Introduction to Logistics Systems Planning and Control

Gianpaolo Ghiani

Department of Innovation Engineering,
University of Lecce, Italy

Gilbert Laporte

Canada Research Chair in Distribution Management,
HEC Montréal, Canada

Roberto Musmanno

Department of Electronics, Informatics and Systems,
University of Calabria, Italy

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John Wiley & Sons, Ltd

Phone (+44) 1243 779777

Email (for orders and customer service enquiries): cs-books@wiley.co.uk

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Jossey-Bass, 989 Market Street, San Francisco, CA 94103-1741, USA

Wiley-VCH Verlag GmbH, Boschstr. 12, D-69469 Weinheim, Germany

John Wiley & Sons Australia Ltd, 33 Park Road, Milton, Queensland 4064, Australia

John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop #02-01, Jin Xing Distripark, Singapore 129809

John Wiley & Sons Canada Ltd, 22 Worcester Road, Etobicoke, Ontario, Canada M9W 1L1

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Library of Congress Cataloguing-in-Publication Data

Ghiani, Gianpaolo.
Introduction to logistics systems planning and control / Gianpaolo Ghiani,
Gilbert Laporte, Roberto Musmanno.
p. cm. – (Wiley-Interscience series in systems and optimization)
Includes bibliographical references and index.
ISBN 0-470-84916-9 (alk. paper) – ISBN 0-470-84917-7 (pbk.: alk. paper)
1. Materials management. 2. Materials handling. I. Laporte, Gilbert. II. Musmanno, Roberto. III. Title. IV. Series.

TS161.G47 2003
658.7–dc22 2003057594

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 0-470-84916-9 (Cloth)
0-470-84917-7 (Paper)

Produced from LaTeX files supplied by the authors, typeset by T&T Productions Ltd, London.

Printed and bound in Great Britain by TJ International, Padstow, Cornwall.

This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

To Laura

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 the customers of the system with the right product, in the right place, at the right time. This ranges from providing the necessary subcomponents for manufacturing, 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, inventory management, transportation management, 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, with less lead time, 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 has 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 last several years around ten per cent of the gross domestic product. Given the significant amounts of money involved and the increased operational requirements, the planning and control 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 planning 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 planning and control requires an integrated, holistic approach, their 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 complete distribution system and process, including the design of distribution centres, terminal operations and transportation operations. The three major components of logistics systems—inventory, transportation and facilities—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. The book concludes with an extensive set of case studies that illustrate the application of the models and algorithms in practice. Because of its rigorous mathematical treatment of real-world planning and control problems in logistics, the 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
Atlanta, May 2003

Preface

Logistics is key to the modern economy. From the steel factories of Pennsylvania to the port of Singapore, from the Nicaraguan banana fields to postal delivery and solid waste collection in any region of the world, almost every organization faces the problem of getting the right materials to the right place at the right time. Increasingly competitive markets are making it imperative to manage logistics systems more and more efficiently.

This textbook grew out of a number of undergraduate and graduate courses on logistics and supply chain management 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 available to reduce costs and improve service levels in logistics systems. For several years, the lack of a suitable textbook forced us to make use of a number of monographs and scientific papers which tended to be beyond the level of most students. We therefore committed ourselves to developing a quantitative textbook, written at a more accessible level.

The book targets both an educational audience and practitioners. It should be appropriate for advanced undergraduate and graduate courses in logistics, operations management, and supply chain management. It should also serve as a 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, probability theory and statistics. We provide a balanced treatment of sales forecasting, logistics system design, inventory management, warehouse design and management, and freight transport planning and control. In the final chapter we present some insightful case studies, taken from the scientific literature, which illustrate the use of quantitative methods for solving complex logistics decision problems.

In our text every topic is illustrated with a numerical example so that the reader can check his or her understanding of each concept before going on to the next one. In addition, a concise annotated bibliography at the end of each chapter acquaints the reader with the state of the art in logistics.

Abbreviations

1-BP	One-Dimensional Bin Packing
2-BP	Two-Dimensional Bin Packing
3-BP	Three-Dimensional Bin Packing
3PL	Third Party Logistics
AP	Assignment Problem
ARP	Arc Routing Problem
AS/RS	Automated Storage and Retrieval System
ATSP	Asymmetric Travelling Salesman Problem
B2B	Business To Business
B2C	Business To Consumers
BF	Best Fit
BFD	Best Fit Decreasing
BL	Bottom Left
CDC	Central Distribution Centre
CPL	Capacitated Plant Location
CPP	Chinese Postman Problem
DC	Distribution Centre
DDAP	Dynamic Driver Assignment Problem
EDI	Electronic Data Interchange
EOQ	Economic Order Quantity
EU	European Union
FBF	Finite Best Fit
FCFS	First Come First Served
FCND	Fixed Charge Network Design
FF	First Fit
FFD	First Fit Decreasing
FFF	Finite First Fit
GIS	Geographic Information System
GDP	Gross Domestic Product
GPS	Global Positioning Systems
IP	Integer Programming

IRP	Inventory-Routing Problem
ITR	Inventory Turnover Ratio
KPI	Key Performance Indicator
LB	Lower Bound
LFND	Linear Fixed Charge Network Design
LMCF	Linear Single-Commodity Minimum-Cost Flow
LMMCF	Linear Multicommodity Minimum-Cost Flow
LP	Linear Programming
LTL	Less-Than-Truckload
MAD	Mean Absolute Deviation
$MAPD$	Mean Absolute Percentage Deviation
MIP	Mixed-Integer Programming
MMCF	Multicommodity Minimum-Cost Flow
MRP	Manufacturing Resource Planning
MSrTP	Minimum-cost Spanning r-Tree Problem
MSE	Mean Squared Error
MTA	Make-To-Assembly
MTO	Make-To-Order
MTS	Make-To-Stock
NAFTA	North America Free Trade Agreement
NF	Network Flow
NLP	Nonlinear Programming
NMFC	National Motor Freight Classification
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
PCB	Printed Circuit Board
POPITT	Points Of Presence In The Territory
RDC	Regional Distribution Centre
RPP	Rural Postman Problem
RTSP	Road Travelling Salesman Problem
S/R	Storage And Retrieval
SC	Set Covering
SCOR	Supply Chain Operations References
SESC	Single-Echelon Single-Commodity
SKU	Stock Keeping Unit
SPL	Simple Plant Location
STSP	Symmetric Travelling Salesman Problem
TAP	Traffic Assignment Problem

TEMC	Two-Echelon Multicommodity
TEU	Twenty-foot Equivalent Unit
TL	Truckload
TS	Tabu Search
TSP	Travelling Salesman Problem
UB	Upper Bound
VAP	Vehicle Allocation Problem
VMR	Vendor-Managed Resupplying
VRDP	Vehicle Routing and Dispatching Problem
VRP	Vehicle Routing Problem
VRSP	Vehicle Routing and Scheduling Problem
W/RPS	Walk/Ride and Pick Systems
ZIO	Zero Inventory Ordering

Problems 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 on the book's website

http://wileylogisticsbook.dii.unile.it,

which also contains additional material (FAQs, software, further modelling exercises, links to other websites, etc.).

Acknowledgements

We thank all the individuals and organizations who helped in one way or another to produce this textbook. First and most of all, we would like to thank Professor Lucio Grandinetti (University of Calabria) for his encouragement and support. We are grateful to the reviewers whose comments were invaluable in improving the organization and presentation of the book. We are also indebted to Fabio Fiscaletti (Pfizer Pharmaceuticals Group) and Luca Lenzi (ExxonMobil Chemical), who provided several helpful ideas. In addition, we thank HEC Montréal for its financial support. Our thanks also go to Maria Teresa Guaglianone, Francesca Vocaturo and Sandro Zacchino for their technical assistance, and to Nicole Paradis for carefully editing and proofreading the material. Finally, the book would not have taken shape without the very capable assistance of Rob Calver, our editor at Wiley.

About the Authors

Gianpaolo Ghiani is Associate Professor of Operations Research at the University of Lecce, Italy. His main research interests lie in the field of combinatorial optimization, particularly in vehicle routing, location and layout problems. He has published in a variety of journals, including *Mathematical Programming*, *Operations Research Letters*, *Networks*, *Transportation Science*, *Optimization Methods and Software*, *Computers and Operations Research*, *International Transactions in Operational Research*, *European Journal of Operational Research*, *Journal of the Operational Research Society*, *Parallel Computing* and *Journal of Intelligent Manufacturing Systems*. His doctoral thesis was awarded the Transportation Science Dissertation Award from INFORMS in 1998. He is an editorial board member of *Computers & Operations Research*.

Gilbert Laporte obtained his PhD in Operations Research at the London School of Economics in 1975. He is Professor of Operations Research at HEC Montréal, Director of the Canada Research Chair in Distribution Management, and Adjunct Professor at the University of Alberta. He is also a member of GERAD, of the Centre for Research on Transportation (serving as director from 1987 to 1991), and Fellow of the Center for Management of Operations and Logistics, University of Texas at Austin. He has authored or coauthored several books, as well as more than 225 scientific articles in combinatorial optimization, mostly in the areas of vehicle routing, location, districting and timetabling. He is the current editor of *Computers & Operations Research* and served as editor of *Transportation Science* from 1995 to 2002. He has received many scientific awards including the Pergamon Prize (United Kingdom), the Merit Award of the Canadian Operational Research Society, the CORS Practice Prize on two occasions, the Jacques-Rousseau Prize for Interdisciplinarity, as well as the President's medal of the Operational Research Society (United Kingdom). In 1998 he became a member of the Royal Society of Canada.

Roberto Musmanno is Professor of Operations Research at the University of Calabria, Italy. His major research interests lie in logistics, network optimization and parallel computing. He has published in a variety of journals, including *Operations Research*, *Transportation Science*, *Computational Optimization and Applications*, *Optimization Methods & Software*, *Journal of Optimization Theory and Applications*, *Optimization* and *Parallel Computing*. He is also a member of the Scientific

Committee of the Italian Center of Excellence on High Performance Computing, and an editorial board member of *Computers & Operations Research*.

1

Introducing Logistics Systems

1.1 Introduction

Logistics deals with the planning and control of material flows and related information in organizations, both in the public and private sectors. Broadly speaking, its mission is to get the right materials to the right place at the right time, while optimizing a given performance measure (e.g. minimizing total operating costs) and satisfying a given set of constraints (e.g. a budget constraint). In the military context, logistics is concerned with the supply of troops with food, armaments, ammunitions and spare parts, as well as the transport of troops themselves. In civil organizations, logistics issues are encountered in firms producing and distributing physical goods. The key issue is to decide how and when raw materials, semi-finished and finished goods should be acquired, moved and stored. Logistics problems also arise in firms and public organizations producing services. This is the case of garbage collection, mail delivery, public utilities and after-sales service.

Significance of logistics. Logistics is one of the most important activities in modern societies. A few figures can be used to illustrate this assertion. It has been estimated that the total logistics cost incurred by USA organizations in 1997 was 862 billion dollars, corresponding to approximately 11% of the USA Gross Domestic Product (GDP). This cost is higher than the combined annual USA government expenditure in social security, health services and defence. These figures are similar to those observed for the other North America Free Trade Agreement (NAFTA) countries and for the European Union (EU) countries. Furthermore, logistics costs represent a significant part of a company's sales, as shown in Table 1.1 for EU firms in 1993.

Logistics systems. A logistics system is made up of a set of *facilities* linked by *transportation services*. Facilities are sites where materials are processed, e.g. manufactured, stored, sorted, sold or consumed. They include manufacturing and assembly centres, warehouses, distribution centres (DCs), transshipment points, transportation terminals, retail outlets, mail sorting centres, garbage incinerators, dump sites, etc.

Introduction to Logistics Systems Planning and Control G. Ghiani, G. Laporte and R. Musmanno
 ISBN: 0-470-84916-9 (HB) 0-470-84917-7 (PB)

Table 1.1 Logistics costs (as a percentage of GDP) in EU countries (T, transportation; W, warehousing; I, inventory; A, administration).

Sector	T	W	I	A	Total
Food/beverage	3.7	2.2	2.8	1.7	10.4
Electronics	2.0	2.0	3.8	2.5	10.3
Chemical	3.8	2.3	2.6	1.5	10.2
Automotive	2.7	2.3	2.7	1.2	8.9
Pharmaceutical	2.2	2.0	2.5	2.1	8.8
Newspapers	4.7	3.0	3.6	2.1	13.4

Transportation services move materials between facilities using vehicles and equipment such as trucks, tractors, trailers, crews, pallets, containers, cars and trains. A few examples will help clarify these concepts.

ExxonMobil Chemical is one of the largest petrochemical companies in the world. Its products include olefins, aromatics, synthetic rubber, polyethylene, polypropylene and oriented polypropylene packaging films. The company operates its 54 manufacturing plants in more than 20 countries and markets its products in more than 130 countries.

The plant located in Brindisi (Italy) is devoted to the manufacturing of oriented polypropylene packaging films for the European market. Films manufactured in Brindisi that need to be metallized are sent to third-party plants located in Italy and in Luxembourg, where a very thin coating of aluminium is applied to one side. As a rule, Italian end-users are supplied directly by the Brindisi plant while customers and third-party plants outside Italy are replenished through the DC located in Milan (Italy). In particular, this warehouse supplies three DCs located in Herstal, Athus and Zeebrugge (Belgium), which in turn replenish customers situated in Eastern Europe, Central Europe and Great Britain, respectively. Further details on the ExxonMobil supply chain can be found in Section 8.2.

The Pfizer Pharmaceuticals Group is the largest pharmaceutical corporation in the world. The company manufactures and distributes a broad assortment of pharmaceutical products meeting essential medical needs, a wide range of consumer products for self-care and well-being, and health products for livestock and pets. The Pfizer logistics system comprises 58 manufacturing sites in five continents producing medicines for more than 150 countries. Because manufacturing pharmaceutical products requires highly specialized and costly machines, each Pfizer plant produces a large amount of a limited number of pharmaceutical ingredients or medicines for an international market. For example, ALFA10, a cardiovascular product, is produced in a unique plant for an international market including 90 countries. For this reason, freight transportation plays a key role in the Pfizer supply chain. A more detailed description of the Pfizer logistics system is given in Section 8.3.

Railion is an international carrier, based in Mainz (Germany), whose core business is rail transport. Railion transports a vast range of products, such as steel, coal, iron ore, paper, timber, cars, washing machines, computers as well as chemical products. In 2001 the company moved about 500 000 containers. Besides offering high-quality rail transport, Railion is also engaged in the development of integrated logistics systems. This involves close cooperation with third parties, such as road haulage, waterborne transport, forwarding and transshipment companies. More details on the freight rail transportation system at Railion can be found in Section 8.4.

The Gioia Tauro marine terminal is the largest container transshipment hub on the Mediterranean Sea and one of the largest in the world. In 1999, its traffic amounted to 2253 million Twenty-foot Equivalent Units (TEUs). The terminal is linked to nearly 50 end-of-line ports on the Mediterranean Sea. Inside the terminal is a railway station where cars can be loaded or unloaded and convoys can be formed. Section 8.5 is devoted to an in-depth description of the Gioia Tauro terminal.

The waste management system of the regional municipality of Hamilton-Wentworth (Canada) is divided into two major subsystems: the solid waste collection system and the regional disposal system. Each city or town is in charge of its own kerbside garbage collection, using either its own workforce or a contracted service. On the other hand, the regional municipality is responsible for the treatment and disposal of the collected wastes. For the purposes of municipal solid waste planning, the region is divided into 17 districts. The regional management is made up of a waste-to-energy facility, a recycling facility, a 550 acre landfill, a hazardous waste depot and three transfer stations. Section 8.6 contains a more detailed description of this logistics system.

Supply chains. A *supply chain* is a complex logistics system in which raw materials are converted into finished products and then distributed to the final users (consumers or companies). It includes suppliers, manufacturing centres, warehouses, DCs and retail outlets. Figure 1.1 shows a typical supply chain in which the production and distribution systems are made up of two stages each. In the production system, components and semi-finished parts are produced in two manufacturing centres while finished goods are assembled at a different plant. The distribution system consists

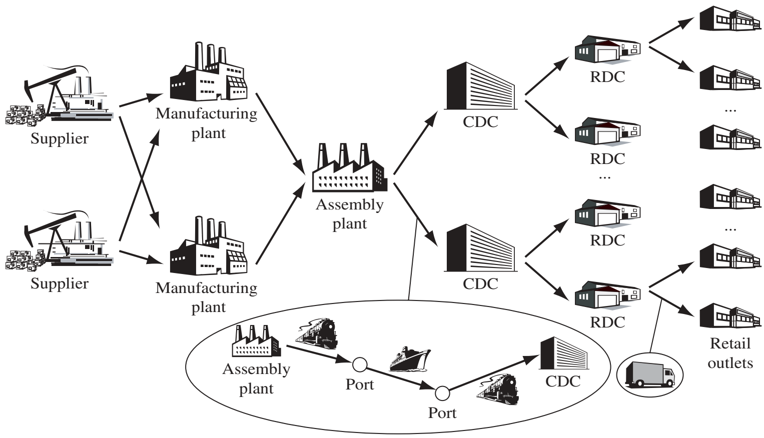

Figure 1.1 A supply chain.

of two *central distribution centres* (CDCs) supplied directly by the assembly centre, which in turn replenish two *regional distribution centres* (RDCs) each. Of course, depending on product and demand characteristics it may be more appropriate to design a supply chain without separate manufacturing and assembly centres (or even without an assembly phase), without RDCs or with different kinds of facilities (e.g. cross-docks, see Section 1.2.2). Each of the transportation links in Figure 1.1 could be a simple transportation line (e.g. a truck line) or of a more complex transportation process involving additional facilities (e.g. port terminals) and companies (e.g. truck carriers). Similarly, each facility in Figure 1.1 comprises several devices and subsystems. For example, manufacturing plants contain machines, buffers, belt conveyors or other material handling equipment, while DCs include shelves, forklifts or automatic storage and retrieval systems. Logistics is not normally associated with the detailed planning of material flows inside manufacturing and assembly plants. Strictly speaking, topics like aggregate production planning and machine scheduling are beyond the scope of logistics and are not examined in this textbook. The core logistics issues described in this book are the design and operations of DCs and transportation terminals.

Push versus pull supply chains. Supply chains are often classified as push or pull systems. In a *pull* (or *make-to-order* (MTO)) system, finished products are manufactured only when customers require them. Hence, in principle, no inventories are needed at the manufacturer. In a *push* (or *make-to-stock* (MTS)) system, production and distribution decisions are based on forecasts. As a result, production anticipates effective demand, and inventories are held in warehouses and at the retailers. Whether a push system is more appropriate than a pull system depends on product features, manufacturing process characteristics, as well as demand volume and variability. MTO systems are more suitable whenever lead times are short, products are costly, and demand is low and highly variable. In some cases, a mixed approach can be used.