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UTC Spotlight

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Characterizing the Tradeoffs and Costs Associated with Transportation Congestion in Supply Chains

The ability for retailers to offer attractive prices to consumers relies on the efficient operation of large-scale supply chains that convert natural resources, raw materials, and components into a finished product. Transportation is key to the efficient operation of these supply chains, which comprise raw material sites, manufacturing and assembly facilities, distribution centers and warehouses, and retail stores—often at disparate locations. Past research has not addressed the impact that traffic congestion can have on supply chain design and performance. But researchers at the University of Florida Department of Industrial and Systems Engineering are filling this void by developing models that integrate the effect traffic congestion can have on production economies of scale and how that congestion can influence supply chain design and performance.

Georgia Tech

Traffic congestion increases the need for transportation resources in supply chains.

The structural design of a supply chain is an extremely complex problem requiring numerous difficult and interconnected decisions. These decisions determine the degree to which a supply chain can meet or exceed competitor performance and customer expectations on product availability and price.

The most salient of these decisions can be described as follows. For each required manufacturing and distribution activity, in how many places and at what locations will the activity be performed?

Enabling multiple locations to perform an activity has inherent advantages and disadvantages. Advantages include risk diversification and an ability to quickly respond to the needs of local markets. Disadvantages include diminished economies of scale and duplication of activities and expenses.

For example, building many warehouses close to markets may reduce transportation costs from warehouses to stores, but the associated facility costs, inventory investment, and transportation cost for serving warehouses might make this an unattractive option. At another extreme, while having only a few warehouses may reduce facility and inventory costs, the associated transportation costs to retail stores may be prohibitive.

Supply chain decision makers must, therefore, consider numerous complicated and interrelated decisions and tradeoffs that affect the ability to offer competitive products. As our example illustrates, transportation costs serve as a key driver of competitive performance.

Our research addresses the fact that the past academic literature has not accounted for the important (but complicated) way in which traffic congestion influences supply chain design and performance. Traffic congestion increases transportation-related costs and delivery lead times, which, in turn, increase the required system inventory investment for meeting desired customer service levels.

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Thus, ignoring the effects of traffic congestion in supply chain design can lead to inaccurate cost projections and suboptimal supply chain design.

Accounting for the impacts of traffic congestion on supply chain design requires considering the individual decisions made by different, independent decision makers. This leads to the consideration of two kinds of competition in supply chains: competition for product sales and competition for limited transportation capacity. We apply the tools of Game Theory and Operations Research to develop mathematical decision models that account for decentralized decisions in a competitive environment.

In particular, we have developed a mathematical model of a competitive facility location and market-supply game with multiple firms competing in different markets via a congested distribution network. As a result of their location and market supply decisions, firms incur transportation costs, traffic congestion costs and facility location costs (congestion costs increase at an increasing rate in the congestion level, as observed in practice). Game Theoretic mathematical tools permit characterizing the best decisions for individual decision makers in equilibrium, when each decision maker's performance is affected by the decisions made by others.

Our mathematical model first characterizes equilibrium supply quantities sent from facilities to markets for a given set of firms' supply facility location choices. An oligopolistic Cournot game determines a Pure Nash Equilibrium (PNE) for these supply quantities (a Cournot game is one in which the equilibrium price in a market is inversely proportional to the total market supply; a Pure Nash Equilibrium is a solution in which each player's strategy is deterministically defined, and no player can be unilaterally better off by deviating from the solution). This enables providing analytical results on how traffic congestion costs influence equilibrium quantities flowing from supply facilities to markets. We then characterize properties of equilibrium location decisions, which permit characterizing how different cost drivers, including congestion costs, influence overall distribution network flows.

These models enable more accurately predicting firms' location and distribution decisions when these firms must utilize congested transportation networks. For the individual firm, this means an ability to more accurately forecast future market equilibrium supply quantities as transportation congestion levels and competition evolve over time. For government planning agencies, these models provide an ability to predict how critical transportation capacity decisions and investments will affect the volume and value of goods flowing to markets, as well as the degree and distribution of transportation capacity utilization by commercial distribution enterprises.

About This Project

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