

Trends & Research Directions in Supply Chain & Logistics Engineering

Chelsea C. White III
Schneider National Chair of Transportation & Logistics
Georgia Institute of Technology
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There are two objectives of this presentation. First, we will present forces and trends that are affecting global supply chain design and logistics (freight transportation and warehousing). Second, we will highlight two – of the many - important research challenges that result from these forces and trends and that those of us with control, operations research, or operations management backgrounds are equipped to address. The first of the two research challenges involves how to analyze, from a supply chain design perspective, low probability, highly disruptive events and hence design resilient supply chains. The second research challenge is determining the value of, and how to extract this value from, real-time data for real time control of a supply chain.

We now provide a brief overview of the past and current situation in manufacturing from the U.S. perspective. We are all aware that over the past several years, it often has been less expensive to manufacture a produce off shore, e.g., in the PRC, and ship it to the U.S. market than to manufacture the product within the U.S. and incur the lesser cost of totally domestic logistics. As a result, many U.S. based manufacturers have made significant investment off shore, and many U.S. based logistics companies, intent on providing service to the globally integrated enterprise, have followed suit and now also have significant assets off shore. All of this has been enabled by an information and physical infrastructure and by trade and tax policies of countries wishing, often quite successfully so, to attract foreign investment.

Very recently, however, and motivated by high fuel costs and fuel cost variability, shippers have been reevaluating their supply chain designs with the thought of moving their supplier footprints closer to the U.S. market. In some cases, for example, this has resulted in the supplier footprint being moved from the PRC to one of the NAFTA countries (Mexico, Canada, U.S.) or the Caribbean. This phenomenon is often referred to as ‘reverse globalization.’ We mention also that shippers are becoming more aware of the (relatively hidden) cost of lead-time (the time needed to transport a good from origin to destination) variance, which can lead to significant inventory levels and concomitant inventory buffer costs. Causes of lead-time variance include weather, border crossings and their concomitant customs and other inspections, congestion, poor schedule synchronization. Besides fluctuating fuel costs, stimulants to reverse globalization include: the rising value, relative to the U.S. dollar, of the PRC’s currency; the geopolitical and financial risk that always exists in global trade; the increasing labor wages in key countries (e.g., PRC); domestic and international freight transport network

congestion; intellectual property and contract law issues in key countries; lack of uniform regulatory interpretation and enforcement; and available alternatives to manufacturing in the PRC (e.g., other Asian countries, the NAFTA countries, the Caribbean).

We believe, however, that reverse globalization is a ‘mini-trend’ that represents a slight reversal in the dominant expansion of off shore manufacturing. Reasons why we predict that reverse globalization will not be a dominant trend include: U.S manufacturing and logistics are now heavily invested in doing business in the PRC; the Asian alternatives are limited, compared to the PRC’s vast labor pool; the PRC’s national government is committed to continued growth and investment of foreign interests; PRC manufacturing and logistics have significant room for productivity improvement; and there are a myriad of ways to reduce fuel costs and lead-time variability, thus reducing the reasons for restoring supplier footprints closer to the U.S. market. These reasons include: mode shifts to reduce energy needs; improved efficiency of each mode (e.g., auxiliary power units on trucks, hybrid vehicles); improved capacity and efficiency of the global freight transport network, vehicles, and vessels; and product and package design to reduce weight and cube.

There are other trends that are affecting the supply chain and logistics industry, three of which are as follows. First, the dramatic global economic downturn is reducing significantly the amount of freight needed to be transported. In order to counterbalance what would be resulting over-capacity, capacity is being removed from the industry by bankruptcy, slower vehicle and vessel speeds (in order to increase fuel mileage), and fleet size reduction of the surviving freight transportation companies. Second, we note interest on the part of shippers in building *resiliency* into their supply chains, where by resiliency we mean preventing and effectively responding to major supply chain and freight transportation network disruptions, an operational risk that has been highlighted by a variety of concerns including: security issues, extreme weather, health issues (e.g., avian flu pandemic), accidents, etc. Third, many foresee that the use of real time data for real time supply chain control represents the next level of supply chain efficiency, resilience, and stability. We will explore the latter two trends in more depth later in the presentation.

We observe the importance of international trade on the U.S. economy by noting such trade represents almost 30% of the U.S. GDP, and this percentage is projected to increase in the (long-term) future.

In order to better understand what we mean by mode shifts, we note that Exhibit 1 provides a description of the various modes of moving freight domestically in the U.S., as a function of service level (which is directly related to the mean and variance of lead time) and price. For example, trucking is more expensive per ton-mile than rail; however, the lead-time mean and variance associated with freight transportation by truck is in general better than that of rail. As a reminder, higher mean and variance of lead-time implies a greater need for inventory buffer and results in higher inventory holding costs, assuming that the shipper intends to hold the consumer service level constant. Thus, freight transportation service and price is a trade off between costs associated with transportation and costs associated with inventory. Exhibit 2 provides a description of

the various modes of moving freight across an ocean, as a function of service and price levels, where we note a gap due to the elimination of land based modes, such as rail and trucking.

Slide 12 provides a rough idea of the relative energy consumption needs for the primary freight transportation modes on a ton per mile basis. Airfreight consumes eight times the energy consumed by trucks, trucks consume four times the energy consumed by rail, and ocean shipping is three times less energy consuming than rail. Once again, however, these reductions in energy consumption and hence in transportation cost can result in an increase in inventory holding costs.

A major contributor to increasing both lead-time mean and variance is freight transportation congestion (at ports, rail heads, on highways, etc.). Major investments are being made in order to improve network capacity thereby reducing congestion. One key investment is in information infrastructure. The assumption is that various types of data, to be listed below, have value for improving – equivalently increasing transportation network capacity - the overall performance of the transportation network and the vehicles vessels that use it. Slide 15 displays at a very high level the U.S. national Intelligent Transportation System (ITS) architecture. This architecture describes how communications and sensing technologies can enable wire-line and wireless communication between vehicles, travelers, the roadside, and transportation communication centers.

Many significant physical infrastructure projects intended to improve the capacity of the global network are either now underway or are in the planning stages, and these include those listed on Slide 14:

- Panama Canal expansion (\$5 billion)
- Build Canada Plan (\$31.3 Billion)
- Punta Colonet, Mexico Container Port
- India to spend \$320 Billion over next 15 years
- Dubai Logistics City
- Santos, Brazil, to double it's capacity by 2016 - other projects in Argentina, Uruguay and Chile
- "Inland Ports" being built in the U.S.A
- China, \$54B over next 10 yrs for port improvements & expansions
- Port projects in Singapore, Hong Kong, Hamburg, and Rotterdam.

Slides 16 and 17 illustrate two of the major physical infrastructure projects now under construction – the Yangshan terminal just off the coast from Shanghai (Slide 16) and the third set of locks of the Panama Canal. The Yangshan terminal will allow Shanghai to be the largest container port in the world (at least for the foreseeable future) with an estimate of 27M TEUs passing through this port last year.

We now come to two general areas of research that I believe represent important areas of supply chain and logistics engineering to which we can contribute. The first is supply

chain resiliency and is focused on downside risk in supply chains associated with low probability, highly disruptive events. The objective is to design and control a supply chain so that it is productive and capable of graceful degradation and rapid recovery if a highly disruptive event occurs.

We distinguish uncertainty and major disruption as follows. Uncertainty, typically modeled by an additive random variable with known cumulative distribution function (cdf), e.g., for the linear quadratic Gaussian problem (LQG), or by conditional probability, e.g., for the Markov decision process (MDP), describes variability in, for example, the demand, supply, congestion, and driver availability associated with the every day operations of a supply chain.

Major disruptions are terrorist activities, extreme weather, SARS, major accidents that interject large and unusual fluctuations in demand, supply, etc., but also change the fundamental structure of the freight transportation network. Examples of major disruptions are listed in more detail on Slides 20 and 21. Such structural change involves removing links and/or nodes of the freight transportation network for a period of time that is appropriately described by a random variable with a perhaps incompletely defined cdf. We envision resilient supply chains as being able to prevent, gracefully react to, and quickly recover from such major disruptions. Importantly, we think of design for resilience as a level of supply chain design beyond lean due to the fact that lean supply chains, albeit highly efficient, can be notoriously fragile in the sense that they can degrade rapidly when subjected to a highly disruptive event. For example, when the plant of a major, single source Toyota supplier experienced a major fire in 1997, Toyota assembly plants nation-wide had to cease production within hours.

From a policy perspective, the study of systems resilience can help to address the following question: how much should be invested in preventing, versus recovering from, a major disruption?

The implications of research involving the design of resilient supply chains can bring into focus quite basic issues. For example, in developing routes for vehicles transporting HAZMAT (hazardous materials), we can consider two objectives: transportation cost and risk. Typically, the cost of traversing two adjacent links is assumed to equal the sum of the costs of traversing the individual links. Hence, in general, cost and reward are adequately modeled by an additive criterion. If each link is associated with a probability that an accident will occur (a measure of risk), then the probability of traversing a path, or series of links, will be multiplicative. If the criterion is either additive or multiplicative, standard versions of dynamic programming are applicable for solving various models of sequential decision making under uncertainty, e.g., LQG, MDP. However, if the criterion is a weighted sum of an additive criterion and a multiplicative criterion, then what is often called the principle of optimality may be violated. Hence, standard applications of dynamic programming may produce sub-optimal policies for the aforementioned HAZMAT multi-objective routing problem, requiring the development of new numerical procedures that take into account this violation.

We now consider the situation where a link or node of the freight transportation network may fail due to a major disruption. We have modeled such a situation as a two-state Markov chain, where the states represent 'the link or node exists and is functioning normally' and 'the link or node has failed'. The probabilities of making transition from the good state to the bad state and from bad to good are related, respectively, to the quality of prevention and recovery. We have analyzed an inventory problem, where the link that may be subject to disruption is the supply chain from supplier to customer and have done a parametric analysis on the good to bad and the bad to good probabilities, thus providing some insight into the relative importance, at least to this simple supply chain, of investments in prevention versus recovery.

The second area of research to which I believe we have much to contribute is real time control of supply chains, based on real time data. The sources of data to which we refer are given on Slide 23 and include inventory levels; production rates; information about vehicles, vessels, or trailers; driver alertness; traffic congestion; weather; and freight status and visibility. Many of these data originate from sensors, are transmitted via communication channels, and hence can be noise corrupted. These data require analysis, which may delay information to the decision maker (presumably, a dispatcher, driver, warehouse or assembly plant manager, etc.). Related questions, listed on Slide 24 are: what is the value of the information contained in these data? Operationally, how can we best extract this value? How do we best deal with data corruption? What is the impact of data transmission and processing delay? Under what conditions will higher quality system observation guarantee improved system performance?

In summary, these are but two of the many important areas of research in logistics and supply chain analysis. We have attempted to put them into the broader context of trends and forces affecting the industry. Hopefully, this presentation will provide you with further ideas for intellectually stimulating and industrially relevant research in logistics and supply chain design and control.

Thank you for your attention.