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Adding a freight network to a national interstate input–output model: a TransNIEMO application for California

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ABSTRACT

The state of the nation's infrastructure is the subject of widespread discussion and comment because it is thought to include many deteriorating and unsafe bridges. Ever since the terrorist attacks of 9/11, there has been increasing concern over the extent to which an attack on infrastructure could result in serious economic disruption. This research develops a model to analyze the economic consequences of an attack on a major element of the highway network. We add a freight network to a national multiregional economic impact model and make freight traffic flows endogenous. The use of a sub-national interstate model recognizes that most infrastructure planning is at the state level and most political leaders' interest is local. We base our approach on the National Interstate Economic Model (NIEMO) and refer to an elaboration that we name Transportation network and the National Interstate Economic Model (TransNIEMO). The new model enables us to study the state-specific and industry-specific economic impacts of some significant changes in the nature of highway freight movements. We tested the model for selected freight movements in and out of California. The results are entirely plausible and encourage us to elaborate and test the model for hypothetical disruptions of freight traffic throughout the US.

1. Introduction

The construction of canals and railroads in the 19th century connected the central lowlands of the US with the outer world, facilitating regional specialization, trade and economic growth and establishing the US as a major supplier of agricultural production to much of the world (USDOT, FHWA, 2004). A century later, President Eisenhower saw the importance of a national interconnected highway system. Since then, the Interstate Highway System has served most of the nation's freight movements, facilitating continuing regional economic specialization and the long-term development of the US economy.

Innovations in transportation technology and expansions of transport infrastructure bring substantial changes (Muller, 2004). Goods are now moved intermodally via diverse routes. Estimating freight movements and shipping costs among regions is essential for making investment plans throughout the economy. The same holds for investments by all the public agencies that manage the highway network system. In this vein, the correlation between freight flow and network vulnerability has been a critical research topic in both economic and transportation impact analysis.

Some insightful previous studies focus on the vulnerability issue of network segments through "disruption indices" that identify the importance of certain network links by their topological location and flow capacity on them (Jenelius et al., 2006). Typically, researchers used a disruption index and the vulnerability index to demonstrate possible impacts from a hostile entity on a targeted transportation network link (Murray-Tuite and Mahmassani, 2005). With these indices, a researcher can verify and determine the critical paths and routes that present a relatively high level of system vulnerability due to significant amount of flows and that have a high importance with respect to network connectivity (Murray-Tuite and Mahmassani, 2005). Although some paths have relatively low levels of system vulnerability serving lesser flows,

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there is no doubt that there are many direct and indirect influential variables which have critical roles in analyzing the robustness of the freight flow network. For instance, the results of supply chain performance analysis given transportation disruption experiments argue for the importance of information sharing and connectivity among entities (Wilson, 2006). Further, some recent studies used indices that demonstrate the degree of overall robustness and network connectivity. The 'Network Robustness Index' (NRI) is a case in point (Scott et al. 2006).

Furthermore, researchers eliminate some nodes or origin–destination (OD) pairs from the target network to identify the correlation between nodal connectivity and flow capacity. Their results show the importance of this field of research to achieve practical results regarding economic impacts and path building methodologies (Murray et al., 2007). These interesting network disruption experiments and associated economic impact analyses motivated our research on regional economic impact analysis at the subnational level, providing not only for a nation-wide analysis disaggregated to the level of states and counties.

Improved analysis is now possible because the Federal Highway Administration (FHWA) has integrated shipments data into the Freight Analysis Framework (FAF). While the FAF data contain important capacity information, the FAF data do not include actual freight flow data on US highway networks by commodity class. Our operational multi-regional input–output model, the National Interstate Economic Model (NIEMO; Park, et al., 2007) was the source of interstate shipments by commodity and non-commodity class. Our research plan was to use both tools to find ways of allocating commodity-specific interstate trade to the national highway network. Any major flow disruption could then be diverted to second-best routes, the costs of the diversion could then be estimated and NIEMO could be used to determine a much fuller inventory of economic impacts.

Up to now, there has been something of a divorce between two important branches of spatial modeling: transportation (and often land use) and economic impact analysis. Integration between these two approaches is important because changes in economic activity have consequences for transportation while changes in the transportation network have implications for economic development.

This study is an initial trial of this focus: We study commercial goods movement and trade between metropolitan areas and its economic cost impacts for the case of a hypothetical terrorist attack on a major bridge. There would be several other costs such as additional inventory holding costs, overnight stay costs, lost sales, and rescheduling costs to be considered. However, only increased shipping costs because of rerouting are considered to estimate direct impacts in this study. We do not focus on estimating total costs and benefits in this paper, and we frequently point this out in our research. Our model works best when it focuses on business interruption impacts. To respond to a real event, we could collect other costs via surveying the relating companies and organizations. However, this study measures partial costs resulting from rerouting rather than the total impacts of an event. Even though this paper reports a California experiment, the success of our proof-of-concept application makes it possible to broaden tests and applications of TransNIEMO to the rest of the US.

While NIEMO is spatially disaggregated only to the state level, the transportation nodes for freight modes are the major metropolitan areas, which are the dominant centers of economic activity. Furthermore, in most states there is one or more major metropolitan area: The non-metropolitan regions in selected cases also account for a significant proportion of state gross domestic product and freight O–D movements. Although local governments are mostly responsible for transportation infrastructure planning within their jurisdictions, most highways serve areas beyond their boundaries.

In previous work estimating the indirect and induced effects of impacts associated with capacity losses at the twin ports of Los Angeles-Long Beach, Gordon et al. (2005) showed that two-thirds of the impacts leak outside the region. But without an interstate model such as NIEMO, we would have had no idea where these leakage effects might occur. In this paper, we describe TransNIEMO, which links the nation's highway network with the interstate model. We describe freight movements between the nation and California and the economic losses from their interruption. We plan to extend the research to achieve a parallel integration of the national and regional railway networks.

2. Niemo

NIEMO is a 47-sector-52 region input–output model that is fully operational. The idea for such a model has a long history stretching back to Isard's suggestion of the "ideal interregional model" (Isard, 1951, 1960) and Leontief's valiant but failed attempt to operationalize a variant of the model in the 1960s. A general single-region (or national) input–output (IO) model is useful for developing an understanding of economic activity within a region in terms of the region's inter-industrial relationships. Because of the simultaneous simplicity and meaningfulness provided by a system of linear, fixed relationships between industries, IO models have been widely applied to analyze short-term economic impacts. In the market economy, inter-industrial relationships play a key role in tracing production changes throughout an economy when final demand for any industry's outputs changes (Miller and Blair, 2009). However, the importance of sub-national models has long been recognized. Aggregation accounts for the loss of information, especially when positive effects in one area cancel negative impacts in another (Park and Gordon, 2005). It is also clear that most politicians have a keen interest in local constituencies. To say that NIEMO has succeeded where Leontief failed is not an immodest statement, but rather a reflection of the improvements in databases and computing capacity over the past 30 years. However, building bridges among the various data sources remained a substantial task.

NIEMO is not merely a replica of the original design as conceived by Isard and Leontief. Rather, NIEMO rests on the successful integration of state-level input–output information with data from the Commodity Flow Survey (CFS). Since 1993, the Commodity Flow Survey (CFS) has been the largest single nationwide data source for freight movement flows (USDOT, RITA and BTS, 2006). The Bureau of Transportation Statistics and the Census Bureau collect CFS data from a sample survey of industries through the Economic Census. Although the CFS provides wide range of commodity shipments and multimodal movement data with 5-year cycle updates of 1997 and 2002, some user groups have not been satisfied with its content details (USDOT, RITA and BTS, 2005). The most commonly addressed weaknesses of the CFS are its incomplete coverage by commodity sectors and regional detail, and its inability to fully capture imported goods trade (Southworth, 2005; Park et al. 2009; Giuliano, 2007). ORNL (2000) showed that the CFS estimates cover less than 75% of all the freight tons moved annually in the US, because the survey drops many establishments classified as farms, forestry, fisheries, construction, transportation, governments, foreign establishments, services, and most retail activities.

Nevertheless, Park et al. (2009) managed to estimate interstate trade flows, applying an Adjusted Flow Model and a Doubly-constrained Fratar Model. The approach depends on 1997 CFS and 2001 IMPLAN data. To reconcile different definitions and