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INTRODUCTION TO LOGISTICS SYSTEMS MANAGEMENT

Second Edition

Gianpaolo Ghiani
Gilbert Laporte
Roberto Musmanno

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Introduction to Logistics Systems Management

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To Laura, Allegra and Vittoria
To Ann and Cathy
To Maria Carmela, Francesco and Andrea

Contents

Foreword

Logistics is concerned with the organization, movement and storage of material and people. The term ‘logistics’ was first used by the military to describe the activities associated with maintaining a fighting force in the field and, in its narrowest sense, describes the housing of troops. Over the years the meaning of the term has gradually generalized to cover business and service activities. The domain of logistics activities is providing a system’s customers with the right product, in the right place, at the right time. This ranges from providing the necessary subcomponents for manufacturing, to having inventory on the shelf of a retailer, to having the right amount and type of blood available for hospital surgeries. A fundamental characteristic of logistics is its holistic, integrated view of all the activities that it encompasses. So, while procurement, warehouse management and distribution are all important components, logistics is concerned with the integration of these and other activities to provide the time and space value to the system or corporation. Excess global capacity in most types of industry has generated intense competition. At the same time, the availability of alternative products has created a very demanding type of customer, who insists on the instantaneous availability of a continuous stream of new models. So the providers of logistics activities are asked to do more transactions, in smaller quantities, in less time, for less cost and with greater accuracy. New trends such as mass customization will only intensify these demands. The accelerated pace and greater scope of logistics operations have made planning-as-usual impossible. Even with the increased number and speed of activities, the annual expenses associated with logistics activities in the United States have held constant for the past several years, around 10% of the Gross Domestic Product. Given the significant amounts of money involved and the increased operational requirements, the management of logistics systems has gained widespread attention from practitioners and academic researchers alike. To maximize the value in a logistics system, a large variety of planning decisions has to be made, ranging from the simple warehouse-floor choice of which item to pick next to fulfil a customer order to the corporate-level decision to build a new manufacturing plant. Logistics management supports the full range of those decisions related to the design and operation of logistics systems.

There exists a vast amount of literature, software packages, decision support tools and design algorithms that focus on isolated components of the logistics system or isolated planning in the logistics systems. In the last two decades, several companies have developed Enterprise Resource Planning (ERP) systems in response to the need of global corporations to plan their entire supply chain. In their initial implementations, the ERP systems were primarily used for the recording of transactions rather than for the planning of resources on an enterprise-wide scale. Their main advantage was to provide consistent, up-to-date and accessible data to the enterprise. In recent years, the original ERP systems have been extended with Advanced Planning Systems (APSs). The main function of APSs is, for the first time, the planning of enterprise-wide resources and actions. This implies a coordination of the plans among several organizations and geographically dispersed locations.

So, while logistics management requires an integrated, holistic approach, its treatment in courses and textbooks tends to be either integrated and qualitative or mathematical and very specific. This book bridges the gap between those two approaches. It provides a comprehensive and modelling-based treatment of the logistics processes. The major components of logistics systems (storage and distribution) are each examined in detail. For each topic the problem is defined, models and solution algorithms are presented that support computer-assisted decision making and numerous application examples are provided. Each chapter concludes with case studies that illustrate the application of the models and algorithms in practice. Because of its rigorous mathematical treatment of real-world management problems in logistics, this book will provide a valuable resource to graduate and senior undergraduate students and practitioners who are trying to improve logistics operations and satisfy their customers.

Marc Goetschalckx
Georgia Institute of Technology
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Preface

Logistics lies at the heart of modern economies. From the steel factories of Pennsylvania to the port of Singapore, from Nicaraguan banana fields to the postal delivery and solid waste collection companies in any region around the world, almost every organization faces the common problem of getting the right materials to the right place at the right time. Indeed, the fierce competition in today's markets has made it imperative to manage logistics systems more and more efficiently. In this context, quantitative methods have proved able to achieve remarkable savings.

This textbook has grown from a number of undergraduate and graduate courses on logistics that we have taught to engineering, computer science and management science students. The goal of these courses is to give students a solid understanding of the analytical tools necessary to reduce costs and improve the service level in logistics systems. The lack of a suitable textbook had forced us in the past to make use of a number of monographs and scientific papers which tend to be beyond the level of most students. We therefore committed ourselves to developing a quantitative textbook written at a level accessible to most students.

In 2004 we published with Wiley a book entitled *Introduction to Logistics Systems Planning and Control*, which was widely used in several universities throughout the world. The 2004 edition of the book received the Roger-Charbonneau award from HEC Montréal as the best pedagogical textbook of the year. In view of this success, we proceeded to prepare a substantially revised edition now entitled *Introduction to Logistics Systems Management*.

This new edition puts more emphasis on the organizational context in which logistics systems operate. It also covers several new results and techniques that have arisen in the field of logistics over the past decade. This book targets an academic as well a practitioner audience. On the academic side, it should be appropriate for advanced undergraduate and graduate courses in logistics and supply chain management. It should also serve as a methodological reference for practitioners in consulting as well as in industry. We make the assumption that the reader is familiar with the basics of operations research and statistics, and we provide a balanced treatment of forecasting, logistics system design, warehouse management and freight transport management. In our text, every topic is illustrated by a numerical example so that the reader can check his or her understanding of each concept before moving on to the next one. We provide at the end of each chapter case studies taken from the scientific literature, which illustrate the use of quantitative methods for solving complex logistics decision problems. Finally, every chapter ends with an exhaustive set of exercises.

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Exercises and Website

This textbook contains questions and problems at the end of every chapter. Some are discussion questions, while others focus on modelling or algorithmic issues. The answers to these problems are available at the book's website (`http://www.wiley.com/go/logistics_systems_management`), which also contains additional material (FAQs, a list of references, software, further modelling exercises, links to other websites etc.).

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List of Abbreviations

1-BP	One Bin Packing
2-BP	Two Bin Packing
3-BP	Three Bin Packing
3PL	Third Party Logistics
AGVS	Automated Guided Vehicle System
AHP	Analytical Hierarchic Process
AIRT	Inter-Regional Association of Transplantation
ANN	Artificial Neural Network
APS	Advanced Planning System
AP	Assignment Problem
ARP	Arc Routing Problem
AS	Air-Stop
AS/RS	Automated Storage/Retrieval System
ASM	Absolute Scoring Method
ATSP	Asymmetric Travelling Salesman Problem
B2B	Business-to-Business
BF	Best Fit
BFD	Best Fit Decreasing
BL	Bottom Left
BTT	Baxter Transfusion Therapy
CDC	Central Distribution Centre
CEO	Chief Executive Officer
CIR	Inter-Regional Centre
CL	Carload
COT	Cut-Off Time
CPFR	Collaborative Forecasting and Replenishment Program
CPL	Capacitated Plant Location
CPP	Chinese Postman Problem
CRP	Continuous Replenishment Program
DC	Distribution Centre
DDAP	Dynamic Driver Assignment Problem
EAN	European Article Number
EDI	Electronic Data Interchange
ELC	European Logistics Centre

EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
EU	European Union
EUPP	European Union Pfizer Plant
FBF	Finite Best Fit
FCNDP	Fixed Charge Network Design Problem
FDA	Food and Drugs Administration
FF	First Fit
FFD	First Fit Decreasing
FFF	Finite First Fit
FIFO	First-In, First-Out
GIS	Geographic Information System
GOD	Great Organised Distribution
GPS	Global Positioning System
ICT	Information and Communication Technology
IP	Intger Programming
IRP	Inventory-Routing Problem
ISO	International Organization for Standardisation
KPI	Key Performance Indicator
LB	Lower Bound
LFCNDP	Linear Fixed Charge Network Design Problem
LIFO	Last-In, First-Out
LMCFP	Linear Minimum Cost Flow Problem
LMMCFP	Linear Multicommodity Minimum Cost Flow Problem
LP	Linear Programming
LTL	Less-Than-Truckload
MAD	Mean Absolute Deviation
MAPD	Mean Absolute Percentage Deviation
MCTE	Multiple-Commodity Two-Echelon
MIP	Mixed Integer Programming
MMCFP	Multicommodity Minimum Cost Flow Problem
MRP	Material Requirement Planning
MS	Multiple Source
MSE	Mean Squared Error
MSrTP	Minimum spanning r-tree problem
MTO	Make to Order
MTS	Make to Stock
NAPM	National Association of Purchasing Managers
NCC	National Classification Committee
NF	Network Flow
NITp	Nort-Italy Transplantation
NMFC	National Motor Freight Classification
NP	Non-Polynomial
NRP	Node Routing Problem

NRPCL	Node Routing Problem with Capacity and Length Constraints
NRPSC	Node Routing Problem – Set Covering
NRPSP	Node Routing Problem – Set Partitioning
NRSPTW	Node Routing and Scheduling Problem with Time Windows
NTC	National Transplant Centre
OCST	Centre-South Organization of Transplantation
PCB	Printed Circuit Board
PZ	Pick Zone
RDC	Regional Distribution Centre
RFId	Radio Frequency Identification
R-LMMCFP	Relaxed Linear Multicommodity Minimum Cost Flow Problem
RPP	Rural Postman Problem
RSM	Relative Scoring Method
RTSP	Road Travelling Salesman Problem
RZ	Reserve Zone
SC	Shipment Centre (Section 6.12)
SC	Set Covering
SCSE	Single-Commodity Single-Echelon
SCTE	Single-Commodity Two-Echelon
SNDP	Service Network Design Problem
SPL	Simple Plant Location
SQI	Supplier Quality Index
SS	Single Source
SSCC	Serial Shipping Container Code
STSP	Symmetric Travelling Salesman Problem
TAP	Traffic Assignment Problem
TL	Truckload
TS	Tabu Search
TSP	Travelling Salesman Problem
UB	Upper Bound
VAP	Vehicle Allocation Problem
VRDP	Vehicle Routing and Dispatching Problem
VRP	Vehicle Routing Problem
VRPMT	Vehicle Routing Problem with Multiple Trips
VRSP	Vehicle Routing and Scheduling Problems
ZIO	Zero Inventory Ordering

1

Introducing logistics

1.1 Definition of logistics

According to a widespread definition, logistics (from the Greek term *lógos*, which means 'order', or from the French *loger*, which means 'allocate') is the discipline that studies the functional activities determining the flow of materials (and of the relative information) in a company, from their origin at the suppliers up to delivery of the finished products to the customers and to the post-sales service. The origins of logistics are of a strictly military nature. In fact, this discipline arose as the study of the methodologies employed to guarantee the correct supply of troops with victuals, ammunitions and fuel and, in general, to ensure armies the possibility of moving and fighting in the most efficient conditions. Indeed it was the Babylonians, in the distant 20th century BC, who first created a military corps specialized in the supply, storage, transport and distribution of soldiers' equipment. Logistics was applied exclusively in a military context until the end of Second World War. Subsequently, it was extended to manufacturing companies in order to determine all the activities aimed at ensuring the correct purchasing, moving and managing of materials. Logistics problems are also increasingly present in the service sector, for example in the distribution of some services such as water and gas, in postal services, in urban solid waste collection, in the maintenance of road and electricity networks and in the post-sales activities of manufacturing companies (*service logistics*).

1.2 Logistics systems

From the point of view of companies, logistics is seen as a system (the logistics system), which includes not only all the functional activities determining the flow

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of materials and information, but also the infrastructures, means, equipment and resources that are indispensable to the execution of these activities.

A logistics system is made up of facilities, where one or more functional activities are carried out (e.g. storage and distribution). Figure 1.1 shows a schematic representation of a logistics system in which the manufacturing process of the finished goods is divided into a transformation phase and an assembly phase, performed in different centres. At the start are the suppliers of materials and components which feed the final manufacturing process. The end part represents a typical two-level distribution system with a tree structure. The Central Distribution Centres (CDCs) are directly supplied by the production plants, while each Regional Distribution Centre (RDC) is connected to a single CDC which has the task of serving the customer, who can also be dealers or retailers.

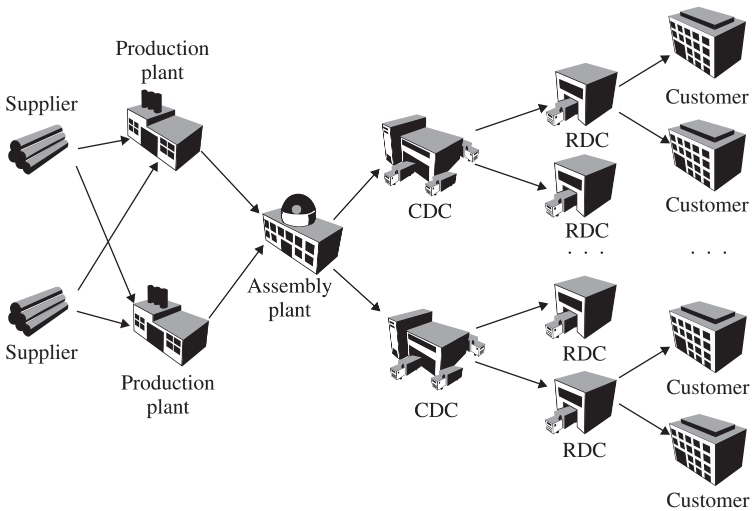

Figure 1.1 Example of a logistics system.

At each facility the flow of materials is temporarily interrupted, generally in order to change their physical-chemical composition, ownership or appearance. In all cases, each logistic activity carried out involves costs which affect the value of the product, constantly adding to it as it draws nearer the facilities closest to the final customer. This added value can be spatial (following e.g. distribution activities) or temporal (owing to storage activities).

Galbani is the Italian leader in the milk and dairy products sector and one of the main actors in the pressed pork market. The Galbani group is currently made up of three independent operational societies, one of them called biG Logistics. This company has the task of managing the logistics activities of the whole group. The logistics system is organized in such a way as to guarantee an efficient synchronization of the internal production and distribution processes of the products, both for the Great Organized Distribution (GOD) and for the channel represented by the traditional retail shops. The distribution network of the company is organized on two levels: there are, between the production plants and the destination markets, a central warehouse and 11 distribution platforms. This solution allows the minimization of the transport times and of the storage times of the goods in the warehouses. As a result, it favours a rapid delivery of the products, strictly respecting the refrigeration chain (deliveries within 12 hours for national distribution and 24 to 36 hours for abroad). The daily products are dispatched directly by the production plants to the central warehouse, located in the area of Ospedaletto Lodigiano, considered a barycentral position with respect to the national markets of the Galbani group. The central warehouse serves, in turn, the second-level platforms with the orders mixed according to their destination (see Figure 1.2). The platforms receive the entering flow of goods from the central warehouse and supply both the Distribution Centres of the GOD and the so-called satellites. The satellites are small-sized stores without stockpiles, with vans used for distribution to retailers. The van operates as a truly travelling store. There are 111 satellites distributed throughout the national territory, with a coverage radius on the provincial scale.

Figure 1.2 Geographical position of the central warehouse (in grey) and the 11 distribution platforms of the logistics system of Galbani.

A logistics system can be represented by means of a directed (multi)graph $G = (V, A)$, where V is the set of facilities, and A is the set of links existing among the facilities used for the flow of materials (see Figure 1.3). There can be several arcs between a pair of facilities, representative of alternative forms of transport services, different routes, or different products.

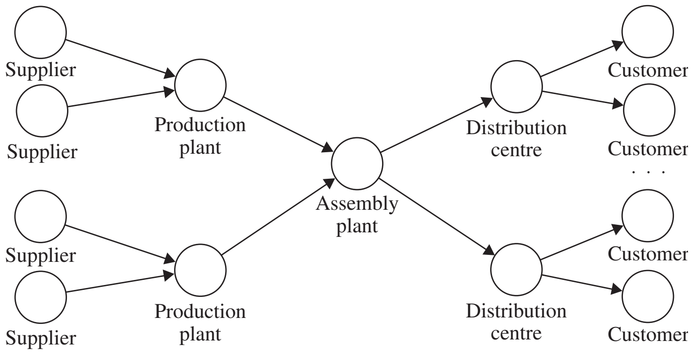

Figure 1.3 Representation of a logistics system system by a directed graph.

The logistics system of Galbani can be represented by the directed graph of Figure 1.4.

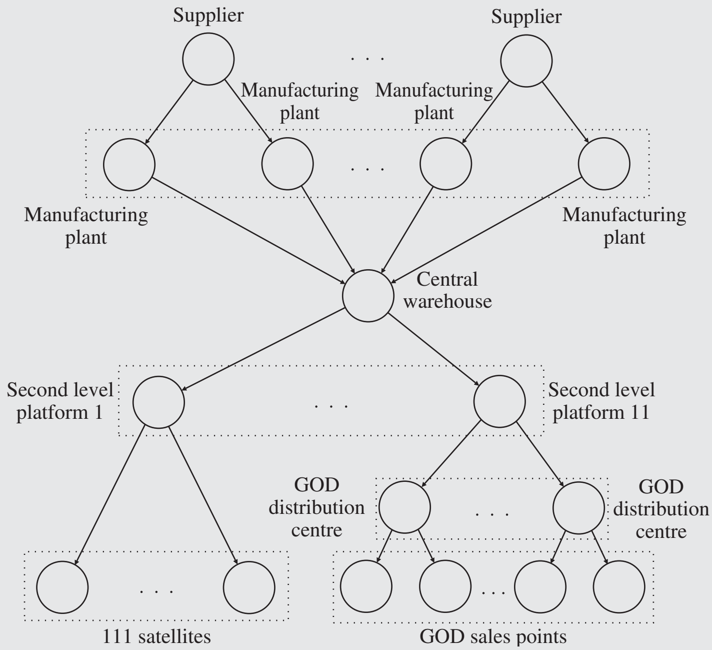

Figure 1.4 Representation by a directed graph of the logistics system of Galbani.

1.2.1 Logistics activities

Logistics activities are traditionally classified depending on their location with respect to the production and distribution process. In particular, *supply logistics* is carried out before the production plants and consists in the management of raw materials, materials and component parts supply as a function of the company's production plan. *Internal logistics* is carried out in the production plants and consists in receiving and storing materials, in picking them up from the warehouse to feed the production lines and in successively moving the semi-finished goods up to packaging and storing the finished product. Finally, the *distribution logistics* activities are carried out after the production plants and before the market. They supply the sales points or the customers. In this schematization, the supply logistics and the distribution logistics are collectively called *external logistics*.

Storage and *distribution* of the finished products are the primary logistics activities, and particular attention will be paid to them in this text. Logistics activities can be conducted by the company itself or can be entrusted to a third party (3PL, or *Third Party Logistics*). These choices are made by the company according to the same logic on which 'make or buy'-type decisions are based. They assume an in-depth knowledge of the nature of the costs that the company bears (fixed costs, variable costs, direct costs, and indirect costs).

When the multinational company Gillette decided to reorganize its logistics system in Turkey in 1999, it entrusted the Exel company with the execution of a series of logistics activities on its behalf, including distribution (both at national and international levels), customs issues, storage of finished products, and repackaging and labelling of the products.

1.2.2 Information flows and logistics networks

Within a logistics system, with the exception of the cases where recycling of product wrapping is provided or where defective components or products are returned, the flow of materials typically moves from the suppliers to the processing and assembly plants, thence to the sales points and finally to the customers. The flow of materials is integrated with an information flow which follows the opposite direction: in the logistics systems of the MTO-type (*Make to Order*), for example, customers' orders influence the production plan and the latter determines the demand for materials and components of the processing and assembly plants. Analogously, in MTS-type (*Make to Stock*) logistics systems, market information (demand recorded in the past, results of possible market surveys etc.) is used to forecast the sales and therefore affects the mode of distribution, as well as the production and supply plans.

The production centres of the Galbani group determine the daily production plan on the basis of recorded predictive data, among others, from the volumes distributed the previous working day. In this case, the 11 logistics platforms gather the sales data recorded both at the GOD and at the satellites, and this information is transmitted to the central warehouse and from there to the production plants.

Hellena is a Dutch company that produces biscuits. The ordering of raw wheat flour is done by fax. Once an order is received and the goods prepared, the supplier provides for the dispatch of the product which must be accompanied by the delivery note. This document must therefore be issued before delivery or dispatch of the goods with specifications of the main elements of the operation (serial number, date, quantity and description of the goods transported etc.) and issued with a minimum of two copies (one must be retained and filed by the supplier and the other must be consigned to the customer together with the transported goods). In this context, two information flows are activated. The first, relative to the sending of the fax, travels in the opposite direction from the transport of the order (from the customer to the supplier) and also uses a different channel. The second, the delivery note, accompanies the consignment, using the same channel as the goods and travelling in the same direction.

An existing information flow (created through fax, email etc.) between a pair of facilities can be represented by an arc. This means that the information network, that is, the set of information flows, can also be represented by a directed (multi)graph, analogously to the network of materials flow.

Networks of materials flow and information networks give rise to *logistics networks* (see Figure 1.5).

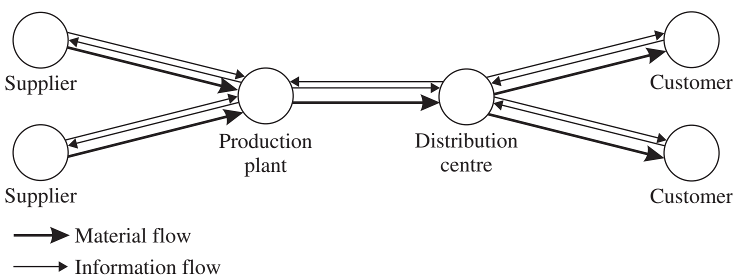

Figure 1.5 Representation of a logistics network.