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# Monitoring delivery chains using multivariate control charts

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ABSTRACT

Delivery chains are concerned with the delivery of goods and services to customers within a specific time interval; this time constraint is added to the usual consumer demand for product or service quality. In this context, we address the idea of using process control tools to monitor this key variable of delivery time. In applications, there are usually several production and delivery sites and a variety of different ways to transport, treat and provide goods and services; that makes the problem multivariate in nature. We therefore propose to control the process using multivariate $T^2$ control charts economically designed with the addition of statistical constraints, a design method called economic-statistical design. We illustrate the application in general through an illustrative example.



## 1. Introduction

One of the main objectives when managing a supply chain is to provide quick, reliable, high quality and economic services and/or products to customers. Using Porter's (1996) value chain approach in which the supply chain includes all activities required to provide a product or service to the final customer, the delivery chain is considered as a part of the flow of goods and services in the supply chain. A delivery chain describes all activities related to the delivery of goods and services to customers in the supply chain. In fact, all activities related to the delivery of products to customers by transportation in a supply chain are included in a delivery chain.

The delivery chain, as the ultimate step of a supply chain, plays an important role in a companies business. As an example, consider a simple business which produces and delivers pizza. Customers want tasty pizza but they want it delivered on time as well. Thus, managers need to control both attributes of their service and/or product. Deming (1986) pointed out that in spite of the involved costs, the benefits of controlling a process can be high in many cases. Forker et al. (1997), Kuei and Madu (2001), Trent (2001), Flynn and Flynn (2005) and Matthews (2006) investigated the application of quality management to supply chains. They established that improving the supply chain effectiveness improved customer satisfaction. Ramos et al. (2007) studied the importance of using quality management activities in the supply chains of Motorola and Rolls-Royce Deutschland companies. They showed that blending quality management activities and SCM would result in higher benefits than their sole application.

In this paper we address the problem of delivery chain control in a comprehensive way through the well-known methods of process monitoring with control charts. Since a delivery chain is characterized by many time variables corresponding to ways between production and delivery sites, the control charts we employ are multivariate. Moreover, control can be costly; in particular, the control costs include the cost of sampling, the cost of poor performance of delivery chains, the cost of adjusting and repairing the delivery process and so on. Effective but expensive control charts schemes result in costs being passed onto the customer. Therefore, methods to monitor delivery chains must be cost effective, and must maintain good statistical properties such as detecting delivery delinquencies as soon as possible and not signaling delinquencies when they do not exist.

The paper is organized as follows. In Section 2, the importance and necessity of economic monitoring of delivery chains and some basic considerations on the use of control charts to monitor delivery chains in general are discussed. In Section 3, the problem is modeled mathematically. An illustrative example is presented in Section 4 while some conclusions are drawn in Section 5.

## 2. Delivery chains and multivariate control charts

The mission of a delivery chain is to provide customers with products within a specified and agreed delivery time. Since there

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may be several production sites (different cities or countries), many customer delivery sites (different cities, countries) and different transportation modes (e.g. trains, planes, trucks, ships ...), the solution is complex.

Establishing a control system on the delivery chain imposes overhead costs to the organization but done efficiently, will reduce costs. Deming (1986) argues this convincingly; more specifically Drucker (1998) argues that in order to compete successfully in the increasingly competitive global marketplace, an organization must be aware of its supply chain and their activities cost and seek economic solutions. Establishing an economic monitoring scheme for the delivery chain will help organizations to reduce costs and optimize customer satisfaction.

### 2.1. A process approach to delivery chains

In order to monitor delivery chains by control charts, the data of delivery chains must be recorded so that identifying unusual patterns and special causes of excessive delays in the routine delivery time of services and goods to the customers can be done. This process of data collection and analysis, of course, is the first step in controlling any process. In particular, some of the important delivery variables include time spent in transporting and delivering products to customers. Then, if the data indicate that the delivery chain process is not performing accordingly, the causes of this poor performance are investigated and removed. For example, data analysis may show that there are predictable shipping delays in using trucks to ship to a metropolitan area because of road improvements being done for a stated period of time. Managers then might want to switch the delivery method to trains during the construction period. In fact, when the mean value shifts to a value that is not the one specified the implication is that the process has changed. When monitoring, which is the focus of this paper, one develops an intervention that accommodates this shift. If the shift is permanent (e.g. suppose a rail system is deemed unprofitable and not used in the future) the change is permanent and the mean value of the process changes. Thus, the process control system must be adjusted. In this case one must estimate the new parameters of the process and recalculate the design. For example, Silver and Rohleder (1999) address this problem in details.

Conceptually the problem is quite simple; applying it to controlling a delivery chain, on the other hand, can be complex.

In the example we present here, near cities and destinations are merged together to form a single node for simplification without loss of generality. Different delivery activities such as air, marine and ground transportations are shown in different branches because companies often have different contracts for different methods of shipping. Fig. 1 illustrates a delivery chain with its time variables. The lengths of the branches in Fig. 1 correspond to the average time needed to complete the job. As is clear, the branches AB and BC are common in all routes and also are significantly longer in time and geographical distance than the others. Thus, there are correlations between the different time variables in the delivery chain. Furthermore, we note that delivery chain performance can be measured indirectly by customer satisfaction level determined by customer survey or directly by on time delivery data.

Because of the above-mentioned correlations, controlling the delivery chain requires the use of multivariate process control, or, in particular, multivariate control charts. Duncan (1956) showed that establishing control charts costs money, but, if designed economically, can save money. So, in this paper, our approach to monitoring a delivery chain is through the use of multivariate control charts that are designed economically. Additionally, to ensure that problems are identified quickly and problems that do not exist are not signaled, we impose constraints on the statistical properties of the control charts, yielding what Saniga (1989) called an economic statistical design.

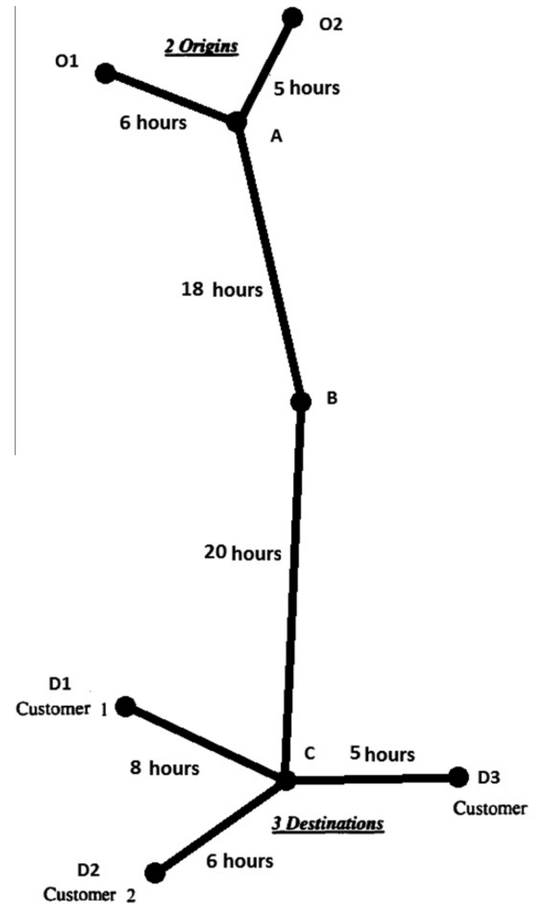


**Fig. 1.** The delivery chain.

### 2.2. The data collection system

When customers place orders, they expect on time deliveries. Furthermore, they expect to receive information regarding the status of the goods, such as loading and unloading times, some information on transits and delivery activities and the expected arrival times and so on. Ideally, customers should be confident that they will have the ordered goods on the agreed time. Customers also require the time schedule of deliveries and need to be notified of any changes in the delivery times. As an example, Fig. 2 illustrates a data collection system used by the TNT express company.

When monitoring delivery chains, determining a source time to record the data is important because if the reference point is not known, observations obtained according to different source points can be misleading and hence control charts lose their efficiency. For example, one might aggregate observations based on when the product is first sent, or when a specific segment of shipping is completed, or when another specific segment of shipping is started. In this paper, we set the source time as the time goods are first sent without loss of generality.

Turning back again to Fig. 1, the quality time variables can be represented by a multivariate quality vector, in which each component represents a route delivery elapsed time from the origin to customers. For example the total elapsed time to deliver goods from production site 1 to customers' location 1 includes $O_1A$, AB, BC and $CD_1$ branches in which the four segment times add up to form the total delivery time. The quality vector then is monitored over time using