Current Trends and Future Challenges in Congestion Management

Aditya Irfansyah
University of Münster
irfansyah@uni-muenster.de

Adam Widera
Chair of Information Systems and Supply Chain Management
University of Münster
adam.widera@ercis.uni-muenster.de

Mark Haselkorn
Human Centered Design & Engineering
University of Washington
markh@uw.edu

Bernd Hellingrath
Chair of Information Systems and Supply Chain Management
University of Münster
bernd.hellingrath@ercis.uni-muenster.de

ABSTRACT

Traffic congestion creates multidimensional impacts that require stakeholders' integration and coordination. This paper tries to close the research gaps in congestion management by examining a case study of integrated solutions of congestion measures and analyzing future challenges in congestion management based on two selected factors. The authors develop the result from the literature study and an expert interview that provides a better perspective on the case study. The study generates a new perspective on reviewing the organizational aspect of integrated congestion management measures. Secondly, it starts a discussion on future challenges in congestion management and connects the domain of future mobility with congestion theories as an independent discussion.

Keywords

Congestion Management, Traffic Incident Management, Intelligent Transportation System, Traffic Management System, Future Mobility, Social Evolution, Future Challenges.

INTRODUCTION

Transportation plays a significant role in shaping human society's advancements (McDaniel 1972). It is one of the main infrastructures that provide vital services to modern society. Physical components of transportation have long lifetimes and require a longer time to change. In fast-growing or densely populated areas, it could lead to many negative impacts; one of them is traffic congestion (Loorbach et al. 2010).

Agglomeration and rapid increase in the urban population creates a higher need for transportation infrastructure and consequently will create traffic congestion problem if they are not correctly planned. Traffic congestion itself is a serious problem that creates multidimensional impacts, including social, economic, and environmental (Li 2005). Therefore, it also needs the integration and coordination of stakeholders in the respective dimensions to solve congestion. Many large urban areas will never solve all of their congestion problems but rather need to manage it to create a reliable and predictable travel condition (ECMT 2007). In a crisis situation, congestion is a major bottleneck that could limit the successful implementation of crisis response. On the other hand, the ability to manage congestion in the normal situation might represent a higher degree of readiness and resilience towards congestion in the time of crisis.

A large number of existing studies that tried to propose or review information systems (IS) addressing congestion management (CM) measures can be found under several technological terms. Examples of those terms are Traffic Management Systems (TMS) (Al-Sakran 2015, Djahel et al. 2015 and Nellore and Hancke 2016) or Intelligent Traffic System (ITS) (Hernández et al. 2002, Chattaraj et al. 2009, Khekare and Sakhare 2013 and Roy et al.

2017). However, the majority of studies discussed the technological aspects of the measures rather than the organizational and social environment that is being served.

The topics of future mobility are considered as well-studied topics. As an example, Scopus indexed more than ten thousand documents that are related to "autonomous vehicles," one of the primary goals of future mobility. In a broader social context, the long lifetimes and inertia of transport infrastructure had led researchers or agencies to create long-term future scenarios and planning. These are ranging from a modest horizon of five to twenty years (Ubbels et al. 2000, EC 2004 and Eurofound 2008) to a very long horizon of forty to fifty years (FTAG 2001, Krail et al. 2007, WEC 2007 and Petersen et al. 2009).

A closer look at the literature on CM reveals research gaps that can be divided into two main areas. The first area is reviewing CM measures that use new technology in their organizational aspects. Even though getting the technology itself ready for implementation is the main goal, discussing the organizational environment where the technology will be implemented is also important to have a successful implementation and full benefit. Another area that lack of research is a separate analysis of the future in traffic congestion. Currently, this topic is discussed as part of the studies that analyzed the future of mobility in general or how the novel technology is better in dealing with current congestion problems. This research tries to close the gap by collecting the discussions from literature and connecting them to the fundamental theories of congestion.

To sum up, the objective of the paper is to explore the definition and aspects of congestion, current trends with an example of integrated solutions in managing congestion, and future challenges in CM caused by selected factors. We use literature studies as the main source of information. We reflect those findings by including documents from an ongoing project of Traffic Incident Management and Congestion Management (TIM-CM) by Seattle Area Joint Operations Group (SAJOG) in Seattle, Washington, USA, as a case study of proposed integrated solutions that followed the current trend of technology. This project set as an example of a possible means of multi-organizational collaboration in managing congestion.

The paper is organized into four sections. The following section sets a background by discussing the definition and aspects of congestion in transportation. In the next section, we explore the solutions in preventing or managing congestion by listing and grouping discussed measures from several studies. This is followed by a case study from an ongoing project in integrated CM as an example of the current trend. In the third section, we describe and discuss the future challenges of congestion caused by selected factors. Finally, the conclusion is presented in the last section.

RELATED WORK

Congestion in Transportation

Definition

Congestion in transportation is a complicated state. It is a situation where a physical phenomenon of vehicles impedes each other's' progression that is described subjectively related to each user's expectations (ECMT 2007). Therefore, there is no universal definition that can describe congestion objectively.

Goodwin and Dargay in ECMT (1999) defined congestion as "the impedance of vehicles impose on each other, due to the speed-flow relationship, in conditions where the use of a transport system approaches its capacity." Cambridge Systematics and Texas Transportation Institute (TTI) (2005) defined congestion as an excess of demand on a portion of a roadway at a particular time that is shown by stopped or stop-and-go traffic conditions. Similarly, VCEC (2006) defined congestion as a "situation where the demand for the use of roads is excessive, resulting in slower than normal speeds." Li (2005) put a reflection of these perspectives on congestion in figure 1 below, where two critical points of congestion are illustrated. The first one is the high concentration of demand, whereas the second one is the state where the capacity of the road is almost fully used. The figure shows that the traffic speed will decrease exponentially as the traffic flow gets closer to the maximum road capacity. There is no standard on determining the starting point of traffic congestion as it depends on subjective assessment. Therefore, the below figure only presents an estimated position of the traffic congestion.

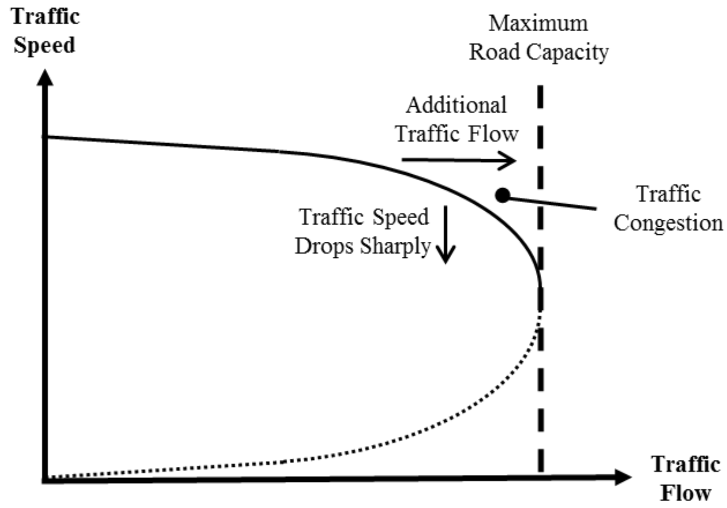

Figure 1. Speed-flow relationship and traffic congestion (Li 2005)

Framework

The discussion on congestion usually starts with how congestion happened and how to manage it. As shown in figure 2 below, Li (2005) described the causal effect between what created congestion and the measures that transport management used to manage it.

A more specific discussion on congestion causes and its categorization will be discussed in the subsection below. Meanwhile, CM measures as responses to traffic congestion will be discussed in the later chapter. The causal loop in this framework suggests that the failure in responding to congestion might fuel the causes and created more severe congestion.

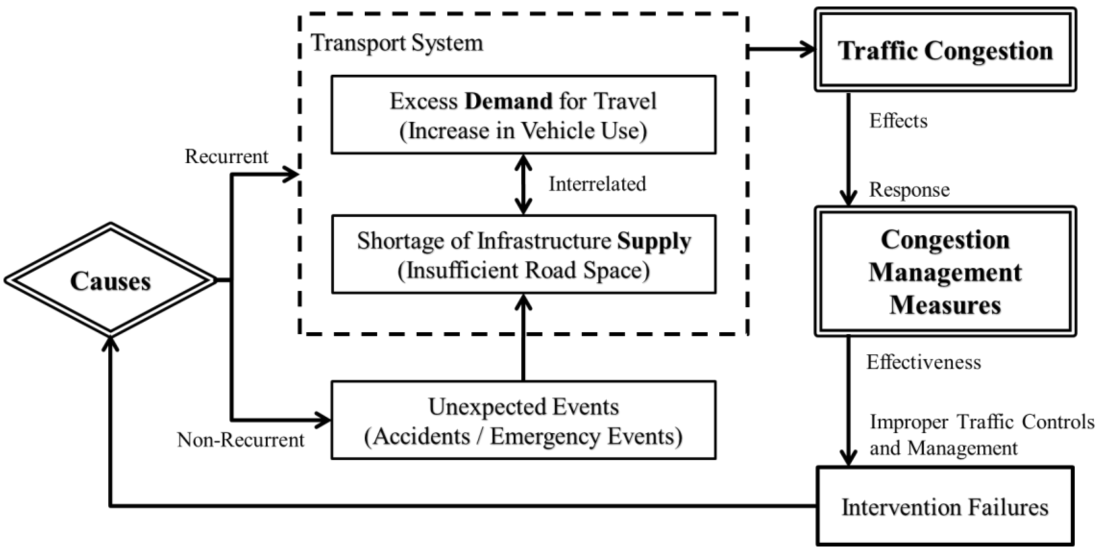

Figure 2. The Framework of Congestion (Adapted from Li (2005))

Causes

Congestion is usually classified into one of the two categories depending on its cause, whether it is recurrent or non-current congestion (ECMT 2007). As the name suggests, recurrent congestion is congestion that happens regularly or periodically on a section of the transportation system. On the other hand, non-recurrent congestion is congestion that happens randomly and unexpectedly.

There are two different views on which category attributed to an instance of congestion. Skabardonis et al. (2003) and Li (2005) use incidents, or the absence of it, as the deciding factor. Their view, as depicted in figure 2 above, is more conservative compared to ECMT (2007). ECMT (2007) included planned events, such as road works, sporting events, and any large events that attracted large masses into non-recurrent congestion. Similar to that view, Systematics and TTI (2005) put out physical bottlenecks from irregular causes in their list of seven root causes of congestion. Six causes that are listed as irregular congestions are traffic incidents, work zones, weather, traffic control devices, special events, and fluctuations in normal traffic. Following the latter perspective, Talukdar et al. (2013) did a literature review on this topic and created a diagram on the causes and their specific example, as shown in figure 3 below.

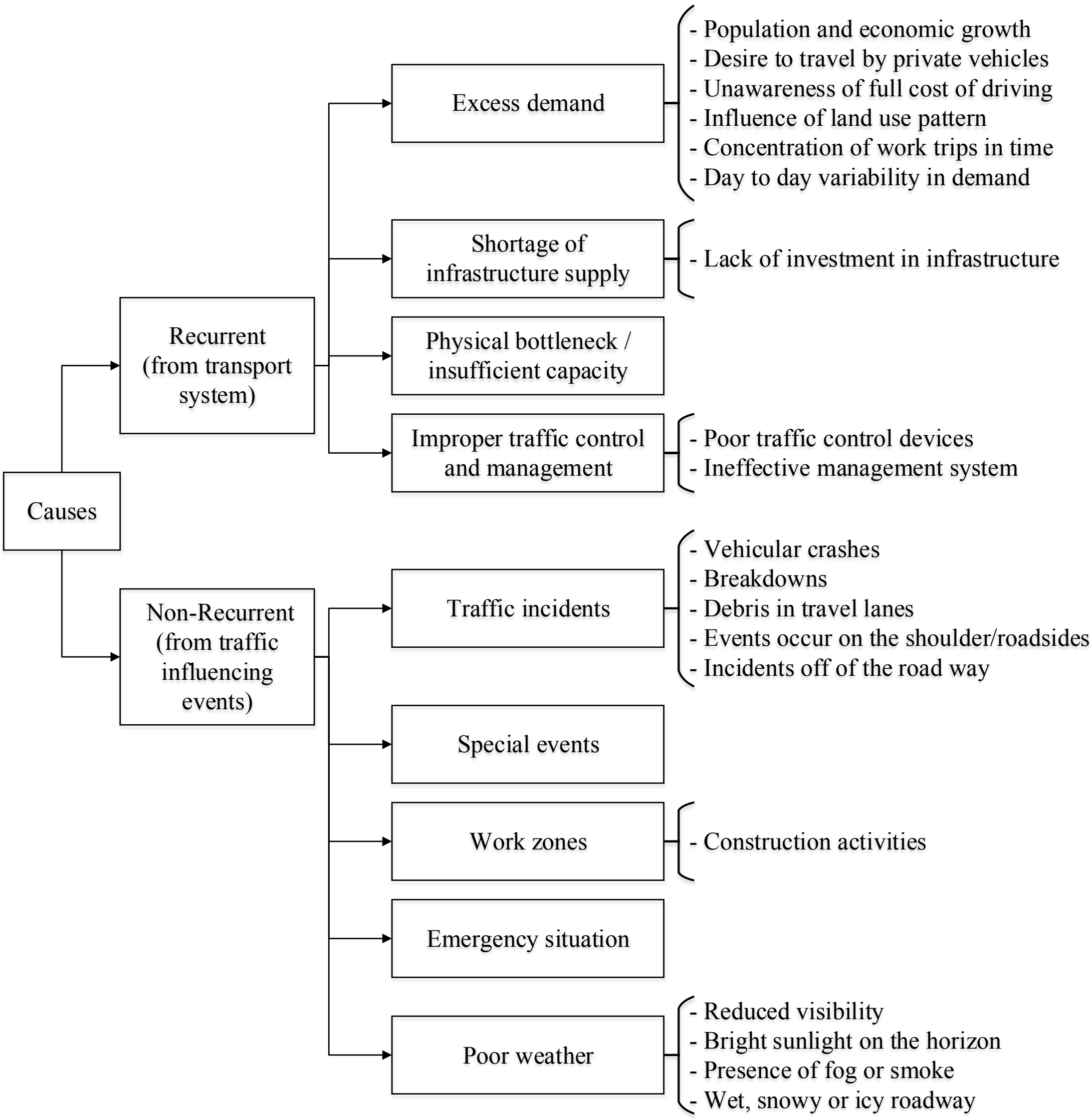

Figure 3. Causes of Traffic Congestion (Talukdar et al. 2013)

Factors

As opposed to congestion causes described in the previous section, congestion factors are deciding on how fast and severe congestion will occur. There are three categories of factors, namely micro-level factors that relate to how traffic is on the roadway, macro-level factors that relate to usage demand, and exogenous factors that relate to activity patterns (ECMT 2007). All of these factors distinguished by how they affect congestion. Factors that are labeled as congestion triggers are the factors that will immediately raise traffic congestion at the micro-level. Meanwhile, factors that are labeled as congestion drivers are the factors that contribute to the creation of congestion incidence and the severity of it. These three factors and the causality are depicted in figure 4 below.

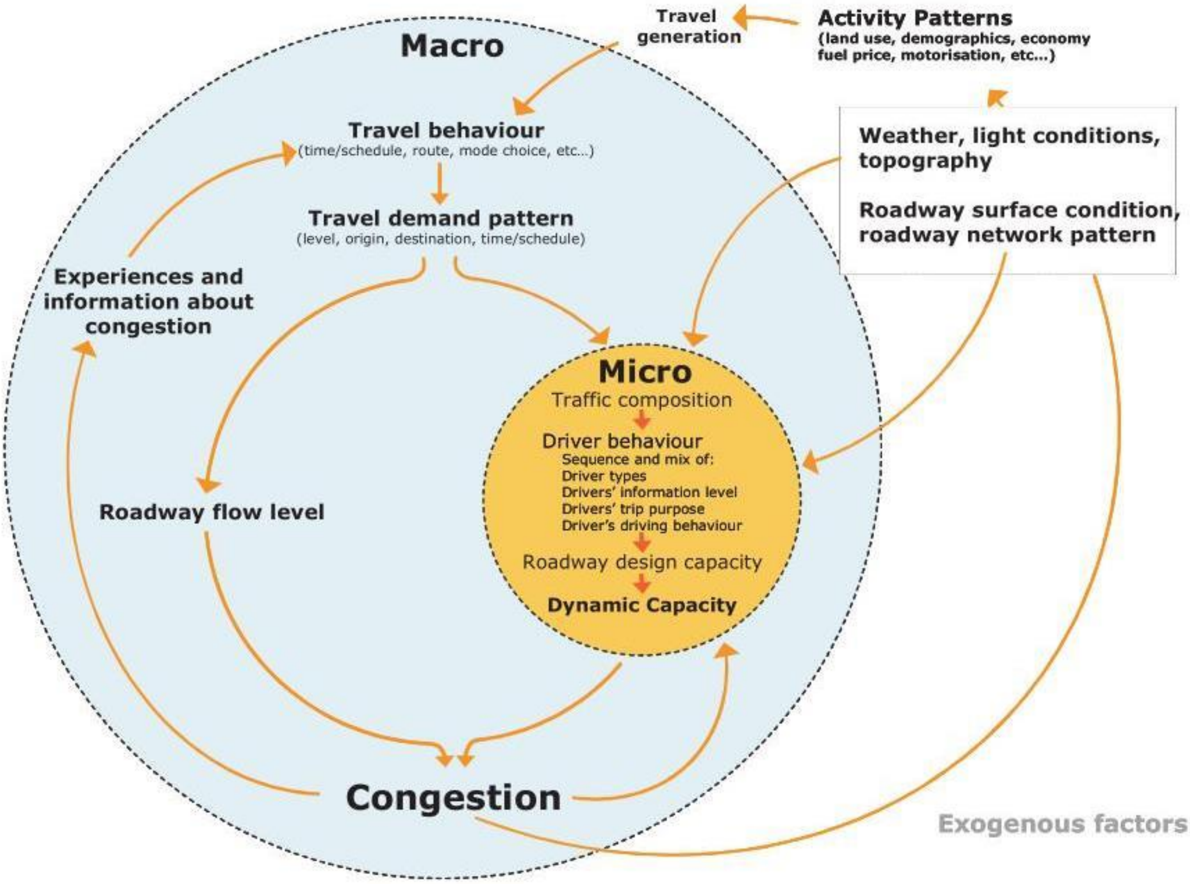

Figure 4. Factors of Congestion (Adapted by ECMT (2007) from Bovy and Hoogendoord (2000))

Congestion Management

Discussed Measures

As discussed in the previous chapter, congestion is a problem that emerges globally. It has led many works of literature from different parts of the world, such as ECMT (2007), Li (2005), Strickland and Berman (1995), Talukdar et al. (2013), and Downs (2005), to discuss management measures that can be implemented to relieve congestion. Management measures of congestion are usually divided into two basic categories, namely demand-side CM measures and supply-side CM measures. Although all the literature reviewed in this section agree with the distinction, some measures, such as pre-trip guidance/information, might fall into the different side in different literature.

Supply-side CM measures concerns with the availability of transport facilities itself and its capacities. With traffic engineering techniques, these measures aim to improve the traffic flow for all users (Li 2005). Prepared from five literature cited in this section, Table 1 below lists measures that fell into supply-side CM measures.

On the other hand, demand-side CM measures are designed to address and reduce traveler demand on transportation systems (Strickland and Berman 1995). These measures can be implemented as a regular or on a specific time to manage non-recurrent congestion or time-specific recurrent congestion. Table 2 below lists measures that fall into demand-side CM measures prepared from five literature cited in this section.

Table 1. Supply Side CM Measures

Group	Measures
Expanding transport infrastructure	• Modifying existing infrastructure • Expanding the road system • Building new infrastructure • Rail construction
Improving public transport	• Developing mass transit • Bus lanes/high occupancy vehicle lanes • Better public transport services • Extending services • Adopting fee structures • Operational improvement • Public transport information provision
Improving traffic operation	• Traffic signal improvement • Traveler information systems • Incident management plans • Road traffic information systems • Pre-trip guidance / information • Monitoring and management of traffic flows • Managing freight operation
Mobility management	• Ridesharing • Promoting bicycle and pedestrian travel • Park and ride facilities
Appropriate institutional arrangement	• Multi-level framework for planning and decision making • Better coordination between national, regional and local
The right combination of policies	• A well-developed congestion management strategy • Developing congestion indicators • Appropriate monitoring plan • Ensuring peoples participation at the policy-making process

Table 2. Demand Side CM Measures

Group	Measures
Economic measures	• Taxation/disincentives (e.g., Congestion / Cordon charges, Electronic Road Pricing (ERP), Linked based pricing system and Road tolls) • Subsidies/incentives (e.g., incentives to the user of ridesharing) • Mixed-use toll roads • Area licensing scheme • Public transportation pass program
Regulatory measures	• Access management or restricted zones • Parking control • Traffic calming • Flexible working hours • Trip ordinances
Land-use policies	• Land-use planning • Site amenities and design
Communications substitutes	• Teleconferencing • Teleshopping • Remote working

Case Study

The case study on this paper discusses the TIM-CM project that is being conducted in Seattle, Washington, USA, by a regional consortium called SAJOG (SAJOG 2017). This project aims to manage congestion in the Seattle I-5 corridor by enhancing mobility and reducing congestion impact from traffic incidents (CoSSaR 2017). The discussion in this section is based on two documents related to the project and an interview with Mark Haselkorn, the project manager of TIM-CM from the University of Washington (UW). The interview helps to clear and emphasize the critical contents of the documents.

The discussion is opened by two subsections that discussed the background of the projects, the managed workflow, the challenges that were discovered, and the solutions that are proposed to solve the challenges. Then, this research explores the organization of several aspects in this project, which are roles of multiple agencies and entities that are managed in the scope of the projects, layering of systems and services that house technologies that are implemented in the projects to help manage congestion; and implementation process.

From the list of CM measures in the previous section, this project can be attributed to some of the supply-side measures that are listed in table 3 below.

Table 3. CM Measures Addressed by TIM-CM

Group	Measures
Improving traffic operation	• Traveler information systems • Incident management plans • Road traffic information systems • Pre-trip guidance / information • Monitoring and management of traffic flows
Appropriate institutional arrangement	• Multi-level framework for planning and decision making • Better coordination between national, regional and local
The right combination of policies	• A well-developed congestion management strategy • Developing a congestion indicator • Appropriate monitoring plan

1. Integrated Workflow

In the initial phase of the project, two teams of Traffic Incident Management (TIM) and CM modeled and refined their processes to create an integrated TIM-CM workflow, as shown in figure 5 below. TIM joint operation consists of Washington State Patrol (WSP), Seattle Police Department (SPD), Incident Response Team from Washington State Department of Transportation (WSDOT), and WSP 9-1-1 dispatch. Meanwhile, CM Joint Operation consists of WSDOT Traffic Management Center (TMC), Seattle Department of Transportation (SDOT) Transportation Operations Center (TOC), SPD traffic division, and SPD 9-1-1 dispatch.

The integrated workflow is modeled in a time-based diagram starting from the moment that an incident was occurred (T_0) to the end state where the normal traffic situation can be observed (T_{10}). In managing incidents, TIM focuses on life-saving and incident clearance. Meanwhile, CM focuses on the congestion caused by the incident itself. Although TIM and CM have different focuses on the impacts of an incident, both need incident information to enable successful collaborative management in mitigating the situation (CoSSaR 2017).

This integrated TIM-CM is a core component of Integrated Corridor Management (ICM) that is implemented on the proposed Virtual Command Center (VCC). VCC will support the enhanced inter-agency coordination of ICM in managing traffic incidents (SAJOG 2017).

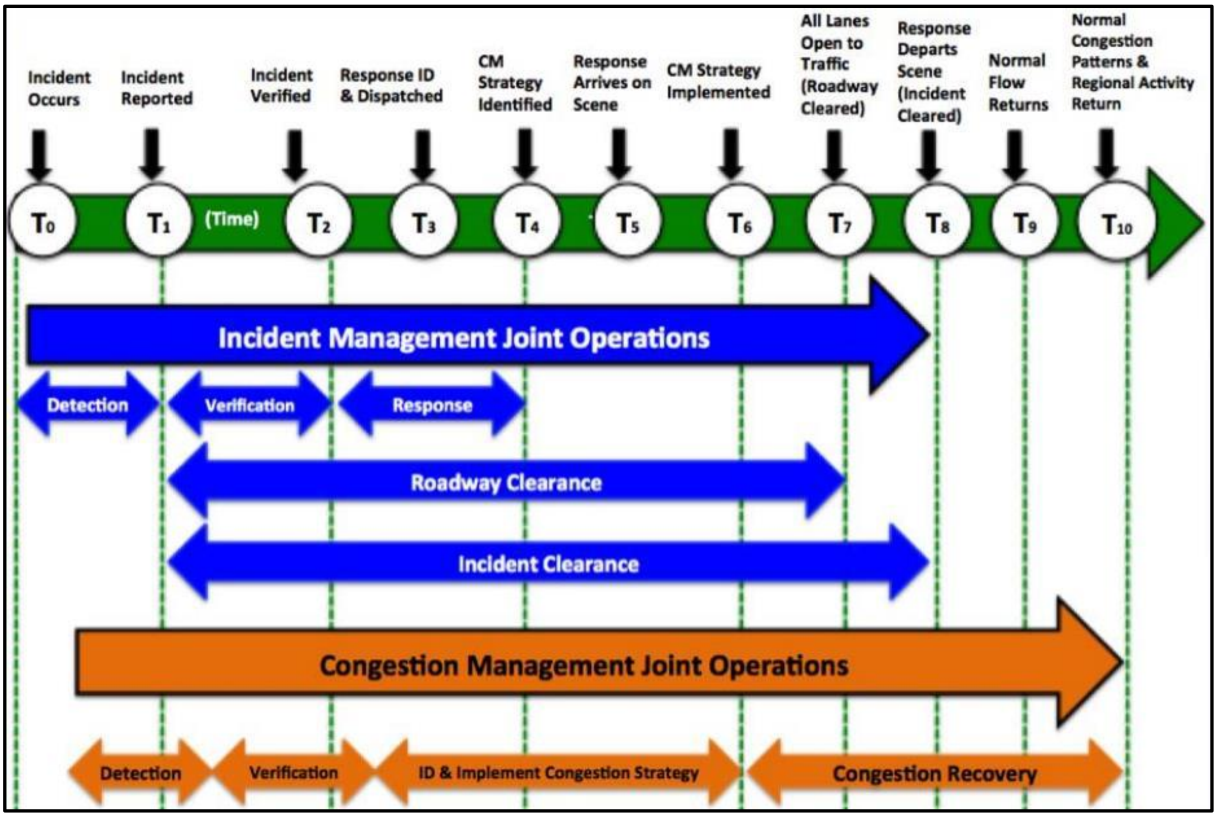

Figure 5. As-Is TIM-CM (CoSSaR 2017)

2. Challenges and Solutions

The project group found the challenges to construct a coordinated TIM-CM in both conceptual phases of analyzing the TIM-CM and technical phase of proposing the VCC. Table 4 below lists the core challenges addressed in the project with their proposed solutions.

Table 4. Challenges and Proposed Solutions in TIM-CM (Combined and adapted from CoSSaR (2017) and SAJOG (2017))

No	Challenge	Solution
1	Both TIM and CM are complex multi-agency, multi-jurisdictional activities that are interdependent yet with distinct goals, methods, and stakeholders.	Create the appropriate TIM-CM joint operations command structure.
2	CM has less defined command structures and processes than TIM, which is guided and driven by pre-existing operational protocols and structures. A CM plan, cannot currently be immediately prepared and launched because operators lack enabling information, structures, processes, and policies.	Interagency Concept of Operations (ConOps) supported by VCC
3	Overcome information-sharing barriers across TIM-CM agencies, especially between law enforcement and transportation agencies.	Cloud-based Information Sharing Environment (ISE) across TIM and CM processes that provides appropriate security and access for handling agency data.
4	Major highway incidents result in severe regional impacts beyond the incident site. Managing incident-generated congestion continues after the incident is cleared, involves a more-diverse group of stakeholders, and covers not only a greater portion of the freeway, but also the interconnected arterials and alternate modes of transportation, as well as the people, facilities and services that rely on transportation infrastructure.	Congestion Analysis Engine and pre-planned ICM options that are triggered and implemented through enhanced VCC capabilities
5	Enhance TIM-CM communication with the public, and engage commuters as stakeholders in the design of TIM-CM enhancements, as well as better communication and coordination with Metro and Sound Transit, the Port of Seattle, private transportation systems, and ride-hailing companies are needed. In addition, an effective means to coordinate with regional employers to address incident impacts on their employees is lacking.	Gather insight into current Seattle commuter behaviors and preferences and Enhanced Public and Private Sector Outreach supported by VCC capabilities
6	CM information flow occurs primarily in a one-way hub-and-spoke model with TIM stakeholders at the center. Understandably, TIM focuses almost exclusively on immediate life-saving response issues and pushes out information to CM stakeholders as a secondary priority. CM stakeholders lack access to law enforcement dispatch systems and have limited access to on-scene responders, limiting their ability to respond proactively to building congestion.	VCC that employs the ISE and shared services to increase desired information sharing without distracting from urgent responder priorities

3. Roles

This project, conducted by SAJOG, consists of nineteen entities of partners from public and private sectors that are working together. Their roles are defined in the SAJOG charter. This group is led by six central public agencies within Washington State as the core working group, namely WSDOT, SDOT, SPD, Seattle Fire Department (SFD), King County Metro Transit (KCMT), and WSP. Meanwhile, other agencies, local partners, and private partners joined SAJOG in the sub-working group (SAJOG 2017).

While the current target of the TIM-CM operation is in the city of Seattle and the surrounding regions that are passed by the I-5 corridor, the involvement of the higher State of Washington is already included in the group. Therefore, a change in public regulations or processes which potentially disrupt the operation of the project can be minimized.

4. Systems and Services

As already hinted on the proposed solutions in the previous chapter, there are several layers of systems and services to articulate the operational needs of ICM. As shown in figure 6 below, there are four layers: an enhanced information sharing architecture/environment, enhanced data sharing and shared capabilities, shared workflow applications that support the ConOps, and the VCC and user experience layer (SAJOG 2017).

Although the technological development of the systems is on the hand of partners working in the sub-working group, the agencies in the core-working group that will use the systems and the services first hand are collaboratively designing the environment themselves. This approach is necessary to minimize issues in system adoption by public agencies. In order to have a seamless connection between different systems that are currently used by different agencies, TIM-CM will be continuously connecting or replicating those systems in ICM's cloud environment.

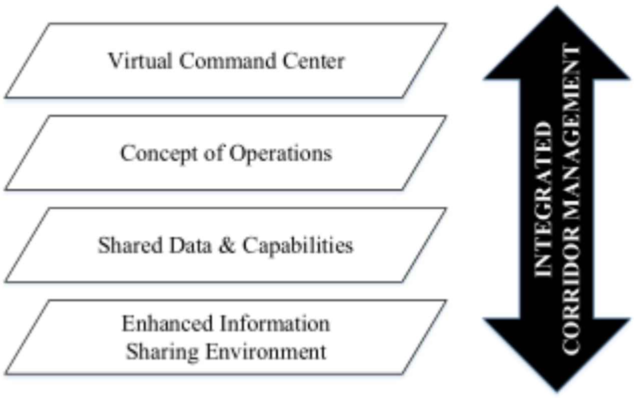

Figure 6. Layers of ICM (SAJOG 2017)

5. Deployment Methodologies

The deployment of VCC is supported by cutting-edge technology provided by the private partners in the group, such as Amazon and Microsoft. The aim is to have a scalable and flexible system to accommodate the variability of the traffic.

As shown in figure 7 below, the deployment methodologies are iterative and agile. This human-centered approach links development and deployment concurrently to allow any issues to be addressed throughout the process.

Additionally, ongoing evaluation and improvement will be conducted iteratively. Emerging and future technologies will be incorporated in the future to enrich the data and capabilities of the systems (SAJOG 2017).

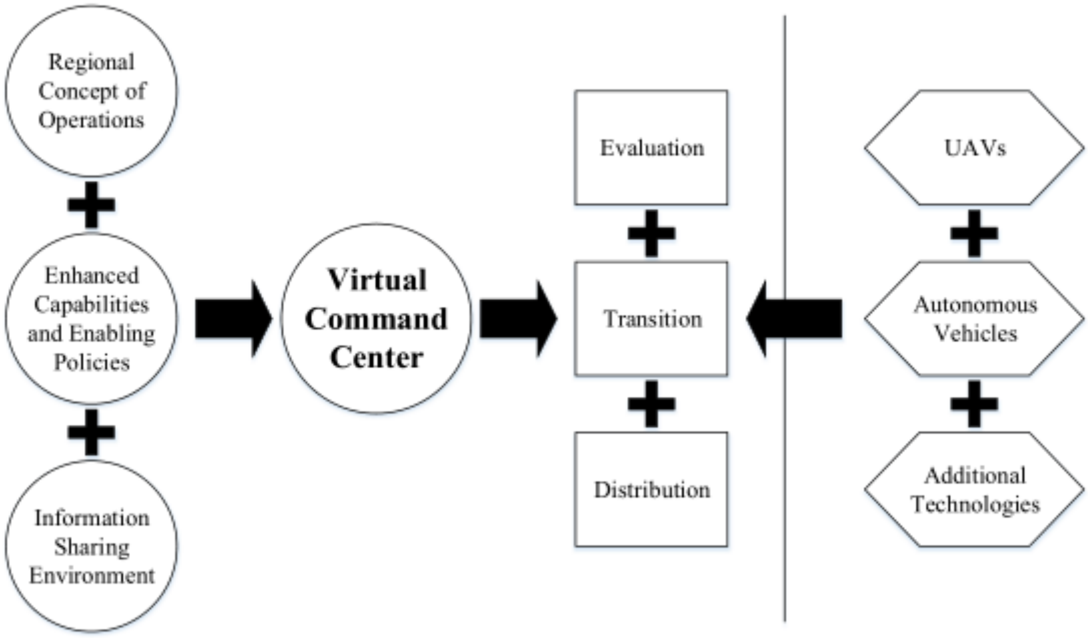

Figure 7. Deployment of a VCC for ICM (SAJOG 2017)

NEW CHALLENGES IN CONGESTION MANAGEMENT

This chapter discusses the current and future evolution in transportation under two selected themes. Then, challenges that are currently happening or will happen as the consequence of the evolution from literature are listed and connected to the aspects of congestion.

Challenges due to Mobility Technology

In addition to the continuous research from the past in improvement of the current mobility technology, such as increasing safety and reducing emission, one of the primary goal of future mobility technology is eliminating human involvement in the form of Autonomous Vehicle (AV).

By eliminating human involvement, AV promise to eliminates some traffic accidents that are caused by human error. This promise will directly reduce the non-recurrent instances of congestion. However, not all kinds of accidents can be avoided by AV. When an instance of an accident is cannot be avoided, an ethical decision by the behaviour of the AV will need to select which outcome it prefers (Bonnefon et al. 2016). This social dilemma, such as sacrificing its passenger for the greater good of saving pedestrians, adds another aspect in the breakthrough AV technology that needs to be convincing to users (Nikitas et al. 2017).

Future projection of the mobility environment is to have a machine-led environment in the form of connected AV that will not only take over the driving function from humans but also having real-time synchronization with other mobility actors (Nikitas et al. 2017). This connectivity is one additional promises on how machine-led mobility could reduce congestion problems. The multidimensional environment of the AV needs multiple stakeholders to control the real-time data supplied by the vehicle. Transportation management stakeholders consortium, such as SAJOG from the case study in the previous chapter, could be the stakeholder that is given some degree of indirect control of AV’s behaviour on the transportation network.

The transition from our current human-driven vehicles into AVs can lead to shared road space between them. This mixed traffic situation could create more problems than current full human-led or future full machine-led mobility (Nikitas et al. 2017).

The challenges discussed above are listed in table 5 below, with its connection to aspects of congestion.

Table 5. Challenges from Mobility Technology

No	Challenge	Relation to Congestion
1	Ethical decisions of AV (Bonnefon et al. 2016)	Driver behaviour (source) and Traffic incidents (cause)
2	Convincing new technologies to users (Nikitas et al. 2017)	Travel behaviour (source)
3	Better decision-making (Nikitas et al. 2017)	Travel behaviour (source) and Driver behaviour (source)
4	Mixed traffic situations (Nikitas et al. 2017)	Traffic incidents (cause) and Driver behaviour (source)

Challenges from Social Evolution

In the context of business, the development of Information and Communication Technologies (ICT) is changing how transportation infrastructure is used. One of the primary examples is that ICT enables broad remote activities and therefore reduces the number of trips needed to conduct business. Schuckmann et al. (2012) list two future projections regarding social perspective on transportation infrastructure; firstly, transportation infrastructure is still an essential service of economics but no longer a deciding factor in the competition for investment. Secondly, the infrastructure of ICT is becoming a stronger driver of economic growth compared to physical transportation infrastructure. These projections show how the business sector might change their perspective on transportation infrastructure in the future.

However, city centers with higher density mean that more users are competing for limited spaces and roads (Sanchez-Diaz and Browne 2018). Together with the advancing e-commerce, the increasing need for goods distribution results in traffic congestion as one of the externalities (Arnold et al. 2017). Several solutions to reduce traffic congestion from goods distributions to shopping centers were already proposed and implemented. Off-peak deliveries and centralized receiving stations are some of the solutions that can be deemed effective in reducing the effect (Dalla Chiara and Cheah 2017). On the other hand, e-commerce's home deliveries tighter and unpredictable schedule would further tighten traffic capacity.

In the context of urban living, Lund et al. (2017) lay several future social constructs that will affect transportation management directly or indirectly, which are:

(1) increased densification of city centers,
(2) changes in the cost of owning a car,
(3) sharing economy or service is getting more acceptance
(4) liveability is more attractive,
(5) private car is no longer a status symbol, and
(6) people are always connected (Lund et al. 2017).

The usage of personal transportation is changing from having a physical car into having access to a car in the form of Mobility as a Service (MaaS). MaaS offers an integrated public mobility solution with similar convenience to the private car (Jittrapirom et al. 2017). Simply put, getting a taxi is changing from having more public transportation attributes (such as waiting for one on the side of the street) to more private transportation (available at any time on a click).

Most challenges in implementing new social aspects in a transportation system lie in security and regulation. The success of transportation platforms such as Uber and DriveNow over conventional taxi shows that acceptance by the prospective user is not a big challenge. Furthermore, some of these platforms, such as Grab and Go-Jek, are evolving into super apps that are able to cater many aspects of the future social construct. Table 6 lists several challenges in transportation caused by the changing of the social construct that can be related to congestion from literature.

Table 6. Challenges from Social Evolution

No	Challenge	Relation to Congestion
1	Unification or integration of future services (e.g., MaaS) to existing services (Nikitas et al. 2017)	Excess demand (cause) and Travel behaviour (source)
2	Different existing policy to implement a full-scale solution (Wosskow 2014)	Travel behaviour (source)
3	Evolution of parcel distributions from B2B to the tighter and unpredictable B2C (Nemoto et al. 2001, Arnold et al. 2017)	Excess demand (cause) and Travel behaviour (source)

CONCLUSION

This research explored and discussed the following topics: the definition and aspects of congestion, the current trend with a case study of integrated solutions in managing congestion, and future challenges in CM caused by two selected factors. The case study is set as an example of how different agencies and sectors, together as the stakeholders of transportation, are able to work collaboratively to propose a joint solution that can help managing congestion.

The absence of a systematic approach in reviewing the literature is one of the limitations in this paper. ECMT (2017) was used as a source in building the initial formation of the supporting literature that were mainly obtained from Google Scholar and Scopus. Subsequently, an iterative approach that adds more queries from the collected literature was applied. A systematic methodology, such as selecting specific years of publication or journal databases, can be considered as an enhancement to this research. The next limitation is the scope of the case study, TIM-CM, as it only focuses on some parts of CM measures in managing congestion.

Further research can enhance this study by comparing several projects of IS-based CM measures similar to TIM-CM from different regions. This comparison can be used to set a standard of the systems and services organization that is required to manage similar congestion problems. Another research agenda is to conduct a literature study systematically to generate a complete and concise outlook of new challenges of future congestion. The outlook is expected to assist practitioners and academics in preventing future congestion by producing well-adapted CM measures.

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