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An intermodal freight transport system for optimal supply chain logistics

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ABSTRACT

Complexity in transport networks evokes the need for instant response to the changing dynamics and uncertainties in the upstream operations, where multiple modes of transport are often available, but rarely used in conjunction. This paper proposes a model for strategic transport planning involving a network wide intermodal transport system. The system determines the spatio-temporal states of road based freight networks (unimodal) and future traffic flow in definite time intervals. This information is processed to devise efficient scheduling plans by coordinating and connecting existing rail transport schedules to road based freight systems (intermodal). The traffic flow estimation is performed by kernel based support vector mechanisms while mixed integer programming (MIP) is used to optimize schedules for intermodal transport network by considering various costs and additional capacity constraints. The model has been successfully applied to an existing Fast Moving Consumer Goods (FMCG) distribution network in India with encouraging results.

1. Introduction

The growing interest in collaborative logistics is fuelled by increasing pressure on companies to operate more efficiently and enhance the productivity of their supply chains. Transportation and logistics management is fast becoming one of the key components of the entire supply chain valuation for many organizations. Due to increasing globalization in recent decades, especially in emerging economies, the importance of logistics management has been on the rise. Traditionally, shippers and carriers have focused their attention on minimizing their own costs to increase profitability, but more recently focus has shifted towards system wide cost reduction to increase profitability of the entire logistics chain. A key component of a logistics chain is the transportation system network. The costs associated with transportation amount to around one third of the total logistics costs which necessitates effective and cost efficient transport coordination mechanisms for managing complex networks involving shipments from manufacturing plants through intermediate distribution centers to customer retail locations.

In many developing economies, majority of the freight transport is undertaken by road based vehicles while rail and water based services remain either largely unutilized or highly disorganized in their functioning and coordination. Road based freight transport has increased significantly over the past few decades in the distribution channels. This rapid increase has led to massive overuse of the road networks without much improvement in the existing infrastructure resulting in various externalities like traffic congestion, increased energy consumption and negative environmental impact. Road capacities, especially outside urban areas, are still inadequate, and several road segments are in inferior condition in the developing countries. In addition, the port and operational transshipment terminals are few in number with low levels of service due

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to lack of berths, supporting equipment and maintenance. In order to address these issues, we focus on an efficient organization of intermodal transport system which can alleviate these externalities based on the current status of the distribution channel of the supply chain network. Our approach in this paper is aimed at taking advantage of intermodal transport wherever possible in a network heavily dependent on unimodal transport.

According to Mahoney (1986), "Intermodality" is the movement of freight via two or more dissimilar modes of transportation. Hayuth (1987) defines it as the movement of cargo from shipper to consignee by at least two different modes of transport under a single rate, through-billing, and through liability. In general, research in the area of intermodal transport systems not only assists in developing effective transport networks, but also contributes to reducing negative impact on environment and energy consumption. In developing countries such a system will drastically improve the utilization of transport resources and services, leading to better scheduling and delivery with lower logistics costs and higher levels of efficiency.

In this paper, an integrated intermodal freight transport system is developed for an established FMCG distribution network in India. The system first analyzes the traffic status of the road based freight vehicles in various operational zones (spatial clusters) of the network at different time intervals. The system then computes a congestion index for that spatial cluster which is then utilized for any decision to engage other transport modes in the network, such as rail and water links wherever available. The decision for engaging another mode of transport is based on the results of optimizing the total costs involved in the intermodal strategy. In this model, rail is chosen as the primary alternative to road due to certain advantages that include better connectivity, regulated schedules, diversified distribution channel and faster delivery time within acceptable transport cost limits. A single alternate also reduces the complexity and is a fair representation of the networks in most developing countries. However, our approach can easily be extended to other available transport modes with time-space representations. The intermodal train service routes are determined under specific time slots when the train services are offered.

The rest of the paper is organized as follows. The next section reviews literature relating to similar work conducted in the fields of spatio-temporal mining and intermodal transport optimization. We then describe the general methodology in detail. The following section introduces the modeling approach utilized and discusses the details of problem formulation. The results are presented and discussed next, followed by conclusions and future extensions in this area.

2. Literature review

In this section, related work in spatio-temporal traffic flow prediction and intermodal transport optimization is discussed which sets the stage for the problem addressed in this paper. From a methodology standpoint, majority of the work in these areas focuses on advanced predictive analytics using non-linear, non-parametric regressive models and integer programming for combinatorial optimization.

2.1. Spatio-temporal short-term traffic flow prediction

Since the 1970s, univariate time series models have been widely used for traffic flow prediction, especially Box–Jenkins autoregressive integrated moving average (ARIMA) models (Hamed et al., 1995). Subsequently, ARIMA and exponential smoothing (ES) models, such as Holt's–Winter's approach, have been used for comparison purposes whenever a new forecasting model for short-term traffic is proposed (Park et al., 1998). Over the past decade, Neural Network (NN) models have been extensively used in the field of transportation engineering. In addition to flow, other traffic parameters including speed (Ishak et al., 2003) and occupancy (Zhang, 2000) have been predicted in real-time by NN models. Several other techniques have been applied to predict real-time traffic flow. Some of these include multivariate state space time series (Stathopoulos and Karlaftis, 2003) multivariate non-parametric regression (Clark, 2003; Smith and Demetsky, 1996), dynamic generalized linear models (Lan and Miaou, 1999), Hybrid fuzzy rule based system approach (Dimitriou et al., 2008) and Kalman filtering models (Okutani and Stephanedes, 1984). Lin (2001) proposed a forecasting model based on the Gaussian maximum likelihood (GML) estimation method to perform one step ahead forecasts using 5-min traffic flow data. Lin's methodology used both current and historical data traffic in an integrated manner. Probabilistic Principal Component Analysis has been effectively employed using intra-day trend of traffic flow series. This largely removes the issue of missing data while keeping prediction errors relatively low (Chen et al., 2012). Better results have been observed for advanced genetic algorithm based multilayered optimization strategy for neural networks (Vlahogianni et al., 2005). Historic aggregated data from large databases of neighboring stationary detectors and congestion analysis was used to predict traffic flow instabilities (Treiber and Kesting, 2012). Recently, support vector regression (SVR) is being widely applied to predict traffic parameters such as travel time (Wu et al., 2004). The major advantage of SVR is that it avoids over-fitting and allows for a faster training process than other algorithms for multi-dimensional data.

A number of incident detection algorithms have been developed over the past three decades. One of the most popular algorithms is the California Algorithm (Payne and Tignor, 1978). This algorithm is based on the logical assumption that a traffic incident increases the traffic occupancy at the upstream portions of the incident and significantly decreases the traffic occupancy downstream of the incident. However, majority of these algorithms are not reliable in differentiating between recurrent and non-recurrent congestion events. The Minnesota Algorithm (Chassiakos and Stephanedes, 1993) attempts