European Journal of Operational Research 253 (2016) 614–624

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

Measures of dynamism and urgency in logistics

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ARTICLE INFO

Article history:
Received 23 December 2014
Accepted 11 March 2016
Available online 18 March 2016

Keywords:
Logistics
Transportation
Dynamism
Urgency
Measures

ABSTRACT

Dynamism was originally defined as the proportion of online versus offline orders in the literature on dynamic logistics. Such a definition however, loses meaning when considering purely dynamic problems where all customer requests arrive dynamically. Existing measures of dynamism are limited to either (1) measuring the proportion of online versus offline orders or (2) measuring urgency, a concept that is orthogonal to dynamism, instead. The present paper defines separate and independent formal definitions of dynamism and urgency applicable to purely dynamic problems. Using these formal definitions, instances of a dynamic logistic problem with varying levels of dynamism and urgency were constructed and several route scheduling algorithms were executed on these problem instances. Contrary to previous findings, the results indicate that dynamism is positively correlated with route quality; urgency, however, is negatively correlated with route quality. The paper contributes the theory that dynamism and urgency are two distinct concepts that deserve to be treated separately.

1. Introduction

Logistic optimization problems aim at minimizing costs while serving customers' transportation requests. The most common problem formalization is the vehicle routing problem (VRP) (Dantzig & Ramser, 1959). Roads are treated as edges of a graph and a traveling salesman problem (TSP) is solved for one or more vehicles represented in such a graph (Flood, 1956). In practice, vehicle schedules are devised offline, after all customer requests have been received, and are applied later on without the possibility to modify the schedules once the vehicles have started servicing.

A number of technological advances have fostered new interest and transformed problems in the domain of logistics. Such advances are the introduction of the Global Positioning System (GPS) in 1996, the increasing accuracy of Geographic Information Systems (GIS), and more recently the development and spread of tablets and smart phones with high-bandwidth internet. Online changing of routes or devising completely new routes is now possible due to the availability of accurate information on the position of all vehicles. These developments open new avenues for increasing customer satisfaction (i.e. relatively fast shipping of goods, even at the day of ordering), while operational costs and environmental impact can be further decreased. In the dynamic variant, the typical dynamic aspect is the arrival time of the request containing the useful information needed to compute optimal routes for the vehicles (Pillac, Gendreau, Gueret, & Medaglia, 2013).

Dynamic logistics is a well researched topic continuing to receive widespread attention (Berbeglia, Cordeau, & Laporte, 2010; Parragh, Doerner, & Hartl, 2008; Pillac et al., 2013). Psaraftis (1995) and later Eksioglu, Vural, and Reisman (2009) devised taxonomies for the (dynamic) VRP, but did not formally define dynamism as such. Pillac et al. (2013) suggested that a better formalization of the dynamics would allow more precise classification of problem instances. Based on such a classification, it would be possible to scientifically assess the quality of algorithms for dynamic logistic problems in different circumstances. For instance, datasets such as those presented in Li and Lim (2001), Mitrović-Minić and Laporte (2004) and Gendreau, Guertin, Potvin, and Seguin (2006) could be classified and compared quantitatively and it would be possible to find specific dynamic properties within dynamic logistics where one class of algorithms performs better

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http://dx.doi.org/10.1016/j.ejor.2016.03.021
0377-2217/

than others. The cornerstone of a formalization of dynamics in logistics is a formal definition of dynamism. Intuition suggests that the frequency of change should be part of such a definition of dynamism. A more dynamic problem is characterized by a more continuous distribution of request arrivals. Static problems, on the other hand, have all requests available at the same time or, alternatively, become available in bursts and thus have a more varying request arrival frequency. Furthermore, different optimization algorithms likely differ in their ability to find near-optimal solutions for highly dynamic problems. When information is clustered together, the available time can be used for devising a good schedule, contrastingly, frequent changes of the problem definition make scheduling in advance almost useless and favor a completely reactive strategy instead.

Lund, Madsen, and Rygaard (1996) proposed the first formal measure for quantifying dynamism in logistic problems. They define dynamism as the proportion of requests known after the scheduling phase (i.e. when vehicles are already shipping) with respect to the total number of requests. Their measure considers a problem where all requests arrive during shipping as 100 percent dynamic. Contrary to our intuition, the relative timing of the requests does not influence the value of this dynamism measure. Larsen, Madsen, and Solomon (2002) recognized the limitation of the measure by Lund et al. and aimed at fixing it by taking into account the urgency of a request. Larsen et al.'s measure considers a request to be more dynamic when announced closer to its deadline. However, this approach fails to measure what intuitively could be considered dynamism, since it does not measure the relative distribution of request announcements. On closer inspection, the concept of urgency is included in the degree of dynamism considered by Larsen et al. Moreover, Larsen et al. showed that for problems with a high dynamism value, the algorithms tested produced a lower quality schedule. Based on their experimental setup, concluding whether the negative correlation between their measure and schedule quality is the result of dynamism, urgency or a combination thereof is nearly impossible.

The present paper investigates whether the experimental observations reported by Larsen et al. are caused by dynamism, urgency or both. We analyze whether splitting urgency and dynamism into separate concepts is desirable. To conduct a sound scientific evaluation, we need to be able to formally define both dynamism and urgency as two separate concepts and to develop the tools for classifying logistic scenarios. These tools enable generating instances of logistic problems with varying levels of dynamism and urgency. The instances are realistic, while capable of sharing common characteristics, excepting differing levels of dynamism and urgency. The dataset thus generated contains instances of the dynamic pickup and delivery problem with time windows (PDPTW), a special case of the VRP that is sufficiently relevant to allow general claims. Further, the dataset, the simulator and all code is available online to allow reproducibility of all results.

The paper is organized as follows. First, the relevant literature is discussed (Section 2). Second, dynamic pickup and delivery problems (PDPs) are formally defined and dynamism and urgency are explained intuitively (Section 3). The novel measures which form the main contribution of the paper are explained (Section 4) and the empirical evaluation is discussed (Section 5). Finally, the conclusions based on the experimental evaluation are presented and the usefulness of the proposed measures to advance the field of dynamic logistics and beyond is discussed (Section 6).

2. Related work

The VRP was first introduced (Dantzig & Ramser, 1959) as a generalization of the TSP (Flood, 1956). A dynamic version of VRP was first studied considering a dynamic version of a special case of VRP transportation of people (Wilson et al., 1977): the dial-a-ride-problem (DARP) (Cordeau & Laporte, 2003). The customer requests (trips from a source to a destination) in a DARP appear dynamically. These type of requests were later formally defined in Psaraftis (1980) as *immediate requests*, distinguished from *advanced requests* that are received before the beginning of the planning horizon.

In this section, we review the existing literature on previously proposed dynamism measures. We also briefly review the state of the art on the dynamic PDPTW.

2.1. Dynamism and measures

The first dynamism measure was introduced by Lund et al. (1996) and later refined by Larsen et al. (2002). Section 4.2 discusses these measures in detail after an intuitive definition of dynamism is presented. Larsen (2000) proposed a framework that distinguishes between weakly, moderately and strongly dynamic systems. The intention of this framework is to quickly find an appropriate algorithm based on the problem's classification.

Beside these works, we have no knowledge of any work that defines measures for dynamism within the field of operations research. Nevertheless, several authors make interesting observations related to dynamism in logistics.

A first observation, by Kilby, Prosser, and Shaw (1998), is that the arrival rate of new tasks in a dynamic VRP is important. If the problem updates constantly, an algorithm will require more restarts than in the case where requests arrive in widely separated bursts. Similarly, Pillac et al. (2013) note that the frequency of updates in problem information have a dramatic impact on the time available for optimization. The statements made by Kilbi et al. and Pillac et al. align with what intuitively could be considered dynamism since the arrival rate of requests is similar to the relative distribution of request announcements.

A second observation, also by Kilby et al. (1998), is about the time at which a commitment to serve a customer at a particular time must be made. The time of the commitment is one of the fundamental questions in dynamic routing. Kilby et al. (1998) define a dynamism-related measure called the *commit horizon*, which denotes the period where the schedule is fixed before the latest possible commit time. The latter is problem-dependent but is often defined as the operation's starting time. Although we did not consider the commit horizon in our study, it may be an interesting property to investigate related to dynamism.

A third noteworthy observation about dynamism in logistics is made by Borndörfer, Grötschel, Klostermeier, and Küttner (1999). In the static DARP, the computed schedule and the schedule executed on the next day often differ significantly because of cancellations of requests, spontaneous requests, vehicle breakdowns and other unpredictable events. This observation suggests that static DARPs are exceptional in practice.

2.2. Literature review on the dynamic PDPTW

Gendreau and Potvin (1998) discussed application domains in which dynamic vehicle routing problems occur, such as dial-a-ride (taxi) problems and courier and repair services. Berbeglia et al. (2010) presented an extensive overview of variants of dynamic PDPs. The dynamic PDPTW is a special case of the dynamic VRP. It should be noted that the dynamic PDPTW is often seen as a stochastic problem, in which some knowledge about the nature of the arrivals is known in advance in a stochastic way, while the actual requests become known only during the operation day (Fu, 2002; Pillac et al., 2013). Psaraftis (1995) remarked, without formally defining near-term, that in dynamic vehicle routing