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Traffic Congestion Effects on Supply Chains: Accounting for Behavioral Elements in Planning and Economic Impact Models

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1. Introduction

As traffic volumes and congestion grows on highways and urban roadways, freight and delivery service operators become increasingly challenged to maintain dependable and reliable schedules. This affects supply chains and truck-dependent businesses both of which are of increasing importance for both public policy and private sector operators. From the public perspective, there is a need to make investment, financing and policy decisions based on an understanding of public infrastructure needs, costs and broader economic stakes involved. From the perspective of shippers and carriers, there are the day-to-day cost implications of delay and reliability as it affects supply chain management, and well as a longer-range need to assess opportunities, risks and returns associated with location, production and distribution decisions. Both perspectives need to be recognized when considering the full range of impacts that traffic congestion can have on the economy.

A barrier to considering these two perspectives together is the gap that exists between theoretical simulation modeling and real world observations of business responses to congestion. A review of research literature reveals a number of theoretical models which posit that the generalized growth of traffic congestion adds to total transport costs for delivered products, causing firms to shift location and shipment size configurations to re-optimize net revenues. However, industry publications and business interviews reveal a wider variety of behavioral responses that depend on the type and timing of congestion delays (bottlenecks at specific ports, intermodal facilities, highways or urban road networks) and their frequency, leading to a range of operational responses as a hedge against both expected and unexpected delay. The nature of the affected parties, and the form of operational responses, can vary widely by industry. The impacts can span different supply chain configurations – including not only the movement of material and parts to producers and then to distributors, but also local distribution and delivery of finished goods to retail markets, and even local delivery of parts and repair services to businesses and households. For service-oriented economies, more sophisticated changes in operations – especially those that depend on efficiency of over-the-road operations – can be limited or entirely foreclosed by congestion. In a broad sense, all of these forms of movement have supply chain elements. And they share a common factor, which is that they are very much affected by the degree of of unpredictability and variation in delays associated with growing congestion.

While there is also a separate line of research on bottlenecks at ports, this chapter focuses on the most ubiquitous and fastest growing form of congestion delay, which is that occurring on urban roads and highways. It examines how growing traffic congestion on urban roads and highways leads to delays for the delivery of both goods and services. It also shows how impacts on urban goods delivery and worker commuting can become interrelated. It covers two forms of congestion delay: (1) *recurring daily traffic delay* that occurs as vehicle speeds are reduced and vehicle queues are increased due to a high volume/capacity ratio on specific corridors at specific times, and (2) *non-recurring traffic delay* that occurs when there are incidents such as collisions, medical emergencies and vehicle breakdowns. These two forms of congestion are related, for the same incidents that would cause little delay at off-peak times can lead to substantial traffic backups during peak commuting periods. In addition, rising traffic volume typically increases the frequency of collisions.

Here, we draw on information from business interviews and findings from prior studies conducted by the authors for North American regional organizations in Portland, OR, Vancouver, BC and Chicago, IL, which examined the business and economic implications of alternative scenarios for future growth of traffic congestion. We provide a framework for defining the different forms of impacts that urban traffic congestion can have on various types of supply chains affecting different industries. We then discusses how performance indicators and economic modeling approaches can be applied to better inform industry and transport planners of the broader consequences of growing congestion so that they can take steps to either minimize it or mitigate its adverse consequences.

2. Past research: Traffic congestion impacts on business and the economy

2.1 Transportation literature

Traffic congestion has been defined as "*a condition of traffic delay (i.e., when traffic flow is slowed below reasonable speeds) because the number of vehicles trying to use a road exceeds the design capacity of the traffic network to handle it*." (Weisbrod et al., 2001). Most transportation literature and transportation impact models treat congestion as a cost factor, comprised of time delay and operating expense (Cambridge Systematics, 2008; Short et al., 2010). However, a premium is often added in recognition of the variability aspect of congestion delay that is masked by focusing just on average delay statistics. Indeed, there is also a growing base of research on freight logistics and time-sensitive delivery which attempts to estimate the magnitude of cost premium associated with travel time reliability and the avoidance of delay for this class of travel (Rao & Grenoble, 1991; Small et al., 1997; Cohen & Southworth, 1999; Grant-Muller & Laird, 2006).

Another line of transportation research has highlighted the business productivity impact of growing traffic congestion. A US study laid out a framework for defining congestion and then viewing the ways in which it can affect regional economic competitiveness and growth by nullifying some of the agglomeration benefits (returns to scale) associated with operating a business in larger urban markets (Weisbrod et al, 2001, 2003). More recent work in the UK has shown how urban road traffic congestion, by constraining the benefits of agglomeration, can serve to reduce achievable levels of productivity in congested urban areas (Graham, 2007). However, all of these studies focused at a general level when discussing productivity and accessibility, and none of them investigated the "micro-level" mechanisms by which businesses actually see their productivity eroded by traffic congestion.

Most of the existing research literature on economic costs of urban traffic congestion is at a very broad-brush level, demonstrating that increased congestion can affect business

productivity by increasing operating costs and reducing the size of market areas served from any given business location. However, there is little information beyond that level to explain the ways in which congestion affects different types of freight movement, different types of businesses, or the ways in which businesses can respond to those conditions. These issues and their economic consequences can only be addressed through more detailed micro-level analysis of business processes and business decision-making.

2.2 Supply chain literature

A separate line of research studies on supply chain behavior have used systems dynamics models to show how traffic congestion can change the optimal decisions of producers, distributors and retailers along a supply chain. The most basic impact is that congestion delay and uncertainty increases requirements for (and hence costs of) product inventory (Disney et al., 1997; Mason-Jones et al., 1997). That, in turn, can affect supply chain behavior by encouraging shipment of smaller lot sizes to reduce cost risk (e.g., Moinzadeh et al., 1997). More recent research has extended this beyond delivery lot size, to also affect delivery frequency, spread of deliveries over time of day, and also total trips made per day (Sankaran & Wood, 2007). Surveys of corporate managers confirm that there is a range of ways in which traffic congestion can affect delivery decisions for retail (Fernie et al., 2000) and trucking industries (Golob & Regan, 2003).

Simulation modeling has also been used to show how traffic congestion can lead to fluctuations along a supply chain, as retailers adjust their inventory which in turn "reverberates upstream" via a "bullwhip" effect on inventory requirements for distributors and suppliers (Lee et al., 1997). However, since significant congestion delays may occur on a non-predictable basis, the optimal responses of affected parties may critically depend on both where they are in the supply chain and the probability of occurrence (Wilson, 2008). In the longer run, firms may also change their location decisions to minimize congestion impacts (Guenes & Konur, 2009). Yet most of these studies are based on simulations, and there has been relatively little attention to the question of how business decisions regarding location, scheduling, and deployment of vehicles and labor resources can also contribute to congestion or be used to minimize the effects of rising traffic congestion.

2.3 Public policy perspective

From a business development and economic growth perspective, concern about congestion impacts on supply chain flows is seen as introducing growing risk for maintaining regional competitiveness in a global economy. This risk is magnified as the move from push to pull supply chains depends on tight schedules and reliable performance, both of which can be threatened by flow uncertainty and variation that occurs as congestion grows (Colledge, 2007). As a result, it becomes important to recognize that decisions made by public planners of transportation facilities and business supply chain planners can interact and involve tradeoffs related to congestion. This becomes most critical as failure to adequately address congestion impacts can cause business relocation away from congested areas (see Geunes & Konur, 2009, for discussion of congestion impacts on business location).

These business cost and location issues have raised concern by various regional business organizations about the future viability of critical industries and freight transportation functions in the face of growing traffic congestion. That has led to a number of studies of the business impacts of urban traffic congestion across North America, including three by the authors of this chapter – conducted for the Gateway Council of Vancouver, Canada

(Delcan and Economic Development Research Group, 2003), Chicago Metropolis 2020 (Economic Development Research Group, 2004) and the Portland Business Council and Oregon Business Alliance (Economic Development Research Group, 2005 & 2007).
These studies are notable because they focused on business and economic impacts, emphasizing need to better understand the economic role of freight movement and its sensitivity to rising traffic congestion. In each area, local business organizations helped to bring in the perspective of senior managers who had a history of dealing with transportation and logistics operations. Many of these businesses had long experience in their region, and were able to provide valuable insight into how their operations had adapted to congestion over time. The Vancouver and Chicago studies included meetings with business organization representatives, while the Oregon study included in-person and telephone interviews with executives of the region's largest manufacturers and distributors. These experiences made it possible to better identify and classify the ways in which traffic congestion affects businesses, their locations, operating procedures and freight shipping patterns. Findings are reported in the rest of this chapter.

3. Categorizing facets and mechanisms of business impact

3.1 General model

Using a wide range of business interviews and studies of facilities and corridors with the most impact on business operations, the three studies pointed to a series of ways in which the growth of traffic congestion affects sectors of the economy. A key finding from all three studies is that the consequences of congestion go far beyond just the travel time and travel cost factors associated with delay and reliability. They also include fundamental impacts on the size of business markets, the scheduling of business processes, the deployment of personnel and vehicles, dispersion of business locations and use of intermodal connections. All of these issues bear directly on either the competitive cost of doing business in a region, or the ability to expand business operations to meet the demands of a growing region.
Although there are many ways of categorizing the impacts of congestion on businesses and the metropolitan business environment, we have defined a taxonomy for describing the ways in which congestion can lead to changes affecting businesses and their operations. It is based on seven types of congestion impact: (a) market & fleet size, (b) business & delivery schedules, (c) inventory management, (d) use of intermodal connections, (e) worker travel, (f) business relocation and (g) localized interactions with other activities. Within each of these seven classes, there are broader aspects of impact on business and the economy, as shown in Table 1. These broader impacts affect public policy insofar as they shift the locations, times and scale of business activities and traffic generation. Each of these impact classes is discussed in greater detail later in this section.
These categories of business and economic impact occurs as the logical consequence of a sequence of conditions, which are illustrated by flowchart in Figure 1. The top of the flowchart shows that congestion effects on delay and its uncertainty have four key elements: (1) they have a spatial pattern of occurrence at sites and routes with a high volume/capacity ratio, (2) they add a level of unreliability to travel times that depends on the degree of congestion and extent to which alternative routes are available, (3) they occur with severity that varies by time of day and is usually most severe during peak commuting periods, and (4) they affect different freight modes (and choices among those modes) depending on the extent to which traffic congestion occurs along truck corridors or access routes to major commercial and industrial clusters, seaports, airports or intermodal rail terminals.

Class of Congestion Impact	Implication for Business and the Economy
Market and Fleet Size	delivery area, market scale, fleet size/type, delivery & reliability cost, assignment flexibility
Business & Delivery Schedules	delivery time shifts, truck dispatch, backhaul operations, relief drivers, operating schedules
Intermodal Connections	access to truck/rail/air/sea interchange terminals
Business Inventory and Operations Management	inventory requirements, stocking costs, inventory management/control, cross-docking opportunities
Worker Travel	worker time/expense; worker schedule reliability, service delivery cost
Business Relocation	distribution from smaller, more dispersed locations, consolidation of production sites
Externalities: Interactions with Other Activities	land use & development shifts, costs passed on to workers and customers

Table 1. Seven Classes of Congestion Impact and Potential Business Responses

Those four elements of congestion affect different aspects of business decision-making, as shown in Figure 1. We can view the business decision process as a sequence moving from fundamental long-term decisions to more flexible short-term decisions, as indicated by arrows moving from left to right on the flowchart. One of the most significant long-term decisions made by a firm is the location decision, followed by the scale of operations at that location. Both can involve significant capital investment. Those decisions, in turn, influence business requirements for workers, logistics of incoming materials and production/ inventory technologies. Outputs and final product distribution depends on the efficiency of the ground transport network (including connections to air and sea ports) to serve existing and future markets.

Of course, short-term adjustments to minimize costs of congestion are typically made in an opposite sequence, starting from the easiest to change, shown on the right side of the flowchart -- shifts in fleet deployment, shipment size and delivery schedules. When necessary, businesses can also move to more capital intensive decisions on the left half of the sequence, such as business size, location and operating model. Ultimately, all of these business location and operation decisions can affect broader changes in land use patterns, transportation demand and public infrastructure performance.

The rest of this section provides a more detailed discussion of each of the seven types of congestion impact, and the ways that these congestion effects influence business decisions and the resulting effects on broader regional development. These discussions draw from findings and examples that emerged from the previously-cited regional business studies, as well as research studies by other authors (as cited in Section 2.3). Examples are provided primarily from a detailed set of interviews with corporate executives that were conducted as part of the Oregon study. The overall objective here is not to quantify or measure the severity of these impact elements, but rather to illustrate the wide breadth of different forms

of impact that can occur, and the ways in which they interact with other elements of business decisions and public policy.

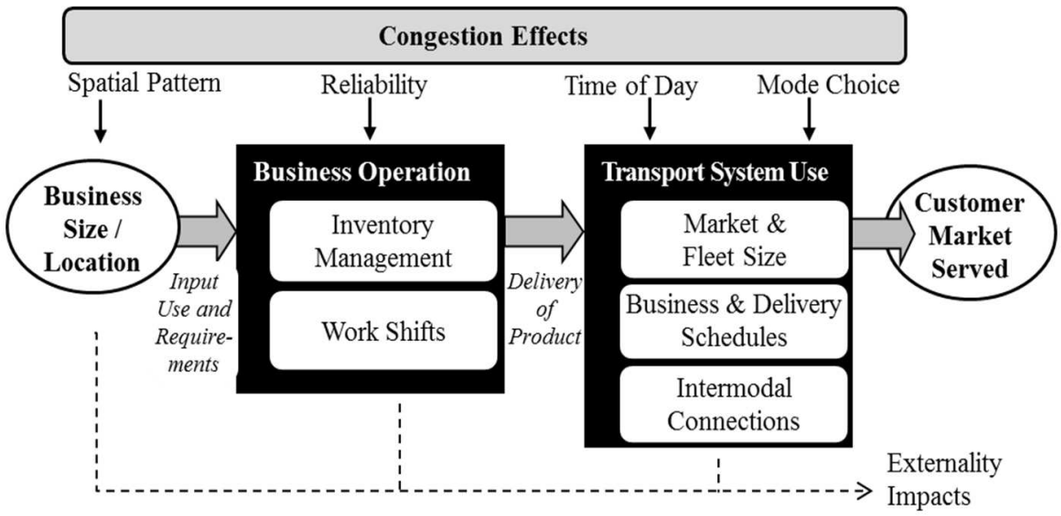

Fig. 1. Conceptual Model of Processes by Which Traffic Congestion Leads to Impacts on Business Activity

3.2 Market & fleet size

Two fundamental decisions for any delivery operation are the market area to be served and the vehicle fleet to serve it. Growth of traffic congestion can affect those decisions and lead to changes in a variety of related cost elements. These impacts can be viewed in terms of: (a) delivery area definition, (b) scale of markets served and (c) fleet size and type of vehicles used. These decisions also affect (d) delivery unit cost, (e) reliability cost and (f) route/ assignment flexibility.

Delivery Area Served - With rising congestion, the time it takes for a truck to get from the warehouse to the first stop/delivery (stem time) has increased in most urbanized areas. In the Portland region, some businesses estimate that it has increased by as much as 50% in the past 8 years. As the peak hour spreads beyond one or two hours, cross-region movements to subsequent delivery stops become more difficult than they have been in the past. In effect, congestion shrinks the delivery area that any one driver and vehicle can serve. This means that there is a need to have more vehicles on the road (to maintain and grow distribution and trucking markets), and routes need to be changed more often. Beyond adding direct driver and vehicle costs, these changes bring added costs for continuing adjustments in scheduling drivers and deliveries.

Market Scale - In addition to increasing the cost of product and service delivery within a core region, the cumulative effects of congestion on the entire distribution network effectively shrinks the boundaries of the area that can be served from any one warehouse or manufacturing plant. This affects the size and dispersion of these facilities, as addressed in the later discussions of business operations (Section 3.5) and business location issues (Section 3.7).

Fleet Size and Vehicle Type - Increasing congestion can mean that it is not possible to make as many deliveries within a shift or delivery run as had been possible in the past. (This was

also noted in prior work by Sankaran & Wood, 2007.) The problem is multiplied for distributors of retail products in growing regions, where there are continuing increases in the number of stores to be served. Together, both congestion growth and market growth call for more inventory as well as more drivers and vehicles. The reduction in driver productivity increases costs to distributors, and it adds more trucks and delivery vans to the mix of vehicles already on a region's roads. For many types of product and service deliveries, an increasing number of firms are thus responding to congestion delays by adding smaller and more numerous delivery vehicles and also relocating warehousing and distribution centers to reduce stem times. That solution also provides both flexibility and an enhanced ability to provide rapid delivery of urgent or missed orders. However, it also adds vehicle cost and increases the volume of truck traffic on roads.

Delivery Costs – Congestion directly affects the cost of deploying crews for delivery of products and services. These effects can include labor and fuel costs due to longer truck operating hours, fewer deliveries or completed jobs per crew trip, and/or greater reliance on added truck and van trips when limits are reached on allowable daily hours of service (for individual drivers).

Reliability Costs - Reliable delivery schedules allow for efficient "just-in-time" processing, but delays effectively undo those opportunities for business efficiency. As a result, Oregon businesses with chronic delivery problems reported that they have had to increase inventories by as much as 5% to 8% compared to 5 years ago (Economic Development Research Group, 2007). Studies in other regions have put the figure in the 8% to 11% range (Netherlands survey in Bozuwa & Hoen, 2005), while others have noted it can be as high as 15% (UK study cited in McKinnon, 1999). Of course, wide differences in reliability costs will always occur, as such costs vary by location (reflecting severity of local congestion) and by industry (reflecting sensitivity to congestion delays at peak times).

Flexibility for Route/Shipment Assignment - Many firms are involved in on-going review of routings and have developed methods for "on-the-fly" rerouting or regular adjustment of departure times, loading and preparation of loads for delivery and other measures. However, some firms – particularly those with large, heavy loads moving between established manufacturing operations, do not have the flexibility to make these adjustments. Slower turn-around between plants requires either adding more vehicles to sustain production, adding shifts, or cutbacks in production schedules. Past surveys of trucking companies have confirmed the interest in enhanced routing and scheduling which becomes particularly critical as congestion grows (Golob & Regan, 2003).

3.3 Business & delivery schedules

In theory, businesses can minimize congestion costs by rescheduling deliveries to avoid peak traffic periods, which are principally morning and evening commuting times. However, in practice, various factors can either limit the ability of delivery operations to adjust schedules or add to adjustment costs. These limitations and costs can be viewed in terms of implications associated with changing: (a) afternoon deliveries, (b) shift starts and relief drivers, (c) morning deliveries, (d) backhaul operations, (e) truck dispatch schedules, and (f) business operating schedules.

Reduced Afternoon Deliveries – The growth of PM peak traffic congestion has reduced, and in many cases even eliminated, late afternoon stock/merchandise deliveries in some larger urban areas. It has pushed starting times into the early morning hours for some businesses involved in transportation and distribution. In large cities, a growing number of

businesses (irrespective of sector), now face restricted operations after 3 PM. Many transportation and warehousing operations have adjusted scheduling so that most vehicles return to the warehouses or distribution centers by the early afternoon. Most consignees have been able to accommodate these early shipping deadlines into their operations. However, if afternoon congestion trends continue, with the implied shortening of the time window for final outbound shipments, manufacturing and transportation operations could find it difficult to maintain current levels of productivity and current final outbound shipment schedules.

Shift Starts and Relief Drivers – For many transportation and warehousing industries, first shift start times for drivers have been moved to very early in the day – often 4 AM to 6 AM. This is because afternoon congestion has become a problem for firms with scheduled deliveries or routes, and most firms want to avoid overtime pay or violating regulations on truck driving hours. (in the US, hours of service requirements are currently under federal review). Some firms have begun to rely on "rescue drivers" to avoid those situations. In addition, evening swing shifts have been instituted in many warehousing and distribution businesses so that returning trailers can be loaded for the next mornings deliveries.

Increased Morning Deliveries - The shift towards very early morning (4-6 AM) deliveries in the retail sector of some larger cities means that larger stores are sometimes now required to have staff loading and stocking in the very morning (2-3 AM) or during swing shifts. Most retailers and produce consignees are reluctant to allow "drop shipments," especially of perishables or high-value retail merchandize. As a result, some retail businesses need to bring staff in earlier in the morning to receive deliveries, adding to business operating cost and imposing burdens of adjustment on affected workers. Some retailers must also accommodate "push" shipments from manufacturers in situations where improved logistics and manufacturing efficiencies have now made order fulfillment a matter of days.

Backhaul Operations - Backhaul efficiencies are important to many transportation and logistics operations as the ability to support efficient backhauls reduces the number of vehicles, number of operators and time required for normal operations by these firms. Backhaul opportunities and efficiencies are more significantly impacted by afternoon congestion than outbound shipments. Thus, the vulnerability of backhauls to afternoon traffic congestion is also greater. Firms that developed sophisticated routing and logistics management practices integrating backhaul management into their processes have more recently noted increased overtime and the need for "rescue drivers" to conform to the new "hours of operation" requirements.

Backhauls are of growing importance in a number of businesses – not just those involved in commercial distribution and retailing operations. Many businesses with their own fleets that are not in these sectors depend on backhaul operations to support various business activities. In Oregon, for example, Providence Health Systems [PHS] generates significant amounts of recycled materials (surgical and non-surgical), plastics and paper. Collection and recycling of these wastes and potentially toxic materials has depended on backhaul for efficient recovery of recyclables. Congestion during backhaul operations is becoming a growing problem because it limits loading times for the evening delivery cycle. As a result, smaller vehicles in greater numbers are now being used to service evening deliveries to the 29 clinics and hospitals served by PHS. Yet impacts of this type, which put more vehicles on roads, are most often not considered in public decisions about infrastructure investment.

Truck Dispatch Schedules - Truck dispatch times are limited by the ability to prepare and load trailers from the time they arrive in the afternoon to the time that they are scheduled to

depart in the early morning. The ability of warehouse operations to assemble loads and stage them for loading in the evening shifts, reposition trailers based on available dock/door capacity and stage trailers for departure is constrained by available time between drop off and whenever trailers with backhaul materials are ready. Increasing the number of trailers on-site is limited by available space and adds costs for redundant equipment. Very early dispatch times also are limited by the ability of businesses to receive goods in early morning hours (e.g., stores in urban areas or manufacturing operations).

Business Operating Schedules – As urban traffic volumes grow, time periods of congestion and associated delay also widen. Delivery operations that start by avoiding the afternoon peak may then move to start shifts earlier in the morning. However, as morning traffic volumes continues to grow in what were traditionally considered shoulder time periods later in the day, available highway capacity limitations start to increasingly affect the operations of businesses that have become dependent on efficiencies of operating in this time period. Ultimately, businesses can experience a shrinking "window of opportunity" to adjust activity schedules and avoid congestion. The combination of avoiding evening peak, experiencing a saturated morning peak and shoulder times that are also operating at capacity can together leave no other feasible time periods to operate and thus result in more serious impacts on the overall scale and cost of business operations.

3.4 Intermodal connections

The impact of congestion delays can be magnified for intermodal freight movements that depend on truck deliveries meeting scheduled connections at: (a) intermodal rail terminals, (b) air cargo terminals or (c) marine terminals. The resulting impacts tend to be concentrated on specific classes of cargo and business locations.

Access to Intermodal Rail Yards and Associated Industrial Park Facilities - Rail yards and rail-dependent industrial parks typically depend on having good truck access. Increasing congestion in core urban areas is a growing concern, as it leads to increasing operating costs and reduced productivity for businesses located at affected industrial parks. This can occur in two ways. First, missed trans-loading schedules add to the time of trucking and unloading crews, and require trucking firms to reschedule their operations. These costs are not immediately recoverable and must be internalized in most businesses as charge-back to missed rail deliveries is not possible. Second, use of broadened pickup and delivery schedules to avoid missed deliveries also carries a cost of vehicle and driver time.

A longer term response being observed in large urban areas such as Chicago is a movement of rail-dependent manufacturing industries to outlying areas, which in turn is also leading railroads to open new intermodal facilities in those same outlying areas. A consequence of this trend is that manufacturing and distribution services are becoming more dispersed, and drays to and from the intermodal facilities are becoming longer. The end result is that there is a growth in total freight vehicles and average distances traveled to support freight intermodal freight movement. This becomes visible as growth in total vehicle-miles (or vehicle-km) of truck traffic.

Access to Air Cargo Terminals - Access to scheduled air cargo services is an important issue for businesses involved with high value cargoes (such as computer chips) and/or time-sensitive cargoes (such as perishables or replacement parts). Access to air cargo services is also important for just-in-time production sites that typically require access to an airport for periodic "emergency" shipments of incoming parts (Hoppin, 2006).

The issue of air freight schedules and capacity is also complicated by access time – especially for those businesses located some distance away from regional airports. Many businesses also rely in inbound shipments from global sources for materials and components involved in manufacturing. Both in-bound and out-bound shipments are consolidated at large airports offering belly capacity or airfreight service at the most competitive costs. Increasingly, time-sensitive imports and exports are being trucked long distances between origin/destination locations and the large international gateway airports. The primary reason for choosing longer and a more costly ground component of the air freight movement is avoidance of congestion (both on major highways and at the airports themselves) occurring at the times that products are ready to ship.

As most air freight is time sensitive, congestion on roads to/from airports can have major economic consequences. For regions served by international air freight gateways, the stakes are even higher, since ground access constraints (caused by traffic congestion) can lead to diversion of demand to other airports further away. While that solution allows businesses to minimize schedule uncertainty, it also comes at a cost of reduced productivity.

The reliance on air-truck transfers makes roadway congestion a particularly critical issue affecting scheduling for international air shipments, such as "high tech" manufacturing that relies on US-Asia production processes. For these shipments, congestion on routes to airports can also affect production schedules. That is because a missed flight can mean loss of inventory and production at the receiving location and the potential imposition of significant cost penalties if production of chip cutting and testing operations is affected.

Congestion on routes to airports also affects business and financial services. For instance, the pickup at overnight courier drop boxes in downtown Vancouver had been moved up two hours, partly in response to growing delay along the congested truck route between downtown Vancouver and its International Airport. Proposals to reduce congestion in major urban areas are focused specifically on addressing these types of problems affecting key freight corridors.

Access to Marine Ports - Major seaports serve as important international gateways for the import and export of goods moving between overseas locations and a broad hinterland. As a result, rail cars and trucks from distances of as far as 1,000 miles or more may converge on port facilities and their access routes. This presents a congestion challenge for ground access routes servicing many major seaports (and was an issue identified in the Oregon and Vancouver studies).

The stakes for trucks delivering containers to port are substantial. A truck that is delayed and misses closing time at the port's truck gate must wait till the next day. Depending on the day, it is possible that the container may miss its scheduled ship and have to several days or longer to get picked up on another ship heading for that same port. If a driver cannot ensure arrival time early enough to prevent that possibility, then it may be necessary to arrive earlier in the morning or one day earlier. Either way, there can be additional driver and vehicle scheduling, time reservation and operating costs incurred because of the congestion delay uncertainty. Some ports are trying to reduce the severity of this problem by extending their hours of operation at truck gates. Some are also instituting truck reservation systems at their container facilities, to even out the truck arrival times.

3.5 Business inventory and operations management

When schedule and fleet adjustments cannot mitigate rising congestion costs, shipper or consignee operations are likely to be directly affected. This may occur in the form of: (a)

increased inventory requirements, (b) added retail stocking costs, (c) added cost of inventory management and control and/or (d) reduced cross docking opportunities.

Increased Inventory - Throughout the 1990s, reductions in inventories increased efficiencies in the manufacturing and transportation sectors. (See Mason-Jones et al., 1997, for a discussion of these efficiencies.) Many economists believe that enhanced inventory management and increasing efficiencies in logistics and supply chain management in that last decade also helped to lengthen economic expansion and moderate business cycle corrections, which were often driven by the need to "work off" excess production and accumulated inventory.

These efficiencies are beginning to erode due to both roadway congestion (on highways) and reduced levels of service at intermodal carriers (primarily major railroads and ocean shipping services). Increased variation in delivery times attributable to congestion, more missed deliveries, and other uncertainties related to maintaining services tied to rail service and maintenance of delivery routes has contributed to keeping more inventory on-hand – both in distribution warehouses and in manufacturing operations.

Most retailers and distributors are faced with rapidly growing inventory management issues. Besides to having to move more of a particular item due increased sales volumes (often with shrinking profit margins), they are also stocking a larger number and greater diversity of items in order to remain competitive with large, "big-box" operators. Increases in volume and mix of products mean space constraints have become critical factors in their ability to serve customers and retail outlets. Inventory management and distribution efficiency are the most important factors in achieving the levels of productivity needed to remain competitive.

Both limited space inside existing warehouses and lack of expansion space encourage just-in-time inventory systems, which are highly dependent on reliable deliveries. Congestion delays can significantly diminish the ability to manage the flow and inventory required in businesses that have rapid inventory turnover. This results in potential lost sales in addition to the costs of managing inventory and receiving emergency, unplanned, or late night/early morning shipments.

Retail Stocking Costs – Many large retail operations depend on high volume sales, especially because margins for competitive retailing operations are constantly being reduced. The primary factors driving higher throughput are the need to offer a greater range of products and the need to provide continuous availability of retail stocks in the face of uncertain delivery delay. Timing of deliveries is critical because it is related to stocking time – the ability to get products on shelves, or from loading docks to in-store storage. Stocking and transfers involving in-store storage often involve shift workers who are at either the beginning or end of their shifts. Delays in receiving deliveries due to highway congestion can result in overtime payments for deliveries at distribution warehouses operated by a retail chain, or in refused deliveries in the case of vendors or third party delivery. In either case, congestion imposes costs that are often unmeasured and unrecognized in traditional modeling or by current cost analysis.

Costs of Inventory Management and Control - Most of the efficiencies in supply chain management over the past decade have been attributable to advances in inventory control and management of materials, components, and finished goods in the supply chain. (Wilson, 2008 illustrates this point by showing how inventory changes can ripple across all elements of a supply chain). Tight inventory controls and accurate accounting for inventory flows are a factor in both achieving profit margins and, arguably, also a factor in the ability of the national and regional economies to weather business cycles.

Squeezing as much efficiency as possible through high levels of automation in warehousing and load management has produced significant efficiencies in warehousing and distribution industries. However, the effects of congestion are eroding the significant progress that has been made in inventory management and warehouse control. Two types of changes appear to be happening simultaneously. First, reductions in labor costs attributable to in-warehouse efficiencies are being absorbed by the costs of the over-the-road operations (more equipment and drivers to deal with congestion and driver hours of service limitations). Second, by re-introducing uncertainty in shipping and receiving attributable to the over-the-road and "last mile" portion of the supply chain system, businesses are forced into looser scheduling , setting lower delivery targets, and adding additional inventory (a reversal of recent trends in lowering inventory) to allow for uncertainty in delivery times.

Impaired Cross-Docking Operations – Congestion impacts are particularly notable for cross-docking operations. Both the efficiency and feasibility of cross-docking operations are tied to the ability of originators to deliver inbound loads within a given window of time needed to reposition loads for outbound customers – typically very early in the morning. Late inbound delivery creates storage and loading problems. As the communications and inventory control infrastructure required to support cross-docking operations becomes more widespread and more critical to improving efficiency and lowering costs of transportation and logistics, delivery reliability will become an even greater issue in the successful adoption of cross-docking in warehouse and logistics management. Insofar as this practice becomes more integrated into transportation and warehousing operations, consideration will be given to locating new facilities in places where congestion is less of a factor in creating uncertainty about delivery times.

3.6 Work shifts

While discussions about optimizing supply chains typically focus on cargo movement, labor is also an input to production processes and a significant component of delivery and distribution services. And in that sense, it can be useful to consider worker travel related costs as part of a broader and more comprehensive view of supply chains. The associated costs may occur as a result of changes in: (a) commuting time and expense, (b) worker schedule reliability or (c) service delivery related travel.

Commuting Time and Expense –Most employers require employees to bear the costs of commuting longer travel times to, from and through congested areas. However, there is also growing evidence that some employers offset some of these higher commuting costs by offering higher wage rates. And yet an even more problematic situation is now occurring -- the change towards earlier start times for shift workers, especially in the warehousing and distribution industries. This is occurring in many congested metropolitan areas to facilitate continued freight operations that rely on over-the-road movements. In some areas, shifts are now being staggered to allow for more efficient operations and these staggered shifts begin as early as 2:00 AM for distribution and warehousing operations attempting to serve areas where congestion is growing. This constitutes a major change in working conditions. In addition, it often reduces the ability of workers to use public transit or ridesharing options, thus representing yet another form of cost increase for workers.

Worker Schedule Reliability - As congestion in larger and rapidly growing metropolitan areas increases, many businesses have noticed an increase in congestion-related delays for scheduled start-times. While such incidental (although increasing) arrival delays can generally be accommodated in service and professional occupations and work

environments, it can pose a more serious problems for production, manufacturing and transportation industries.

The costs of start-time delays and arrival reliability are difficult to quantify and have not traditionally posed a noticeable problem for businesses. However, the increasing frequency of start-time delays and the cumulative burdens of congestion on business operations are beginning to focus management attention on all aspects of congestion and its costs for business operations. This trend is illustrated by a recent US national survey of 1,200 construction contractors, which found that 93% of responding firms reported traffic congestion is affecting their operations, 64% reported at least one day of productivity loss per worker annually due to congestion, and 73% reported that congestion adds more than 1% to their total cost of doing business (Associated General Contractors, 2010). While the survey respondents may not be a totally random sample, the results nevertheless underscore the importance of traffic congestion as a source of loss for construction firms.

Service Delivery Related Travel - Increased traffic congestion can also affect vehicle movement during business hours. Such impacts have been reported by larger businesses including utility companies, the insurance industry and major regional-serving businesses such as hospitals and medical facilities. The Oregon study found that business travel between offices, for meetings and for project-related team conferences is also becoming adversely affected by growth in traffic congestion. This has resulted in more "on-the-clock" (employer paid) travel time for senior managers as well as project and departmental staff, and therefore less productive time spent managing and addressing operational issues. While conference calling and virtual meetings are being pressed into service more frequently, each of these options has distinct disadvantages that have become evident with their use over time. Transition from historical multi-site operations for larger, more concentrated operations centers imposes significant costs for businesses, and compounds the commuting time/expense burdens borne by workers in these industries.

3.7 Business location

Site location and expansion decisions typically shift as products, markets, technologies and input requirements evolve over time. As traffic congestion can effectively constrain both labor markets and freight delivery markets, it can also be a factor affecting the location or relocation of both: (a) distribution center sites and (b) production sites.

Relocation of Distribution Centers - Increased travel times that result from congestion can effectively shrink the distribution radius of existing distribution operations, making both existing service and expansion into new regional markets more difficult. In addition, a major factor in providing logistics support outside of a metropolitan area can be the effect of congestion on limiting outbound (morning) truck trips and the timing of afternoon return trips. Afternoon returns, which often include backhauls, can create an overtime/over-hours situation for the drivers involved, thereby increasing costs and reducing productivity for both the vehicles and the drivers. This further cuts into the cost-effectiveness of distribution operations because efficient backhaul management is one aspect of logistics management that traditionally provides competitive advantages to these firms.

As a consequence of these congestion effects, many new warehousing, distribution and transshipment facilities locate far from the metropolitan areas traditionally "home" to such operations. In the New York metropolitan area, warehousing serving the ports of New York and New Jersey are currently operating in central New Jersey. In several regions, major manufacturers and food distribution businesses have located new distribution and

warehousing operations further away (as much as 200 miles or 320 km) from the core metro markets in order to remain competitive in serving multiple markets.

Relocation of Production Facilities - The location of production on the part of most manufacturing companies is a complex decision that is based on a unique combination of factors such as labor, materials and markets. However, transportation has historically played a role in these decisions. In the Oregon study, almost all of the businesses interviewed and several of the retailers involved in manufacturing also operate globally – with manufacturing spanning multiple continents and regions of the globe (including Africa and the mid-East). This means that for manufacturers, levels of traffic congestion and the ability of transportation infrastructure to support efficient production processes is an important factor in their decisions about where to locate new product lines, how and where to position various aspects of intermediate and final production, and where they may best serve growing or emerging markets for their products.

3.8 Externalities: Interaction with other activities

As production and distribution activities shift location, partly in response to growth in traffic congestion delay, those decisions also lead to "externality impacts" – i.e., impacts on outside parties including (a) residents of urban areas and (b) workers at affected industries.

Localized Effects of Land Use and New Development - Warehousing has traditionally located at the edge of cities, and it continues to be located in "edge" areas of many urban regions. In regions experiencing population growth, though, firms that originally located in relatively low-density areas in the past may now be facing higher levels of congestion on crowded segments of highways and arterial roads that they depend upon for serving their customers. The result can be not only congestion delay, but also increasing difficulty with access to major arterials (such as turning movements from warehouse gates onto local roadways) due to infill and "densification" in areas that were once semi-rural. Expansion, especially of warehouse and distribution facilities, is often limited both by new and proposed non-commercial land uses and by significantly higher land costs. Using existing facilities with greater intensity may also be limited to the existing footprint for some transportation and warehousing operations.

For manufacturing businesses with regular, high-volume movements between intermediate and final production sites, a series of factors may significantly increase the time needed to move intermediate products, partial assemblies and raw materials. This may occur as a combination of generalized highway system congestion and specific bottlenecks where there is reduced capacity on elements of the arterial roadway system (such as bridges and viaduct underpasses). In some urban areas, especially where older manufacturing sites have been incorporated into new mixed use developments, the associated gentrification and conversion of older and unused warehousing space has combined with traffic congestion to compound delays in routine shipment patterns.

Externalizing Congestion Effects on Workers – As businesses make adjustments to minimize congestion costs (such as shifting hours of operation or site locations), one obvious way that they can "externalize" their costs is by passing on requirements to employees to change their work hours and/or commuting distances. As previously noted, workers asked to shift to early or late work times may find that public transport is unavailable or poorly supported at those times. And when distribution sites are moved to outlying areas, workers may also find that their commute travel times and costs are also increased, while their options for alternative forms of transportation are reduced or eliminated.

While providing adequate alternative transportation is clearly not a traditional role of private businesses, the effects of congestion expansion across the workday, operational decisions required to address the business costs of congestion, and business location decisions can together shift the cost and time burden of maintaining job access to employees. These effects also tend to be most pronounced for longer-term employees who have worked at the same location and in the same industry for many years.

4. Implications for transportation & economic modeling

4.1 Transportation modeling

The preceding discussion, covering seven classes of economic impact, indicates the importance of distinguishing key dimensions of congestion in transportation forecasting and impact models. This includes the composition of affected traffic (distinguishing trucks and service vehicles for supply chain impacts), time of day and spatial pattern of congestion, and effects on intermodal connectivity. There are several key reasons:

- *Time Periods* – Congestion can affect both truck and service delivery travel at specific times of day. For industries that are most affected by congestion delays and schedule unreliability, there are important differences in the extent of their options to modify work shifts and delivery schedules. These options vary by industry depending on abilities to operate and ship during morning, afternoon and/or evening periods.
- *Spatial Patterns of Congestion* – For industries that are most dependent on closely integrated logistics, congestion can affect deployment and use of truck fleets, and that can lead to subsequent changes in the number, location and dispersion of manufacturing and distribution facilities.
- *Intermodal Linkages* – Ultimately, every change in congestion along a segment of the road network is likely to affect access from some areas to airports, marine ports or rail intermodal facilities. Conversely, every change affecting the activity at an airport, marine port or railroad facility is likely to also affect traffic levels on its access routes. Thus, congestion impact analysis calls for an intermodal perspective.

In an attempt to address these key dimensions of impact, all three of the impact studies identified in Section 2.3 (Vancouver, Chicago and Oregon) relied on regional travel demand forecasting systems to assess current and potential future congestion. In each case, the models could distinguish truck movements from car traffic to estimate peak vs. off-peak truck traffic changes and to include intermodal connections. Those analyses were also supplemented by special studies that identified conditions affecting: (a) highway corridors with particularly high levels of truck movement, (b) key rail and truck corridors providing access to industrial zones, and (c) road corridors serving airport, marine port and/or intermodal rail facilities.

4.2 Implications for economic impact modeling

The traffic modeling developed for all three of those studies was used in a transportation economic impact framework now called TREDIS (Transportation Economic Development Impact System). This economic framework incorporates a multi-modal structure that is sensitive to changes in passenger and freight cost, travel time reliability and access conditions by mode and time of day. The access measures include size of labor markets and same-day delivery markets as well as connectivity to intermodal ports, terminals and gateways. Measures of change in transportation system performance and access are applied

to information on how various industries rely on different combinations of transportation modes and inter-modal connections for access to supply chain and delivery markets. In this way, changes in modal performance and access conditions lead to different impacts on cost and economic growth opportunities for various industry sectors. (For a summary of TREDIS and discussion of model design policy issues, see Weisbrod, 2008.)

While all three studies required multi-modal analysis, there were very different policy issues in each case. For Chicago, a particularly critical issue was capacity and access for truck movements to rail yards and industrial corridors. For Vancouver, a critical issue was capacity of access routes to seaport and airport facilities. For Portland, Oregon, a critical issue was region-wide truck delivery times for warehousing and distribution facilities. Yet despite differences in local issues, all three cases shared a common need to examine economic impacts of congestion growth, and to do so from a multi-modal perspective.

Another notable element of assessing economic impacts is the ability to distinguish between local-serving industries and "traded industries" (that serve national or international markets). It is important to recognize that even when businesses adjust delivery and worker shift schedules to avoid peak congestion, those activity shifts have some incremental cost for affected businesses. As noted in the Portland report: "*. . . local-serving businesses either absorb added costs and reduce their profits or pass these costs on to people in the region. Trade-oriented businesses though, can and do move their operations to locations outside the region.*" (Economic Development Research Group, 2005, p.10). All three regional studies (Chicago, Vancouver and Oregon) calculated employment and income growth impacts of alternative scenarios involving rates of traffic congestion growth. The estimated impacts calculated by TREDIS varied by industry and over time, but in each region they represented total GDP impacts that are quite substantial – ranging from US $476 million/year in Vancouver to US $2.4 billion/year in Chicago. It is important to note that the variation in impact found in these studies was due to differences in the specific transportation scenarios as well as characteristics of the regional economy and freight infrastructure (sources cited in section 2.3).

5. Conclusion

In examining a range of congestion impacts on supply chains and related business activity, several conclusions arise. First, it is clear that supply chain simulation models based on systems dynamics can be useful to illustrate why congestion delays and uncertainty lead businesses to shift schedules, delivery lot sizes and sometimes even locations. However, the insights provided by interviews and discussions with businesses presented in this chapter show that there can be many more facets of congestion impact and associated change in business organization and behavior beyond those typically identified in such models. Specifically, congestion impacts can go far beyond mere changes in operating cost, to also affect the size and nature of business organizations, production processes and customer markets served. And businesses can have a wide range of responses, depending on the type of affected business activity and the nature of congestion growth.

In this chapter, we described 26 different elements of business impact and response to traffic congestion growth, grouped into seven broad classes. These impact elements are inter-related and they tend to occur as a logical sequence, as illustrated by the conceptual model presented in Section 3.1. They can be important to consider in planning processes, policy development and economic impact analysis models. There are some situations where the economic impacts of traffic congestion can be less than expected because businesses adjust their operations to help mitigate congestion costs. However, in other situations, the

economic impacts of traffic congestion can be greater than expected because of additional impacts on workers and on operators of other transport modes. In addition, there are effects on land use and business location patterns -- all of which are unaddressed by models that assess the direct cost impacts of delivery delay. Many of these additional elements of economic impact take place slowly over time and may not be noticed until their consequences are severe (i.e., entire business operations are rescheduled, reconfigured or relocated), at which time it may be too late to reverse business decisions.

Finally, it should also be clear that it can be misleading to focus research and policy attention on the overall incidence and average magnitude of congestion impacts on businesses as a group, since impacts can vary widely depending on the type of affected business activity (location, products or services offered, degree of localization of suppliers and customer base, and modal dependencies) and the nature of local congestion growth (including its severity, spatial and temporal patterns of incidence). In other words, even if only a small fraction of businesses change their fleets, locations or markets in response to congestion growth, the impact can be very important for particular business sectors. This can have significant economic development and public policy implications for some local areas, occupations and industries, especially if these business sectors are those for which future region-wide growth and development are dependent. It can also lead to a much wider and varied set of consequences for regional economies, as demonstrated by the examples of regional economic impact studies. Future policy and planning should consider and account for these distributional consequences.

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Supply Chain Management - New Perspectives

Edited by Prof. Sanda Renko

ISBN 978-953-307-633-1
Hard cover, 770 pages
Publisher InTech
Published online 29, August, 2011
Published in print edition August, 2011

Over the past few decades the rapid spread of information and knowledge, the increasing expectations of customers and stakeholders, intensified competition, and searching for superior performance and low costs at the same time have made supply chain a critical management area. Since supply chain is the network of organizations that are involved in moving materials, documents and information through on their journey from initial suppliers to final customers, it encompasses a number of key flows: physical flow of materials, flows of information, and tangible and intangible resources which enable supply chain members to operate effectively. This book gives an up-to-date view of supply chain, emphasizing current trends and developments in the area of supply chain management.

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