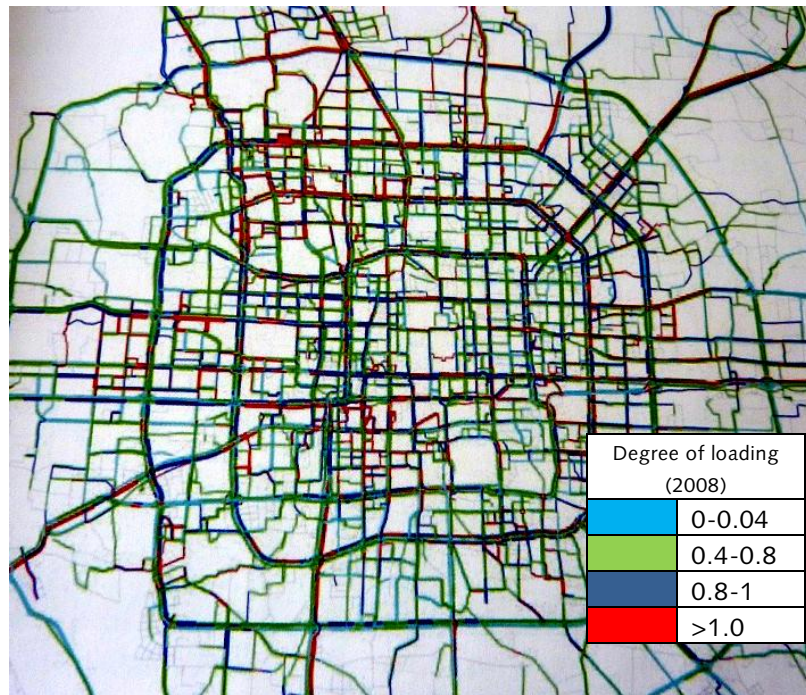
3.1.4 Traffic and Transport Market

This layer shows the traffic performance under the traffic service as supply and transport service as demand.

Indeed, the explosive expansion of automobile is a reflection of more prosperous life. However, when the traffic market cannot facilitate the demand, more and more vehicles only cause mutual decrease in mobility.

Travel speed during morning peak hour on express ways is on average 35.6 km/h, and 23.1 km/h for major roads. During evening the figure is a further lower with 30.4 km/h on expressway and 19.9 km/h on major roads (Beijing Transport Annual Report, 2009).

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Figure 3.7: Vehicle Growth
Source: Beijing Transport Annual Report
2009



The map above shows the degree of loading (volume/capacity rate) on a typical peak hour day in 2008. It can be observed that on the ring road, especially the 3rd ring, loading factors reached almost 1 at most sections, indicating an overwhelming situation on high grade roads.

In a nutshell, from the general traffic components, the traffic background in Beijing differs a lot from other developed countries. Featured by:

- Traffic service: grid structure, five central oriented ring loop, extensive increase road network capacity in the past years, weak structure
- Transport service: booming vehicle amount
- Economic service: long distance, long travel time commute traffic
- Transport and traffic market: low travel speed, high loading factor

3.2 Traffic feature

As described already in the TRAIL model, the traffic in Beijing has its unique characteristics under such traffic system background. On the one hand, certain capacity limitations are caused by objective aspects of limited land space and road structure. For example, urban expressway shares similar design approach but enjoys limited freedom due to the special allocation. On the other hand, traffic flow type and driving behavior, or driving habit, lead to further reduction in capacity may have worsen the situation. Take weaving as example. Therefore, only with a profound understanding from both sides as a basis can traffic management measures be well targeted.

This part provides insight into the traffic features of the network in Beijing. In the process, problems under the current situation will be unveiled.

3.2.1 Expressway Feature

Similar to freeway, expressways are enclosed type and free of traffic lights all way through. However, the supposed “uninterrupted flow” is in reality hardly maintained on urban express roads due to its special allocation and traffic condition in urban area. Compared with general freeways or highways, some unique features in Beijing expressways are found through site investigation as follows.

(1) Same layer level

The closer to the centre urban area, the denser road and land use settlements are. Expressways in Beijing have much interaction with general urban roads in order to gather and disperse the long and median distance through traffic. For ease of settlement and convenience of interchange with local traffic, mainline on expressways in Beijing is designed the same layer level parallel to surface road except for upgraded overpass at major road intersections, which is contrast to the general elevated highway. The main road and surface road are separated with either greens or physical barriers.

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Figure 3.8: Layout of urban expressway



The side effect of such same surface layout is the breakdown of secondary and feeder roads where no overpass exists. The ring road expressways in this sense act as a city walls with only limited gates to go through, therefore the utilization value and accessibility of low level roads are reduced.

(2) Virtual ramp space

Ramps are sections of roadway that provide connections from one motorway facility to another motorway facility or to another non-motorway facility. In most traffic system, the urban part and freeway part are clearly separated via on-ramps and off-ramps as interfaces. While in Beijing, such distinction is rather vague. Due to the layout of urban expressway, no room in vertical left for such special buffer ramp lane. Instead, traffic approaching the expressway can only stored on the rather short interface space, which is only approximately 20 meter long, the rest will spill back onto adjacent surface road. Similarly, the “off ramp” flow merges directly into the surface road traffic once it is off the expressway. In this sense, surface road in the system takes the role of “virtual ramp”. The interface traffic is thus with comparatively

less separated buffering space, if not well organized, may easily interfere the traffic either on main expressway or surface road.

(3) Ramp setting

To facilitate the accessibility of urban traffic and necessary linkage with other types of urban roads, entrance and exit points on urban express roads are more frequently set compared to general freeways.

The following table shows the ramp setting condition on four urban ring roads in Beijing.

Table 3.2: Ramp information

#Ring Road	Ring length (km)	Inner Ring		Outer Ring		Sum
		Entrance	Exit	Entrance	Exit	
2nd Ring	33	33	28	26	29	116
3rd Ring	48	53	54	48	56	211
4th Ring	65	37	43	36	38	154

It can be seen, the average distance between adjacent entrance ramps on 3rd Ring road is the shortest, only about 950m. On 2nd Ring road, entrance ramps appear every 1100m. On 4th Ring, the average distances in between are bit higher. Further, if including the off-ramps, traffic on surface road meets with a ramp approximately every 500 meters. The distance from a ramp towards the upstream or downstream intersection sometimes is only 100 meter to the secondary road and 200-300 meters to the major road, the disturbance of in and out flow from the mainline may thus easily affect the traffic at intersection, and vice versa. Besides, most entrance and exit ramp appear in pairs in on-ramp upstream and exit downstream type, the weaving sections range from 100m to 200m in length.

(4) Trip Composition

Although ring roads are designed mainly to serve for long distance or median distance traffic, in real practice it is not true. Due to the urban allocation, short distance trip are often induced on to expressway as well. The regional trip less than 2 kilometres account for 20% on the 2nd and 3rd ring road (Quan et al., 2005). This part of so called expressway "rat-runners", frequently merge on and off ramp, are relatively posing more traffic burdens.

(5) Bus and bus stops on expressway

To promote public transport, a lot of public traffic bus lines are switch onto the expressways in purpose of traffic priority. Big size and slow moving buses, acting as moving bottlenecks, disrupt the passenger car stream, thus lower down the expressway capacity. Collected data shown, the percentage of bus on main expressway accounts for 5-8% during peak hour and 2-3% during off-peak (Wang et al, 2006).

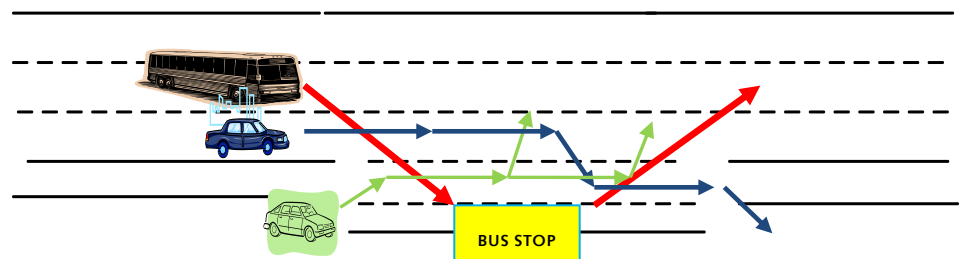
In addition, some bus stops are located on the expressway to facilitate the "express buses". The location of the stop is usually close to entrance and exit ramp. Although facilitated with additional lane, the lane change of such long size vehicle inevitable aggravated the weaving capacity loss in the interface section. As shown in the left picture, the acceleration lane for entrance vehicles fails to play its role in such case. Further, the width of bus stop lane is only two thirds of normal lane, which is approximately same width with bus itself. Apparently, the bus seldom can be fit that well to the specific lane, likely to occupy two lanes. The merging passenger cars may therefore difficult and afraid to

make use of the buffering lane right beside the bus lane. In this sense, the chaos on such merging area result in a severe bottleneck, road safety is endangered as well. Figure 3.10 casually stretches the flow weaving performance in the adjacent of the bottleneck area.

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Figure 3.9: Bus stop at ramps



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Figure 3.10: Illustration of weaving at bus stop



3.2.2 Other Feature

Apart from the above expressway features, some other characteristics are observed in Beijing traffic on urban roads:

(1) Wide road with mix traffic

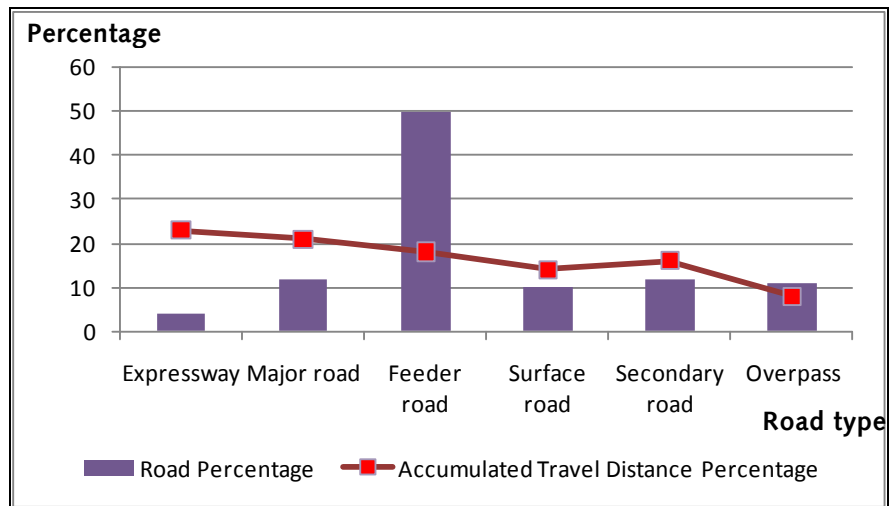
The average road width in Beijing is 18.7meter, which is one of the highest among other metropolis under same scale (Yang, 2009).

In addition to wide lanes and high vehicle demand, the flow composition is characterized by highly mixed traffic. With large amount of slow moving bicycles and pedestrians, the traffic signal phasing is even more complicated. Under most cases, no intermediate traffic signal is set for bicycles and pedestrian crossing, the long clearance time further extended the evitable signal cycle. In addition, the allowed conflict stream of right turning traffic with other streams (especially pedestrian and bicycle) on the one hand shorten the cycle time, but poses potential safety problems. Hence, due to such complication in flow from various directions on the wide intersection area and chaos occurs from time to time caused either by conflict streams or weak road user's regulation behaviour under intolerable long waiting.

(2) Unbalance traffic distribution

Collected floating probe figures, the following diagram depicts the road utilization rate of different road types (Weng et al, 2008). Expressway accounting for only 5% in road length in practice shares about 25% trip length. While the utilization rate of feeder road is less than half of its road length. It is obvious that road users have a bias and dependence on higher grade roads. Trace to the cause, it may be an integrated result of both objective and subjective factors. On the one side, the road network is not good in structure. Especially the lower grade road is of low accessibility, a lot of one direction dead end feeder roads make the so called microcirculation on low grade road a problem, therefore road users are forced to use main road as priority rather than taking a risk in detouring on the unknown small roads. In other cases, although feeder roads alternatives do exist, drivers either recognizes for unfamiliar on the network or neglects with conventional thinking, since the low speed limit, frequent stops and long traffic signal cycle at intersection are not preferred. Consequently they will still opt for crawling in congestion on the crowd but "uninterrupted" rapid expressway.

Figure 3.11: Road kilometre travelled by different grade of roads



3.3 Traffic policy

As a fast developing city, building and expansion was regarded as the top policy choice in Beijing in the past decades, both traffic services for public and private transport. In order to set up a basic and complete network system as most other metropolises do, and to sustain a growing automotive demand as well as economic growth, huge amount of capital on highways has been and is to further devoted to.

Although the return of investment for infrastructure is high as well, for example the newly built 6th Ring is estimated a return 10 times of the investment in twenty years. The 100 million capital per kilometre infrastructure (6th Ring road as example) can be hardly affordable. Besides, Beijing urban area is characterized by high coverage of historical relics (42% geographic coverage), the road expansion and construction possibility is very limited. And the fact that new roads lead to new congestion as a vicious circle, especially when urban area is almost approaching the ends nowadays, is calling for attention. This has been already shown in the previous traffic system description.

From the pricing perspective, extending to demand regulation methods, the government has dared to deploy packages of measures. The car usage restriction, which prohibits every car from driving in urban area (inside 5th ring area) on one weekday according end license plate number, has implemented from 2008. Besides, the trucks are strictly forbidden to enter the urban area during daytime. Moreover, it is planned to double daytime parking fees in downtown areas in order to ease downtown traffic congestion. A congestion pricing scheme is under consideration as well. Lack of public acceptance, the implementation remains an obstacle.

Facing the severe mobility challenge in the future, it is realized that priority should be turned to a more cost-effective approach of "Utilization" for a sustainable development. On the one side, the kind of "chaos" traffic on current infrastructure in Beijing leaves a lot of room for exploring the potential of traffic management, especially dynamic management to minimize capacity-reducing factors on existing infrastructure. Beijing has switched to seek opportunity on the management instruments. A good start of effort has been made on traffic management in the recent decade.

Since 1998, the government have launched the initial program of ITS based traffic management. The successful bit of Olympic Games of 2008 further promotes the development of it. Till the end of 2009, the planned two phases of the master project has almost completed with an accumulated investment of 880 million RMB. The resulting system involves detection on ring roads, actuated signal control, digital police positioning by GPS and dispatching, VMS and other information release approaches, etc. A simple description among the above ones that related to this study will be followed.

➤ Traffic detection and monitor:

Tens of thousands of detection equipments are installed in expressways and main aerial road within urban network of Beijing (inside 5th ring) covering 30% of area, which are just like the nerve endings of the city and automatically collect 24-hour operation data such as road traffic flow, flow rate, speed, occupancy rate, etc. On the expressways, the monitoring is through ultrasonic wave and microwave devices (shown in Figure 3.12). On urban roads, detection coils are buried underneath the ground near intersections and transmit information to detectors via electronic induction. Besides, high definition cameras and video devices are installed along the ring roads identifying individual vehicles (plate number) and reporting audio information.

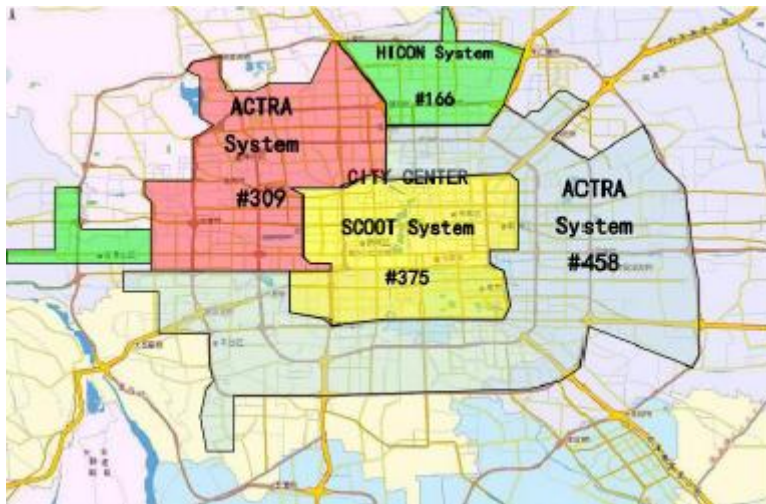
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Figure 3.12: Microwave Device



➤ Actuated intersection system

In the past years, actuated signal systems of different kinds have been applied on main intersection in the urban area (indicated by Figure 3.13). The control system can automatically calculate, in accordance with the real-time traffic flow, the timing scheme, and conduct the maximum passage control during the rush hours, coordination control in normal conditions, and induction self-adaptive control in conditions of smooth traffic flow so as to achieve normal traffic along the arterial roads.

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Figure 3.13: Actuated system in urban area



➤ VMS

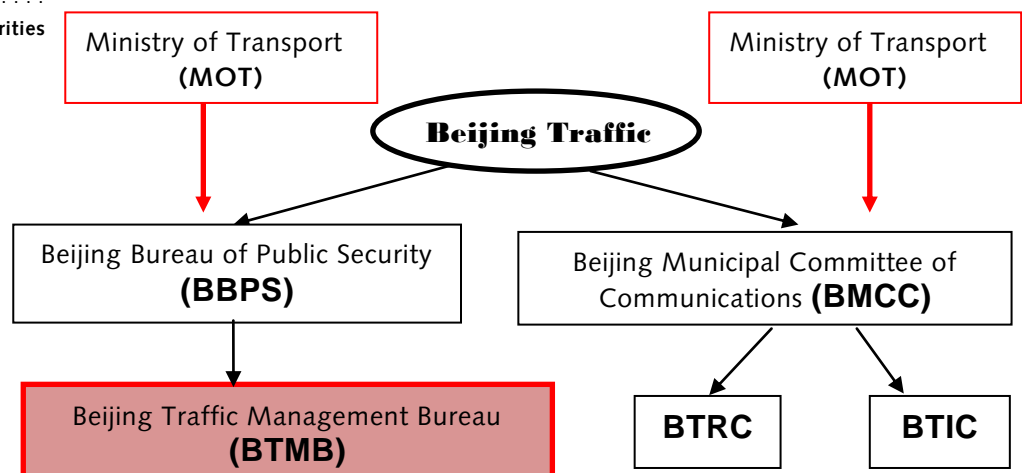
At the sites of ring roads and arterial roads in Beijing where congestion is prone to take place, 228 large-scale out-door variable message signs are installed, which are refreshed every two minutes and show 1.96 million real-time information of road conditions every day.

Another 1400 million RMB is allotted for the coming three year in ITS development the 3rd phase in Beijing. More effort on traffic management instrument can be expected.

3.4 Authority and ITS structure

The figure below indicates the main authority parties in the traffic system in Beijing. Two main components are Beijing Bureau of Public Security and Beijing Municipal Committee of Communications.

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Figure 3.14: Beijing traffic authorities



Among them, the main traffic authorities directly involved in the system and the corresponding function role played are indicated in the table below.

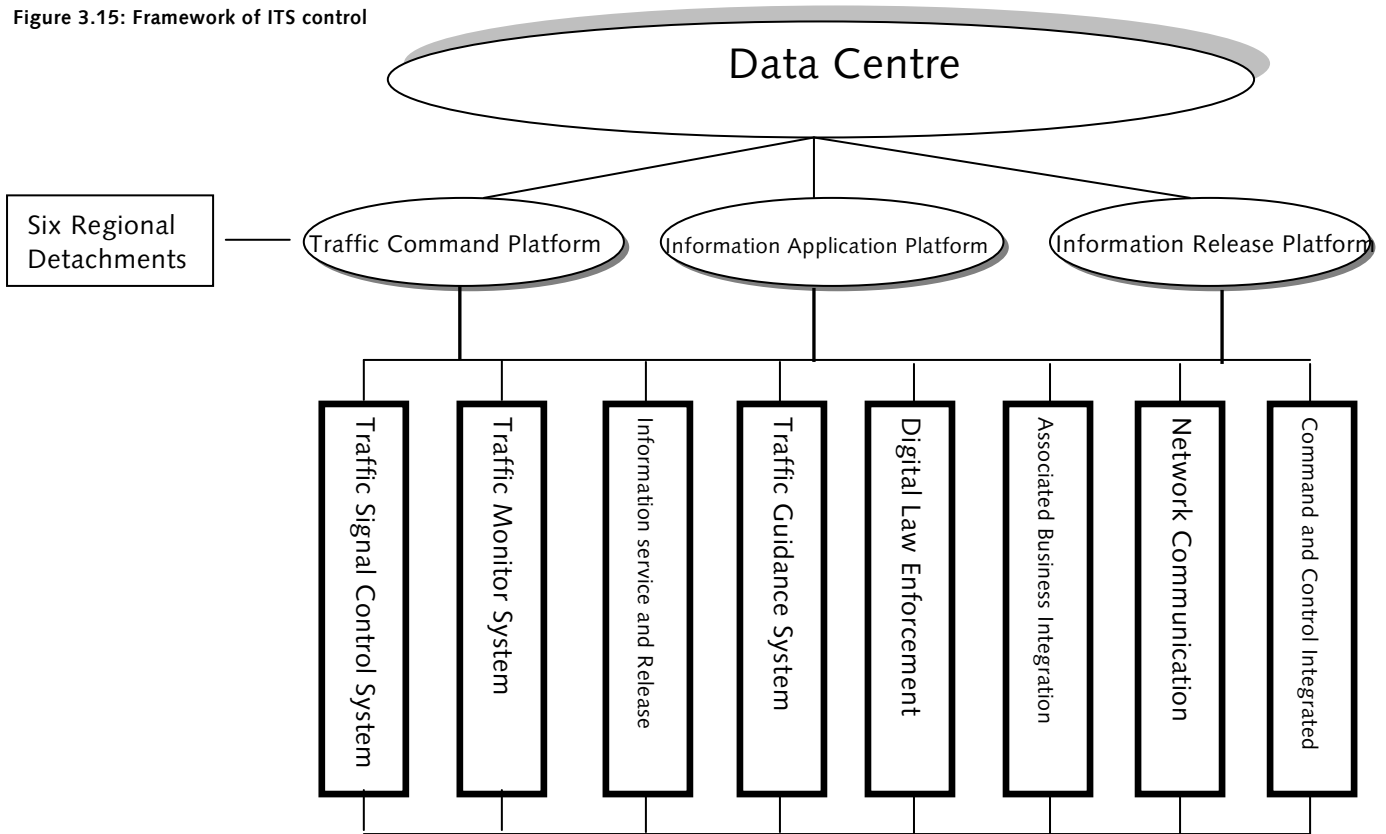
Table 3.3: Actor role in Beijing System

Actor	Authority	Function	Perspective	Geographic
Policy Maker	Beijing Municipal Committee of Communications (BMCC)	Make sound choice for budgets and the allocation of responsibilities	Long term	Whole network
Network Operator	Beijing Traffic Management Bureau (BTMB)	Install and Apply the solution in their daily fight against congestion	Medium Term	Network wide and regional
System Operator	Beijing Traffic Management Bureau (BTMB) and regional detachment	Implement traffic solution in daily operation	Short term	Corridor
Traffic Engineers	Beijing Traffic Information Centre (BTIC); Beijing Traffic Research Centre (BTRC)	Invent new possibilities for traffic control and system design	Long term	Large or regional area

It can be seen that, Beijing Traffic Management Bureau and its regional detachments, to some extent, “monopoly” the traffic management on all roads in Beijing daily traffic operation.

In recent years, the Beijing Traffic Management Bureau, under the general framework of intelligent traffic control has carried out in a comprehensive manner the programming and construction of an intelligent traffic management system. Now the intelligent traffic management system has been initially completed whose core is based on the data centre, and is supported by three platforms and eight under layer systems, as shown in the figure above (Sui, 2010). Thereby, modernization in traffic control, digitalization in management, networking in information and automation in office work has been preliminary achieved.

Figure 3.15: Framework of ITS control



Among the three platforms, the traffic command platform is the main actor in responsibility of unified command and dispatching the traffic measures in daily practice, especially under non-recurrent situations. With the under layer systems report as the basis, and integrated data analysis from the upper data centre, dispatching plan are settled in reaction to different occasions.

3.5 Conclusion

The Beijing traffic network related issues have been generally reviewed in this Chapter. In a nutshell, Beijing road structure has its unique characteristics in traffic service, transport service and economic activity, the resulting traffic and transport market performance show a gap between demand and supply thus resulting in high congestion. Afterwards, 5 typical features are pointed out, which should be taken into special consideration when developing traffic measures. And finally a review of Beijing current traffic policy is carried out. An inclination could be found on traffic management, especially dynamic traffic management (ITS), thus providing good opportunity for further research and study.

4. Measure Design

In the preceding chapters, firstly the basic traffic system components and the corresponding traffic performance in Beijing has been represented and compared from a macroscopic point of view. Afterwards, road network layout and flow characteristics are further analysis in microscopic aspect, pointing out the typical difference and limitations the traffic is organized, problems and bottlenecks under such circumstances are revealed within the process.

Based on these local finding and take examples from the analogy researches and example experiences in other countries, this chapter aims to explore the opportunity of traffic management measures which could best tailor to these specific features under the predefined traffic background.

Thus, the main question to be answered in this chapter follows:

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Research question of Chapter 4

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| <ul style="list-style-type: none">● What kind of traffic management measures might be adequately applicable to Beijing situation in dealing with traffic congestion? |
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In an attempt to develop suitable measures, the objective and approach is first raised, and step wise method design towards specific problem area is conducted.

4.1 Design objective and approach

Overviews of the status quo, the following objectives are recognized in this study:

(1) Ameliorate the influence of capacity decrease factors at sensible area

As we can see, some capacity decreases are caused not by physical factors, but the mass in vehicle behaviour which manually create or severe the bottleneck (e.g. bus stop weaving). By better organize the streams at these areas; the potential capacity can be created. The sensible areas involve weaving section on either mainline or parallel surface road, and at intersections of major roads.

(2) Improve the flow on mainline expressway

As the main skeleton of the whole network, the smooth flow operation on expressway is of most importance. According the fundamental diagram, the fact that high V/C ratio overwhelms the road section would ultimately bring advantage to none of the "participants" on the way. To first optimize the flow on critical links with higher flow rate, the density on these road should be controlled within the optimal limitation, in such a way traffic involved can enjoy the advantage of uninterrupted flow dynamics. This can be realized with a certain kind of volume "demand" control under the concept of "slow in quick out". "Slow in quick out" concept aims to on the one side to regulate and slow down the inflow under saturation traffic condition. On the other

side, facilitate the outflow to leave the expressway quickly. In this way, the volume of traffic on the expressway optimally controlled. The focus areas are mainly on ramp and off ramp points.

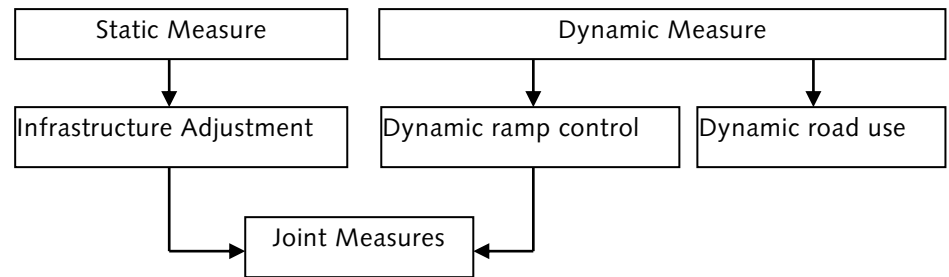
(3) Optimize the uneven distribution of traffic

In case that road supply is limited, it is rather more essential to make use of existing room, each available road, either low or high grade. Except for route guidance among high grade roads where real time information available, the fact that feeder roads still have potential to develop and hold traffic would be a point to dig into, especially in case of non-recurrent situation. The focus areas are intersections, diverting points and streets with directional traffic.

4.2 Local Measure Design

This section will recommend several alternatives of measures from basically two approaches on local level: Infrastructure adjustment and dynamic traffic management control. The latter one includes the dynamic ramp control and road use. And joint measures working in tandem with both infrastructure and dynamic control are considered afterwards, which may potentially generate better result. As to each method recommended, application area, problem, method description, advantages and limitations are elaborated.

Figure 4.1: Frame of local measure design



4.2.1 Design Approach

As indicated in the fundamental diagram in Chapter 2.2, the capacity of a highway is complicated into two definitions: free flow capacity and queue discharge capacity. Such is among other things due to the capacity drop phenomenon caused by the differences between the capacity of a motorway link, a motorway bottle-neck (on-ramps, off-ramps, weaving sections), and other stochastic nature of the capacity (Hoogendoorn, 2008). In this study, the measures are designed aiming at the bottle-neck sections.

First the cause of the capacity decrease on bottle-neck area has to be distinguished. Capacity of a single lane of the roadway, the flow q can be determined as follows

$$c = \frac{1}{\frac{1}{n} \sum_i h_i}$$

Here h_i indicates the minimum time headway. Such relation indicates clearly that the capacity is related to driver behaviour. In the bottle-neck sections this is specifically influenced by the lane change behaviour. Thus, the merging area at the two ends of the ramp link, and the weaving area on the mainstream motorway where lane

Equation 4.1

changing manoeuvres required are the main “turbulence” in capacity drop to focus.

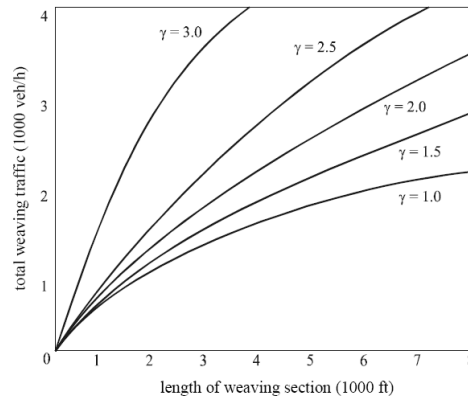
In the 1965 HCM, the definition of weaving capacity is expressed by number of lanes, weaving demand and a weaving influence factor γ (Hoogendoorn, 2008).

Equation 4.2

$$SF = \frac{V_{w1} + \gamma V_{w2} + V_{o1} + V_{o2}}{N}$$

The weaving influence factor γ is a function of the total weaving traffic demand and the length of the weaving section, as shown in the graph below.

Figure 4.2: Weaving influence factor γ



Hereby, the weaving demand, weaving section length and lanes needed for weaving, which are the considering factors in the traffic management design in the thereafter to ameliorate the capacity drop.

Further, the improvements of an increase in capacity can be theoretically implied by the queuing model. The queuing model to determine delay is not a realistic description of the real traffic process, the main deviation being that vehicles are stored vertically in a queue. Nevertheless with this model the delay can be calculated. Here, a simple use of such model is performed to indicate the traffic performance gain with an improvement on capacity.

Figure 4.3: Illustration of weaving section



Taking a weaving section as example, due to the capacity drop caused by flow weaving, the usable capacity is less than the physical capacity. Suppose on the weaving section the average lane capacity is 1400 veh/hour. The departure curve is straightforward and equal to $D(t) = 5600t$

The demand during the first 20 minutes is 1600 veh/h on main stream and 1200 veh/h on onramp link. The rest of the hour the demand is decrease by 10%. Thus the arrival curve can be expressed as:

Equation 4.3

$$A(t) = \begin{cases} 6000t & t \leq 1/3 \\ 5400 \left(t - \frac{1}{3}\right) + 6000 * 1/3 & t > 1/3 \end{cases}$$

The number of vehicles in the queue is given by the difference between the arrival and the departure curve $R(t) = A(t) - D(t)$. Clearly, the maximum queue length occurs when $t = 1/3$ h, and is equal to $R(1/3) = 133$ veh. The queue has dissolved when $A(t) = D(t)$, which occurs at $t=1$, thus the queue lasts for one hour.

If through certain traffic measure, the capacity drop could be reduced. Suppose a capacity gain is 5%, the departure curve then is described by $D(t) = 5880t$. The demand remains the same.

With the same calculation approach, we can easily get the maximum queue length decreased to 36 veh. And the queue can be dissolved earlier at $t=0.416$, thus the queue lasts for only 25 min.

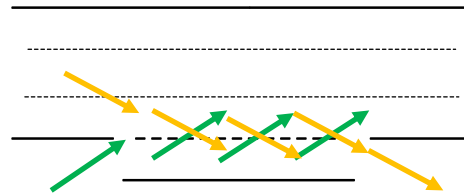
Noted, the above theoretical approach considers the queue in vertical, which in reality is not true. However, conceptually from the above calculation the effect of queue length decrease and delay time improvement can be expected.

4.2.2 Infrastructure Adjustment

A.1. Mixed Weaving Section

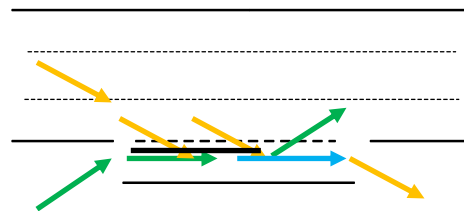
- *Application area:* Paired entrance and exit sections, where distance between entrance ramp and exit ramp is shorter than 200 meters.
- *Problem:* On such short transition section, traffic entering and leaving the expressway may inevitably perform conflicted multiple lane change manoeuvre, the complicated cross weaving section poses severe decrease in effective capacity and potential safety hazard.

Figure 4.4: Illustration of current weaving



- *Method description:* To reduce the stream confliction by separating the entrance and exit oriented streams. Mark the merging area into two sections as sketched in Figure 4.55. The original section is now divided into two sub-sections. In the first part, vehicles from on ramp are not allowed to merge into the main stream until the marking ended in the second section.

Figure 4.5: Illustration of weaving marking

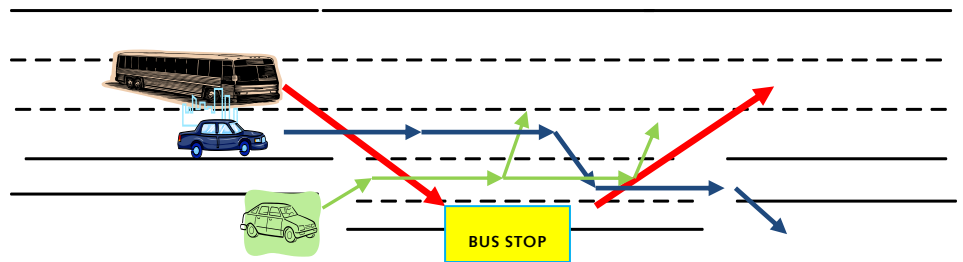


- **Advantage:** Ease the lane change manoeuvre, force inflow to accelerate on the buffering before merging into through traffic, benefit for the smooth outflow.
- **Limitation:** when the volume of entrance flow is very high, limited space of inflow merging may cause over storage on the buffer lane, blocking the exit ramp.

A.2. Weaving Section with bus stop (peak lane)

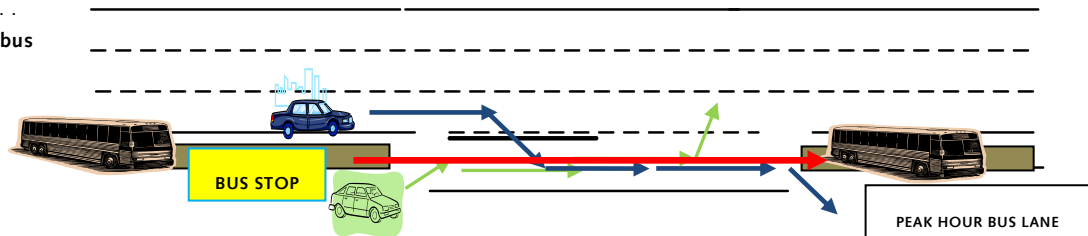
- **Application area:** Expressway with bus stop close to ramps
- **Problem:** the above entrance and exit weaving section in this case is worsened because of the bus influence on the section. Moreover, due to the large size and low speed, the lane change manoeuvre of bus brings about even more significant influence on through going and other merging traffic.

Figure 4.6: Illustration of current bus stop weaving



- **Method description:** Use the on-ramp upstream adjacent space on emergency lane as bus stop (if no emergency exits then the use the outer lane). Use similar merging section design as method A.1. If situation possible, except for merging section, emergency lane can be use as dedicated bus during peak hour, or even all day through.

Figure 4.7: Illustration of improved bus stop weaving

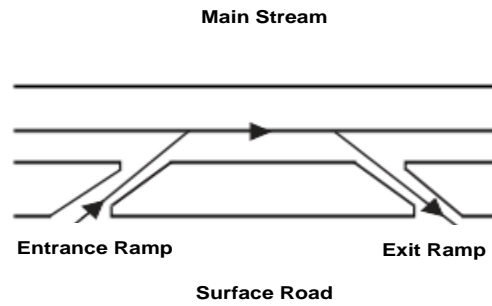


- **Advantage:** Apart from the advantages in measure A.1., this option compared to current situation can minimize the influence of bus lane change manoeuvre. In addition, on the merging section, the bus is on its acceleration phase, the speed of which close to the merging vehicles on the merging section, thus could share nearly homogeneous speed.
- **Limitation:** bus lane occupies the emergency lane may lead to problem or negative impact if in the event of an emergency or breakdown

A.3. Weaving Section Relocation

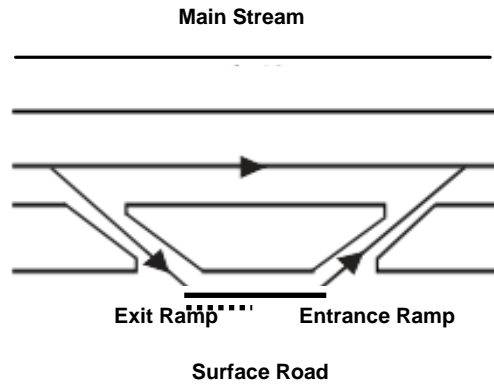
- **Application area:** Paired Entrance-Exit mode ramp sections with limited short weaving distance available due to short distance to adjacent major intersections
- **Problems:** lack of sufficient smooth weaving space on the mainline, conflict stream cause disturbance on main stream

Figure 4.8: Entrance-exit mode



- *Method description:* Change the Entrance-Exit mode to Exit-Entrance mode assisting with weaving marking on surface road

Figure 4.9: Exit-entrance mode

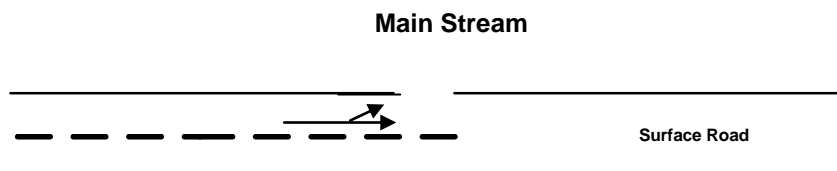


- *Advantage:* speed on surface road is slower than expressway, thus the weaving section (decelerate/accelerate section) required can be shorter. Switching the weaving section from mainline to surface road, smooth the traffic on the mainline. Moreover, in further design, the control of onramp traffic flow can be adapted to the upstream off ramp flow.
- *Limitation:* capacity on surface road can be decreased, without surface road corresponding control, the spilling back entrance flow may block exit ramp

A.4. Virtual On-ramp Section

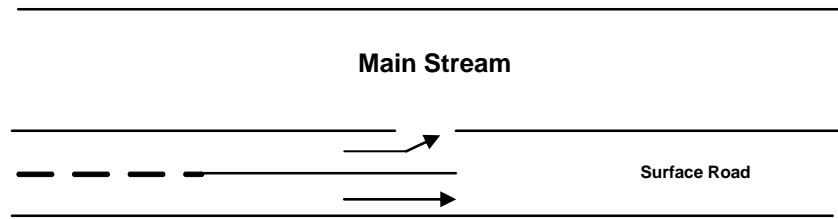
- *Application area:* ramp points which leave a certain upstream distance on surface road (longer than 200 meter) away from the nearby intersection
- *Problems:* no dedicated space provided to store the entrance vehicles as regular ramp, the surface road around the entrance point is often disturbed by the deceleration vehicles towards the entrance, and thus stuck the through passing traffic

Figure 4.10: Illustration of current Onramp section



- *Method description:* Limit the left lane to only ramp traffic 30-50 meter upstream the entrance point by road marking, create dedicated space for on-ramp traffic

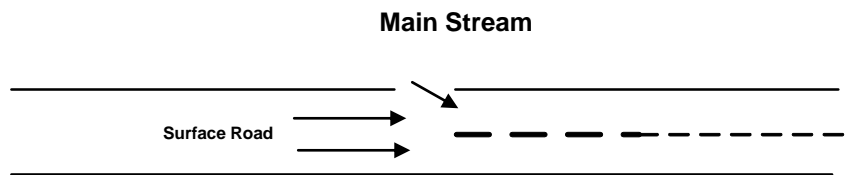
Figure 4.11: Illustration of Virtual Onramp section



- *Advantage:* separate the flow (before deceleration) in advance of the current bottleneck point, thereby smoothing the through passing traffic. Moreover, the entrance traffic close to the expressway can have a better sight of the traffic situation, easier and safer for gap seeking and merging performance. Further, such method can effectively prevent from conflict stream at entrance point.
- *Limitation:* on-ramp traffic storage lane may either too empty or crowded leading to unbalanced lane use on surface road

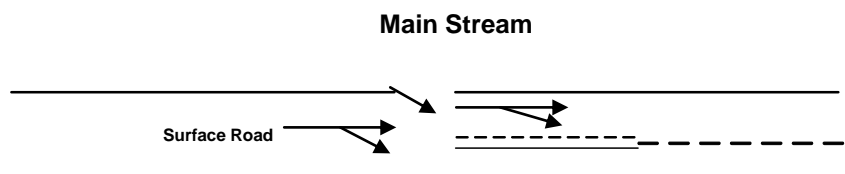
A.5. Off-ramp Section

- *Application Area:* Off ramp section close to intersection or with limited space to facilitate off ramp traffic
- *Problems:* Traffic from the mainline cannot exit the ramp smoothly due to traffic congestion on surface road, leading to spill back on the expressway



- *Method Description:* create dedicated lane for off ramp traffic for a length of 50-80 meters by lane marking, off ramp vehicles can always switch to the outer lane while the through going vehicle on can only use outer lane at the adjacent of the exit point

Figure 4.12: Virtual Off-ramp section



- *Advantage:* reserved space on surface road for off ramp traffic, promote the outgoing flow to merge onto the surface road easier under congestion situation, thus relieve the traffic volume stress on expressway. Prevent from off ramp spill back on to the mainline.
- *Limitation:* Off ramp dedicated lane may either too empty or crowded leading to unbalanced lane use on surface road

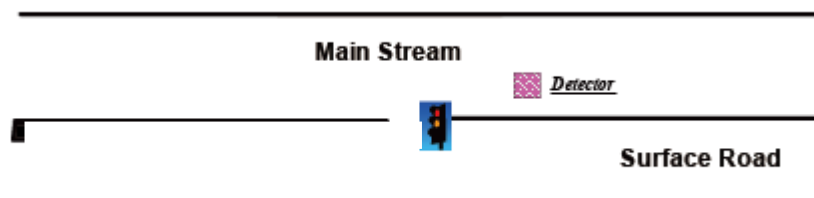
4.2.3 Dynamic Ramp Control

Above discussed are all static solutions, limitation and disadvantages may occur for lack of response to flow dynamics. In the section, some applicable DTM methods are introduced. Likewise, five aspects analysis are also provided for each measure.

B.1. On ramp control

- *Application Area:* Ramps on congestion expressway
- *Problems:* when the density of vehicle on expressway exceeds the critical point, the flow performance deteriorates. Moreover, the platoon of entrance traffic may cause disturbance on the mainstream, congestion may further spill back.
- *Method Description:* Ramp metering is implemented via installation of traffic lights at freeway on-ramps that dynamic control the amount of traffic flow allowed onto the motorway at predetermined intervals. The traffic lights are operated in dependence of the currently prevailing traffic conditions on both the motorway mainstream and the ramps. The dynamic control can be based on either feedback or feed forward control algorithm, and on different parameters gathered by detector. For example, metering rate can be on the basis of e.g. estimated spare capacity (Dutch RWS algorithm) or on the basis of other estimated parameters (e.g. critical occupancy downstream as in ALINEA).

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Figure 4.13: Illustration of ramp metering

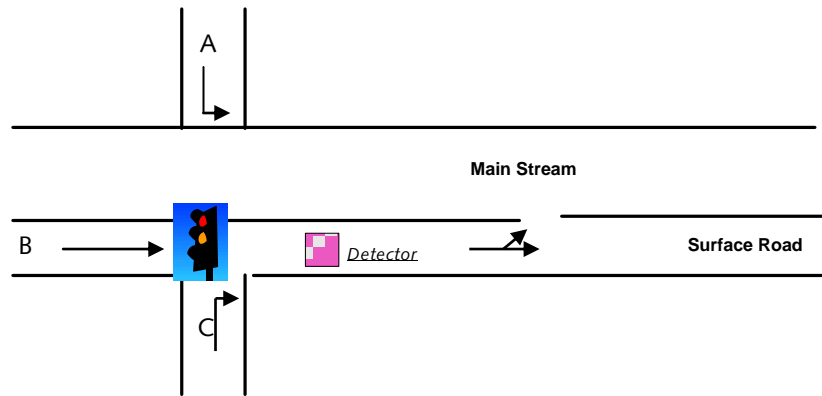


- *Advantage:* Restrict and regulate the rate and volume of incoming traffic onto the main stream, prevent merging traffic in platoons, reduce the congestion on main stream, improve the traffic safety. Moreover, such delay may be sensitive to short distance travellers, thus reducing the attractiveness of expressway to these travellers, decrease the so called "rat runners".
- *Limitation:* Congestion shift from mainline to on ramp, in Beijing's case, congestion may shift onto the parallel urban road, and may further spill back influence the adjacent intersection

B.2. Diverted on ramp control

- *Application Area:* ramp points close to upstream major road intersection on parallel surface road, limited place to store on ramp traffic
- *Problems:* due to bottleneck at on ramp, traffic spill back to lock the intersection
- *Method Description:* Divert or extend the on-ramp space to upstream surface road and main road prior to intersection. When vehicles are detected high occupancy certain distance (e.g. 2/3 of distance to intersection) upstream of entrance ramp, the signal phasing of adjacent intersection needs to be changed in order to control on-ramp traffic crowd into surface road. In the following situation in Figure 4.14, vehicles towards on ramp come from 3 directions: A, B and C. The green phase of left stream from A and straight stream from B can be postponed or temporarily compassed. While right turning from C cannot be controlled by traffic light. The timing change can be referring to history data on the percentage of ramp traffic of each stream.

Figure 4.14: Illustration of diverted ramp control

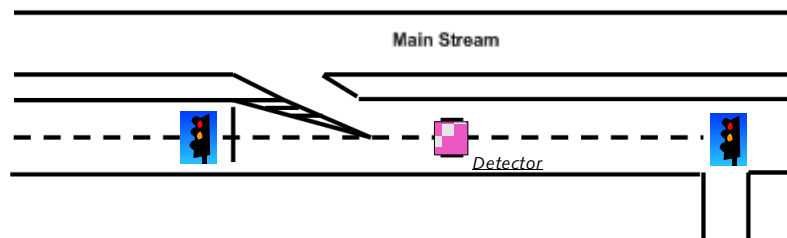


- *Advantage:* alleviate the congestion on surface road near onramp bottle neck, prevent from intersection blockage
- *Limitation:* complicated setting, the delay or shorten of green time may interfere the upstream traffic on those directions

B.3. Off ramp control

- *Application Area:* Off ramp adjacent to intersection downstream
- *Problems:* through going traffic on surface road queued at intersection, block the exit. Off ramp traffic cannot merge smoothly onto surface road, causing spillback on expressway
- *Method Description:* A traffic light is installed upstream the ramp on surface road. When vehicles are detected high occupancy at the downstream of off ramp, the traffic light before the ramp will be automatically turned to red, thus leave downstream section priority to off ramp vehicles.

Figure 4.15: Illustration of off-ramp control



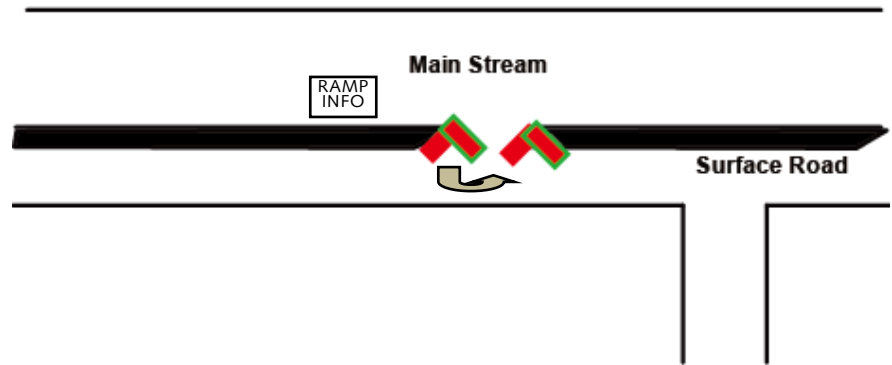
- *Advantage:* reserved space on surface road priority to outgoing traffic, promote the outgoing flow to merge onto the surface road easier under congestion situation. Prevent from off ramp spill back onto the expressway.
- *Limitation:* Surface road upstream congestion

B.4. Changeable Ramp

- *Application Area:* On ramp upstream to secondary or feeder road and off ramp downstream, or any ramp along the expressway
- *Problems:* the traffic on expressway cannot be smoothly evacuated and make use of secondary road especially in case of non-recurrent situation on mainline
- *Method Description:* Taking advantage of the layout of Beijing expressway, the set and change of ramp direction is rather easy. Rotatable barrier can be designed at sensitive location as shown in Figure 4.5. To facilitate, a ramp info board or traffic signal should be set to inform travellers the direction of the ramp. At ramps where sufficient space left, simple board (VMS) inform can be applicable controlling the ramp direction. However, ramp change is

preferred be used only in cases of non-recurrent situation. Similar design can be also allowed for virtual ramp setting, where the ramp only opens to use under special situation.

Figure 4.16: Illustration of changeable ramp



- *Advantage:* facilitate the quick evacuation off the expressway, and redistributed onto secondary and feeder roads
- *Limitation:* confuse of ramp direction, influence the route decision pre-trip

4.2.4 Joint static and DTM measure

As discussed, every measure has its advantage but also limitations, a combination of certain measures. Infrastructure adjustment measures can be facilitated by dynamic measures. The combination can somehow make up for a deficiency of both, being optimal statistically and reactive to current situation, thus likely promote better solutions under some circumstances. The following table shows the possible combinations.

Table 4.1: Measure List and Combination pairs

Method No.	Name	Integrated Method No.	New Measure No.
A.1.	Mixed Weaving Section	B1,B3	C.1.
A.2.	Weaving Section with Bus stop	A1,B1,B3,A4,A5	C.2.
A.3.	Weaving Section Relocation	A1,B1,B3,A4,A5	C.3.
A.4.	Virtual On-ramp	B1,B2	C.4.
A.5.	Virtual Off-ramp	B3	C.5.

So far, the measures investigated for Beijing situation aiming for the 1st and 2nd objective are proposed. With the theoretical interpretation, these measures are of potential to help to ameliorate weaving capacity influence and hence improve expressway flow behaviour. Subsequently, measures toward the 3rd objective would be discussed.

4.2.5 Dynamic road use

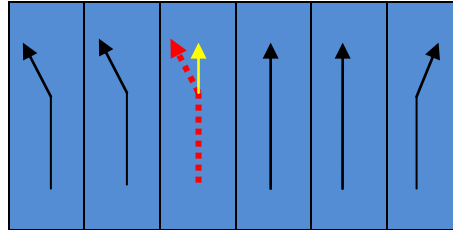
The ensuing of measures in this part are aimed at the objective three to facilitate a more even distributed traffic making better use of existing room on an arterial level and further on network level.

D.1. Changeable intersection turning bay

- *Application Area:* major road intersection with multiple lane allocation buffers for traffic towards different directions, where second stop on certain directions is often observed

- *Problems:* unbalanced flow allocation, second stop on certain directions
- *Method Description:* Since the right turning traffic in Beijing is usually under no control of traffic light, one right turning bay allocation is usually observed and sufficient for this direction. The rest of lanes at intersection are assigned for buffering left turn and through going traffic. Taking advantage of multiple lane allocations, the allocated traffic direction on one in the middle (in between the through going lane region and left lane buffering region) can be designed to be dynamic. It can be realized either by LED screen or two side board to inform the drivers on the state of junction lane allocation point.

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Figure 4.17: Illustration of changeable intersection lane allocation



If during the previous cycle time, the dynamic lane is assigned for straight passing traffic and maximum green time is not fully used (in actuate signal control), while the left turning traffic with two lanes reached maximum green time with still remaining traffic left in queue detected, then the dynamic lane would turn to allocate left turning traffic in the next cycle to facilitate the larger capacity need on this direction. Besides, it can also be made for special use in cooperate to traffic guidance.

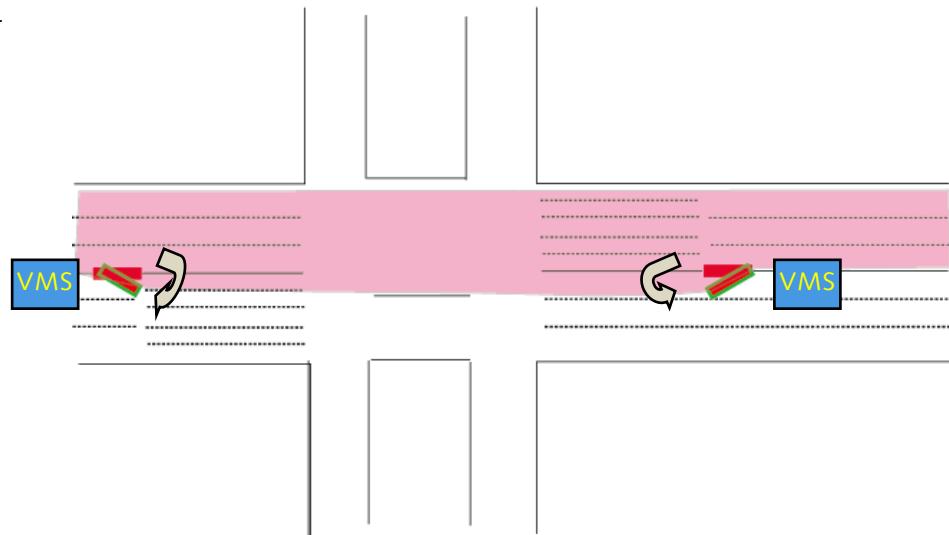
- *Advantage:* dynamic response to traffic space towards different direction, avoid unbalance on lane allocation, potentially shorten the cycle time.
- *Limitation:* when both directions are with relatively heavy flow, frequent change lane allocation may cause some confusion and problems.

D.2. Tidal lane

- *Application Area:* Wide road section(major roads), with high flow direction factor during certain period
- *Problems:* unbalanced flow directional allocation, one side heavy congestion while the other direction leave free room
- *Method Description:* Two kinds of tidal lane can be designed. First is temporary use lane of the opposite direction. Second is additional dedicated tidal lane.

The figure below shows the beginning and ending section of the first kind of tidal lane. A rotated barrier is designed, under cases one direction shares the major flow (e.g. peak hour), and the barrier would turn to borrow one lane from the opposite direction, creating the temporary tidal lane. VMS panel or other alert device and signs should be located upstream the lane diversion point to inform the change of lane direction. When the peak period is over, a set of clearance time is required before the lane returns to normal direction allocation.

Figure 4.18: Illustration of tidal lane



In the second case, the tidal lane is separated and dedicated from normal traffic; the operation is similar to first design.

- *Advantage:* more efficient use of available lane space
- *Limitation:* the change of lane direction, allocation and clearance need quite long time, when flows of two direction change, not able to adapt to in short time.

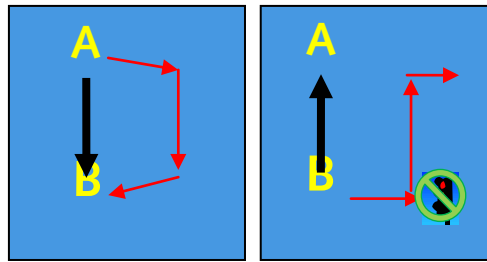
D.3. Static route sign

- *Application Area:* At applicable feeder road diversion point
- *Problems:* unbalanced traffic distribution, traffic overwhelmed expressway and major roads, while secondary and feeder roads are not made use of.
- *Method Description:* Before routing the traffic, it is important to first investigate and route-mining. By analysis the road function in the certain area, search and open up the potential applicable feeder roads and alleys. Two aspects should be considered. The first is the road feature, width, capacity and turning radius whether fit for vehicle of all sizes. Secondly, whether the surroundings (school, resident) along the road would be affected by induced traffic, applicable time period.

If alternative detouring route available, the static sign showing the route information can be put at the diversion points, and guide board would be preferred to set along the detoured route as well to guide the drivers in the unfamiliar network. When time limitation exists, the board can be set two side way, only display the alternative route under specific time period.

Moreover, the uninterrupted right turning routes, and non-signalized intersections would likely to be preferred by road users, which could be indicated on the board.

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 Figure 4.19: Illustration of static route sign



- *Advantage:* remind and guide users of alternative low grade road, promote micro-circulation in the region, and distribute the traffic congestion on high grade roads.
- *Limitation:* may cause congestion on low grade roads, leading to a mass and safety threaten due to narrow layout, thus the choice of route and time informing is critical

D.4. Dynamic VMS panel

- *Application Area:* upstream of important diversion point, e.g. on and off-ramp, intersection, etc.
- *Problems:* unbalanced traffic distribution
- *Method Description:* Displace real time traffic flow information of a certain adjacent region of major roads, and inform the ramp rate (queue on ramp). Enable incident report and route advice provide. More analysis regarding VMS would be provided during simulation.
- *Advantage:* divert part of VMS responders to the alternative route which may alleviate the current congestion road section
- *Limitation:* Information available to everyone, uncertain on the response rate, may lead to new congestion

4.3 Integrated Measure Design

The general control architecture and three basic principles have shown in PPA research project introduction (Chapter 2.3), providing a very good approach of integrated measure management strategy for both recurrent and non-recurrent situations.

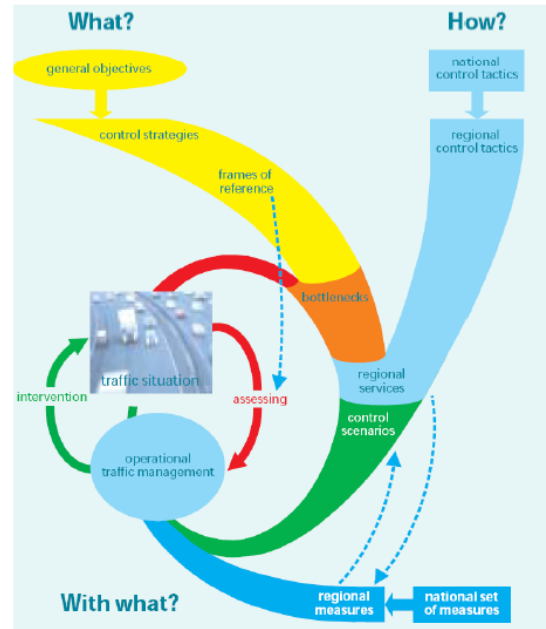
Here, taken the Dutch INM approach in mind, the strategy design would care more on the integrated measure functional property at each phase, offering a different perspective of approach.

In this approach, non-recurrent situation as incident is of the initial concern in this study. Firstly, incident is one major cause of congestion as shown by literature. Official estimates indicate a percentage of 13 of the Dutch queue are caused by incident, in USA the percentage is high to 50% (Knibbe, 2004), and in Beijing the figure is estimated to be approximately 25% for 2009. Secondly, under the high overall V/C ratio on roads in Beijing, the network is more fragile; incidents are easily encountered and may tend to cause long queues in no time. Thirdly, since incident occurs unexpectedly on a local level and likely to upgrade to larger region congestion upstream, the integrated approach which considered being responsive and graceful degradation should be match with the need. Additionally, "secondary incident" upstream the site would be likely happened caused by the downstream disturbance of the first incident. Last but not least, from a modelling approach, INM

approach can be much more easily designed and evaluated under incident situation. In this sense, in this study, the discussions on INM measures are mostly based on the measure taken under incident situation.

Proposed in the GGB approach, the so-called corkscrew model represent the ITS design methodological framework. This will be used for the guideline in the design.

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 Figure 4.20: Overview of the corkscrew model as used in Dutch DTM design practice.



Three basic questions depicted are the “what”, the “how”, and the “with what”.

- What do we want to achieve with ITS in a chosen network?
- How we would like to achieve the objectives?
- With what pertains to the actual implementation of these control scenarios?

The answer to the first question is definitely being to reduce the effect of incident, both to the impacted vehicles and optimize the network influence as a whole. The bottleneck area in this non-recurrent case is the incident link and the direct upstream links.

To achieve the objective, above all, measures should be taken to relieve the traffic pressure on incident link by reducing the traffic demand towards certain direction. And besides, on a network level, the diverted vehicles should be assisted to reduce the side effect on other routes.

Regarding to the “with what” question, measures designed at each phase should meet with the functional requirement of the phase.

The approach used in this study thus follows three basic lines being method geographic location, method active period and method characteristics.

Geographic location

Local and general locations are distinguished in the geographic location. Local location is the direct upstream link, the very last diversion possible location, where the impact of the incident being the most severe. And

general location refers to far upstream (arterial level) where the impact may be delayed or even no direct impact on the location itself.

Method active period

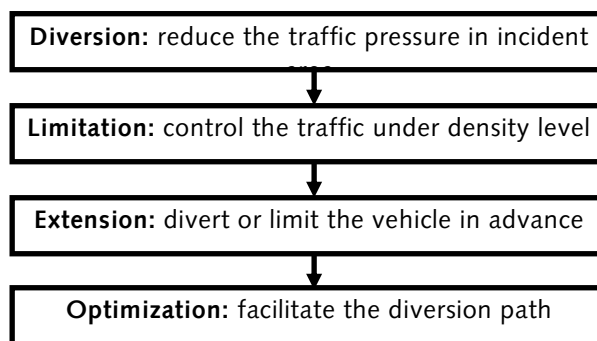
The method period can be limited to incident duration period, or extend longer in order to deal with likely lagged effect or counter effect.

Method characteristics

And the method applied can be either soft or hard, either motivate for reroute or provide limitation in a way or another.

Hereby, a step-wise graceful grade Integration phase approach is defined, a description on each phase and applicable measures are discussed below.

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Figure 4.21: Integration logic framework



1. Phase 1: Diversion

In the first phase response to a detected incident case, when queue starts to propagate in the incident link, the vehicles upstream the link are directly influenced. To lower down the queue propagation speed, it is essential to immediately decrease the flow demand right towards the incident area. Thus it is rather critical to inform the right approaching vehicles, and divert them to another route at first possible diversion point with DTM responsive measures.

VMS panel is one of the most applicable measures. By immediately inform the users at the first diversion point, either the off ramp to service road or the link towards another alternative route, the demand contribute to the queue can be lower. However, the response rate under such active measure is not known. Besides, if there exists no off ramp but an on ramp, the changeable ramp measure can be applied. When on ramp is rotate to an off ramp, not only offers an opportunity diversion point for traffic on expressway to evacuate. Moreover, in the measure index in Appendix B, Dynamic lane marking on off ramp and dWiSa panel can play a role in diverse the demand as well.

2. Phase 2: Limitation

Besides diversion soft measure on local location, to further control the demand, limitation measures can be integrated to restrict or at least slow down the flow on to the congestion links adjacent to the incident area. Under phase 1, the number of response users is unknown. To ensure the reduction in demand upstream, hard measures are here to integrate. This phase can be linked with the principle of sweet to sour.

On expressway, the applicable limitation measure is usually by ramp control. For example, on ramp closure, ramp signalized control, and

besides ramp coordinated control can be applied. Besides, speed limitation panels can be applied to control the demand to some extent as well.

3. Phase 3: Extension

In this phase the measures are not limited to the links in the proximity of the site, but on a rather general location distributed along the upstream expressway (arterial level control). Thus the vehicle would take reaction before they embark onto the congestion link.

Both the sweet measures and sour measures applied in the first two phase can be designed here on the location a distance to the incident area at this phase. Some cooperated measure design, like ramp metering cooperation would be applicable here.

4. Phase 4: Optimization

When more vehicles are diverted, the influence on the alternative route may encounter traffic performance decrease. To reduce the indirect impact on the alternative route due to the traffic diversion, and facilitate the diverted vehicles, integrated measures are designed in phase 4 regarding specifically for the alternative routes. The precondition is that, diverted routes are to be identified.

The detour routes on highway links can be assisted with lane signal control. For instance, opening up emergency lane or closing the lane upstream the merging point on the alternative route to facilitate the merging behaviour. On urban roads, virtual off ramp design, diverted on ramp control, two board static VMS panel towards secondary road, changeable intersection turning bay, etc. discussed in the previous section may be applicable. Signal timing change cooperate with the demand increase on surface road would also offer help to quick balance the diverted traffic.

4.4 Conclusion

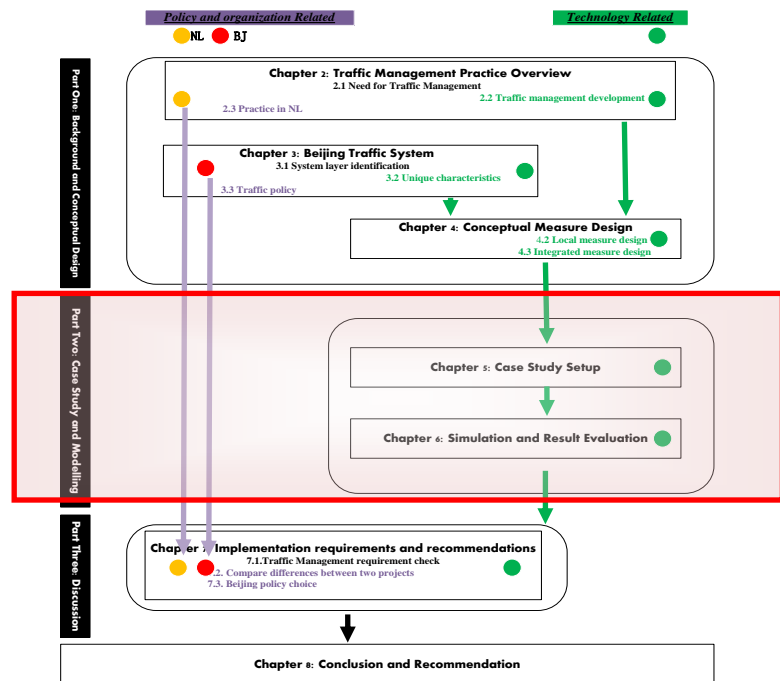
In this chapter, various design measures are adaptive to Beijing situation are carried out in an attempt to solve the specific problems observed in the previous chapters. Advantages and limitation do exist for each measure, thus specific local situation should be investigated and considered before they can take effect while not posing much side effect. Finally, a function based 4-phase approach for integrated management under incident situation is proposed.

Part Two: Case Study and Modelling

In the previous study, a general picture of Beijing traffic has been given, characteristics, problems and specific measures were preliminarily investigated. In this chapter, the case study on a selected regional network of the municipality of Beijing is further looked into. This sample area is used to evaluate the traffic management measures, especially more from a regional level traffic management perspective.

First, a general introduction of the selected area is presented referring to basic infrastructure geometry and functional area distribution. Traffic conditions, typical problems are then identified and corresponding solutions are proposed on a local level.

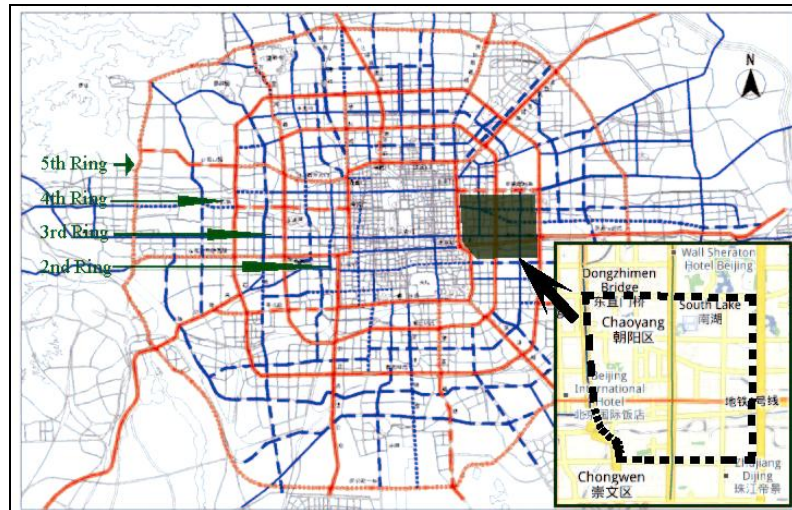
Then the effects of measures are evaluated by model simulation approach for the study area under some assumptions. For this, inevitably, traffic simulation models are needed. A mesoscopic tool DYNASMART-P is chosen based on the simulation objective and software availability. The study area network model is then set up and calibration conducted to some extent. The results obtained by the initial model are utilized then as a benchmark to observe the improvement offered by the different control measures adopted. Afterwards, possible measure responsive integration approach is considered for a non-recurrent situation under different scenarios. The modelling performance are compared and discussed on several selected criteria. Finally, some discussions are made on the result of the modelling.



5. Case Study Setup

The study area is located in Chaoyang district on the east of the city centre, in between the 2nd and 4th ring expressway, from Guangqu Road in the south and north to Chaoyang Park South Road. The region covers an area of 21km², 4.3km in south-north and 4.8km in west-east direction.

Figure 5.1: Study Area Location



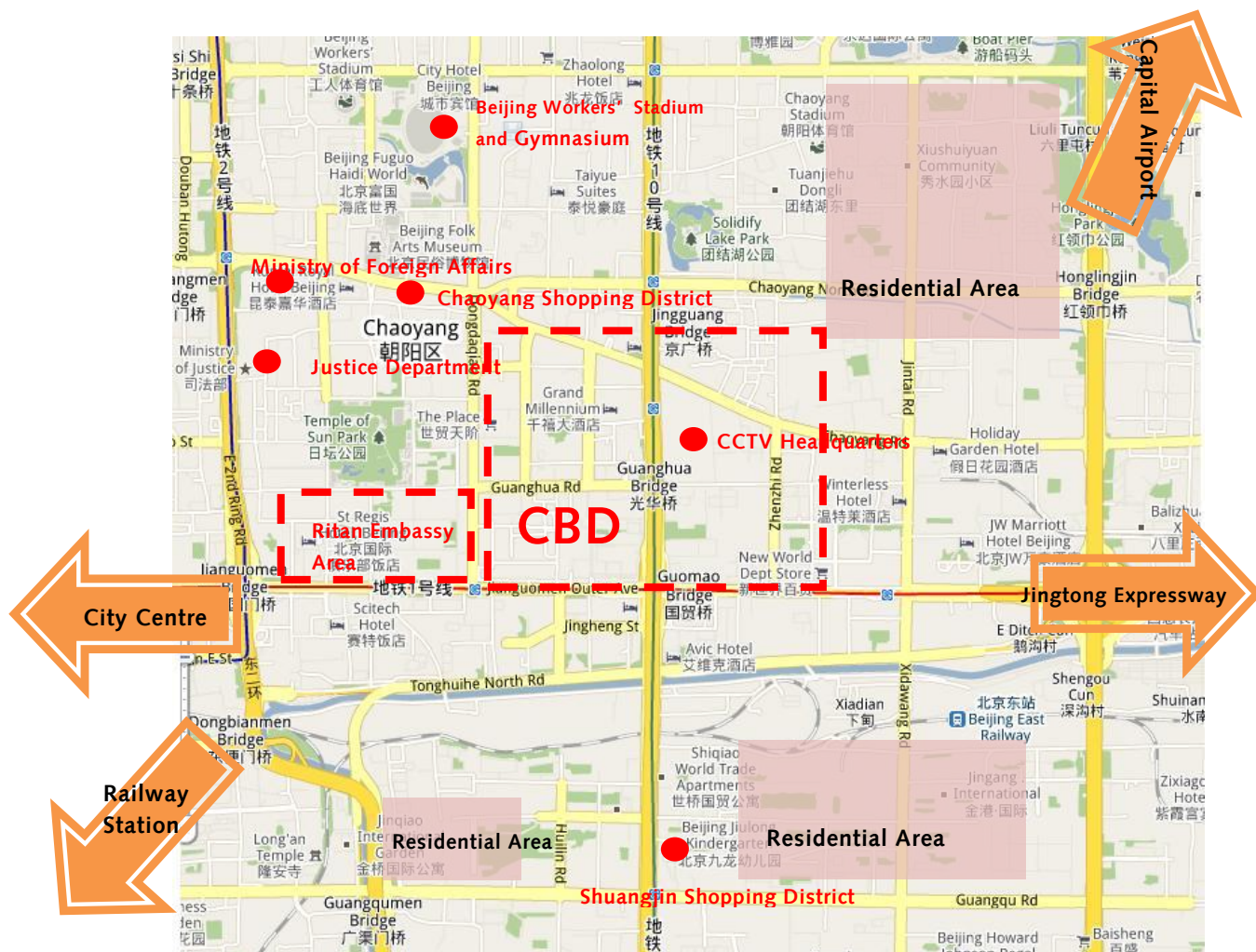
5.1 Functional Geometry

Geographically situated to the east of the city centre, several important traffic sources of attraction (Business District, Government Department, Entertainment Area, etc) located in the area. Adding on the passing traffic towards either the city centre, this part of network undertakes high traffic load.

Main Traffic Source of Attraction in Area:

- Government Department: Ministry of foreign Affairs, Justice Department, CCTV Headquarters, Ritan Embassy Area, etc.
- Business District: CBD
- Entertainment Area: Beijing Workers' Stadium, Shopping District
- Residential Area
- Main Adjacent areas of attraction: City Centre, Beijing Railway Station, Capital International Airport, Jingtong Express, etc.

Figure 5.2: Study Area Functional Geometry



5.2 Infrastructure Geometry

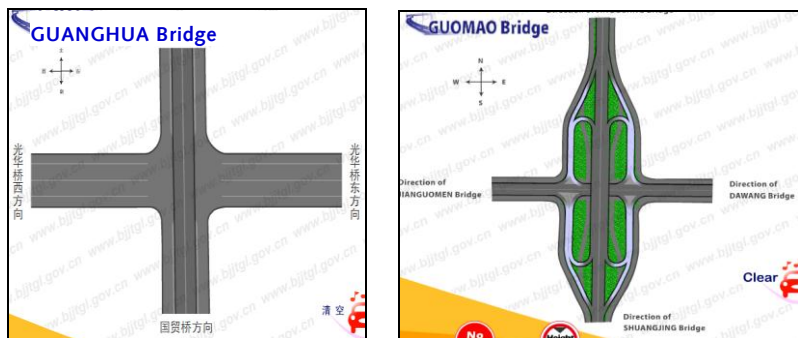
1. Road and Intersection Bridge

Within the region, there are different grade of roads which can well reflect the typical network structure in Beijing. Three sections of ring express road towards North-South is included in the area, interact with major urban roads with either multilevel interchange or single expressway overpass. Tonghuihe North Road is a radiate expressway linking directly 2nd Ring road and 4th Ring road. Major roads in the area include five west-east oriented, and two north-south oriented. Distance between major roads blocks are approximately 1000-1500 meters.

Figure 5.3: Study Area Infrastructure Geometry



Figure 5.4: Illustration of intersection Overpass Bridges (Right: Multilevel Interchange; Left: Single overpass)



Detailed infrastructure geometry features are shown in the table below.

Table 5.1: Infrastructure Geometry

	Lane	Lane at intersection	Speed Limit (km/h)
Express Way			
2nd Ring(N-S)	3		80
3rd Ring(N-S)	3		80
4th Ring(N-S)	4		80
Tonghuihe North Road (W-E)	3		80
Major Road			
Gongrentiyuchang North Rd/Nongzhanguan North Rd/ (W-E)	3	6	50
Chaoyang North Road(W-E)	4	5	50
Chaoyang Road(W-E)	4	6	50
Jianguomen Road (W-E)	4	6	50

Guangqu Road(W-E)	4	8	50
Xidawang Road (N-S)	3	5	50
Dongdaqiao Road(N-S)			
Parallel Surface Road	2-3	3-5	50
Secondary Road	2	3-4	40
Feeder Road	1	2	30

2. Ramps

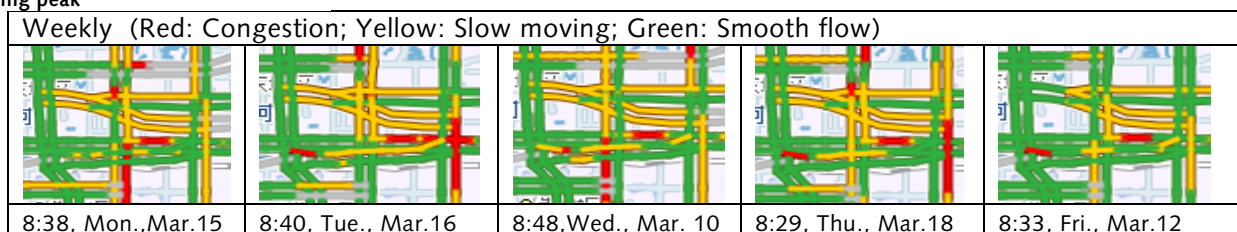
Except for several ramp links connected with upgraded interchange overpass bridges similar to normal highway, virtual ramps as interface take the role of interchanging expressway traffic and urban traffic. 2nd ring road has the highest ramp density, sums up to 18 ramps (8 entrances, 10 exits) on inner ring and outer ring. The distance to the adjacent intersection is only 200 meters on average. Altogether 13 ramps are set on 3rd ring, the distance towards intersection is much longer, approximately 300 meters. On the 4th ring, most parts are designed upgraded mode express way, the number of ramps is the least of all.

5.3 Network performance

Referring to the real time traffic information released on the internet, and the personal experience on the site, it is found that during the peak hours, traffic congestions widely spread in the region on high grade roads. Traffic streams run in slow speed and high density.

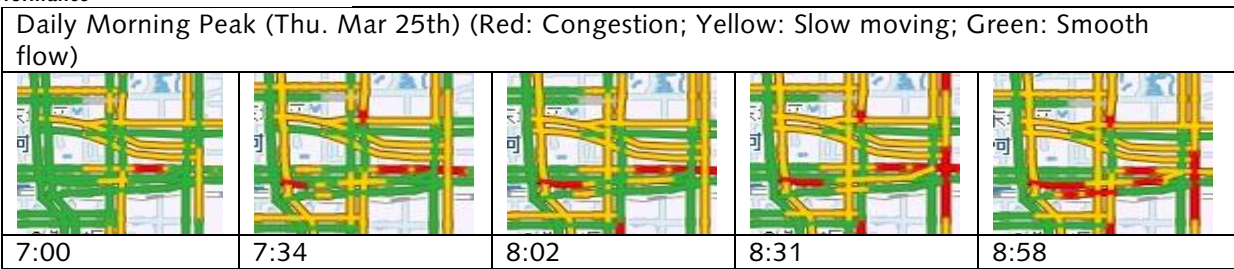
First, Figure 5.5 indicates an example weekly performance at 8:30 in the morning. It can be seen that on the observed weekdays, the congestion locations differ a little bit, but some roads are shown in high density almost every day. Among four expressways, the 3rd and the North-South direction of 4th ring road are relatively more congested. One of the most serious problem sections lies on the Jianguo Road in between 3rd and 4th ring, where adjacent to CBD area. The East-West direction on Chaoyang North Road and both directions on Chaoyang road are often moving rather slow as well.

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Figure 5.5: Weekly performance during morning peak



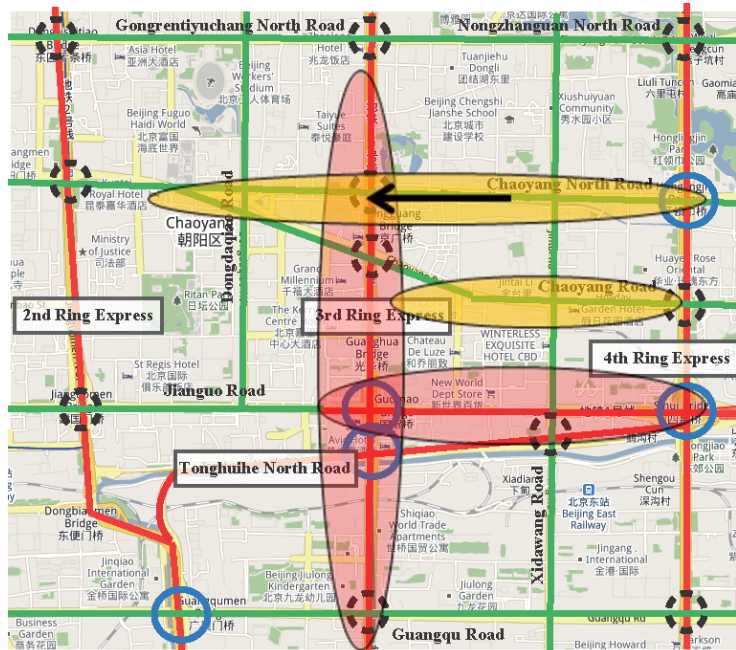
Next, from a typical week day peak hour observation, it can be seen that CBD area is often the problem origin, starting from an earlier time during peak period. After some time, congestion spread over to the whole region.

Figure 5.6: Daily Morning Peak performance



In general, traffic is most of the time with highest density on the following links marked in Figure 5.7 (red: congestion; yellow: slow move) This would be used as a reference performance in model calibration in later chapter.

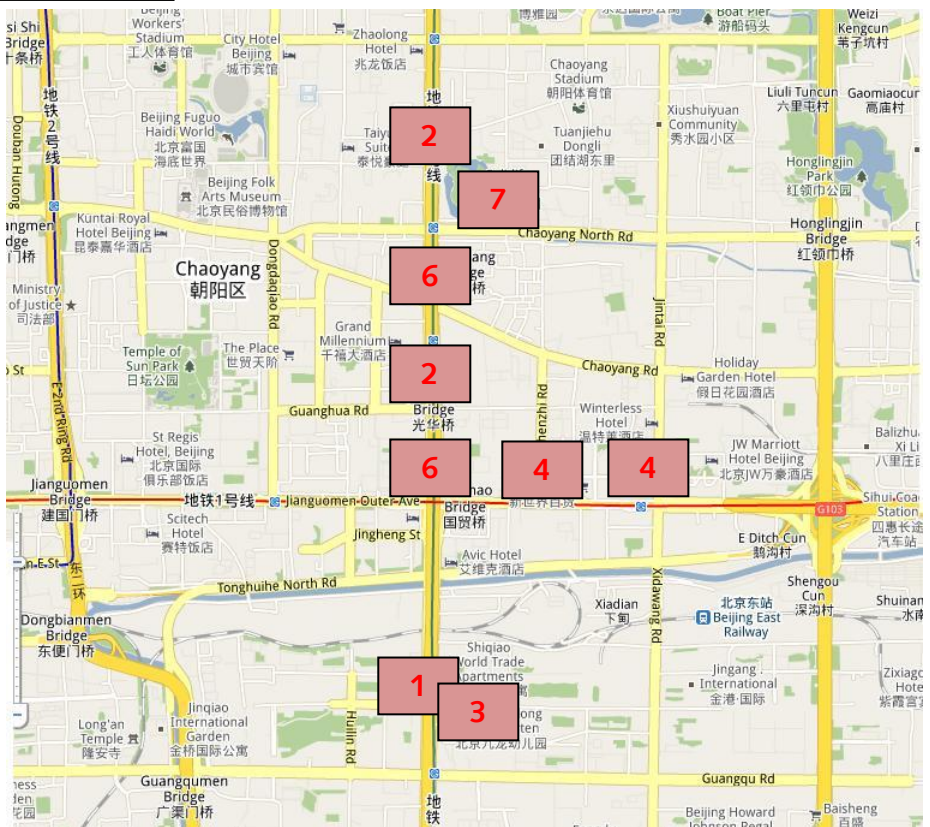
Figure 5.7: General performance



5.4 Local problems

Most typical problems discussed in the previous chapters can be found in the area. In the following analysis, the location of the problem will be illustrated, the corresponding measure is mostly chosen from Chapter 4 (Table 4.1). In this study, for the ease of effect evaluation, the focus method test region would be limited to 3rd ring and adjacent urban roads.

Figure 5.8: Problem Location



1. Bus stop at ramp

Location: Downstream of the Shuangjin Bridge
Measure: C.2.

Figure 5.9: Bus stop between paired ramp (Shuangjin Bridge)



2. Short distance paired ramp

Location: Downstream Guomao Bridge and Downstream Jinguang Bridge
Measure: C.3.

Figure 5.10: Paired ramp (Jinguang Bridge)



3. On ramp stuck

Location: Downstream Shuangjin Bridge and others
Measure: C.4.

.....
Figure 5.11: On ramp (Shuangjin Bridge)



4. Off ramp spill back

Location: Jianguo Road, nearby CBD and others
Measure: C.5.

.....
Figure 5.12: Off ramp spill back
(Jianguo Road)



5. Intersection long cycle time and chaos

Location: Chaoyang Road
Measure: D.3., restrict bicycle left turning, bicycle and pedestrian intermediate traffic light

.....
Figure 5.13: Intersection (Chaoyang Rd.)



6. Road directional traffic

Location: Chaoyang North Road
Measure: D.4.

.....
Figure 5.14: Chaoyang North Rd.



5.5 Conclusion

The surveyed study area is given a general introduction in this chapter. The basic traffic components show typical Beijing system characteristics, and the most typical problems pointed out in the part one can be found in this study area. Thus it is worthwhile to test measure in this region.

6. Simulation and result evaluation

Other than theoretical approach, field test, the study chose model simulation approach as the first trail to evaluate the traffic management measures effect on a network level.

Before traffic measure effects can be evaluated, a suitable model network should be setup with software. Thus the software choice is the foremost step.

Thereby, the following question ought to be answered first in this chapter:

.....
Research question 1 in Chapter 6.

- What is the simulation tool choice and how is the validation of the tool?

After investigation on the tool properties and functions, a basic model is to setup for the study area based on certain assumptions. With a relatively calibrated network model, some of the applicable traffic management measures, both local and integrated, could be then embedded into the network as different scenarios. The effects of the designed scenarios are to be compared with the benchmark derived from reference situation, the following research questions are afterwards expected to be answered.

.....
Research question 2&3 in Chapter 6

- What is the potential effect of the designed local measures?
- How can DTM measures be responsively integrated for a non-recurrent situation? and what effect can be expected?

Finally, a discussion on the model and simulation results and conclusion will be given.

6.1 Simulation software

6.1.1 Simulation Software Choice

Traffic models may be classified according to the level of details with which they represent the traffic system. Considering the distinguished traffic entities and the description level of these entities in the respective flow models, three main types are generally accepted: microscopic, mesoscopic to macroscopic (Hoogendoorn, 2001).

Macroscopic simulation models depict the traffic entities at high levels of aggregation in flow, speed and density on a statistic basis without having to explicitly represent vehicles. The model may assume that the traffic stream is properly allocated to the roadway lanes, and may employ an approximation to this end. The simulation performed in high speed for networks of large scale, especially suitable of urban traffic network planning and management study.

On the other side, a microscopic simulation models are aimed at describing detailed information on both the space–time behaviour of the systems' entities. The models distinguish and trace single cars and their drivers for each time step. From which, an individual driver's

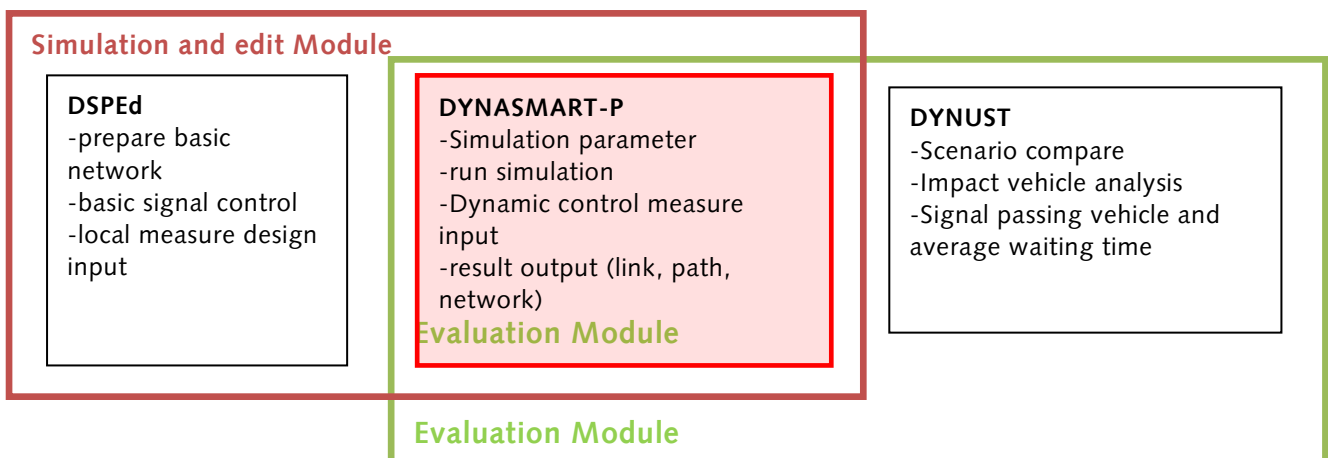
adjustment of speed or lane position in reaction to other lead or adjacent vehicles, or roadway conditions can be observed.

Mesoscopic models combine properties of both microscopic and macroscopic simulation models. The mesoscopic models' unit of traffic flow is the individual vehicle, and they assign vehicle types and driver behaviour, as well as their relationships with the roadway characteristics. Their movement, however, follows the approach of macroscopic models and is governed by the average speed on the travel link. As such, mesoscopic models provide less fidelity than microscopic simulation tools, but are superior to travel demand models, in that, mesoscopic models can evaluate dynamic traveller diversions in large-scale networks (FHWA, 2008).

In this study, judging on the study network scale, microscopic model would be not applicable for the slow running time on such a scale. On the other hand, by implementing the DTM responsive measures, not only the macroscopic network elements are expected for evaluation, the rich representation of microscopic details like route choice would be preferred to be traced in such a way capturing the individual traveller response. Due to the trade-off between modelling simplicity and sufficient level of detail, the lately developed mesoscopic modelling tools with would be best fit.

In this study, DYNASMART-P 1.4 version is an available mesoscopic model to take the role of simulation. Besides DYNASMART-P (DSP used as short form hereafter) as main simulation model, the perform of model case study is also assisted with DSPEd 1.3, which is necessary for setting up the basic network and prepare input files. Moreover, DynusT 2.0.1 Beta Version (Dynamic Urban Systems for Transportation), which is considered being an updated DYNASMART-P mesoscopic model by the University of Arizona, enables more functions of DTM and tools for effect evaluation. Besides, it offers a more convenient way for comparing different scenarios. Therefore, three models are combined for this study in complementing each other. The following figure shows their role in the following study. Details of the main simulation module model DYNASMART-P are followed.

.....
Figure 6.1: Software Function



6.1.2 DYNASMART-P introduction

The main simulation model used in the following study is the DYNASMART-P (Dynamic Network Assignment Simulation Model for Advanced Road Telematics) version 1.4, originally conceived and developed at the University of Texas at Austin. The software was developed primarily for the U.S. Federal Highway Administration's Research and Development Program aimed at studying the effectiveness of ATIS based traffic control strategies at network level and thus providing policy support.

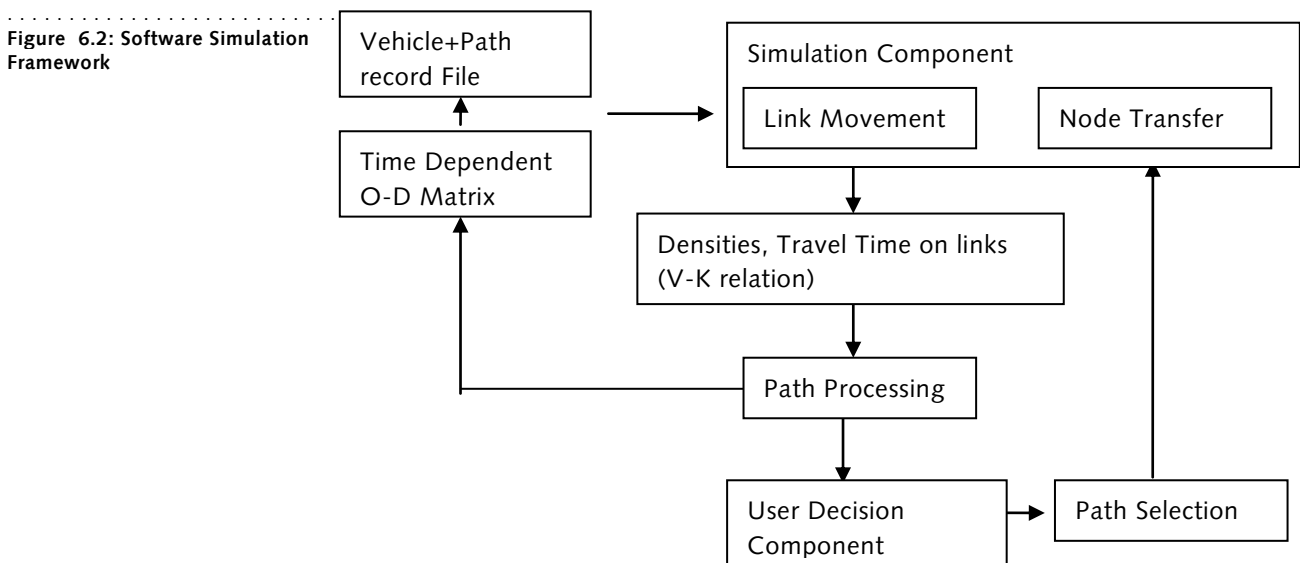
The model is primarily an offline descriptive analysis tool for the evaluation of information supply strategies, traffic control measures, and route assignment rules. It is an intelligent transportation network design, planning, evaluation, and traffic simulation tool. As mentioned, the model is mesoscopic in a sense that it, to an extent, achieved a balance between representation detail of both macroscopic model and microscopic model. To be specific, the model is based on simulating individual vehicle movements according to macroscopic flow principles (Jayakrishnan, 1994).

On the one side, the model is able to model individual drivers of different pre-defined user class, and track the location of drivers on a disaggregate level, producing the trajectory of each vehicle in the network, from origin to destination, including intermediate activity stops.

On the other side, during each simulation interval, a vehicle's prevailing speed is affected by vehicles in front/ahead of it, including those in the (immediate) adjacent lanes but the stimulus of a vehicle's speed response is represented in a macroscopic form (Chiu, 2006). Vehicles are moved in discrete bunches according to macroscopic speed-density (v-k) relationship. Aggregation statistics are generated at varying level, performance measures for each link and defined route are provided.

6.1.3 DYNASMART-P model framework

Given the time-dependent vehicle input, network representation, link characteristics as well as control parameters, the simulation assignment approach adopted in DYNASMART-P integrates traffic simulator, path processing mechanism and user decision component into a single simulation-assignment framework, as shown below. The major components are described hereafter.



➤ *Vehicle Generation and destination*

The traffic generation is based on the time-dependent zone-to-zone Origin-Destination matrix. Different from some other macro and mesoscopic models, DSP doesn't abstract central node as generation and destination point. Instead, generation links and destination nodes can be specified by users for each zone, the ratio of which determined on the trip distribution fractions calculated from OD data.

Besides OD as demand input, DYNASMART-P can utilize disaggregate trip plans in a pre-defined trip chain for each traveller as well. The trip plan is often the generated result obtained by a previous simulation run by with OD matrix, in such way different scenarios can be more comparable under certain situations.

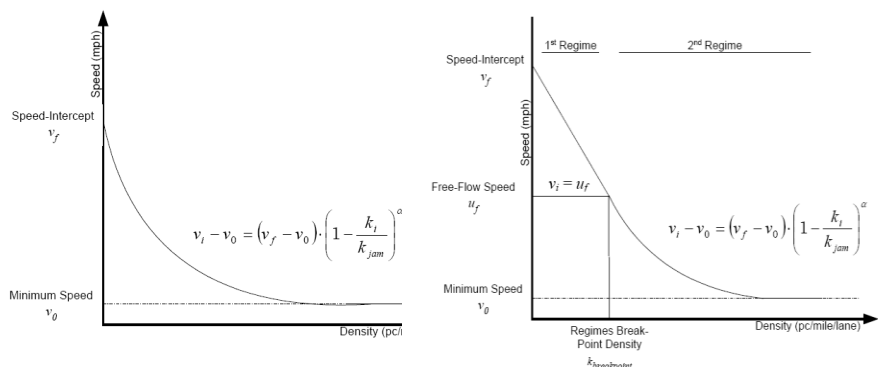
➤ *Traffic simulation component and flow model*

Different from conventional macroscopic models which coupled with a speed-density relationship and the identity $q=kv$ (where v is the average speed) and solved numerically using discrete steps and discretized highway segments. DSP, however, moves the vehicles according to the prevailing local speeds and keeps track of their positions, which means the vehicle flux across link boundaries is based simply on the number of vehicles reaching the link boundary during each time step.

The basic movement follows link movement and node movement. The vehicle movement during each time step is based on the speed in the link resulting from the density at the end of the previous time step. All moving vehicles in a link move at the same speed during each time step, depending on the density (Jayakrishnan, 1994). The k-v model utilized in DSP is shown below.

DSP uses a modified Greenshields model for traffic propagation. In the current version, two types of the modified Greenshields family models are available. Type one is a dual-regime model in which constant free-flow speed is specified for the free-flow conditions (1st regime) and a modified Greenshields model is specified for congested-flow conditions (2nd regime). (DSP1.6 Users' Guide, 2009). Type two uses a single-regime to model traffic relations for both free-flow and congested-flow conditions which is suitable for explaining the arterial roads, where have signalized intersections from time to time, meaning that such a phenomenon may be short-lived, if present at all.

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Figure 6.3: Modified Greenshields model (Left: single-regime model; Right Dual-regime model)



Vehicle location on each link are decided with the above two steps, either be still on the certain link or exceed the link length adding into the queue list for transfer. Afterwards, the number of flow can be

transferred to next link is investigated, performing node pass, and finally vehicle locations and queue list are updated. Then back to step one, the density of each link can be updated at every time step by tracing the actual physical position of the vehicle. The details of the algorithm and some confusing point are discussed in Appendix C.

➤ *Path Processing Model*

The path processing component of DYNASMART determines the route-level attribute for use in the user behaviour component, given the link-level attributes obtained from the simulator. Judging on the different user class, DYNASMART can be deployed to operate in two modes, differ mainly in the assignment component applied. The first mode represents a one-shot simulation assignment, vehicles are assigned a path at the beginning of the simulation, the path can be current-best path, one of the path from K-Shortest paths, random path or any pre-determined historical paths according to the choice selection of the user. While the second mode conducts a heuristic iterative procedure, in which a consistent iterative assignment procedure of either User Equilibrium or System Optimal is targeted. Paths package in this mode keeps on update and compare during each run, taking into account traffic evolution in the network at future time, until the convergence reaches an accepted threshold value.

It should be noted, however, assigning the best path to vehicles when they are generated does not guarantee that these paths will remain optimal at the end of simulation, in the one-shot simulation-assignment. Such a procedure merely assigns a path to each vehicle once it is generated, and unless this vehicle receives en-route information or encounters a VMS, this vehicle will be forced to maintain its assigned path for the complete simulation. These paths will invariably cease to become the shortest paths as the simulation progresses.

This is especially influential for the study in this report, which models a sub-area in the centre urban area. Under such a scale of network, frequent signal light waiting time can be an essential section in path travel time delay. Moreover, in condition of actuated control signals, the path assigned at the beginning of simulation would hardly maintain optimal during the simulation.

6.1.4 Software Evaluation

As above introduced, DYNASMART-P model utilizes macroscopic speed- concentration equations, rather than the conventional flow relation how volume is measured and relate to other two basic parameters in the model, and how such a model perform from a microscopic point of view which has to do with the later local measure design. Some odd phenomenon is found in the model as far as the author is considered; a simple experiment is designed for check and profound understanding of the model. The details of the experiment and results are presented in Appendix C.

Summarizing the experiment results, the confusing points in the finding are lies in:

1) Volume performance

The MOE performance of volume measured on a certain link is not constrained by the link capacity, while more resembles the demand of the upstream link. The cause of such measurement is thought to be accounted for the lack of node pass constrains set in the

-
- programmed algorithm.
- 2) Queue propagation
The queue is observed starts first from bottleneck link instead of the upstream of the bottleneck link. The queue propagation is somehow kind of conflict with the fact in reality.
 - 3) Fundamental diagram
The diagram derived by the model performance flow and density shows rather odd shape.
 - 4) Link length sensitivity
The link volume shows high sensitivity to link length, thus it can be concluded that physical link length plays an important role in the current algorithm of node pass coding.
 - 5) Saturation flow rate and service flow rate
Changing of the two parameters does not result in the effect as expected. For example, change the service flow rate (capacity) does not shown an increase in density on the certain link.

The above analysis based on the first trial of the model does represent some unknown algorithm and thus, as I am consider, are somewhat "defects" of the simulation model itself. Without coding reference and other more detail literature reference, it is by far hard to make clear the issue, or to further correct the problems. And it is certainly beyond the scope of this essay work.

Given the above findings, although DSP does not provide full satisfying performance compared to all the ideal tool criteria, it did emerge as the most fully featured of the candidate tool in DTM functions and integrated management test. Whereas, these finding may serve as a reference in the further application of the model and evaluation of the result, in order to have a reasonable result as far as possible.

6.2 Reference case Network Preparation

6.2.1 Assumptions for the model

Several assumptions are firstly addressed:

- Only car traffic is considered in the model, in other words, the feature of mix traffic are not reflected in the simulation
- All links have 0% slop, thus no such slop capacity reduction factor is considered
- To enable a smooth loading of traffic, the generation links are supposed to have more lanes than reality
- No personal guidance equipment is considered, and users are with the same familiarity level about the traffic network
- Vehicles are not allowed to change their departure time, destination or cancel the trip
- All vehicles if defined the same user type are considered homogenous in route switch threshold value regardless of departure time, travel destination and road condition
- For different methods applied into the network, the same path assignment at large would be used, in a sense that the likely induce traffic are not taken into consideration

6.2.2 Basic Input File

-Link characteristic

Based on the road structure in real life, the links are assigned with associated link length, link number, speed limit, etc. (shown in Table 5.1)

-Traffic model

According to the link attribute, different model types are distinguished to freeway, main arterial roads, feeder roads, ramps, intersection exchange, weaving section, and etc. (shown in Table 3.1)

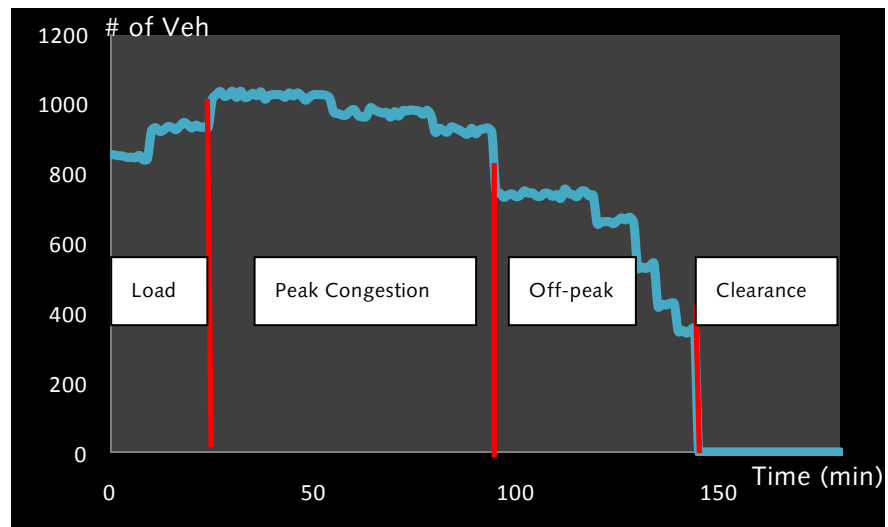
-Intersection control

Lack of source on detailed intersection signal timing plan, the actuated signal timings are assigned manually according to experience. However, as known, in reality the cycle time is relatively long (up to 3-5 min green time for some directions during certain period), such setting would cause severe deal lock in the model which differ from reality. Besides, in real practice kind of coordination between adjacent signals are considered, while in the software not yet possible. Moreover, in such a small network, too long signal time can be an decisive section in calculating current path travel time in path assignment when vehicle is generated. In this case, it is likely to assign a vehicle to very odd path which is not true in reality. Thus, the setting of signal time is generally shorter than reality (2 min maximum). The timing plan is checked and modified during the calibration process from time to time.

-OD demand

The original OD matrix was generated by OD reverse deduction based on the traffic flow counts on major links deduced from macroscopic model TransCAD. However, the setting of TAZs (traffic analysis zone), road settings and the modelling performance not being satisfactory, an adjusted OD matrix is deduced in this project with more reasonable TAZs division. Further, to ease the interpretation of the result, a clearance time is set to enable all vehicle finish their trips. Then there is no need to distinguish between complete vehicles and incomplete vehicles in MoE performance evaluation. The following figure shows the four-period demand levels during the simulation period.

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Figure 6.4: Demand Level Profile



-Other parameter settings

Other factors regarding to simulation interval, statistic collection, K-shortest path calculation and update interval, indifference band, freeway bias, etc are set with reasonable value respectively.

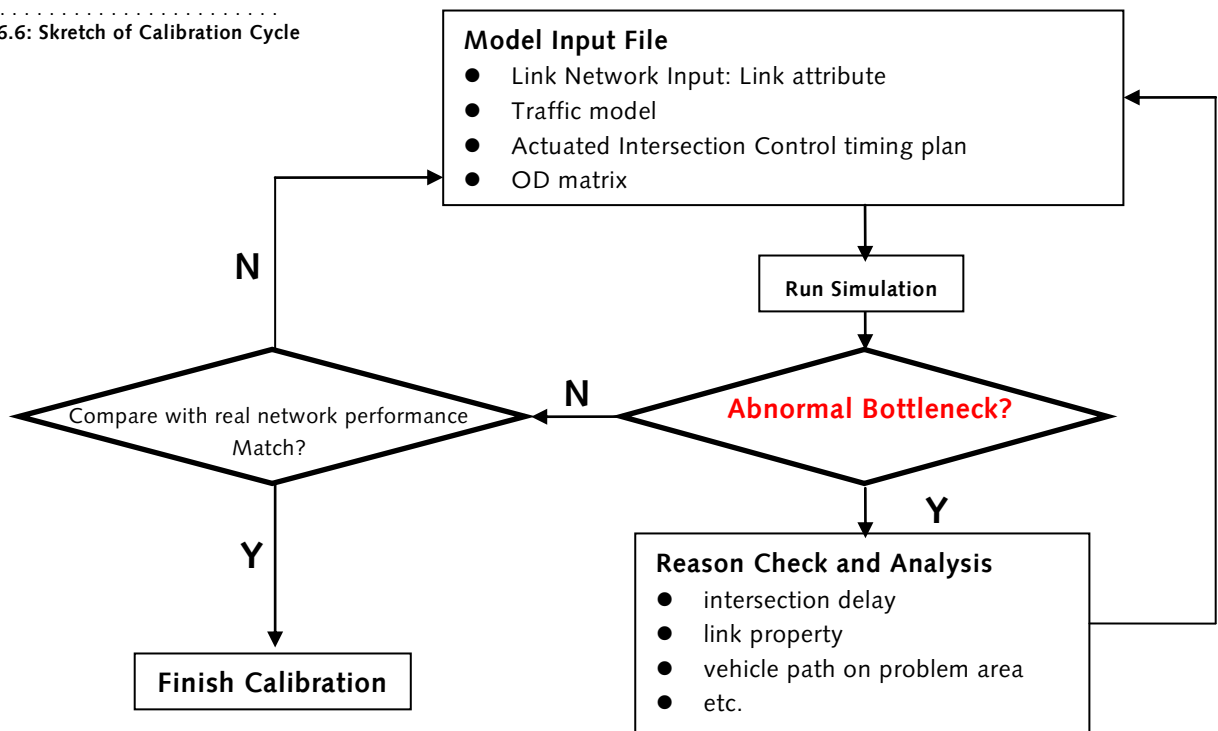
Figure 6.5: Basic Network Setup



6.2.3 Model calibration

The network links characteristics and traffic controls at intersections were calibrated during the network preparation step. Errors were fixed and some calibration parameters adjusted according to the results of the trail runs following the calibration cycle.

Figure 6.6: Sketch of Calibration Cycle

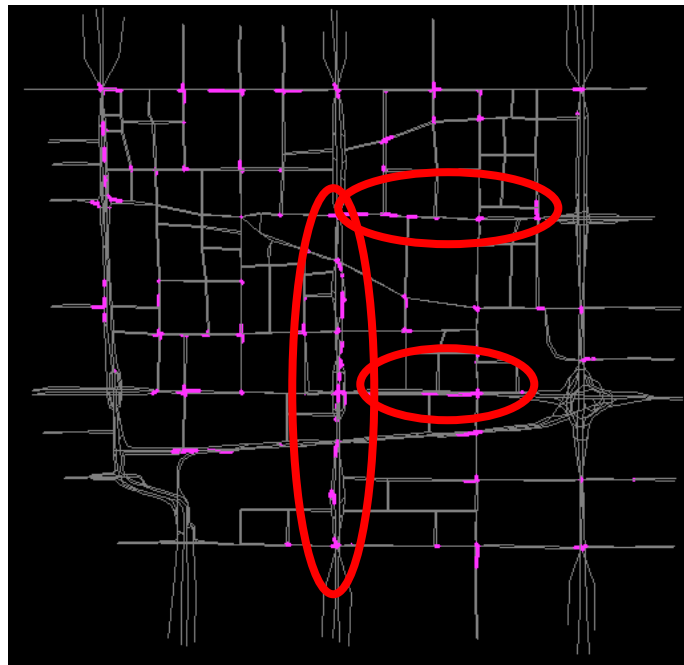


Calibrate the simulation model to mimic the real situation is always not an easy task; main difficulties in the calibration lie in:

- As mentioned in path processing model (Chapter 6.3), offline model assigns the vehicle with the current best path at the time of loading
- Urban signal timing influence in path assignment, result sometimes in odd path
- Model algorithm limitation and defect in performance indication
- Lack of reliable OD demand data. Basic OD matrix used in the model originally derived from another macroscopic model with different model algorithm, thus not being fully compatible

After trials and repetitive adjustment, the resulting model has 1029 links, 61 actuated signals and 30 zones. 123,371 vehicles are generated during the 180 minute simulation period, the model can somehow reflect the comparative density performance on critical links matching with the general performance observed in real life (Figure 5.7).

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Figure 6.7: Calibrated model queuing performance at time 80 min



However, due to time, skill and model limitations, the calibration result is not that satisfactory. It should be admitted that the congestion level simulated is lower than reality, and some local problems are not yet reflected so well. For instance weaving sections as bottleneck in reality do not causing much congestion, instead the signal timing queue propagation seemingly affects more severely on either surface road or further spillbacks onto expressway. Lack of further information and technical support, an extensive calibration could not be conducted in this study.

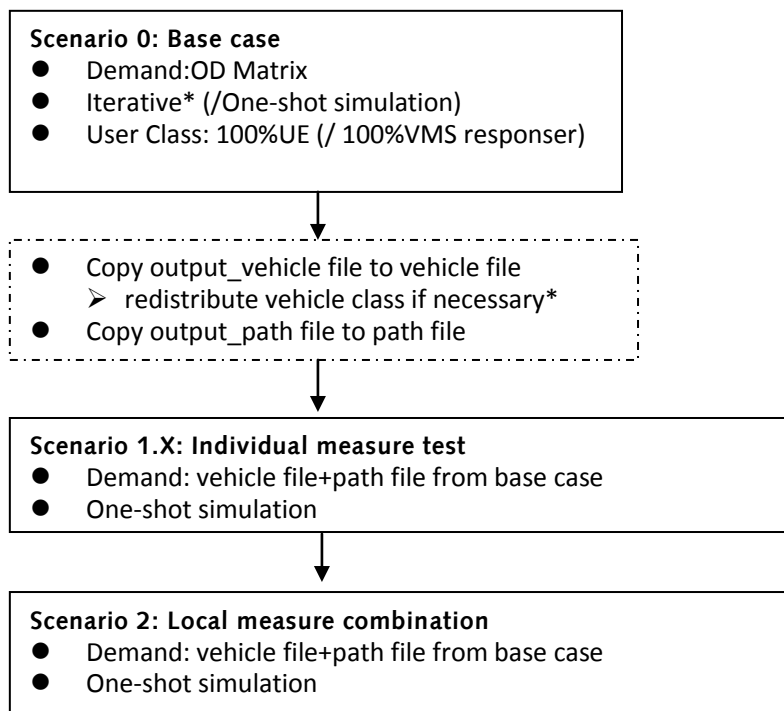
6.3 Local Measure Network Modelling

6.3.1 Local measure simulation scenarios description

Local problem areas in the study area have been identified in Chapter 5.3. Some of the measures conceptually designed in Chapter 4.2 dealing with the specific problems are to deploy and evaluate the network effect in this simulation study.

The following framework shows the modelling scenarios. In Scenario 1.x, individual measures specific to local problems described in Chapter 5.3 are embedded into the network respectively. And afterwards the network effect of combinations of these measures is to investigate in Scenario 2.

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Figure 6.8: Local measure simulation process



*Note: One-shot simulation and 100% VMS is used in this study

Some measures are found difficult to simulate and compare with current approach, for example changeable intersection turning bay, changeable ramp, weaving section relocation. And as to others, experiment tests are done, it is found detailed designs inapplicable in such a mesoscopic simulation tool due to the tool limitations. Thus the measures are realized by pre-assuming the improvement in capacity. Due to the fact found in experiment test that direct capacity increase cannot be well-modelled in the software by changing the service flow rate parameter. Such improvement is further found can be somehow expressed with traffic model parameter adjustment. Of course, another indirect approach can be to design a virtual incident case deliberately changes the capacity. In this study the first approach would be performed, the second could be left to try for further study. Details of experiment tests can be found in Appendix C and D.

The following table shows the individual measures applied in Scenario 1.X in this study. Figure 6.9 indicates the location of the applied measures.

Table 6.1: Individual local measure scenarios

No.	Scenario	Measure embed approach	Assumption?
1.a/b	On/off virtual ramp lane	Change traffic model parameter	yes
1.c	Weaving marking	Change traffic model parameter	yes
1.d	Tidal lane	Lane setting adjustment	
1.f	Ramp metering	DSP functioned	

The following figure further indicated the modelled location in each scenario.

Figure 6.9: Methods Application Area



In the first run for reference case, vehicles are generated according to OD demand matrix. The intention was to perform user equilibrium iteration to get the initial path file and vehicle for later simulation, however, the plan failed to follow. The obstacle lies in the disability in redistribution of the vehicle class (to VMS responsive) in DYNASMART-P 1.4 version used in the study. Thus, in the first run one-shot simulation is directly assigned to users. For the consistence throughout the whole simulation study, 100% VMS users (Class 5) are assigned. Under no VMS measure scenarios, they act the same as non-responsive user group (Class 1).

After vehicle file and vehicle path file are generated from the first run, the activity chain option as demand input can be used. It enables every vehicle hold to their original path in every run thus results are more comparable among different scenarios under a different network

condition. Here, assumption was made that vehicles do not change their driving paths due to the traffic measures applied. In other words, induced traffic is not in consideration.

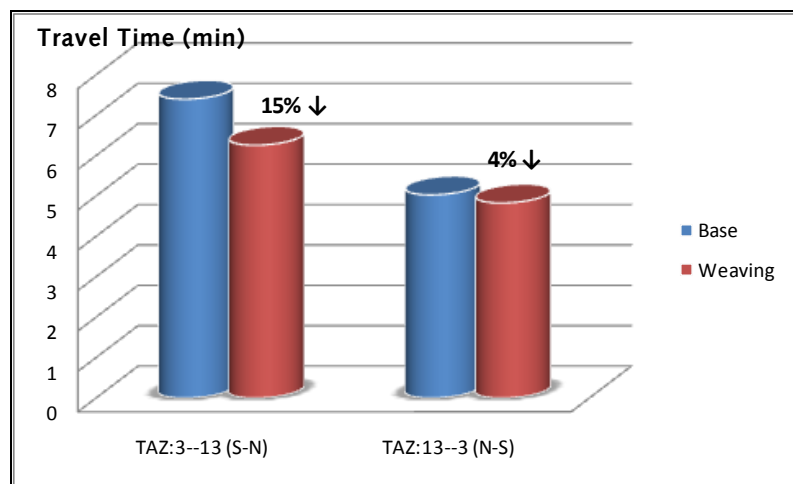
6.3.2 Critical Path Performance

Firstly, in order to have an initial picture of performance on a route level critical path are looked into for two scenarios with the output tool “vehicle path analysis” in DYNUST which measures the vehicle travelled and average time between each OD pair (TAZs)..

Among all the measures tested, two might be critical on path (arterial) level, Scenario 1.c weaving improvement on 3rd Ring, and Scenario 1.d Tidal lane allocation for the heavy directional traffic on Chaoyang North Road, east to west direction.

Method 1.c Weaving

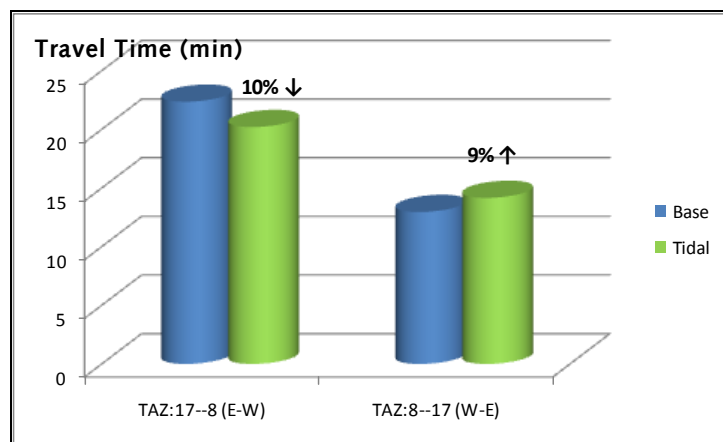
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Figure 6.10: Travel time on 3rd throughput under Weaving Marking



As can be seen, the weaving improvements do help to improve the travel time experienced by throughput traffic on 3rd Ring road. Moreover, on the south to north direction, improvement has reached 15%. It can be preliminarily deduced that the higher the current travel time, the more significant improvement can be enjoyed.

Method 1.d Tidal Lane

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Figure 6.11: Travel time on Chaoyang North Road under Tidal Lane allocation



In this measure, the 6 lanes on Chaoyang North road are reorganized in observing the obvious directional traffic phenomenon during morning peak. In this case, the original 3 lane each direction assignment is reallocated to 4 westward and 2 eastward. The simulation shows similar percentage change on either direction, but a 21.2% improvement has been enjoyed when referring to total vehicle travel time on the route taking two directions into consideration.

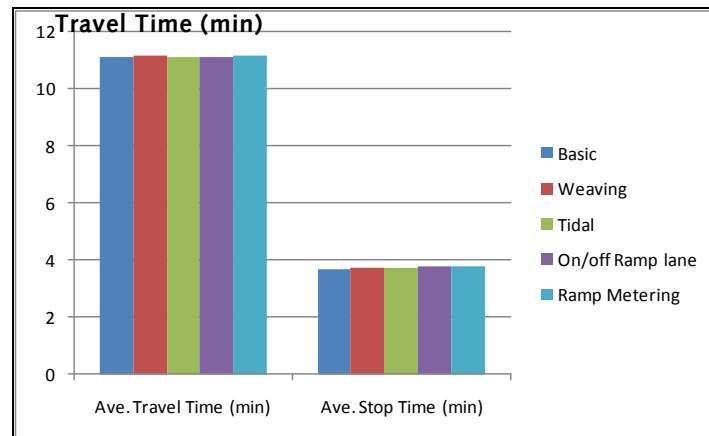
6.3.3 General Network wide performance

Summary MOE data are concluded in the following table. The average travel time, average stop time and average speed are collected from the summary file. And further, the performance respectively on different grade of roads are compared, these figures are based on timely report, being the average of instant average freeway speeds and arterial speeds during the simulation period.

Table 6.2: General Performance of Local measure scenarios

No.	Scenario	Ave. Travel Time (min)	Ave. Stop Time (min)	Ave. Speed (mph)	Freeway Speed (mph)	Arterial Speed (mph)
0	Basic	11.113	3.689	17.307	47.15	30.92
1.c	Weaving	11.15	3.708	17.247	47.19	30.94
1.d	Tidal	11.129	3.745	17.282	47.2	30.91
1.a/b	On/off Ramp lane	11.116	3.774	17.300	46.93	31.04
1.f	Ramp Metering	11.169	3.766	17.219	47.03	30.92

Figure 6.12: Local Measure Performance Diagram



The orange shadowing cells represent the best performance scenario under each MOE criterion. Comparing the performance of the method scenarios, unexpectedly, the basic scenario without any local measure generates the best performance as indicated by the summary file. The average of time instant speed on two kinds of roads do show some influence for certain measures though traffic volume difference for each time period not scaled when calculating the average.

As far as the author is considered, with this experiment, it may be too early to draw the conclusion that the measures are effective or not with this simulation. The measures respectively applied in the model are only

on very limited locations, the influence on a network level would be rather trivial. And it could be found that the differences in MOE performances actually are minor between scenarios (less than 0.1min in average travel time). Under such case, the influence of the modelling process itself may be rather accounted more for the network results.

6.3.4 Embedded Local Measure Simulation

The above local measures are embedded together in Scenario 2. The table below concluded the network performance.

.....
Table 6.3: General Performance of Local measure combined scenario

No.	Scenario	Ave. Travel Time (min)	Ave. Stop Time (min)	Ave. Speed (mph)	Freeway Speed (mph)	Arterial Speed (mph)
0	Basic	11.113	3.689	17.307	47.15	30.92
2	Local Measures	11.198	3.754	17.175	47.17	31.03
	Improvement	-0.76%	-1.76%	-0.76%	0.04%	0.36%

Even here, when local measures are combined, the resulting performance figures seemingly not that of potential. From a general perspective, the methods lead to deterioration which indicated that the implementation of different measures can have counter effect on each other. While, the time instant average of freeway and arterial travel time calculated respectively experience an improvement. Again, the difference here is not obvious.

6.3.5 Section Discussion

Unexpectedly, the local measures do not result in improvement under recurrent situation on a network level. The reason may be various accounting for measure design, network setup and model performance.

First, the assumptions made on individual measure improvement, which is here indicated by traffic model adjustment may not be a good approach. The side effect on the measures can be a cause of deterioration. Besides, as a mesoscopic model, the flow dynamics are considered rather on a macroscopic level, the detailed behaviour change due to infrastructure adjustment cannot be well interrelated. Thus in the model, the translation of real design concept to model language is rather difficult, so the simplified embed attempt might not be matched. Further, the model algorithm and measurement approach discussed above might result in confusing interpretation, and the cause might also be the weak reflection of problems area on the basic calibrated model. Last, the random error of in simulation process or measurement process might be also accounted for. Reason can also be that the model was originally tuned for reference case, and the performance of the latter scenarios may perform some defects with change on infrastructure under the same path input. Therefore, it is hard to draw a conclusion for the designed (and already simplified) local measures here. And the mesoscopic model, in this sense, is not like to be that effectively model to the local designed measures, the focus of the modelling would be recommended for integrated management part.

6.4 Integrated Measure Network Modelling

As mentioned in the software introduction already, DYNASMART-P is an innovative dynamic network analysis and evaluation tool which is especially capable of modelling intelligent transportation network design. DYNASMART-P allows consideration of an expanded set of dynamic management measures, compared to both conventional static assignment models and traffic simulation tools (H. Mahmassani and H. Sbayti, 2009). And the coordination and integration of methods on the software are still under research and development, thus it is worthy to make use of such a model in testing some integrated measures at the first phase.

A non-recurrent situation is designed in the study area according to the integrated approach proposed in Chapter 4 to evaluate the integration of measures, especially DTM measures in evacuating the impacted vehicles and recover the normal traffic.

6.4.1 Incident Location

Two incidents are respectively modelled on Jianguo Road west-east direction as shown in Figure 6.13. The incidents are set to occur during the most congested time period on the same link but differ in severity.

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Figure 6.13: Incident Location

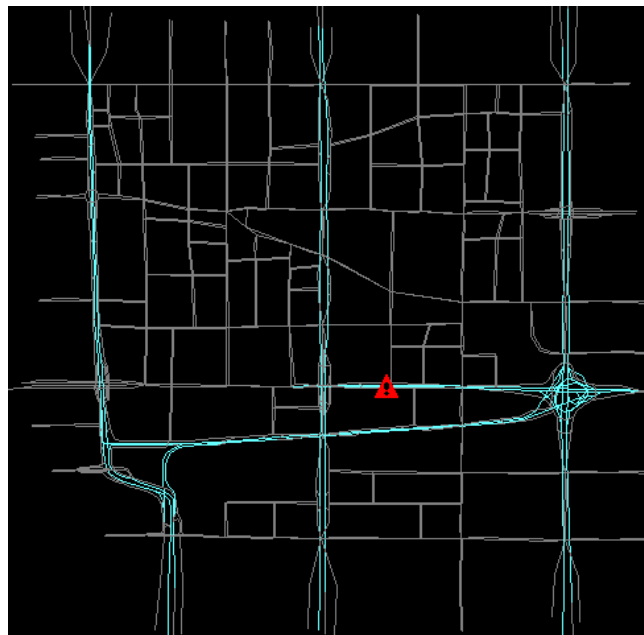


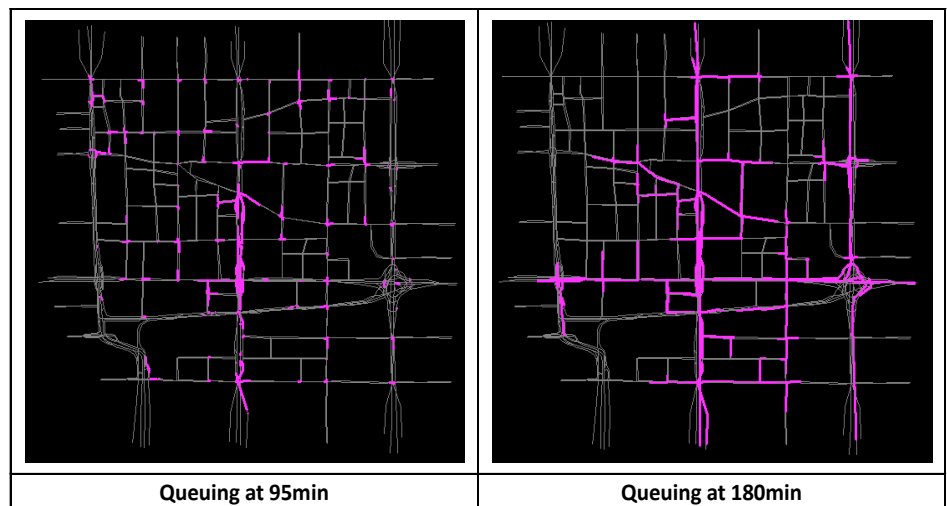
Table 6.4: Incident Information and Performance

	Duration	Severity*	#vehicle output*	Ave. Travel Time (min)	Ave. Stop Time (min)	Ave. Speed (mph)	Ave. Travel Distance (mile)
Incident1	50-75min	0.6	123371	11.731	3.829	16.395	3.205
Incident2	50-80min	0.7	96575	22.363	2.877	7.185	3.101

*Note:

1. the severity of an incident indicate the capacity reduction rate during the incident duration, for example, 0.6 means that incident reduces the link capacity by 60%.
2. In incident case 2, the vehicles have not yet cleared during the planning horizon, actually a deadlock occurred there and further extend to the whole network, thus the vehicles can hardly move out. In this sense, the statistics of other MOEs are not likely taken into consideration those incomplete vehicles.

Figure 6.14: 2nd Incident deadlock extension



6.4.2 DTM Measures in DSP

Limited by software capability, the following DTM measures are applicable in the designed modelling evaluation. In reality, measures can be a lot more.

1. VMS panel

Firstly, VMS panel is nowadays considered to be the most potential in real time traffic guidance in case of non-recurrent situation. Three issues are essential in traffic management to have VMS generate good effect, being display content, active location, and active period.

In DYNASMART-P, three kinds of VMS panel display content can be modelled.

➤ Speed Advisory

Speed Advisory applies at VMS locations when the density exceeds a pre specified value. Then, all the vehicles are assigned the advised speed.

➤ Congestion Warning

The congestion warning VMS displays descriptive information of road network traffic condition. The congestion warning VMS is effective when the concentration of downstream link reaches the maximum concentration. A defined fraction (by user) of vehicles are considered as non-captive drivers, who would evaluate the VMS information and divert if a better path exists at that time and position to their ultimate destination, either best or random from K-shortest paths.

➤ Route Advisory

Route Advisory offers prescriptive information of specific route advice. It is distinguished between optional and mandatory detours. The difference is that under mandatory VMS, all VMS responsive users have to divert their path, while optional detour VMS offers drivers the option to follow the detour path or keep their original path based on the boundedly rational decision rule. The boundedly rational path switching rule states that users switch from the current path at a decision point if travel times savings on an alternative route exceed a threshold value (Peeta, Mahmassani, 1995).

However, it should be noted that the VMS panels simulated in the model differ in some aspects compared to real situation. In the model, the detected region of congestion warning is limited to direct downstream link, and the activation segment is only the link where VMS is located. In other words, vehicle would not react only if it reached the link, and the divert point is the end of the link. This is not true in reality, where a wider region traffic situation actually can be displayed on the screen. The accessibility to the information is also not limited to only the link upstream on. Especially under the Beijing situation, where surface road is on the same horizontal plan with expressway, VMS can be observed on both road sections. Thereby, driver in reality can choose to go by expressway or surface road before the on ramp link if expressway congestion is detected, which cannot be well modelled in DSP. And for prescriptive route advice VMS panels, in the software, it would not concern whether there happens an incident or not and whether the original response vehicle path passes through the incident link. It generally only offers every vehicle reaching it a optional route advice based on the vehicle path upstream traffic condition.

The activated location and period can be specified by user in the model, different activate approach and combination can lead to different result.

2. Ramp metering

Ramp metering is another important DTM measure utilized in a lot of countries.

Ramp metering in DYNASMART-P is modelled by adjusting on-ramp flow rates based on the flow and downstream capacity of mainline freeway lanes. The logic implemented is similar to Papageorgiou's ALINEA (M.Papageorgiou, 1991), which is a relatively simple feedback-control mechanism.

Equation 6.1

$$q_t = q_{t-1} + \alpha (\beta - OCC)$$

Where:

q_t = ramp flow rate (veh/lane/h) for the t^{th} period

OCC= Measured downstream occupancy (percent time)

α = Occupancy-to-flow conversion rate (veh/lane/h/percent time)

The default parameter settings ($\alpha = 0.32, \beta = 0.2, OCC = 0.5$) are used in the following modelling. The coordinated ramp metering cannot be currently realized with DYNASMART-P.

3. Intersection Signal Timing

On arterial roads, the main DTM control method is intersection signal timing, actuated timing can be simulated. However, coordinated actuated control is not yet explicitly modelled. The timing plan can be designed into different phases in corporation to the integrated traffic management approach as proposed, although not yet realized in current version.

6.4.3 Integrated measure simulation scenarios description

Recall the integrated traffic management approach described in Chapter 4, four-phase logic approach is used in the case study.

With the (potentially) applicable measures designed for each stage, the following table shows the scenarios to model in this study. A detailed description of each scenario will be followed right after.

.....
Table 6.5: Integrated measure scenario list

Integration Phase	Scenario No.	Scenario Measure	VMS responsive rate
Diversion	1.1	Limited Local Warning VMS	10%
	1.2	Limited Local Warning VMS	25%
	1.3	Limited Local Warning VMS	50%
	1.4	Limited Local Warning VMS	75%
	2	General time Local Warning VMS	30%
Limitation	3	Add ramp metering	
Extension	4	Add Extend Warning VMS to general location	30%
	5	Add Optional Detour VMS on general location	
Optimization	6	Add Signal Timing plan	
	7	Add Weaving Capacity	

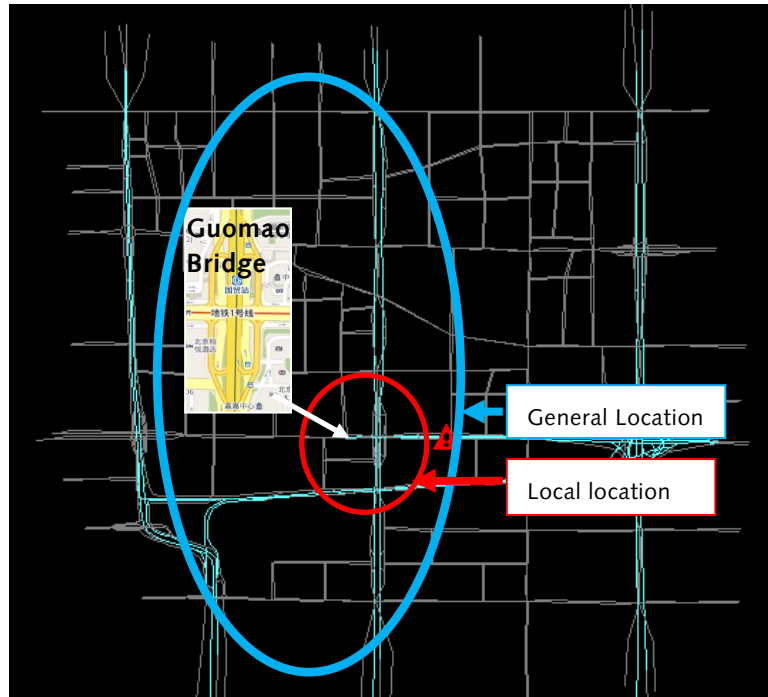
1. Phase 1: Diversion

In the first phase response to a detected incident case, when queue starts to propagate in the incident link, the vehicles upstream the link are directly influenced. To lower down the queue propagation speed, it is essential to immediately decrease the flow demand right towards the incident area. Thus it is rather critical to inform the right approaching vehicles, and divert them to another route at first possible diversion point with DTM responsive measures. Two scenarios are considered in this phase.

Scenario 1: Congestion Warning VMS on local location during incident duration time

In this case, the local location is defined as the area the last diversion possibility of upstream of the Guomao overpass bridge, and general location pertains to far upstream on three directions.

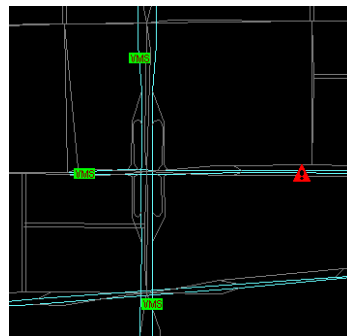
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Figure 6.15: Indication of location distinguish



In this first step, three congestion warning VMSs directly upstream the incident location are deployed, where offer the last possibility for vehicles towards incident direction to change route on the overpass bridge.

The VMS active period is 60min to 90min in both cases. And different responsive VMS users are consider non-captive drives (10%, 25%, 50%, and 75%), meaning the percentage of users who would take VMS information into consideration and compare with their initial path assignment. Indeed, the percentage of non-captive drivers, in other words the responsive drivers, is unsure. Here only an assumption is made. Due to the time limitation, one of the sub responsive scenarios would be taken into the further measure scenario.

.....
Figure 6.16: Indication of S1:local VMS panels



Scenario 2: Congestion Warning VMS on local location during general time

The same VMS panels as in scenario 1 are set, but only activate time extend further 30 minutes to 120min.

2. Phase 2: Limitation

Besides diversion soft measure on local location, to further control the demand, limitation measures can be integrated to restrict or at least slow down the flow on to the congestion links adjacent to the incident area. On expressway, the applicable limitation measure is usually ramp control with on ramp closure (by design virtual incident to reduce capacity), ramp signalized control. In the study ramp metering is modelled.

Scenario 3: Ramp Metering

Three ramp metering devices are set during the incident duration period with default parameters. The locations of the modelled controlled ramps are on the upstream of the incident link on each direction.

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Figure 6.17: Indication of S3:ramp metering



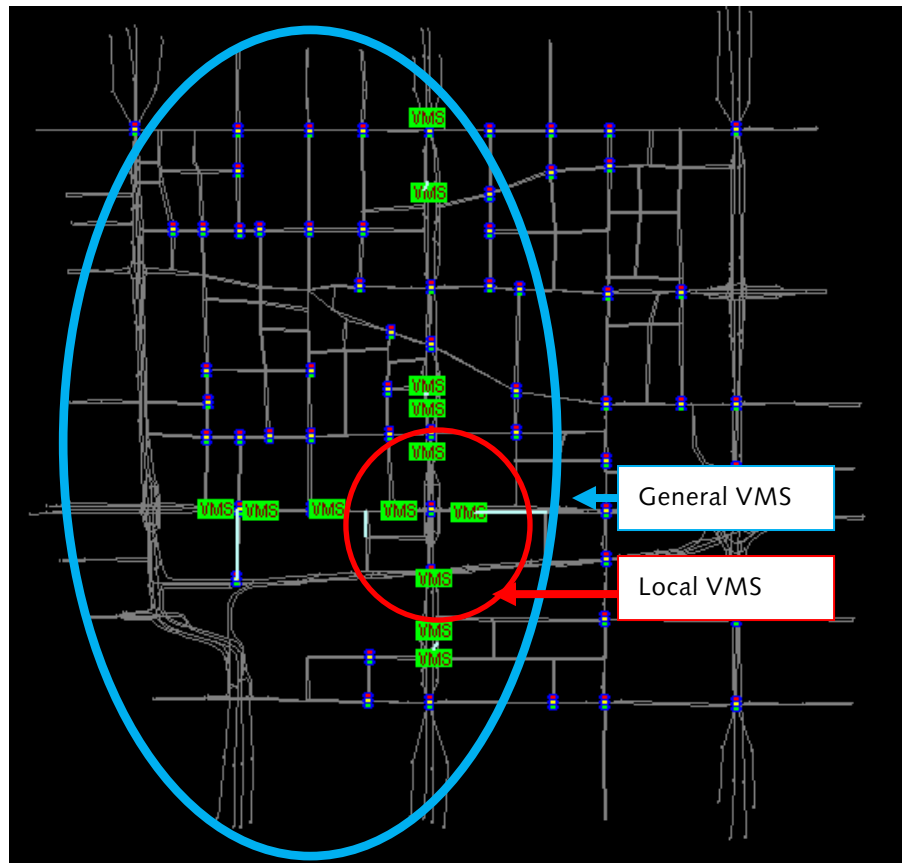
3. Phase 3: Extension

In this phase the measures are not limited to the links in the proximity of the site, but on a rather general location distributed along the upstream expressway. In such a way performing measures to the vehicles which may possibly soon contribute to the queue in advance. Warning and optional detour types of VMS panels are applied in the study in this phase.

Scenario 4: Congestion Warning VMS on general location

On the further upstream links, more VMS panels are activated during the incident duration time. The VMS with a distance from the incident area is supposed with a lower user response rate. The activate time of the panel ends 20 seconds after the incident is cleared.

Figure 6.18: Indication of S4: VMS general location



Scenario 5: Optional Detour VMS

Optional Detour VMS advises drivers a detour route to compare with their current path, depending on the boundedly rational decision rule to decide whether to comply or not. In the case, optional detour VMS is set upstream the off ramp some distance before the diversion area, where density may not exceeding the warning level to activate congestion warning VMS, but optional detour VMS would already encouraged vehicles to change route for detecting the far downstream link occurs congestion on the path. In this way, vehicles are alerted to change the route in advance before joining into congestion downstream.

4. Phase 4: Optimization

When more vehicles are diverted, the influence on the alternative route may encounter traffic performance decrease. To reduce the indirect impact on the alternative route due to the traffic diversion, and facilitate the diverted vehicles, integrated measures are designed in phase 4 regarding specifically for the alternative routes.

Scenario 6: Signal Timing plan

The detour routes are usually surface link, where too many vehicles on certain direction may cause congestion. Signal timings are here to correspondingly cooperate with the change on optional detour routes. It can be realised by adding maximum green time on certain direction.

Scenario 7: Weaving Capacity (lane signal control)

The detour routes on highway links can be assisted with lane signal control, e.g. Temporary use of emergency lane on certain direction,

especially to facilitate the merging process on detour links can be helpful.

Noted: at this phase, measure 6 and 7 are not yet embedded into the model because of current version is not yet completely capable of performing various phase signal timing (Scenario 6), and Scenario 7 cannot be modelled as responsive active. Here a proposed plan of design scenario 6 is conceptually provided in Appendix E as an example of optimization approach.

6.4.4 Network Performance Evaluation

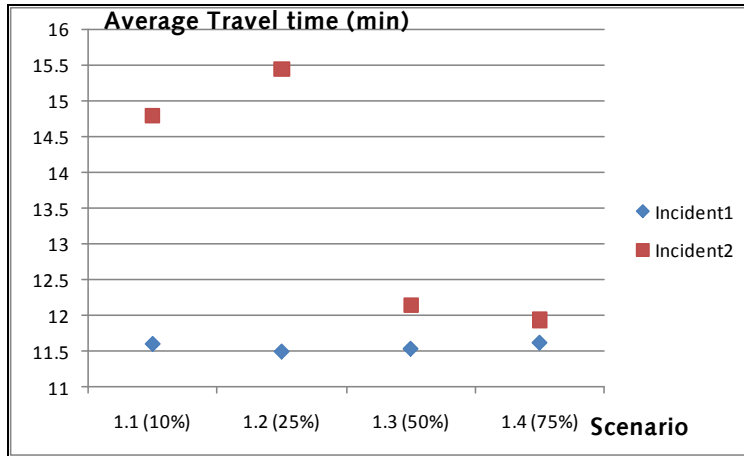
The following table concludes the network wide result found by adopting the different integrated traffic management strategies under two incident cases of different severity for scenario 1 to scenario 5.

Table 6.6: Integrated measure network performance

	Scenario Measure	rate	Ave. Travel Time (min)	Ave. Stop Time (min)	Ave. Speed (mph)	Ave. Travel Time (min)	Ave. Stop Time (min)	Ave. Speed (mph)	Vehicle incomplete during simulation		
			basic Inc1	11.113	3.689	17.307	basic Inc2	11.113	3.689	17.307	
				11.731	3.829	16.395		22.363	2.877	7.185	26796
1.1	Limited Local Warning VMS	10%	Measure	11.597	3.802	16.605	Measure	14.797	3.915	12.523	7574
1.2	Limited Local Warning VMS	25%		11.49	3.776	16.762		15.454	3.938	11.897	8717
1.3	Limited Local Warning VMS	50%		11.529	3.803	16.719		12.146	4.03	15.945	0
1.4	Limited Local Warning VMS	75%		11.614	3.841	16.597		11.937	3.95	16.222	0
2	General time Local Warning VMS	30%		11.579	3.823	16.659		12.26	4.065	15.847	0
3	Add ramp metering		11.428	3.789	16.858	11.968	3.947	16.176	0		
4	Add Extend Warning VMS	30%	11.464	3.788	16.805	12.041	3.993	16.081	0		
5	Add Optional Detour VMS		11.434	3.777	16.848	11.727	3.885	16.477	0		

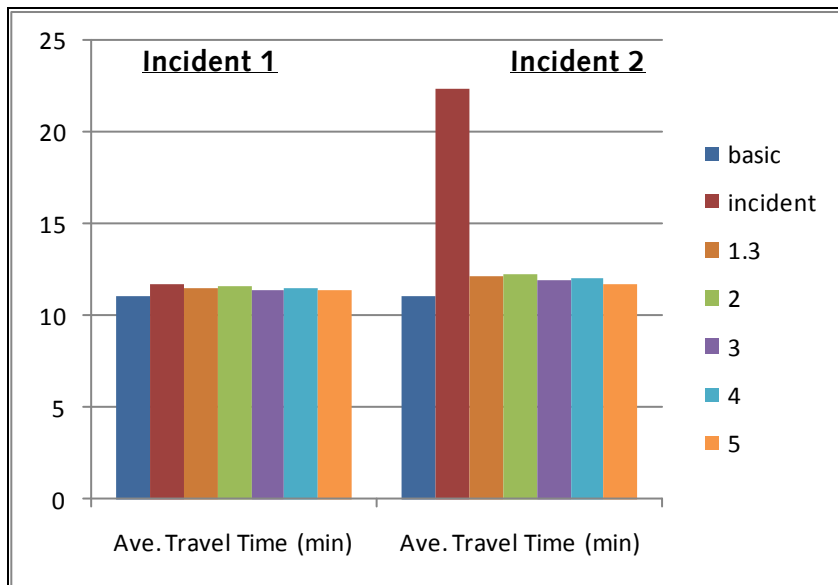
Scenario 1.1-1.4 are utilizing the same congestion warning VMS panels at the same location and active during same period, but with different VMS user responsive rate. Under the first incident case, the best performance can be obtained if 25% of the users are VMS responsive. And in the more severe incident case 2, only with up to 50% of VMS responsive users, the network would not result in a deadlock and all vehicles are able to finish their trip during the simulation period. For a comparable purpose, in the later scenarios where add-on measures are further applied, 50% user responsive rate would be used for these 3 local location congestion warning VMS panels.

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Figure 6.19: Average travel time in Scenario 1



Comparing the simulation result of different scenarios, it can be concluded that the level of measure embedment should depend on the incident severance. It is not the case that more measures deployed; a better performance can be always obtained on the network level. In incident 1, the optimal integration (improvement 2.6%) would be Scenario 3, congestion warning VMS activated at the local location during incident duration time with integration of local ramp metering control. On the other side, the simulation result of incident 2 indicates that the further extension of measure on scenario 3 would be able to enjoy more improvement if there encounters a more severe incident.

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Figure 6.20: Network MOE of different scenarios



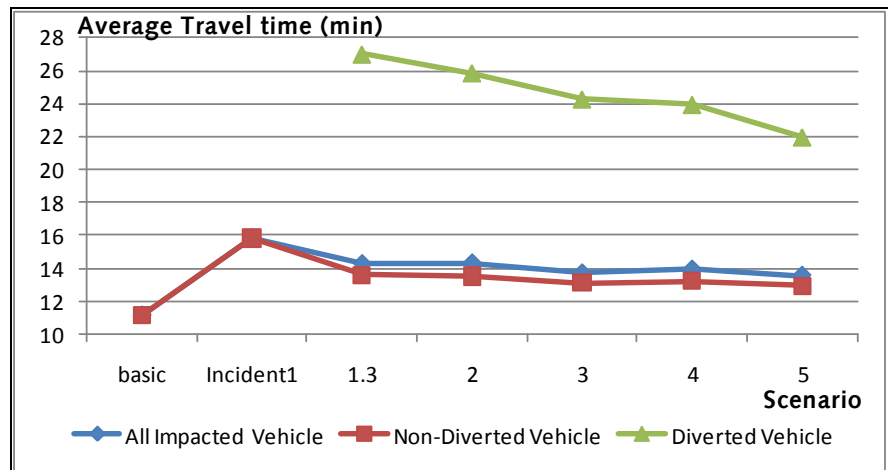
6.4.5 Impacted Vehicle Evaluation

DYNUST has an “impacted vehicle analysis tool” which identifies the impacted vehicles and reports their paths and travel times. Impacted vehicles in the model are defined as those vehicles that have paths passing through the incident area. Noted, here impacted vehicle included all vehicles use the incident link during the simulation time, thus the vehicles passing the link before the incident in reality should not have any influence by the incident are also counted.

In the basic scenario, an extremely small capacity reduction (1%) is added on the incident location during an extremely small time period (1 min), thus to extract the impacted vehicle performance under recurrent situation used for further comparison. 8136 vehicles altogether pass through the link during the simulation period are considered to be "impacted vehicle".

The simulation results for impacted vehicles are summarized in Tables in Appendix E, including the performance of all impacted, diverted and non-diverted vehicles respectively.

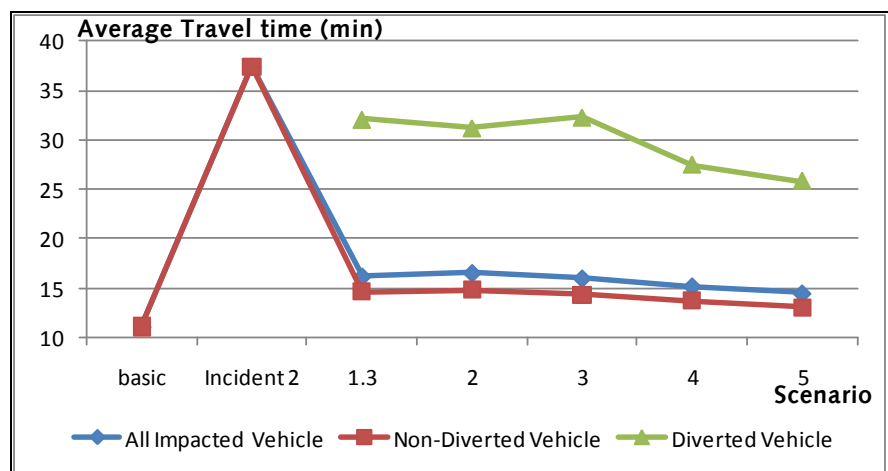
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Figure 6.21: Average Traffic Time for impacted vehicles under Incident 1



Compare the average travel time of different user groups in incident 1, it can be seen that the performance of non-diverted vehicles are close to all impacted vehicle performance. It has been explained that here impacted vehicles refer to not only those pass through the incident link during the incident period, so most of the "impacted" vehicles actually are under normal situation. In this sense, the performance of non-diverted vehicles and diverted vehicles are not comparable.

Whatsoever, it can be observed that the more measures are taken under the same responsive rate; diverted vehicles are able to enjoy more decrease in travel time. If considered all the impacted vehicles as a whole, scenario 5 weights out the best rather than scenario 3 in network performance evaluation.

.....
Figure 6.22: Average Traffic Time for impacted vehicles under Incident 2



Under a severer incident 2, the performance is seemingly the same trend as incident 1. Difference lies in only that for scenario 3, in which ramp metering is applied, the diverted vehicles are likely to be influenced more, showing a higher travel time compared to other scenarios.

6.4.6 Critical Route

Further look into detail route assignment performance. On the basis of scenario 5, those diverted vehicle paths are investigated. The following paths are observed as critical OD flow of interest with the highest amount of diverted vehicles in each case.

.....
Table 6.7: Critical diversion OD pair

incident 1			incident 2		
Origin Zone	Destination Zone	#vehicle	Origin Zone	Destination Zone	# vehicle
3	16	9	3	15	21
	17	10		16	8
	18	11		17	18
	23	29		19	23
6	1	14		23	29
	24	12		24	10
13	24	10	6	1	29
28	15	12	11	1	18
	19	11	13	16	11
29	15	10		24	16
			27	19	12
			28	1	11
				15	14
				19	19

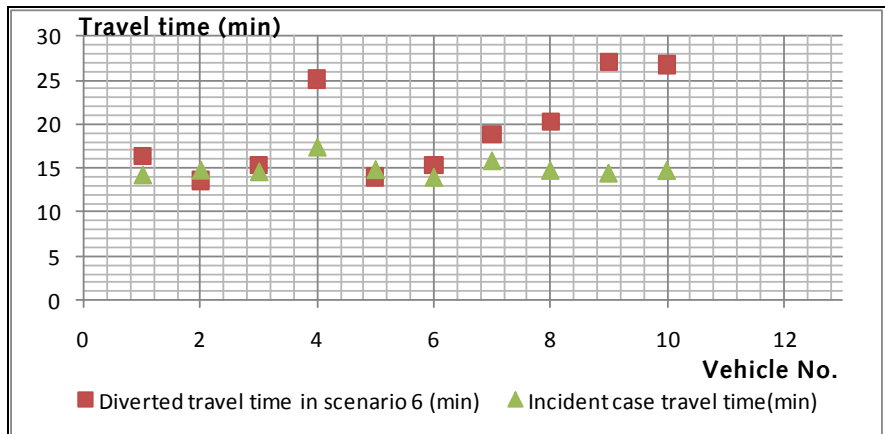
Table 6.7 has concluded the critical diverted vehicle OD groups. Here, we take one of them as an example to dig into the comparison of every individual diverted vehicle performance. OD pair 3 to 17 is one of the most affected OD. 183 vehicles in total demand and 79.8% using the path indicated in red during the simulation period.

Figure 6.23: A Illustration of Critical OD in analysis (OD 3-17)

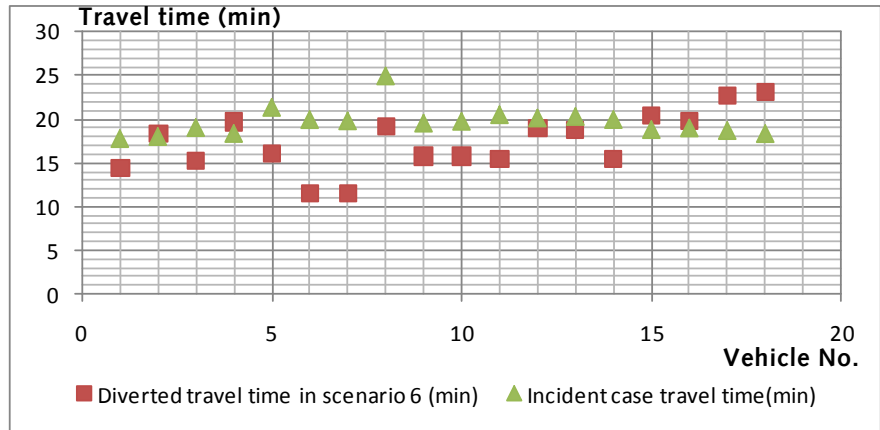


Given no optimal route assist measure yet provided, the travel time experienced by each diverted vehicles in scenario 5 (with optional route advise VMS) and their initial travel time in incident case are extract from the path data and compared in the following graphs, for detail figure can be refer to Appendix G.

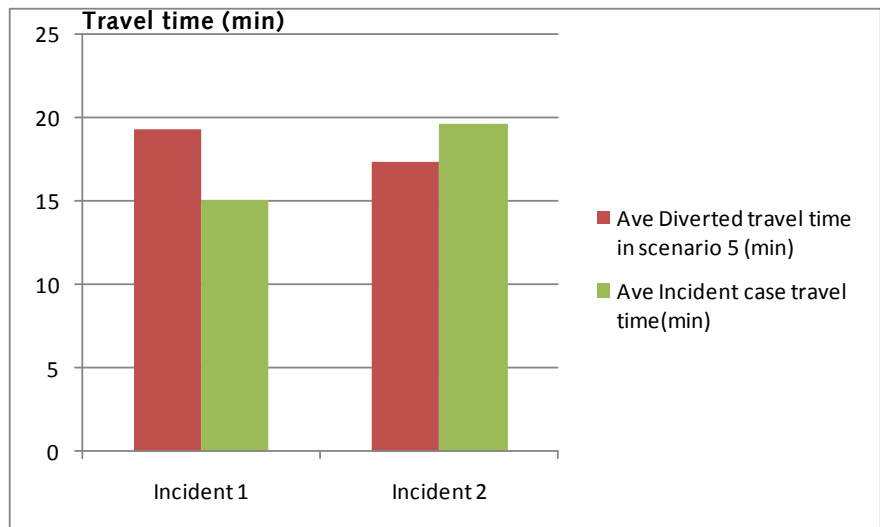
Figure 6.24: Traffic Time compare under Incident 1



.....
Figure 6.25: Traffic Time compare under Incident 2



.....
Figure 6.26: Average Traffic Time compare



As can be seen, in incident case 1, the diversions for most vehicles don't actually experience a better travel time, although according to the VMS algorithm and boundedly rational path algorithm they should be. And in more severe incident case two, most diverted vehicles enjoy a shorter travel time by diversion. Whatsoever, it can be concluded that diversion choice might not outweigh the original path. The current travel time estimation for the path may not doom to be a better "option". In Beijing situation it may be more uncertain. The signal time under current estimation can hardly match with the actual waiting time when vehicle arrives at the intersection in a future time. And the rather long signal cycle makes it even harder for ensuring the optional path being an optimal.

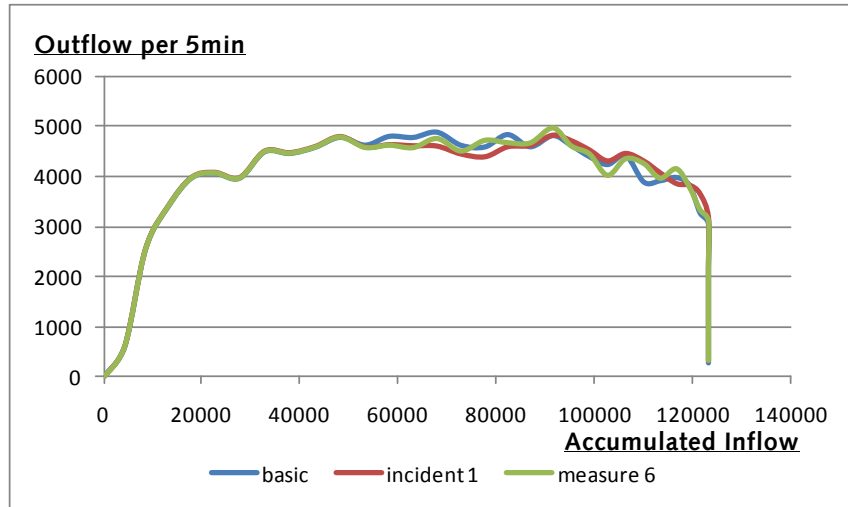
More integrated methods in phase 4 on the alternative route to optimize and support such diversion are thus needed. In this study the modelling of phase 4 is not conducted.

6.4.7 Macroscopic Fundamental Diagram

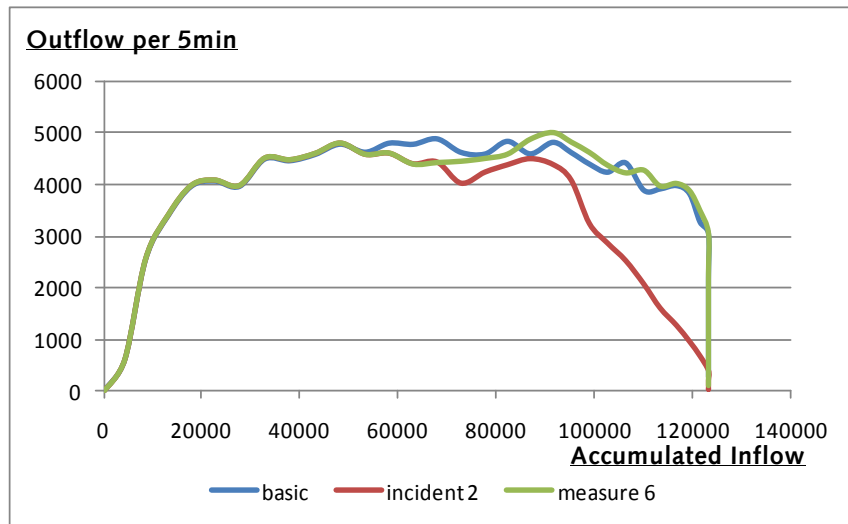
The final remarks are made from a macroscopic network capacity perspective. With outflow and inflow data provided in the summary file, the following Macroscopic Fundamental Diagram are drawn, showing the relationship between accumulated inflow and the interval outflow

(here 5 min). In both cases, the integrated management measures show more recovery ability after the incident case.

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Figure 6.27: Macroscopic Fundamental Diagram under Case 1



.....
Figure 6.28: Macroscopic Fundamental Diagram under Case 2



6.4.8 Section Discussion

Under non-recurrent situation, the integration of DTM traffic management methods would potentially have obvious impact on network traffic performance. The improvement of which depends on the different scenarios taken for different incident situation. If the incident case only temporarily interfere the traffic in the adjacent area, certain local measures (in this case, warning congestion VMS and ramp metering at limited location activated during limited time period) would be enough to offer best help for the overall network recovery. And the further management upgraded control in region or time would only bring side effect onto more vehicles not directly impacted. Under the case of a severer incident caused network blockage, the guidance seems to be of more importance. With the incident (the resulting congestion) information available to direct impacted downstream traffic, reaction could be taken immediately. The further extended integrated measures avoid queue from propagation, and assist measures if could be modelled, less side effect could be expected.

Thereby, two cases indicate that to achieve the best integrated management effect, the decision point of the level of integration according to different cases is important. Such an approach is only feasible if there exists a framework for the transport policy in which the application of ITS has a place and from which priorities can be derived, in fact this is one of the obstacles facing by the policy makers when such integration approach is to practice in reality. Moreover, here some assumptions are made such as the responsive rate, boundedly threshold rate, etc. And in reality, it is rather difficult to concisely capture the user response.

Last but not least, the rather complicated urban area with lots of signalized intersections with long cycle time on surface roads makes it rather hard for estimating travel time. And complex disperse distribution of vehicles in urban area makes it even harder to provide publically an optional path.

6.5 Conclusion

In general, it should be pointed out that DYNASMART-P is still limited in function to present the designed measures.

The local measure tests hardly show improvements in regard to network performance, which is unexpected. The possible reason for that may account to the software ability, the model calibration, the problem area reflection, model algorithm and random error as discussed already.

As to integrated traffic management simulation case, with 3 out of 4 in the designing framework experimented in the model, the result show a rather significant improvement of situation. While, depending on the incident influence degree, different level of integration phase is required to generate optimize effect in terms of network performance as a whole. The decision point hereby is a crucial issue for policy makers taking the uncertain user response into consideration.

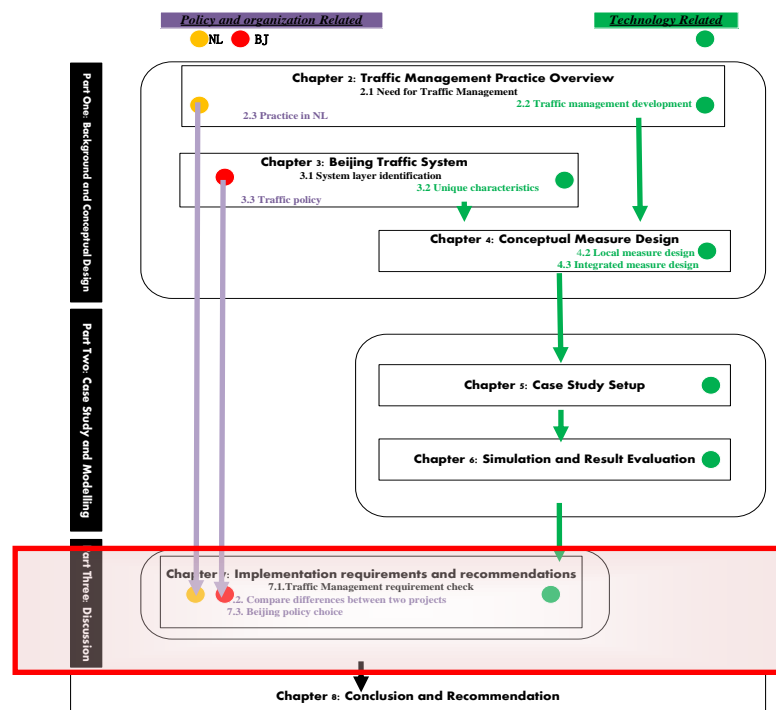
The last remark refers to the tool's fitness in demonstrating Beijing situation. As it is developed and calibrated mainly for US highway, in this sense, the unique traffic system described already in previous chapters might not fit that well to the model variables, thus the network characteristics and corresponding user behaviour cannot be well represented.

Part Three: Discussion

In Part one, the unique feature of Beijing traffic system has been investigated. Based on the foreign experiences and Beijing local situation, specific local measures are designed tailoring to the unique traffic problems in Beijing situation. These measures are theoretically promising to solve the local problems. Integrated approach with the applicable measures is then conceptually proposed with a four-phase integration approach.

Modelling approach was chosen for case study in Part two. Firstly, the study area was investigated, measures were recommended for specific problem locations. DYNASMART-P tool was then used to model the site and test both the local and integrated management methods. However, the modelling approach in the study does not achieve well the objective due to various reasons, especially for local measures the model can hardly tuned to test. The integration test does show good results by the model, but in practice the operation would be still an obstacle to further overcome.

Based on the above facts, this chapter is to further investigate the potential of implement and development for traffic management instruments. Requirements are checked from technical, policy and cost perspectives. And then compare to the Dutch case, a SWOT analysis is done on utilizing traffic management as an instrument. As a concluding, recommendations are provide towards the future of traffic in Beijing.



7. Implementation Requirements and Recommendations

Taking into consider the findings, this chapter is developed to discuss from a policy point of view, in an attempt to answer the question:

Research question of Chapter 7

- How should traffic in Beijing be dealt with to accommodate the economic growth in the future?

7.1 Beijing traffic management

Given the various problems lie in current Beijing traffic, the designs suggested in the part one and initial integrated approach in part two offers opportunity for a better traffic solution. With the experience of developed countries, and under the existing efforts, traffic management should be the trend and need to be continuously paid attention to in the future.

This part aims to give some discussion and recommendation regarding traffic management issues, and explore further the requirements and fulfilment for each approach on technical, organizational and cost perspective. In such a way, provide a general view on the management instrument for Beijing towards the future development.

7.1.1 Local Measures

1. Step from every minor improvement on local static traffic management

First, efforts should be focused on the local problems caused by defect or limitation in road design or unregulated flow dynamics with simple static traffic management measures (mainly infrastructure adjustments). Some of these sensitive areas in Beijing current network have been found in this research. Improvement on those local bottlenecks can be achieved with simple measures with designs in Chapter 4 which may be with itself minor influence on network level, but would provide aggregated effect if coped properly.

Technical Requirement:

Those local static measures designed in the study and also other researches are mostly easy to implement. While before measures can be put into use in practice, they should be further evaluated the effectiveness on the specific local traffic condition by either model simulation or by site field test respectively.

Organizational Requirement:

Since, the influence area is rather local, the traffic conditions at local sensitive areas and approaches are to investigate mainly by regional departments. The deployment of change should be submitted to centre administration of Traffic Management Bureau for approval. Approaches of measures may be different in an attempt to adapt to specific local problem, however, in general should at best keep the same. Otherwise, it would be a problem to have the drivers to follow in different areas.

Cost Requirement:

The change here is considered to be only minor change on infrastructure or other static approach. Cost is generally not a bit issue in most cases.

2. Continuous dynamic traffic management development

Next to that, the first trial on DTM investments has already shown effects, although the coverage is still rather low at the time compared to other cities. Only with dynamic measures can responsively capture the flow dynamics, thus the flow can be automatically adjusted to attain the control objective. With the large amount of vehicles in Beijing, the status network itself is rather vulnerable and unreliable, thus it is especially in need of DTM measures. Continuous DTM development is called for and to be planned sharing a large piece of cake in the future blueprint.

Technical Requirement:

Given the urban characteristics, the highway oriented DTM measures in Beijing ought to be extended to a higher coverage spreading also over surface road and main urban roads where problem exists time to time with variable flow dynamics. More measures could be developed with intelligent innovation of dynamic management as some examples given the study.

Technically, the algorithm of DTM measures are more complicated and the effect as well. In this study, new measures are only conceptually proposed, the detail algorithm and parameter settings are not yet discussed. In this sense, the chosen of algorithm (for example: different ramp metering approaches) and parameter setting (threshold value for dynamic change) are to further adjust according to local data and infrastructure allocation before deployment. This requires also microscopic simulation of flow dynamics and field experiments.

An important basic hardware required for the DTM measures are detecting devices, with which prevailing traffic state is captured. The existing detector system is mainly on ring road and main intersections. To deploy more DTM measures, more detecting and monitoring equipments are to implement at certain locations (e.g. virtual ramp). In addition, more sources of real-time information should be investigated and integrated to report state better, like floating car, mobile data, etc.

And for soft DTM measure like VMS panel, the user response is one of the main obstacles in measure effect prediction, this should be done by critical observation and investigation on traveller behaviour and the so call "value of time" in react to different information type and content.

Organizational Requirement:

Although DTM measures usually serve also local problems, regional authority may fulfil the organizational requirements. However, the technical requirements like detection system and information release (for VMS measure) calls for a rather systematic investment and organizational management.

Under the current Beijing organization architecture, the different measures are under monitored by different central application systems. The main DTM measures like VMS and actuated signal control are included in two application systems; the central system can be detailed

to each monitor section for specific adjustments. For newly measures except for the above two, one of the monitor sectors in the under layer systems should be assigned take the responsibility (for example for: ramp control system), or new ones should be developed. (Refer to the Framework of ITS control, Figure 3.15)

Cost Requirement:

The starting up of the DTM, either the devices or operational systems, calls for quite large capital investments. Besides, daily operational cost and device maintenance cost are required from time to time. While, in the long run the return rate is considerable as well. The government promotion is the main force for such investment.

In the past decade, as reported, 880 million RMB has been ploughed to the investment of ITS of various kinds in accumulation. And another 1400 million are allotted for the coming three years in ITS development in Beijing. While it is rather difficult to estimate the real cost and benefit.

7.1.2 Integrated Measures

Integrated traffic management be set in schedule

A preliminary case study in Beijing urban area have shown that the effects of integration DTM measures outweighs isolate control, and significantly improve the network traffic performance for non-recurrent situation compared to no measure taken scenario.

In Beijing, as more DTM measures are to deploy, it is high time that the government get insight also into the topic of integrated traffic management at the same time when completing the DTM blueprint. It should be realized that it is the future and the way to play the full potential of DTM measures. The benefit of starting DTM based integration investigation at the current initial phase of DTM development lies in an advance consideration of the connection possibility, either for technical interface of individual measures or operational and organizational structure. Thus, reduce the cost in reinvestment for further integration in the future.

Technical requirement:

In the study, only a simple plan is investigated for a certain incident occasion. In reality, such measure responsive approach is a lot more complex. Apart from the technical requirement in the individual DTM methods, in a measure responsive approach cycle more issues are here to state to enable the execution of integrated network management.

➤ **Detection and release of information**

The launch of integration plan is based on the detection data, especially the incident case. The quick and correct capture of the state change is of importance, thus in quick reaction for starting the appropriate management plan. Further the end of the integration measures again depends on the detection information indicating the recovery of the traffic state. Besides, the release of information and monitor of real time information are essential in the control process as well. And above the requirement of individual DTM measures, here the geographical coverage of detector data, the timely and accurate information are essential in the network wide integration approach.

➤ **Integration plan and decision support**

In the case study, it has already been pointed out that the effect of congestion alleviation depends on the design of specific integration plan. Given various traffic type of traffic condition, complex interaction between measures, lack of insight into network dynamics in particular facing non-recurrent situations, it is a complicated task for traffic control centre and traffic management practitioner to interpret monitoring data and to pose the diagnosis to an observe problem manually in no time.

In an attempt to raising the plan, an ideal auto-reactive approach between measures is called for. However, it is rather difficult to realize. The inherit algorithm and device requirement behind are nowadays still lack of research. Another way of decision support system in assisting for operation, as a first step, is promising in taking the responsibility.

Tasks for such a decision support system include:

- 1) Identification: monitor the traffic state and diagnosis the problem
- 2) Prediction: given the prevailing traffic conditions, predict demand and candidate control scenarios
- 3) Advise: present the operators with the control scenario that yields the optimal predicted traffic conditions

Various approaches have been tried and tested, which include rule-based, case-based, or agent-based reasoning. Examples are FRED (Freeway Real-time Expert System Demonstration) (Ritchie, 1990), the agent system TRYS (Cuenca et al, 1995), BSES (Boss Scenario Evaluation System) (Hoogendoorn et al, 2003), etc.

Again, local traffic characteristics are to taken into consideration in Beijing. A self-learning-based decision support system, by DHV group, BETIMES (Beijing Traffic Integration and Model Evaluation System) is being developed for Beijing Traffic Management Bureau to support their decision on DTM measures. The system generates, evaluates and recommends traffic control plans that enable the operator to define more precise the incident characteristics and select the relevant control scheme. The system application results is not yet known, but it can be expected further development in DSS would help to realize the integrated management and of great help in alleviating traffic congestion.

Organizational Requirement:

To realize the integrated management, a centralized decision maker is in need to assign the management plan or operate the DSS system.

In the described organization structure in Beijing, one of the three platforms ----- Traffic Command Section under the authority of Beijing Traffic Management Bureau can take the duty. As an intermediate platform, on the one side it receives shared data from the upper layer data centre. On the other side, it exchanges and processes the management plan to the application subsystem sectors. Moreover, the six regional detachments (police personal support) are also under dispatch of the centre command platform.

When more DTM measures are to include, an under layer system recompose may be necessary, and the balance of optimization in

different system need to be cooperate to balance a trade-off, and provide optimal solution for network as a whole.

Cost requirement:

Besides the planned basic DTM measure investment, other cost mainly for the effort of a higher quality of data collection and traffic monitor. Besides, investment may be mainly in research and operational cost for decision support system. Further, if to build automatic cooperation between measures itself, the “communication” methodology may need to invest. At the time it is hard to estimate.

7.1.3 Traffic Management Requirements Conclusion

The following table concludes the discussion above; the red line indicates the current state of fulfilment in Beijing.

Table 7.1: Table of Measure Requirements and fulfillment

	Local Measures		Integrated Measures
	Static	Dynamic(DTM)	
Technical Requirement	<ul style="list-style-type: none"> • Easy to implement • Effect evaluation 	<ul style="list-style-type: none"> • Measure innovation • Detection and control device • Knowledge on user response • Effect evaluation 	<ul style="list-style-type: none"> • DTM settlement and network coverage • High quality detection and release of traffic state network wide • Integration plan support
Organizational Requirement	<ul style="list-style-type: none"> • Regional authority localized management • Central authority approval and unified control 	<ul style="list-style-type: none"> • Regional authority localized management • Systematic management 	<ul style="list-style-type: none"> • Central monitor and command • Regional authority cooperation
Cost Requirement	<ul style="list-style-type: none"> • Low 	<ul style="list-style-type: none"> • High starting up investment • Medium operational and maintenance cost 	<ul style="list-style-type: none"> • High operational and maintenance cost

— Current (possible) fulfilment of requirements
■ Fully fulfil ■ Almost fulfil ■ Not yet fulfil

Generally, at the time, Beijing is somewhere at the initial phase of local dynamic management measure development. The prevailing situations of higher grade roads are quite well detected. However, most of the DTM measures systems are imported or inclined from foreign practice, the technology development of measures adaptive to Beijing traffic feature not yet at its mature phase. And the coverage of the measures, especially the fact that still lots of sensitive area are under no control indicates a long way to go before a complete system. But still quite a large lag behinds the integrated management requirements. The newly developed organizational structure can basically accord with the requirements, efforts should be paid more on the operational quality and efficiency. And refer to the cost requirement and the return benefit value, without reliable figures and estimations, it is hard to expect from this research.

7.2 Beijing and Dutch comparison

This study was initially proposed by the DVS in an attempt to investigate the integrated management opportunity in developing cities like Beijing based on the Praktijkproef Verkeers management project in Amsterdam (PPA). After, various aspects has been discussed pertain to Beijing situation on the issue of traffic management, a comparison between two example projects would be conducted for conclusion.

1. Different development phase

First, it should be realised that the two countries differs much on the current development phase of traffic management. In the Netherlands, the policy choice has long ago given favour to traffic management development, the government ceased originally construction projects while switch to the management alternative. With the continuous technology development, a rather complete system has set up. While in the Beijing case, the construction projects are still undergoing, it is until only the last decade that initiated the research and attention on traffic management. Therefore, in some sense, the development of the advanced traffic management and infrastructure construction are synchronous and calls for a great-leap-forward development to catch up with the developed countries both in technology and management philosophy.

2. Highway traffic vs. Urban Expressway traffic

In both projects, measures are designed for promoting the traffic conditions on the high graded road as priority. However, the different traffic system backgrounds lead to different approaches of traffic control.

In PPA project, most measures are designed directly on the highway, either optimizing the merging flow on a local level or extending to reorganized flow by lane use allocation. This can be realized in that A10 together with the adjacent highway themselves make up a network enable diversion and rerouting. And the highway is with distinctive interface buffering ramp to the urban traffic, therefore the urban traffic has little interactive with the high way system. And as the outer region of the urban area, the destination of the traffic are rather monotonous, thus flow can be organized on quite a long sketch of road section. Moreover, the traffic demand is a lot lower than that in Beijing, so drivers do have higher speed expectations on highway.

In Beijing project, although aims set also mainly to improve the expressway traffic, the measures are more concern of the influence of urban traffic on expressways. Besides weaving on expressway, the traffic condition on surface road has close interactive relation to the expressway performance around the ramp sections. Moreover, the fact should be realized that 80-90% of the roads are under saturation flow, and the flows are frequently interrupted by high density ramp settings, thus room left for arterial level organization on expressway is little.

3. Difficulty in each project

In PPA project, the implementation of the proposed approach may lie in:

- The harmonious inoculation to the old measures

The development of DTM has already experienced over two decades, the devices and measures applied are already matured. A possible

difficulty may be a the new measure monitor and management system cannot well match with the old ones, new investments are called for a retreat of some parts in the already exist instruments

➤ **Control organizational issue**

There is a distinction in highway management sector and urban management sectors in Dutch management structure. And the cities in Netherland are rather small. Thus, if to implement on a larger network scale, a lot of actors are involved to engage and approval processes needed before the project can test and finally apply into practice.

In Beijing situation, more difficulties currently lie in the traffic background and technical perspective, some already discussed in the previous part, and here a list of main obstacles is made to conclude:

- Complicate network structure
- Disperse distribution of traffic origin and destination in urban area
- Acquisition of reliable real-time information
- Weak micro-circulation
- Frequent signal intersection interference
- High traffic demand
- Generally high V/C rate thus room left for reorganize traffic limited
- etc.

4. Potential Lesson to learn

The two projects under two cities share similarity and also difference. As a developing city who has just alarmed of inefficient use of traffic system, and started its master piece of traffic management, there is a lot of experience to learn from various aspects. From system architecture, control concept to individual measures as a way to solve the traffic problems. It is found that most problems do not differ much from those in the Netherlands, and the general approach can be translated, however, tailor to local situation should be minded during the process.

From the Dutch side, some problems (with objective reasons) in Beijing could serve to be an alarm in the way the Dutch network in urban area is to develop. Other than that, the mix traffic feature with a large share of cyclers is the same unique feature in two countries, the experience of which can be learned from. Apart from that the experience in urban traffic management may same share some of the similarities in big cities in the Netherlands, which can jointly in search for a better solution.

7.3 Beijing policy choices and suggestions

7.3.1 SWOT analysis on Beijing INM implementation

Finally, the SWOT analysis is carried out to evaluate the Strengths, Weaknesses, Opportunities, and Threats involved for the policy choice on advanced and integrated traffic management approach. Judging all these factors in consideration, recommendation would be given on policy choices towards a better future of traffic in Beijing.

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Table 7.2: SWOT analysis on Beijing INM implementation

Strengths	Weaknesses
<ul style="list-style-type: none"> ➤ Less political and public acceptance obstacle ➤ Cost less than infrastructure development 	<ul style="list-style-type: none"> ➤ Urban network limitation ➤ Complicate network structure ➤ Weak micro-circulation ➤ Mix traffic feature

➤ Environment friendly and sustainable development	➤ High demand and V/C rate
Opportunities <ul style="list-style-type: none"> ➤ Potential improvement can be optimistically expected on network performance ➤ Basic detect and monitor system available ➤ Basic organizational structure available ➤ In advance systematic consideration of INM during initial phase of traffic management development 	Threats <ul style="list-style-type: none"> ➤ Traffic regulation and traveler response ➤ Continuous explosion of automobile ➤ Localized technology innovation ability

7.3.2 Policy recommendation for Beijing traffic management

1. Pay attention traffic management development in accordance with infrastructure development
2. Strategic plan and guide DTM/INM development, avoid unnecessary reinvestment
3. More international cooperation, introduction of advanced technology from foreign countries and learn from foreign experience
4. Accelerate technology innovation, develop measures and tools adaptive to Chinese traffic features
5. Promote cooperation between systems, sectors; government and enterprises

7.3.3 Other policy instrument

With previous discussion and simulation results, it should be concluded that traffic management is a necessary but not the solution to Beijing situation.

At the present phase, the fact that extremely high demand volume and severe congestion is in need for more urgent and strong measures. The other two "B"s, construction and demand management instruments are still of necessity. These measures mainly cover the following four aspects.

1. Improve Network Structure

As pointed out in Chapter 3, the road type structure and road usage structure in Beijing is rather not an ideal one compared to that of other developed cities. The lack of secondary road and feeder road, lots of existing dead-end road leading to a weak micro-circulation. If this question not solved, the more expressways there to exist, the higher grade road dependence likely to be induced, a more balanced traffic distribution would never be the case. This may lead to even higher pressure of high grade roads, and the accessibility kept low still.

Therefore, attempting for "utilization" as the objective, the first step in Beijing situation would be the improvement on physical network structure itself in order to make better use of existing capacity. This does not simply mean build more secondary roads, but rather the

connection and linkage of roads, search for opportunity to open up the dead roads, and make the micro-circulation more smooth.

2. Promote public transport and mode transfer

Facing the extremely high population density, thus the high travel demand, extensive and efficient public transport is of essential in such a metropolis city.

In Beijing, emphasis on promoting public transport has been set as priority for long. Extensive fast transit subway system, numerous bus lines, and the recently developed BRT system are bringing effect. However, the public transport mode choice ratio is still considered low in all modes compared to other similar scale metropolis (Weng, 2009). The system itself needs to improve on area coverage and detail design, for example the bus stop on expressway and BRT system operation. Moreover, the transfer system should be of an issue to focus, either the transit between public transport modes (subway BRT and bus line) or with other modes, especially with private automobiles with P+R system. A convenient transit between modes can attract more traffic onto public transport, especially for long distance travel where fast transit modes shows the most advantage. In this way, a well compensation between modes is likely to take effect. Besides, the ITS development in regard to public transport shows potential, the intelligent dispatching, bus real-time information release, intersection priority, etc would lead to better operation. Last but not least, policy support plays an important role in the promotion, economic lever in this sense is needed.

3. Demand management

Whatever supply provided, there is always a limitation in meeting a threshold demand level. In Beijing situation, the astonishing automobile explosion in the last decades is assumed to continue. The demand management in this case is a necessity avoiding a collapse in limited traffic resource. Measures such as already performed usage recitation according to plate license, staggering working time thus the departure time have already show effect. Further, congestion pricing based on time or region might be an issue to cope with the high demand in the future.

4. Urban development mode

Finally, from a macroscopic point of view, the city structure itself is also account for high congestion. The urban sprawl in Beijing is different from that of other western developed cities. A more prosperous city centre results from the expansion rather than weaker centralization experienced by western cities is a result of weak organization during the urbanization process (Weng, 2008). Such urban develop mode causes a longer travel route experienced by commuters. The lack of corresponding transportation system coping with such sprawl further lead to more severe traffic concerns. Therefore, a smart urban growth mode is called for, and the development of traffic system is should be accompanied by urban plan.

8. Conclusion & recommendation

The objective of the study is to conceptual design traffic management measures, and to investigate the potential of traffic management in the municipality of Beijing city in China. The objective is attained with two parts of study by answering several research question proposed in the introduction. In this chapter, the research process and the work done during the process will be first reviewed. Main findings and resulted will be presented afterwards. Based on the findings, a discussion on the result will be conducted and conclusions be derived. Finally, recommendations for policy makers and further researches are proposed.

8.1 Approach review and main research findings

In this section, the research approach review including the main findings is summarized. These findings will be used to support the answer to two main research questions in Section 9.2 to be followed.

8.1.1 Part 1: Background and Conceptual Design

The first part is conducted to get a background overview of the traffic management measures. A conceptually design measure approaches specifically adaptive to Beijing situation are performed afterwards. The findings for the sub-research questions in Chapter 2 to Chapter 4 are concluded as follows.

Research question of Chapter 2

- Why traffic management is a promising alternative to deal with increasing traffic congestion?

Traffic management is the monitoring and control of traffic based on existing infrastructure. The needs of management and the trend of traffic managing development mark it a promising alternative facing increasing traffic congestion.

The need of traffic management is explicated from two perspectives. From theoretical perspective, either the conventional fundamental diagram on link base or network based macroscopic fundamental diagram, the optimal utilization of existing infrastructure is found only when traffic demand controlled certain density (accumulation volume in macroscopic fundamental diagram) point. By means of traffic management control, the shape of diagram may be changed and the state point on diagram may be moved. In this sense, traffic management offers potential in improve traffic condition. Else, from a policy perspective, the merits and faults of three general policy instruments are compared based on the TRAIL layer framework. It is concluded that the measures attempted for utilization (traffic management) weights out building and demand management means in social and economic perspective, thus should be firstly and continuously paid attention to.

Afterwards, the traffic management development is given an overview. The trend indicates more applications of responsive measures called

“Dynamic traffic management”. Much practice has shown a positive effect with these dynamic approaches, while the fact that the locally operated measures are not yet exploited to its full potential from a network perspective calls for attention of co-operated management of measures. The practices and (initial) researches of such coordination and integration of measures have foreseen certain potential prospects, yet field test still limited.

In chapter three, the next 3 questions regarding Beijing situation are further investigated.

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Research question 1 of Chapter 3

- How traffic network is composed in Beijing situation?

Following the TRAIL layer framework, the traffic network in Beijing is elaborated for each layer components. It is found the network components in Beijing have its unique network characteristics.

- Traffic service (infrastructure supply)
 - overall distinctively grid structured road network
 - five central oriented ring express roads as urban skeleton
 - weak road type structure, low accessibility in microcirculation with lack of secondary road
- Transport service (travel demand)
 - explosive expansion of vehicle increase and such rate is expected to continue accumulating more than 5.5 million vehicles in 5 years, which would yield even more extreme pressure to the prevailing traffic service
- Economic service
 - high central oriented demand traffic
 - long distance, long travel time commute traffic
- Transport and traffic market
 - low travel speed
 - high loading factor

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Research question 2 of Chapter 3

- What typical features and flow characteristics lie in Beijing traffic?

Under the abovementioned general traffic and transport structure, the road designs at some sensitive points are different from most other metropolis cities, and thus the flow characteristics as well.

Comparing urban expressway in Beijing with general freeway, five specific features are identified:

- Mainlines on expressway are with the same layer level with parallel surface roads
- The interface ramp space linking local traffic and expressway traffic is only approximately 20 meters in length. The adjacent surface roads, to some extent, act as “virtual ramp” to store and relieve traffic. As a result, lacking of interface between expressway traffic and urban traffic cause far severe influence on both cases. (for instance, unsmooth relieve of exit traffic leads to spill back on expressway)
- To facilitate the accessibility of urban traffic, the density of on and off ramps along the express way are so high (per 500 meter on average) which results in frequent traffic lane change and flow interruption

- Paired on-off ramps with short weaving distance (100-200 meter) lead to large capacity drop caused by weaving behaviour
- Short distance trips (less than 2 kilometres) account for relatively high percentage (20%) brings about frequent flow interruption
- Public bus lines run and set bus stop along expressway, such moving bottlenecks lead to an alleviation of flow behaviour, especially on the weaving sections.

Besides, the other significant specialties include:

- The main road in Beijing is with 3-5 lanes, average road width in Beijing is 18.7 meter.
- The flow composition is characterized by highly mixed traffic, with large amount of slow moving bicycles and pedestrians
- Problematic intersections with long cycle time
- Unbalanced traffic distribution among roads types, expressway undertake 25% trip length, while low grade roads are with low utilization rate

Foreseen the need and potential of traffic management, gaining the knowledge of specialty and problem in Beijing situation, in chapter 4 methods are conceptually looked into.

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Research question of Chapter 4

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| <ul style="list-style-type: none"> • What kind of traffic management measures might be adequately applicable to Beijing situation in dealing with traffic congestion? |
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The design objectives are set to 1) ameliorate the influence of capacity decrease factors at sensible area 2) improve the flow on mainline expressway as a priority and 3) optimize the uneven distribution of traffic

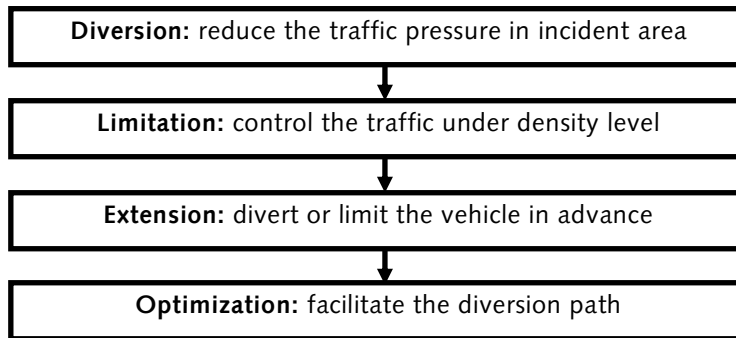
A queuing model is first applied offers the theoretical algorithm and effect of the measure approach. The basic static infrastructure adjustment measures, as the easiest means, are firstly looked into focusing on the sensitive sections of weaving section and “virtual” on and off ramp on surface roads. Lane marking in different approaches is used to separate and reorganized the flow towards a more regulated way. Measures are graphic described in details in section 4.2.1. It is theoretically expected that such minor change would better optimized the current chaos on these sections. Dynamic ramp control measures with different kinds of signal use responsive to the prevailing traffic are further designed adaptively to Beijing situation. Some combined uses of the above measures are recommended and anticipated to further make up the deficiency of individual ones. Measures on a higher level aiming to adjust the uneven distribution of traffic on arterial are suggested afterwards. Changeable intersection turning lane, tidal lane, static and dynamic route sign are the measures considered applicable and of potential.

Finally, the design of traffic management measure, especially dynamic measures, is recommended for an integrated approach under incident case. A stepwise 4-phase integration logic framework based on a function approach is raised as a guideline, shown as below.

Above all, measures at local locations should be activated to divert the traffic at the very first upstream diversion point. Apart from that, sour

measures are to integrated for restriction the demand upstream. Thirdly, the measures further be expended onto a general location level to inform the vehicles take reaction before reaching congestion link. And finally optimization measures are to assist the diverted vehicles, and decrease the indirect effect on urban traffic.

Figure 8.1: Integration logic framework



8.1.2 Part 2: Case Study and Modelling

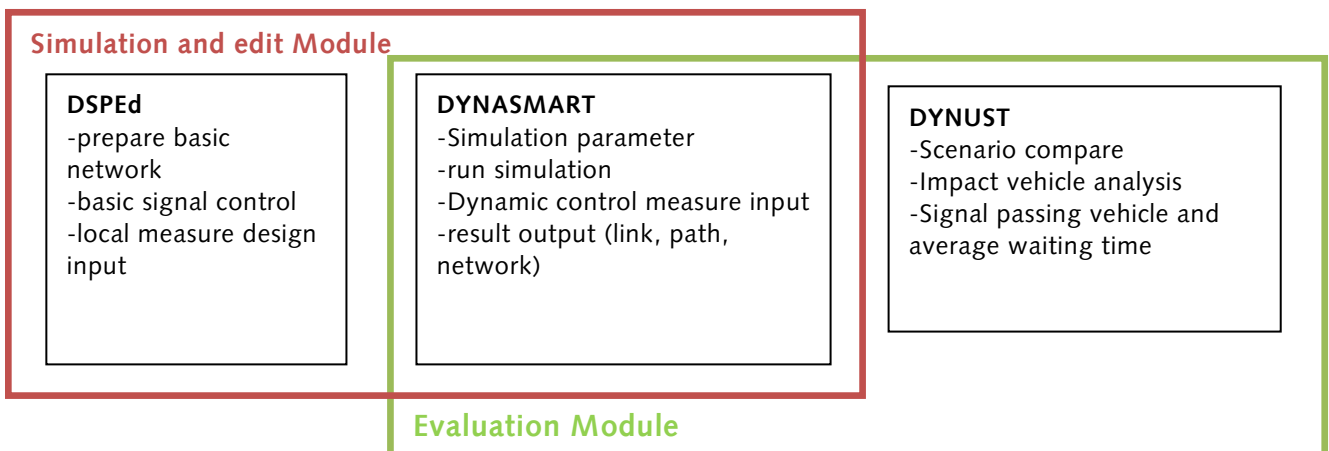
In part 2, a case study is carried out with simulation approach. The findings for the sub-research questions in Chapter 5 to Chapter 6 are answered as follows.

Research question 1 of Chapter 6

- What is the simulation tool choice and how is the validation of the tool?

The study area traffic components are investigated from functional geometry, infrastructure geometry and traffic performance aspects. Typical network feature and unique problems (focus on 3rd Ring expressway and adjacent region) can be found in the study area. Simulation tool is chosen taking consideration the network scale, detail of representation, and the ability in modelling DTM measures. Mesoscopic simulation tool DYNASMART-P, although defects and limitations found during experiment (See Appendix), did emerge as the most adequate simulation program of the candidate tools. Apart from DSP, another two assisting programs DSPEd and DYNJUST are used in the simulation study, the functions of the three tools respectively are indicated in the following figure.

Figure 8.2: Simulation Module tool choice



Under certain assumptions, the network was build up with basic infrastructure elements, initial OD demand matrix, control elements and plausible parameter settings. Following the model calibration cycle, abnormal bottlenecks are fixed and OD demand matrix is adjusted repeatedly and gradually according to the reference real network performance. However, it should be admitted the final calibrated model is still not that satisfactory in reproduce the real situation.

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Research question 2 of Chapter 6

- What is the potential effect of the designed local measures?

The specific problem areas under recurrent situation identified in the study region are assigned with measures designed in the previous part. Due to the model ability, assumptions and simplifications are made in transforming the measures into the model. Two scenarios levels are tested, first with each measure respectively implemented (marked Scenario 1.X) and followed by a scenario all local measures input at once (Scenario 2). One-shot simulation is performed under each scenario with same vehicle and route choice as reference case, thus making the result comparable in a sense.

In scenario 1.X level, critical path performances for certain measures (e.g. 3rd expressway link, tidal lane link) do show improvement in route travel time. However simulation results on a network wide performance (both scenario 1.X and scenario 2 case), indicated by average travel time, show not an improvement, instead somehow a minor counter influence, which is not expected. As far as the author is considered, based on the available result it is far too early to draw the conclusion that the measures are effective or not. Various affecting reasons may be accounted for and should be further look into:

- the assumptions made on individual measure improvement reflected by traffic model adjustment
- calibrated network not representing the local problems of well
- side effect of the designed local measures on a network level
- the indication of MOE presented by DSP
- random errors lie in simulation and measurement process
- etc.

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Research question 3 of Chapter 6

- How can DTM measures be responsively integrated for a non-recurrent situation? and what effect can be expected?

Two incidents of different severance levels are designed during the peak demand period in CBD area; the duration is 25 min and 30 min respectively. Seven scenarios are proposed integrated one-by-one following the 4-step integration approach described in Chapter 4, being diversion, limitation, extension and optimization.

In general, both case result in an obvious improvement. In the lighter incident case (case 1), the optimal scenario occurs in the 2nd phase of "Limitation" in which ramp metering restrictions of inflow are coupled with warning VMS panels activated on local location during a incident duration time. Such division and limitation lead to an improvement of 2.5%. The severer incident case 2 causes a deadlock in the upstream region in the non-control network. With implementation of integrated traffic management till the 3rd phase with "Extension" in which warning VMS is set from local location to general location, assisting

with ramp metering being activate to control the demand and optional VMS upstream provide route information in advance, a 47.6% of improvement in average travel time can be achieved. Regarding the impacted vehicles, the diverted vehicles enjoy benefit in average travel time saving when more measures are integrated. The shapes of macroscopic diagram show in two cases as well the ability of integrated approach in recovering the network performance after the incident case. However, the change of route following advice doesn't ensure a time saving compared to keep the original route, as shown by selected critical route analysis tagging a number of individual vehicles under scenario 5. Yet, it is expected, if the last phase of optimization measures applied, the diverted vehicles be likely to perform better. Overall, the effect of the proposed integration approach could be beneficial to decrease the impact of incident on the network level, and the improvement of which depends on the different steps taken for different incident situation.

8.2 Conclusions

Answering the three main research questions makes the conclusion and discussion.

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Research question of Part 1

- What measures can be of potential in dealing with the congestion problems in Beijing?

From researches and practices, traffic management has been found a valuable instrument and being a cost-benefit policy instrument. Traffic management, especially dynamic measures and the measure integration, aims to amend the capacity loss due to non-optimum utilization thus restore the potential capacity on the existing infrastructure. While measures are only valuable and efficient if adapted to local situations and specific problems. The Beijing traffic is featured by its network structure, infrastructure design, high volume mix traffic demand and already overwhelmed situation. Structure limitation and defects, the rather unregulated driving behaviours leave much room for traffic management to take effect.

Traffic management measures should first be considered on local level for sensitive road sections. To promote first the smooth traffic on the expressway link, road markings at weaving area on expressway and ramp area on the parallel surface road are focused. Adding on prevailing traffic responsive DTM methods complete the conceptual design. In this way, traffic flow on expressway link can be expected to act in a more organized way in an attempt for relieving the demand pressure on expressway. Except for amendments on expressway, potential on intersection, on roads with unbalanced directional flow, on feeder roads not yet triggering traffic can be exploited further facilitating with certain traffic management measure. As more measures are to develop and to place, measure themselves, traffic flow alike, need to be organized to play a better role, especially under non-recurrent situation. The integrated management approach provides a guideline.

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Research question of Part 2

- What effect is expected for traffic management measures in Beijing situation?

Under the current DSP model, the network effect of the proposed local traffic management measures is hard to draw the conclusion. The various reasons are mentioned above already. However, these minor problematic locations do deteriorate the traffic a lot, ought to be paid attention to with adaptive and effective measures.

As to integrated traffic management simulation case under non-recurrent situation, the result shows a rather significant improvement of situation. More traffic can be evacuated in advance before be involved into deadlock situation, and the network can be recovered to its normal status after the incident faster with route along integrated responsive and effective measures taken. While, depending on the incident influence degree, different levels of integration phases are required to generate optimize effect in terms of network performance as a whole. The decision point hereby is a crucial issue for policy makers.

Further, it is found that diversion doesn't always promise a better choice for individual vehicle. It is especially an issue in Beijing situation under weak interface buffering area, rather complicated urban traffic and weak microcirculation in handling sub-regional traffic, etc.

In a nutshell, traffic measures and their integration approach would be able to improve the traffic conditions in Beijing. Although special local issues lie in as obstacles to deal with before achieving further progress.

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Research question of Part 3

- How should traffic in Beijing be dealt with to accommodate the economic growth in the future

With the requirement fulfilment check for each traffic management phase on theoretical and organizational perspective, and then compared with the Dutch case. Beijing is found with a basic network for DTM measures been setup in the past few years. The general organization structure framework is as well in an orientation benefit for monitoring and implementing different DTM measures. Considering the strength, weaknesses, opportunities and threats towards enhancing DTM and INM development, the advanced traffic management instrument is concluded of potential under current background situation. However, at the time construction and demand management instruments are still of necessity to make deficiency on the weakness and threats points, together bring about a bright and sustainable further of Beijing traffic.

In a nutshell, the study meets the research objective. Traffic characteristic are profoundly investigated. Conceptual traffic management measure designs are performed based on local findings. The potential of traffic management instrument are evaluated and discussed from both theoretical and policy organizational approach.

8.3 Recommendations

The report proposed traffic management measures and integration approach for the municipality of Beijing. And the initial effects are evaluated through a modelling approach. Based on the process and results presented, recommendations and suggestions are proposed at the end for RMS-DVS and further research.

➤ Use Beijing as a test bed for traffic management test

Beijing, concerning its currently mass traffic situation, lots of room of improvement and potential are to be expected from traffic management. The initially developed and the government promotion on ITS development offer good motivation for launch more researches and test on traffic management and integrated management. Since it is at the initial phase of DTM development, the plan and deployment could be step ahead systematically consider in a broad network perspective. Although more technical difficulties may lie in such a complex system network, on this other side rich experience might be gained during the process and can be of treasure when the approach is to implement in other cities.

➤ Conduct cost benefit analysis

Due to the information availability, the cost and benefit ratio factors are not yet considered in the discussion. While, it is indeed an issue essential for policy makers.

➤ INM under cases other than incident

In the study, the INM measures approach are only discussed and modelled for incident case. Further approaches should be investigated also for other non-recurrent situation, for instance, measures under different weather condition. And as to a more recurrent case, a more general approach ought to call for more study on either algorithm and control methodology.

➤ Local measure tests and evaluation

In the research, the mesoscopic model used didn't achieve the evaluation of proposed local measures. To detail represent the lane change behavior and car-following behavior in the weaving section, a higher level of microscopic simulation should be further performed. For the simple measures, field test would be a more direct way to attain the effect.

➤ DYNASMART-P algorithm profound study and improvement

DYNASMART-P is found a good tool in testing various dynamic traffic management measures. And the rich interpretation of results provides ways for detail evaluation and analysis. However, some limitations are found in the simulation and indicator measurement. At this moment, the understanding of some details underlying in the software (e.g. node pass algorithm) thus the interpretation of results (e.g. link volume) is still limited. The causes of misinterpretations (e.g. queue propagation) and unrealistic limitations (e.g. the minimum speed cannot be zero) need to be amended for a more realistic model representation.

➤ Model setup and calibration

In this report, the empirical data of demand is generated originally by TransCAD and then calibrated in DYNASMART. Different algorithms in two tools further decrease the accuracy of link performance with the deduced OD. Another embedded approach with MATLAB plug-in to DynaBuilder (which is an assisting network edit tool of DYNASMART) for

OD deduction based on observed link volume in this sense a better way to investigate.

Moreover, other difficulties in calibration of the model lie in the research are caused by model limitation, information availability or calibration technique. It is advised to perform more investigation and more trial-runs on changing different traffic and behavior parameters with more reliable basic data for comparison. Thus enable a better reflection of the traffic conditions and problems in the study area in Beijing. It is whereas indeed not an easy task.

➤ Simulation process

In the report, simulation is done with assumptions further abstract the reality. For instance, only one-shot simulation with same vehicle path input is considered supposing no induced traffic, user response rate for traffic measure is only test with a given number, departure time change or travel plan change not yet take into account, mix traffic feature not captured, etc. Moreover, the representation of the measures is limited as well. These factors indeed influence the effects in practice, and should be further considered in future research.

➤ Other model choice for Chinese case study

Each modeling tool has strong points and as well limitations in itself. Some points for other model choices are suggested here.

Since DYNASMART-P is originally designed for US freeway research, and the study is under a Chinese urban situation. Freeway traffic has lots of difference compared with urban traffic as discussed already, and so is the driving behavior. A model calibrated for freeway in this sense may not inherently represent the urban traffic in China on some local traffic characteristics. A potential candidate tool could be DynaCHINA (Song, 2006) which a specially built a real-time traffic estimation and prediction system as it is described. The tool is developed featuring the local situation and driver behavior to Chinese situation. Yet, other aspects of the model need to be investigated on the task applicability.

Other improving choice could be engaged an integration with microscopic model. As described in DynusT guidebook, DynusT group recently developed tools with integration of microscopic model, convertor to VISSIM, CORSIM, VRIGEN, etc. In such way, the tool enables the transformation between microscopic model and mesoscopic model, thereby a better representation of the situation can be expected and meeting with the evaluation requirement.

➤ More profound research on measure from control algorithm and network performance prediction

The initial research has shown following a rather simple conceptual approach. While to perform a better evaluation of the measures, more profound algorithm, complex interactivity between measures and the corresponding effect under different level of integration for different cases are in need for further investigation.

➤ Research on more advanced ITS approach

Nowadays, in most developed cities in-vehicle guidance devices have already been prevalently used among drivers. Further, the information communication is no longer limited to vehicle to infrastructure, but vehicle to vehicle are considered the promising future of advanced traffic system.

Researches on those factors in integrated traffic approach should be an issue to taking into account towards the future development.

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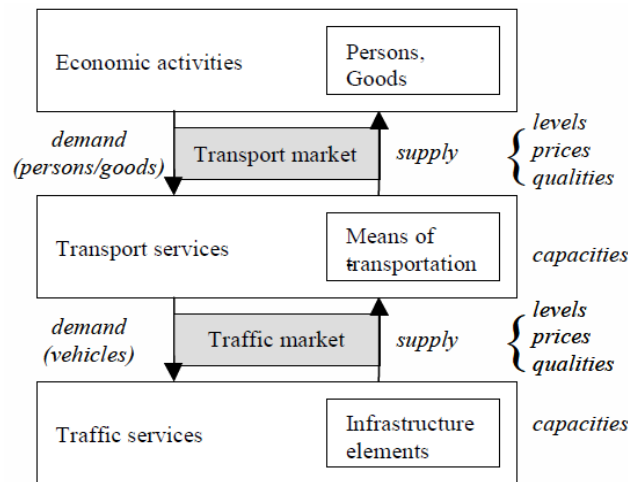
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Appendix A: TRIAL layer model

The layer model provides a framework to analyze the transportation system. The basic model (Schoemaker et al. (1999)) consists of three layers: Economic Activities, Transport Services and Traffic Services and two markets between them (as shown in Figure 5.1).

1. Transport Market between activities and transport services;
2. Traffic Market between transport services and traffic services.

Figure A.1: TRIAL transport system model



The Activity-layer is the origin of traffic, which relates to the activities performed by people, companies, and organisations. Since trucks are restricted inside urban area in Beijing during daytime, the activities discussed in this report mainly refer only to trip demands of individual residents' daily life.

The Transport Services-Layer offers transport vehicle facilities to people. This layer provides a supply pattern in mode, space and time for the transportation of people. Each shares different level of service (e.g. travel time, reliability), prices, and quality (e.g. comfort).

The Traffic Services-Layer provides the possibility for vehicle demands to make a trip. Traffic services thus consist of various traffic infrastructures and the regulations for using these infrastructures. In road traffic, the traffic services refer to roads of different priorities and functions. And for rail based public transport, tracks are regarded as infrastructure supply as well.

As to the two markets in between, both are intermediate phases to balance the demand and supply. The Transport Market yields the actual trip patterns for travellers differs in mode, time and space. The Traffic Market generates the actual trip pattern of vehicles. The actual supply is not necessarily identical to the demand pattern, indeed it is the unbalance situation in the above two markets that lead to most traffic problems.

Appendix B: Local traffic management measures

B.1 Objective of Point Traffic Management

The main objectives of local management can be described as follows:

- Control the level of throughput/total flow, prevent from capacity drop
- Minimize queuing, shockwave, spillback influence
- Improve flow operation, improve efficient capacity

Point traffic management is aiming to improve the traffic performance on the most important roads. Thus, the further local measure design will give priority flow on freeway. Freeway characteristics will be discussed first; measure approaches will then be put forward and followed by an overview of possible measures and their potential effect.

B.2 Freeway Characteristics

A freeway is a type of road designed for safer high-speed operation of motor vehicles between important destinations through the elimination of at-grade intersections.

This is accomplished by preventing access to and from adjacent properties and eliminating all cross traffic through the use of grade separations and interchanges. Because traffic never crosses at-grade, there are generally no traffic lights or stop signs. The crossing of freeways by other routes is typically achieved with grade separation either in the form of underpasses or overpasses.

Access to freeways is typically provided only at grade-separated interchanges, though lower-standard right-in/right-out access (known as ramp) can be used for direct connections to side roads. In many cases, sophisticated interchanges allow for smooth, uninterrupted transitions between intersecting freeways and busy arterial roads. However, sometimes it is necessary to exit onto a surface road to transfer from one freeway to another.

Moreover, desired speed on freeway is usually higher urban roads. Free and smooth travel is the ideal situation.

In a nut shell, the characteristics of freeway are: (1) No at-grade intersections (2) access from surface road or another freeway through ramps (interface) (3) high speed

B.3 Local Measure Review

With the above discussed traffic flow characteristic, freeway feature, control objective in consideration, the efficient use of freeway can be realized through traffic management measures specific in the following approaches:

- A. Inflow control at on ramps
- B. Smooth outflow at off ramps
- C. Facilitate weaving process at merges and weaving area
- D. Optimize the flow distribution

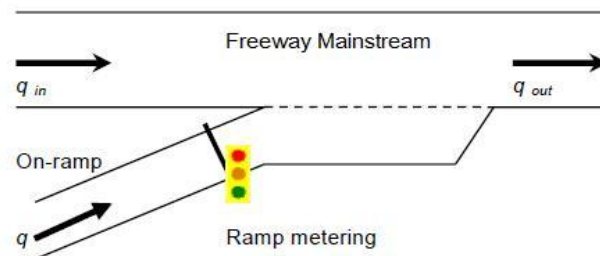
Various traffic measures have contributed to the efficient use of freeway in many countries from different perspective. And some others are designed theoretically but not yet practically tested, including some proposed in the Praktijkproef Amsterdam project. In this part, the measures will be introduced and classified in above mentioned four approaches. Noted the classification is not definitely mutual exclusive.

Objective A: Inflow control at on ramps

Measure A.1. Ramp Metering

Ramp metering is implemented via installation of traffic lights at freeway on-ramps that dynamic control the amount of traffic flow allowed onto the motorway at predetermined intervals, as shown in. The traffic lights are operated in dependence of the currently prevailing traffic conditions on both the motorway mainstream and the ramps. The dynamic control can be based on different parameters and control algorithms. For example, metering rate can be on the basis of e.g. estimated spare capacity (Dutch RWS algorithm) or on the basis of other estimated parameters (e.g. critical occupancy downstream as in ALINEA).

Figure B.1: Illustration of Ramp Metering



Effect:

1. Remain stable traffic stream on main road under critical value, prevent from capacity drop
2. Major reduction of shockwaves and spillback to upstream (blockage to off-ramp) (Middelham, 2006)
3. Discourage drivers from exiting the facility for a short distance to avoid congestion on the motorway (locally known as "rat runners") (Middelham, 2006)
4. Improve merging process and safety
5. Increasing effective capacity

Disadvantage: ramp metering may have adverse effect on the network depending on ramp storage capacity. When the flow waiting on the ramp is too high to storage, it may spill back to urban road.

Objective B: Smooth outflow at off ramps

Measure B.1. Node Geometry Adjustment

Insufficient off ramp capacity may create spill back on to freeway and lead to traffic breakdown on the main stream. The measure adapts the geometry layout by creation of an additional deceleration lane from the middle and thus widening of the junction with a lane. Moreover, the weaving behavior is separate to two location and time period, which enables more chances and less conflict in approaching the off ramp.

Figure B.2: Illustration of Node Geometry Adjustment



Effect:

1. Increase off ramp capacity, less intervene on main stream
2. Improve lane change behavior
3. Increase effective capacity

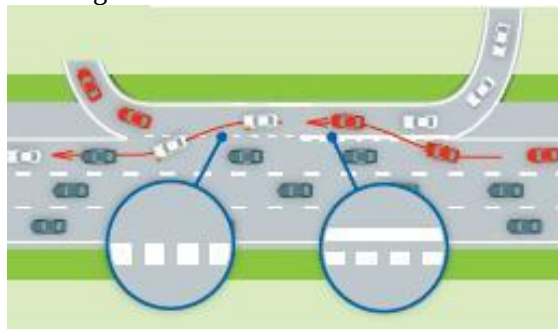
Disadvantage: the additional space is needed on the highway.

Objective C: Facilitate weaving process at merges and weaving area

Measure C.1. Weaving Section Marking

Under weaving section where on ramp and off ramp are close (meter?), the cross weaving is often the most complicated and dangerous. Such weaving may influence the effective capacity use. Adjustments are made with road markings and traffic signs to take apart two streams. As shown in Figure B.3, the original section is now divided into two sub-sections. In the first part, vehicles from on ramp are not allowed to turn left onto the main stream. If together with ramp metering installed at on ramp, the ramp intervals in between two on-ramp vehicles creates sufficient gap for vehicles oriented off ramp to safely change on to the weaving section.

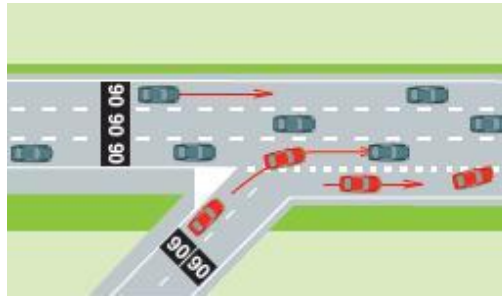
Figure B.3: Illustration of Weaving Section Adjustment



Measure C.2. Speed Regulation

Vehicles usually lower down the speed below normal free speed when there is merging behavior. Unanimous at lower speed limit in the vicinity (?) of weaving area reduce the speed variation, prevent from incident causing by sudden speed change of the predecessor. More than that, speed regulation leads to easier and safer merging behavior, creating effective capacity.

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Figure B.4: Illustration of Speed Regulation



Measure C.4. Junction Lane Control

Further, to facilitate merging processes, the right lane can be temporarily closed using dynamic traffic signal, thus reduce concentrate conflict of main stream and merging stream.

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Figure B.5: Illustration of Junction Lane Control



Measure C.5. Dynamic Lane Marking

At times of congestion the hard shoulder lane of the freeway is used, adding a plus lane. This results in the merge conflict on the shoulder lane. Dynamic marking directs traffic from the on-ramp to the hard shoulder, the merging point moves further along the freeway allowing drivers to attain a more appropriate location to merge into the traffic.

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Figure B.6: Illustration of Dynamic Marking



Objective D: Optimize the flow distribution

Measure D.1. Speed Harmonization

The dynamic speed harmonization system monitors traffic volumes and weather conditions along the freeway. If sudden disturbances occur in the traffic flow, the system modifies the speed limits accordingly, providing users with the quickest possible warning that roadway conditions are changing, thus decrease secondary incidents. Moreover, speed harmonization can further contribute by delaying the point at which flow breaks down and lower down the chances of stop-and-go conditions.

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Figure B.7: Illustration of Dynamic Speed Harmonization



Measure D.2. Rush lane :Hard Shoulder Lane/Plus Lane/Tidal Lane

Temporary additional lane use (usually hard shoulder lane) is to facilitate the higher capacity need during peak hours, most of the time this measure is deployed with lower speed limitation. The certain extra lane is opened for travel use when traffic volumes reach levels that indicate congestion is growing.

Hard Shoulder Lane: the right lane on freeway normally leaves as emergency lane.

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Figure B.8: Illustration of Hard Shoulder Lane



Plus Lane: In addition to allowing temporary use of the right shoulder, the Dutch also deploy the use of traveling on a dynamic lane on the median side of the roadway. As Figure B.9 shows, the left lane is also known as the plus lane, or a narrowed extra lane provided by reconstructing the existing roadway while keeping the hard shoulder.

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Figure B.9: Illustration of Plus Lane



Tidal Lane: the lane is built in the middle of the road with dual direction depending on congestion flow during the peak time. For example, the freeway connects the city center with suburb, the lane operates in the morning peak inbound direction toward the center and outbound in the evening.

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Figure B.10: Illustration of Tidal Lane



Disadvantage: emergency lane is occupied in case of hard shoulder lane used as rush hour lane.

Measure D.4. Route Guidance

Route guidance is provided either with static board or dynamic panels (known as DRIP-dynamic route information panel or VMS- variable message sign).

Static board informs driver with basic information of main and the preceding direction, motorists thus can have a clear view and get prepared to make reasonable weaving for their route choices.

Besides, the provision of dynamic route information on overhead sign gantries can further in response to real-time recurrent and nonrecurrent congestion. The signs provide en-route guidance information to motorists on queues, travel time, delay time, major incidents, and appropriate routes. The information can be distinguished from current and predicted.

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Figure B.11: Illustration of Route Guidance



Measure D.5. dWiSta Panel

dWista (dynamic Wegweisung mit integrierter Stauinformation) panels, the concept originated in Germany, is an integration of static and dynamic route information. The dynamic information used to supply information or alternative route choice to motorist in case of disorders. If there is no disturbance, the board remains empty.

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Figure B.12: Illustration of dWiSta Panel



Measure D.6. Unraveling

This measure involves the dynamic allocation of lanes to through traffic and local traffic with potential of substantially the weaving process. Especially in cases of non-recurrent situation, for example exhibition events, football games which may temporarily concentrate large traffic flow, the method enables better lane allocation.

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 Figure B.13: Illustration of Dynamic Speed Harmonization



The following table provides a score card on the potential benefits for the above discussed measures.

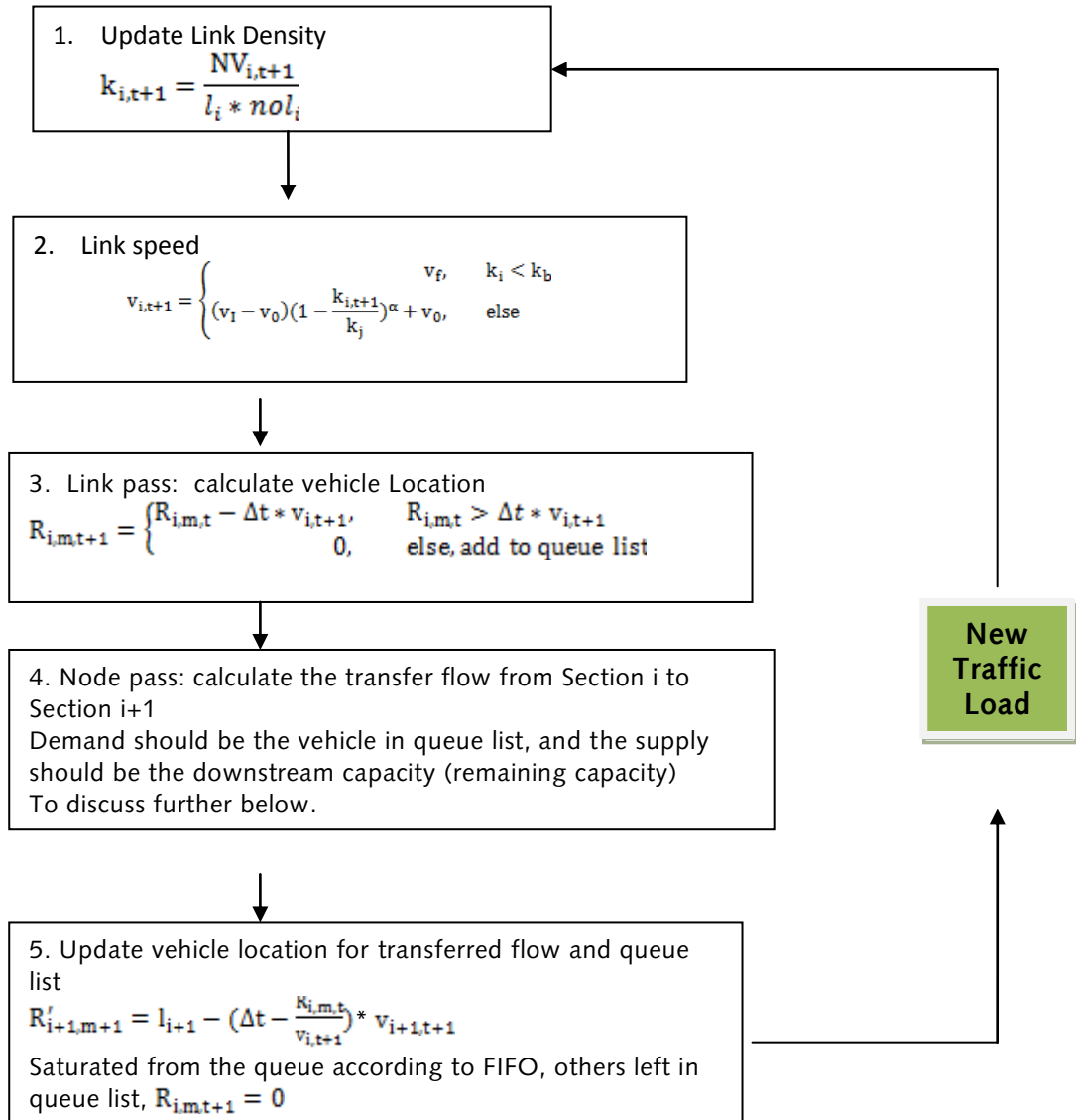
Table B.1: Measure potential benefit score card

	Measure	Potential Benefit						
		Increase throughput	Travel Speed	More uniform driver behavior	Delay onset of freeway breakdown	Increased trip reliability	Road Safety	Environment impact
A1	Ramp Metering	++			+		+	
B1	Off ramp Node Adjustment	+	+	+		+		
C1	Weaving Buffer Extension	+		+	+		+	
C2	Weaving Marking	+				+	+	
C3	Speed Regulation	+		+			+	+
C4	Junction Lane Control	++		+			+	
C5	Dynamic Lane Marking	+			+	+		
D1	Speed Harmonization	+	+	++			+	+
D2	Rush Lane	++	++			+		
D3	Route Guidance	+			+	+	+	+
D4	dWiSta Panel	+	+	+		+	+	
D5	Unravelling	+	+	+		+	+	

Appendix C: DYNASMART algorithm and experiment

The following diagram shows the described steps (Hyejung, 2009), noted in step 4, the functions are not given due to some questioning point in the model which will be discussed in the experiment below.

Figure C.1: Simulation Algorithm



Reference:

- $K_{i,t}$ =density in section I during the t time step
- $NV_{i,t}$ = number of vehicles on link during the t time step
- L_i =length of I link
- Nol_i = number of lanes of link i
- $V_{i,t}$ =mean speed in section I during the t time step
- V_f = free flow speed
- V_i =speed intercept

V_0 = minimum speed
 K_b =density breakpoint
 K_j =jam density
 α =capture the sensitivity of speed to density
 $d_{m,t}$ =distance of the vehicle can advance during the t time step
 Δt =simulation time interval
 $R_{i,m,t}$ =distance to beginning of next downstream link

● Evaluation of DYNASMART-P with experiment

As above introduced, DYNASMART-P model utilizes macroscopic speed- concentration equations, rather than the conventional flow relation how volume is measured and relate to other two basic parameters in the model, and how such a model perform from a microscopic point of view which has to do with the later local measure design. Some odd phenomenon is found in the model, to illustrate and discuss the above issues, a simple experiment is designed for check and profound understanding of the model. Three questions and related reference issues are discussed in this part.

Figure C.2: Simple test network

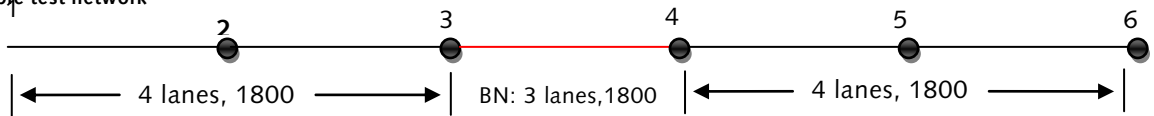


Figure C.2 depicts a simple network. It is a piece of typical highway link. The link between Node 3 and 4 represents a bottleneck segment in a four-lane freeway section. The capacity of the freeway is assumed to be 1800 vphpl. The table below shows 4 level of demand input into the model.

Table C.1: Simple test demand and performance

Demand Level	Generated Vehicle	Average TT of finished trip(min)
1	4038	4.06
2	5400	4.06
3	5937	7.8
4	6742	12.92

1. Volume

As already given in the model algorithm model framework, the measurement of density and speed are link based. While about the measurement of volume is not shown in the framework. The question of the definition of “volume” then is raised. How and where the volume is measured on each link?

Figure C.3: Volume output on bottleneck link (Node 3-4)

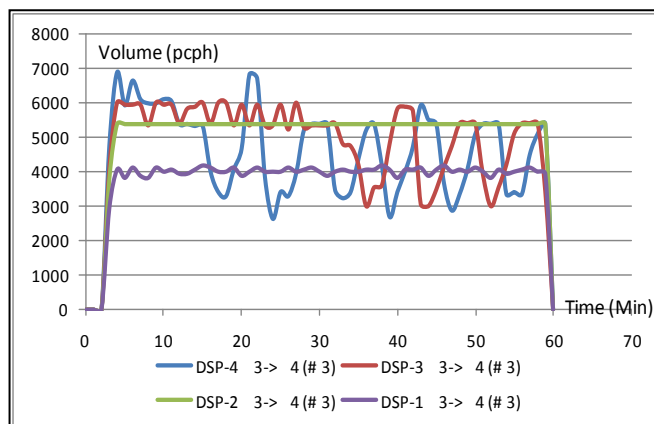
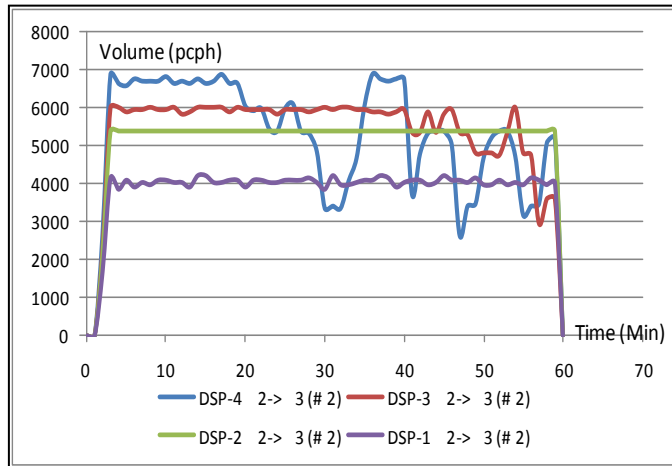


Figure C.4: Volume output on link upstream bottleneck (Node 2-3)

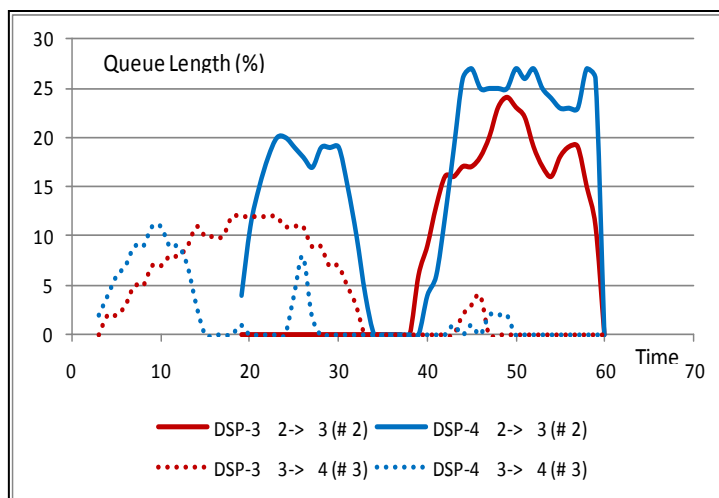


Performing the given model, the above two figure of volume measurement is gained respectively for bottleneck section (Node 3-4) and upstream link (Node 2-3) based on the simulation results. If the volume measures the outflow of a link, the flow rate of upstream link should not go beyond the downstream bottleneck capacity of 5400 pcph in total even under high demand cases. On the other hand, if the volume represents the inflow instead of out, then the exceeded capacity part of bottleneck volume in the first teens of minutes seems not plausible. Rather resembles demand flow from the upstream, instead of the actual flow on the link. In this sense, the measurement of volume is kind of confusing here.

2. Queue Propagation

The above figure depicts the percent queue length on the bottleneck link (dotted line) and corresponding upstream link (solid line) of the two high demand scenarios (the other two scenarios no obvious queue is generated). It can be observed that the queue starts first from the bottleneck link and later on propagate to the upstream link, such phenomena, however, contradict with the fact that in reality, the queue should begin at the upstream bottleneck link (Node 2) if the downstream of bottleneck link (Node 3 to 4) has no extra capacity reduction.

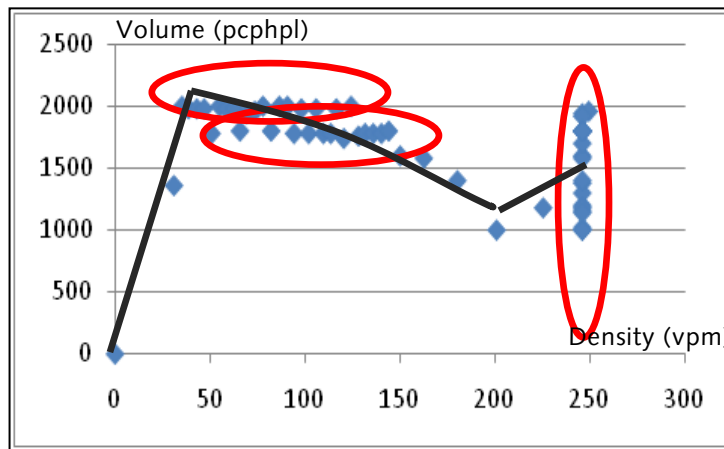
Figure C.5: Queue Length percentage



3. q-k model

Further, the q-k relationship is investigated in the experiment. Noted, same parameter settings for v-k model ($V_i=92$, $k_b=30$, $V_f=70$, $k_j=200$, $\alpha=2$, $V_0=6$) are given to all links and cases throughout the experiment. The following figure represents the q-k performance on the bottleneck link in 3rd case. The “defect” volume exceeding part has already mentioned. Besides, performance at the saturation part after the density reaches density break point and at the jam part when extreme density of 250 pcu per mile seems also odd to understand. According to the first order theory, the relation should resemble the shape of solid line. Noted the congestion speed (indicated by minimum speed) in the model cannot be set zero (otherwise vehicle would not move again once reach minimum speed, result in network deadlock), and capacity reduction phenomenon cannot be effectively modelled on a mesoscopic level. However, confusion exists on the maximum flow, there is a conflict between the direct link setting and the one v-k model represented.

Figure C.6: q-k Fundamental Diagram



The following two issues may be the essential part causing above observed three phenomena.

1. Volume measurement
2. Transfer flow constraint factor

Hyejung Hu (2009), in his Phd. essay also discussed some of the similar queue propagation phenomena in DYNASMART-P. At his point, he explains the deficiency as the lack of constraint of a flow rate capacity constraint when calculating the transfer flow, instead merely modelled using the downstream link space capacity constraint in step 4, the equation which he illustrate the current model with the following equation:

Equation 0.1

$$q_{i,t+1} = \text{Min}\{VQ_{i,t}, [k_j * l_i * \text{no}l_i - (NV_{i,t} - VO_{i,t}), k_j * l_i * \text{no}l_i]\}$$

Where,

$q_{i,t+1}$ = transfer flow from section I to section i+1 during time step t

$VQ_{i,t}$ = number of vehicles in the queue list of link I during time step t

$VO_{i,t}$ = number of vehicles exit link I during time step t

k_j = jam density

l_i = length of link i

$\text{no}l_i$ = number of lanes

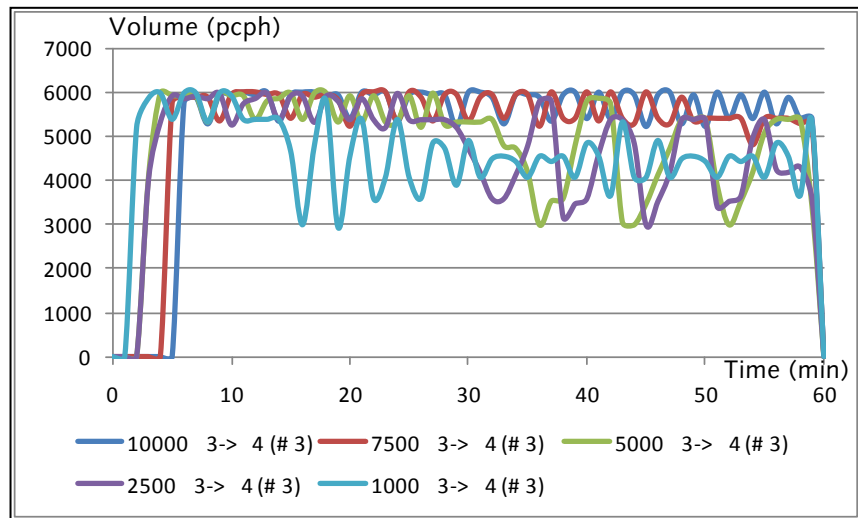
$NV_{i,t}$ =number of vehicles on link i during t time step

As shown in the above equation, the original link-based model depends only on the physical link length but no influence on the link capacity. Another two experiments are then conducted to examine his finding on the model.

a. Link Length Sensitivity

The network was reconstructed with various link length: from 1000ft to 10000ft, each section remaining same length in all cases. Same demand input is assigned (case 3 in the experiment). As shown in the volume result below, the longer the length the higher the volume, in the two longest routes, link capacity seemingly play no role indeed.

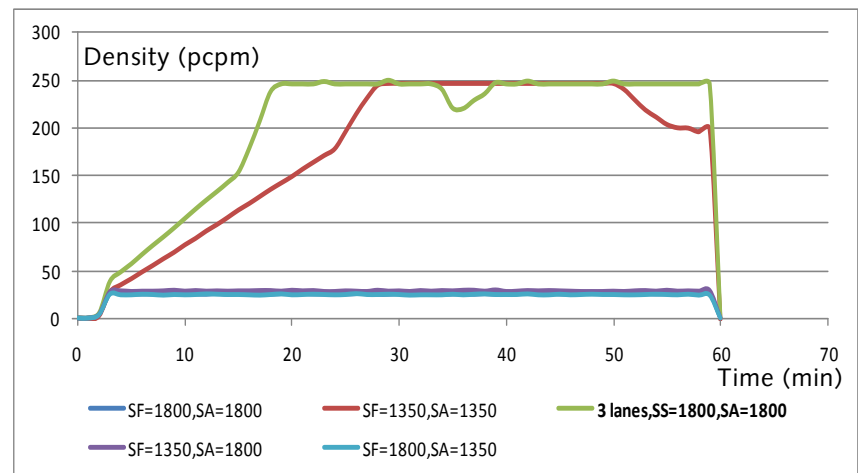
Figure C.7: Volume comparison on bottleneck link form different link length scenarios



b. Saturation flow rate (SA) and Service flow rate (SF)

Under the link attribution, service flow rate and saturation flow rate are parameters could be changed by the user. The maximum service flow rate is the maximum capacity of a given lane providing the upper limit of the flow rate through a section under any conditions. For freeway, the rate is expressed in pcphpl. The saturation flow rate is applied to downstream vehicles discharging from a queue. Modify the original model with either one of the factors or both of the factors result in the following performance. (4 lanes all through except for reference 3 lane bottleneck case, demand case 4)

Figure C.8: Density comparison with change of SA and SF



It can be observed that changing either of the two parameters would not cause a capacity reduction in this case, and the performance remain similar to the base case. While, if both parameters are changed, congestion does occur, the level of which is not as severe as the similar case with 3 lanes.

Service flow rate / Capacity: $4 * 1350 = 3 * 1800 = 5400\text{pcph}$

The finding indicated that, these two factors do constrain and influence the lane capacity volume and flow performance. However, the change is not as expected, and by far it can be hard to know the details of the influence exactly.

- **Conclusion**

The above analysis based on the first trial of the model does represent some unknown algorithm and thus, as I am consider, are “defects” of the simulation model itself. Without coding reference and other more detail literature reference, it is by far hard to make clear the issue, or to further correct the problems. And it is certainly beyond the scope of this essay work. Whereas, these finding may serve as a reference in the further application of the model and evaluation of the result, in order to have a reasonable result as far as possible.

Appendix D: DYNASmart algorithm and experiment

Scenario 6:

On the basis of scenario 5, those diverted vehicle paths are further investigated. The following paths are observed as critical OD flow of interest with the highest amount of diverted vehicles in each case.

Table 0.1: Critical diversion OD pair

incident 1			incident 2		
Origin Zone	Destination Zone	#vehicle	Origin Zone	Destination Zone	# vehicle
3	16	9	3	15	21
	17	10		16	8
	18	11		17	18
	23	29		19	23
6	1	14		23	29
	24	12		24	10
13	24	10	6	1	29
28	15	12	11	1	18
	19	11	13	16	11
29	15	10		24	16
			27	19	12
			28	1	11
				15	14
				19	19

The critical original zones are marked on the following graph. Referring to the allocation of optional and congestion warning VMS, most diverted traffic are likely to take the ramp off the original expressway and use the marked N-S and W-E surface road path marked by yellow arrows. The direct affected intersections are Node 349 and Node 58.

Figure 0.1: Indication of Scenario 6



Under the same initial path assignment, the difference on off ramp link volume and intersection average delay time is summarized in the following table.

Table 0.2: Diversion volume and intersection delay time comparison

Scenario	Off ramp 1	Intersection N58 Average Waiting time (second)		Off ramp 2	Intersection N349 Ave Waiting time(second)	
		Left	Through		Left	Through
Incident1	647	120	59	839	103	86
Scenario6	717	120	67	947	81	93
Incident1	463	129	62	544	103	85
Scenario6'	763	120	70	955	77	104

Compare the waiting time when VMS guidance is applied, the through path waiting time has obviously increased, thus adjustment phasing during the incident period should be assigned. (E.g. add 5 second more on through going direction, detailed plan ought to be tested)

Appendix E: Local measure individual test in DSP

Before the measures could be embedded into the modelled study area network, a translation of actual design to the model of these measures should be conducted. Individual model experiment are specifically designed to test the effectiveness of the measure when it is employed alone, and at the same time, these experiments are aimed to check the model ability of such changes under a mesoscopic model.

Some reasonable effect assumptions would be made on local level, and through the local measure individual test, appropriate parameters which match with the assumed condition would be later embedded to the study area model. Due to the model limitation, in the report, only a few measures which can be somehow directly realized in the model are tested.

D.1 Basic Ramp Weaving Section

Unlike in microscopic models, there is no simulation of lane-changing manoeuvres or car-following in such a mesoscopic model. Lanes themselves are not explicitly simulated, but the number of lanes specified for each link determines the effective lane miles on the link and, thus the variations of density and speed on the links (Jayakrishnan, 1994). In this sense, no weaving manoeuvre is considered in the model itself, to mimic such essential capacity decrease factor in reality, bottleneck is to manually build up.

The following experiment models a typical on-and-off ramp weaving section on ring road, the parameter is set as reference which can effectively represent somehow the current situation. The results obtained are used then as a benchmark to observe the improvement offered by the different control measures adopted.

Figure E.1: Basic local measure test Model illustration

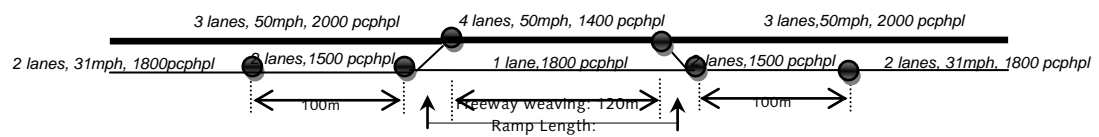
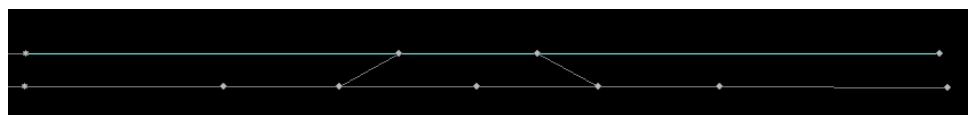


Figure E.2: Basic local measure model in DSP



In the settings, the upper figure shows number of lanes, speed limit and capacity per lane in pcu per lane per hour in order. The mimic of weaving effect can be likely realized in two ways in the model, either by changing both the saturation flow and service flow rate, or directly change the v-k model shape with modified critical parameters. However, as mentioned already, the influence of service flow rate and saturation rate is rather complex and vague in the model algorithm, so is the effect on MOE performance (especially volume performance), the

knowledge on this parameter is still limited. Here the direct change of basic link based v-k parameters would be a better and easier choice to represent the change of vehicle behaviour on the specific links.

Before setting the v-k model parameter for each link, a further analysis should be conducted on the model itself. Take dual-regime model on freeway as an example

Equation E.1

$$v_{i,t+1} = \begin{cases} v_f, & k_i < k_b \\ (v_i - v_0) \left(1 - \frac{k_{i,t+1}}{k_j}\right)^\alpha + v_0, & \text{else} \end{cases}$$

Where,

$V_{i,t}$ =mean speed in section i during the t time step

V_f = free flow speed

V_i =speed intercept

V_0 = minimum speed

K_b =density breakpoint

K_j =jam density

α =capture the sensitivity of speed to density

Among the above parameters, V_i and α are most likely to reflect vehicle behaviour on different section of roads. A sensitivity test is performed, result is shown below.

Figure E.3: V-K model under different V_i

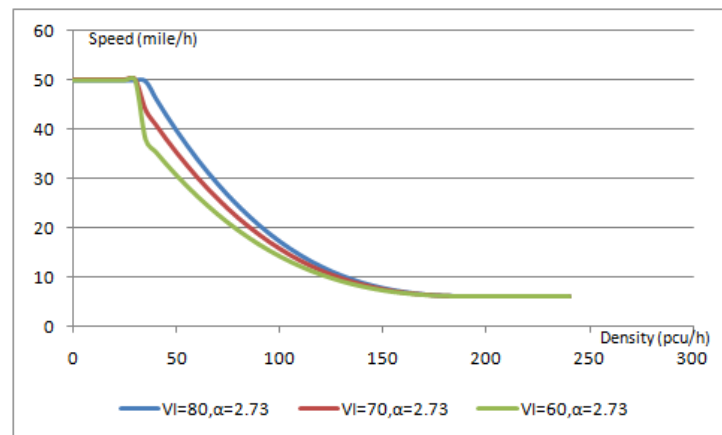
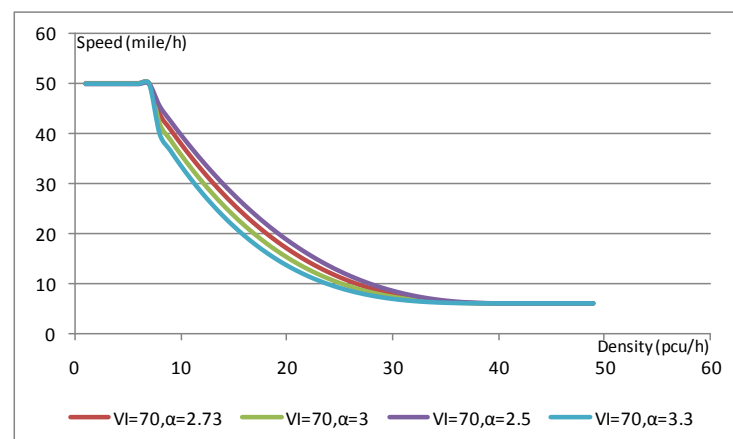


Figure E.4: V-K model under different α



It is shown that, different setting of these two parameters can both cause a change on the shape of v-k relation. The higher the speed intercept (or the lower the α), the more effective capacity could be

used during the same saturated situation. In single-regime, only α is considered.

The following table shows the model parameter settings in the reference case, for general links default value are used.

Table E.1: Traffic Model Parameter on Different type of links

Model area	Speed Intersection	α	Density Break point	Jam density	Minimum Speed
Freeway (D)	70	2.73	30	200	6
Freeway weaving(D)	70	3.3	30	200	6
Ramp(S)		1		120	10
Surface road(S)		1		120	10
Surface weaving(S)		2		120	10

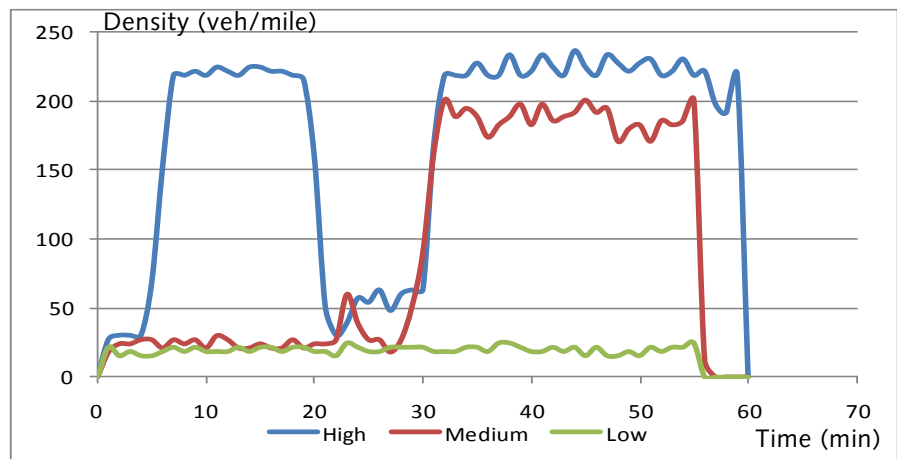
Three levels of demand are tested, named low (<bottleneck capacity), median, high (>bottleneck capacity). All vehicles finish their trip during the simulation period. The following table concludes the general performance.

Table E.2: Basic model MoE

Demand Level	Total Vehicle Input	Ave. Travel Time (second)	Freeway Ave. Speed (mph)	Arterial Ave. Speed(mph)
Low	4036	0.872	50	28.22
Median	5063	1.24	41.03	26.18
High	6066	2.85	25.42	22.90

The model reflects that the higher the demand, the severer the congestion problem would be caused. The performance of the weaving section on expressway appears to be the main source of interference on freeway speed.

Figure E.5: Density on Weaving Section

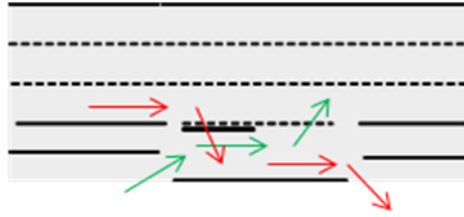


On the arterial road, the on ramp section generates long queue when demand is high, the through going surface traffic are impacted as well.

D.2 Individual Local measure in DSP

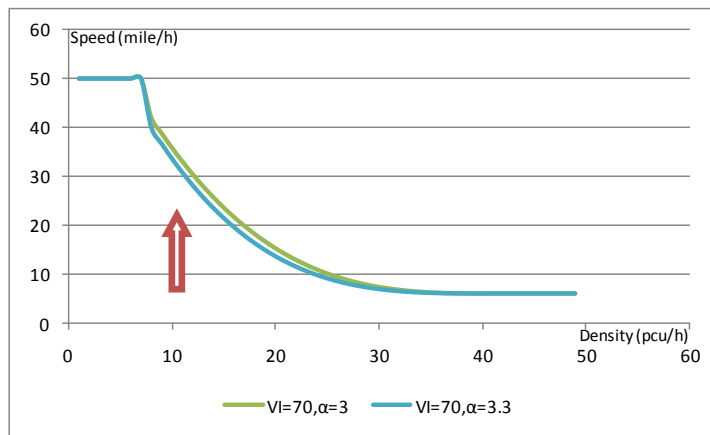
Measure 1: Mixed Weaving section

Figure E.6: Weaving Design in Reality



In Chapter 4.2.1, a mixed weaving section which aims to separate the entrance and exit flow is introduced. How such a measure would change on weaving behaviour is beyond the modelling capability of this mesoscopic model. Therefore, a capacity improvement would be set as an assumption, which can be plausibly accepted and generate effect. As discussed already, direct change of model parameter would be the choice in mimicking the improved weaving behaviour. The sensitivity parameter α assumes to decrease from 3.3 to 3.

Figure E.7: V-K model under different with lower α



Measure 2: Virtual Off-ramp

Figure E.8: Off-ramp Design in Reality

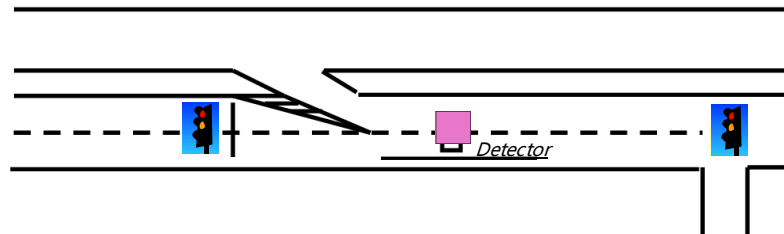
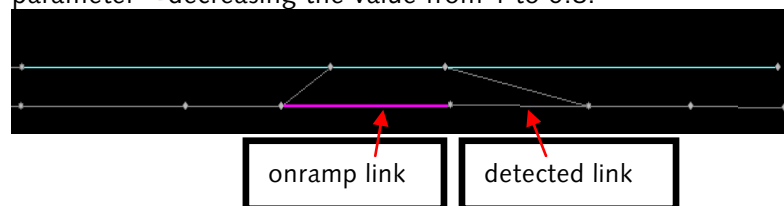


Figure shows the method design in Chapter 4.2.1. By extending the offramp, a virtual ramp is realized. However Detector function is not yet applied in the software, Here, an on ramp metering is represented as detector instead, which no exactly but somehow simulate the effect. Furthermore, no weaving maneuver can be modeled by DYNASMART, the advantage of weaving by road marking on the offramp (right allowed, left restrict) is translated into an improvement in v-k parameter α , decreasing the value from 1 to 0.8.

Figure E.9: Off-ramp Design in DSP

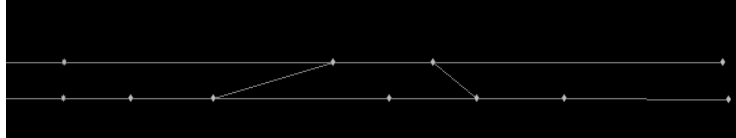


Measure 3: Virtual On-ramp

Figure E.10: On-ramp Design in Reality



Figure E.11: On-ramp Design in DSP

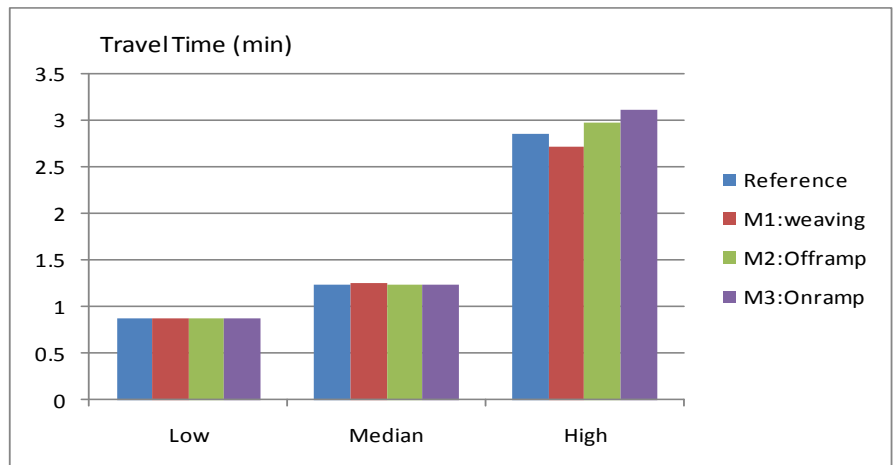


As to the virtual onramp measure, the DTA measure that intersection signal timing corresponding change to detector can be hardly realized in the current software. Therefore, only infrastructure adjustment by extending onramp link is modelled to test.

D.3 Performance Evaluation

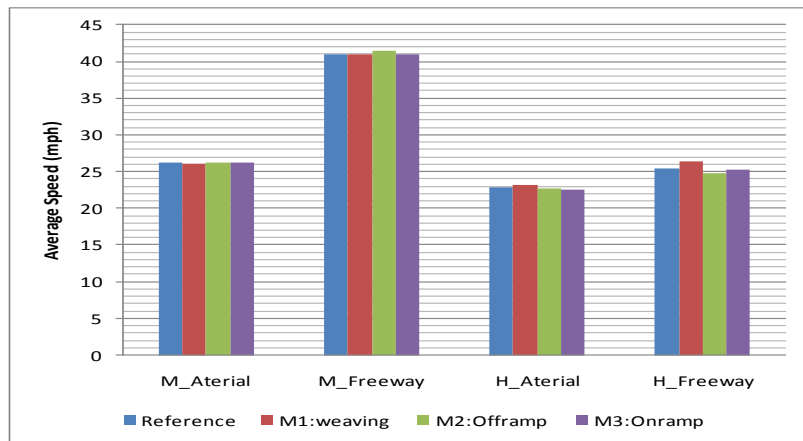
Performance of the measures is compared from several aspects. Figure 3.12 below shows first the network average travel time experienced by all vehicles. When the demand is still relatively low, the performances among measures have minor difference. Since in this case, the bottleneck area has still enough room to handle either weaving or merging traffic. When the demand becomes high, the mix weaving section redesign measure will have quite obvious effect in improving on total performance compared to the reference situation. While the infrastructure change on ramps and surface road didn't help much on the overall performance.

Figure E.12: Average Travel Time Comparison



When average speed on different road type is looked into, a minor improvement could be found under median demand case if off ramp infrastructure is adjusted. In the case of more vehicle input, weaving option stands out to be the best with improvement speed on both arterial and freeway links.

Figure E.13: Average Speed on Arterial and Freeway



Finally, detail route performance is compared under high demand situation. The cells marked yellow the routes travel time is improved, and vice versa. Obviously, only the weaving measure can enjoy time saving for vehicles on all routes, and the onramp infrastructure adjustment measure can bring advantage to only those use the on ramps. While the offramp measure, unexpected, caused a decrease in travel time for whatever route.

Table E.3: Average Travel Time on Different routes

Path Route	Reference	M1:weaving	M2:Offramp	M3:Onramp
Freeway through	3.16	2.99	3.28	3.56
Surface through	1.84	1.8	2	1.84
Onramp	1.98	1.98	2.1	1.88
Offramp	3.61	3.44	3.69	4.02

Generally speaking, only the weaving section marking under the assumed link performance model improve can generate better local network performance. The detailed design of ramp weaving space on surface road didn't produce, or cannot constantly serve to a better network performance. This may be the cause of measure itself, the level of translation the measure into the model, but may also be the mesoscopic model's limitation in realizing such detail designed measures, and the defects discussed in the last chapter, like link length, may influence the result as well.

Uncertain about the modelling result reasoning, a simplified change is thus made on the last two measures with no detail design, but indicating the potential improvement on the v-k model change (on parameter α from 2 to 1.5). The settings would be used in the network simulation in the later part.

Appendix F: Diverted vehicle travel time analysis

Table F.1: Diverted vehicle travel time compare for Incident 1 (OD 3-17)

Vehicle ID	Diverted travel time in scenario 6 (min)	Incident case travel time(min)
58311	16.31	14.31
61037	13.62	14.85
61233	15.33	14.66
62400	25.12	17.47
63093	13.98	14.91
67115	15.4	14.04
68754	18.83	15.92
71791	20.27	14.83
72185	27.07	14.51
72482	26.77	14.8
Summary	10	19.27

Table F.2: Diverted vehicle travel time compare for Incident 2 (OD 3-17)

Vehicle ID	Diverted travel time in scenario 6 (min)	Incident case travel time(min)
56650	14.35	17.75
58311	18.35	17.99
59204	15.31	19.01
60657	19.73	18.34
62400	16.05	21.32
62794	11.58	19.92
63093	11.54	19.78
63874	19.14	24.91
66914	15.78	19.52
67115	15.74	19.73
67402	15.44	20.48
68562	18.96	20.11
68754	18.76	20.28
69337	15.49	19.93
72575	20.36	18.78
73176	19.76	18.97
73463	22.66	18.67
76210	23.15	18.32
Summary	18	17.34167

Appendix G: Integrated modelling: Impacted vehicle simulation result

Table G.1: INCIDENT 1 Impacted Vehicle Analysis

	All impacted vehicle			Non-diverted impacted vehicles			Diverted Impacted Vehicles			Impacted Vehicle Volume		
	Travel Time (min)	Stop Time(min)	Travel Distance(mile)	Travel Time (min)	Stop Time(min)	Travel Distance(mile)	Travel Time (min)	Stop Time(min)	Travel Distance(mile)	Total Impacted	Diverted Vehicle	Diversion Rate
basic	11.131	2.913	4.306	11.131	2.913	4.306	-	-	-	8136	0	0%
Incident	15.832	4.025	4.307	15.832	4.025	4.307	-	-	-	8136	0	0%
1.3	14.258	3.667	4.376	13.6	3.358	4.31	27.017	9.668	5.653	8136	339	4%
2	14.305	3.686	4.392	13.541	3.32	4.319	25.873	9.233	5.499	8136	504	6%
3	13.694	3.724	4.364	13.137	3.459	4.312	24.266	9.7	5.532	8136	345	4%
4	13.925	3.698	4.362	13.24	3.344	4.309	23.932	8.874	5.143	8136	521	6%
5	13.841	3.625	4.37	13.136	3.283	4.305	23.827	8.466	5.278	8136	537	7%
6	13.552	3.557	4.347	12.941	3.229	4.309	21.939	8.066	4.869	8136	552	7%

Table G.2: INCIDENT 2 Impacted Vehicle Analysis

	All impacted vehicle			Non-diverted impacted vehicles			Diverted Impacted Vehicles			Impacted Vehicle Volume		
	Travel Time (min)	Stop Time(min)	Travel Distance(mile)	Travel Time (min)	Stop Time(min)	Travel Distance(mile)	Travel Time (min)	Stop Time(min)	Travel Distance(mile)	Total Impacted	Diverted Vehicle	Diversion Rate
basic	11.131	2.913	4.306	11.131	2.913	4.306				8136	0	0%
Incident	37.403	3.363	3.015	37.403	3.363	3.015				8136	0	0%
1.3	16.218	4.764	4.484	14.665	4.111	4.304	32.092	11.444	6.326	8136	725	9%
2	16.576	4.908	4.517	14.846	4.182	4.322	31.211	11.05	6.168	8136	860	11%
3	16.027	4.684	4.498	14.356	3.996	4.3	32.318	11.39	6.426	8136	757	9%
4	15.222	4.544	4.464	13.751	3.855	4.314	27.474	10.289	5.716	8136	827	10%
5	14.642	4.393	4.453	13.117	3.721	4.297	27.344	9.989	5.752	8136	872	11%
6	14.507	4.349	4.445	13.042	3.732	4.298	25.801	9.107	5.572	8136	934	11%
