Fundamentals of Production Logistics
Preface to the 1st English Edition

In recent years, the Logistic Operations Curves Theory has raised increasing attention in the international scientific community of operations management. This has encouraged us to present an English translation of the second German edition. The Logistic Operations Curves Theory continues to be developed and will be further expanded.

Our sincere thanks is addressed to Daniel Berkholz, a research engineer at the Institute of Production Systems and Logistics (IFA), Leibniz University of Hannover, as well as the translator Rett Rossi for their enthusiasm and never ending efforts to help us find a sound, scientific path through the jungle of new variables and terms not used in traditional literature.

We wish our readers a fruitful discourse with our ideas and look forward to receiving any feedback you may have.

Garbsen, December 2007

Peter Nyhuis
Hans-Peter Wiendahl

Preface to the 2nd German Edition

The first edition of this book was met with very positive resonance. Numerous questions and suggestions provided an incentive for us to continue working on the Logistic Operating Curves (LOC) and to let the new results flow into this second edition.

The range of validity for the Logistic Operating Curves Theory has been extended by Schneider, who developed the Manufacturing System Operating Curve (MSOC). The MSOC makes it possible to establish Logistic Operating Curves for manufacturing areas with randomly networked workstations.
The Schedule Reliability Operating Curves (SROC) developed by Yu are a completely new approach. Yu has succeeded in deriving an approximation equation for describing the schedule reliability of a workstation.

The Storage Operating Curves (SOC) were expanded by Lutz to include the so-called Service Level Operating Curves (SLOC). Based on them and in analogy to the Bottleneck Oriented Logistic Analysis for production areas the Logistic Storage Analysis was developed. Quantifying the logistic potential in a storage area and identifying the measures necessary for exploiting it are essential elements of this method of analysis.

By linking the Bottleneck Oriented Logistic Analysis with the Logistic Storage Analysis the logistic interactions within a supply chain can also be understood. The potential can be determined with regards to the service and stock levels including over a number of value adding stages. Moreover, these can be aggregated and expressed as a total potential. Thus, there is now a fundamental and consistent analysis method available for quantifying the inherent relations between the logistic objectives in production systems, in the different storage stages, and in the entire supply chain.

We would like to express our heartfelt appreciation to Stefan Lutz, Michael Schneider and Kwok-Wai Yu for their support in developing the new sections.

To all of our readers, including both those who work in research as well as practitioners, we hope to provide continued inspiration and practical support in overcoming their logistic problems. We welcome the chance to receive your constructive criticism, suggestions and any experiences you may have in applying the Logistic Operating Curves Theory.

Hannover/Munich, Summer 2002

Peter Nyhuis
Hans-Peter Wiendahl

Preface to the 1st German Edition

For many production enterprises, the possibility of distinguishing themselves from their competitors is frequently possible due to a shorter delivery time and higher delivery reliability. This requires firmly controlling the internal throughput times and schedule adherence. At the same time cost relevant goals such as stable and high utilization as well as low stock levels in the raw material, semi-finished and finished goods stores cannot be forgotten. Solving this well known dilemma of operations planning is the object of countless efforts from researchers and practitioners alike. In the 1960s, great hope was set in the methods of Operations Research, in particular in queuing theory. However, due to the complex boundary conditions of job shop and series production, queuing theory was unable to establish itself. Even simulations did not provide the hoped for breakthrough due to the large amount of effort required especially for a company’s already running operations.
The Funnel Model and the Throughput Diagram that is derived from it, developed by Prof. Hans Kettner and his assistants at the Institute of Production Systems and Logistics, Leibniz University of Hannover in the 1970s was thus met with great interest. In particular, it attracted attention because the logistic objectives throughput time, WIP, utilization and schedule reliability could for the first time be presented visually and conclusively. The Load Oriented Order Release method that arose from there and the further developed Load Oriented Manufacturing Controls were widely accepted in job shop production.

The Logistic Operating Curves (LOC), developed later within the context of simulation analyses, quantitatively described the impact of the WIP on the utilization and throughput time also for the first time. Due to the huge efforts required for the underlying simulations, the LOC were impractical and therefore limited to theoretical applications.

It was Nyhuis’ habilitation in the early 1990s that initially made it possible to simply calculate the Logistic Operating Curves based on the combination of an ideal manufacturing process model suggested by von Wedemeyer with experimental and empirical supported analyses. Consequently in the years following, an extensive field of application opened up both in research and on the production floor.

For the first time, the models of the Logistic Operating Curves for production and storage processes are comprehensively described in this book. In addition, the necessary formulas are derived step by step, and a comparatively simple computational scheme using data that is standard in manufacturing and storage controls is developed from there. Thorough tests with field data and extensive simulations prove how the individual equation parameters influence the order and capacity structures. Thus making it possible to estimate the accuracy of the information even when the original data is inaccurate or contains errors – as is frequently the case on the shop floor. Through a comparison with queuing theory and simulations, both the advantages and the limitations of Logistic Operating Curves are clearly identified.

The usefulness of the Logistic Operating Curves is evident in numerous theoretical and application based projects conducted by the Institute of Production Systems and Logistics. Currently the Logistic Operating Curves are mainly applied: in dimensioning WIP buffers and WIP areas when planning factories; conducting a Logistic Positioning for manufacturing areas and stock levels with respect to the throughput time, utilization and WIP; in production control in order to continually improve the logistic objectives; in parametrizing lot size determination, throughput scheduling, and order release in PPC systems as well as in Bottleneck Oriented Logistic Analyses for developing the hidden logistic potential of the throughput time and WIP. Further foreseeable application possibilities include guiding construction and development areas, extending the Logistic Operating Curves to include schedule reliability, cost-wise evaluating production processes with different WIP situations and evaluating supply chains beyond the manufacturer’s borders.

This book is based on a large amount of theoretical and empirical work at the Institute of Production Systems and Logistics, some of which goes back twenty or
more years. Most notable here are the dissertations from Bechte, Dombrowski, Dräger Erdenbruch, Fastabend, Gläßner, Lorenz, Ludwig, Möller, Penz, Petermann, Scholtissek, Springer and Ullmann. Each of which have focused on various aspects of modeling, planning, and controlling production based on Throughput Diagrams and Logistic Operating Curves. Every one of the authors has thus contributed to the Logistic Operating Curves Theory.

We would like to wish all of our readers, including both those who work in research as well as in the industry, inspiration and practical use in overcoming their logistic problems. Furthermore, we would be grateful for constructive criticism, suggestions and experiences in applying the Logistic Operating Curves Theory.

Hannover, Summer 1999
Peter Nyhuis
Hans-Peter Wiendahl

Translator’s Notes

Translating the Fundamentals of Production Logistics has provided a unique and extremely pleasurable challenge – one that I hope we have successfully met. Seeing that the theory, tools and applications presented here have only been partially exposed to an English language audience, the terminology for discussing them has up to now not fully existed. This of course is often the case when introducing new concepts. However, Prof. Dr. Nyhuis and Prof. Dr. Wiendahl also had a goal in mind when choosing these terms: They wanted to target an as broad as possible international audience who are interested in logistics and curious about what approaches to a logistic theory are being made elsewhere. What this meant for the translation was trying to find clear, self-explanatory terms and implementing them consistently. We hope that we have managed to achieve this. Nonetheless, just as the authors hope to hear from readers with regards to their experiences and thoughts I too hope that you will also let the authors know if mistakes or areas lacking clarity are found. After all, this edition of the Fundamentals of Production Logistics is meant to initiate discussion and is therefore hopefully just a beginning.

As this is a translation of the German edition and not a new English edition, the majority of bibliographical references are also German. Those that are in English have been marked with an asterisk e.g. [Wien-95a*], in order to be easily identified.

Berlin, December 2007
Rett Rossi
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Index of Abbreviations and Variables

General Terms (as index or suffix)

act  actual value  
AP  angulation point  
i  indices  
is  intersection point  
m  mean value  
max  maximum value  
med  median value  
min  minimum value  
mw  mean weighted value  
n  number of events, orders  
nd  normal distribution  
s  standard deviation  
t  mean value calculated by LOC Theory 
   (as a function of the running variable t)  
(T)  value at time T  
tar  target value  
v  coefficient of variation

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<td>WIP</td>
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<td>WIP_A</td>
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<tr>
<td>WIP_b</td>
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</table>
Abbreviations

BN: bottleneck
FCFS: first come — first served
FIFO: first in — first out
KPI: key performance indicator
LPT: longest processing time (rule)
MS: manufacturing system
OP: operation
Slack: minimum slack (rule)
SPT: shortest processing time (rule)
WS: workstation

Logistic Operating Curves

COC: Cost Operating Curve
DDOC: Delivery Delay Operating Curve
ITOC: Inter-Operation Time Operating Curve
LOC: Logistic Operating Curves
LOC Theory: Logistic Operating Curves Theory
MSOC: Manufacturing System Operating Curves
OROC: Output Rate Operating Curve
PCOC: Production Cost Operating Curve
RLOC: Relative Lateness Operating Curve
ROC: Range Operating Curve
SLOC: Service Level Operating Curve
SOC: Storage Operating Curve
SROC: Schedule Reliability Operating Curve
TROC  Transport Operating Curve  
TTOC  Throughput Time Operating Curve  
UOC  Utilization Operating Curve  

**Methods and Analyses Based on the LOC Theory**

BOLA  Bottleneck Oriented Logistic Analysis  
FROS  Flow Rate Oriented Scheduling  
LOOR  Load Oriented Order Release  
LOSA  Logistic Oriented Storage Analysis  
TOLS  Throughput Oriented Lot Sizing
Chapter 1
Introduction

Change is both a typical and necessary characteristic of the evolutionary process. Although companies frequently consider it a catalyst for critical situations, there is more to it than problems, risks and dangers. A company opens up new possibilities by positioning itself actively and early, consciously grasping these factors and bearing them in mind when planning its future. Doing so it distinguishes itself positively from its competitors and thus creates new potential.

Working proactively during economically stable times is particularly important in this case. The risk that effective measures cannot be introduced quickly enough often originates in not being able to recognize relevant changes. Companies are ready to make alterations, especially in times of crisis. However, they often no longer have the energy or reserves, or are in a position where they need to make considerable cuts. The demand to be permanently innovative regarding products and processes is thus continuously and emphatically present ([Zahn-94], [Warn-93]). Companies need to develop strategies oriented on the future and possible solutions based not only on knowledge of their weaknesses and previous mistakes, but also in consideration of their business goals. Once established, these need to be pursued resolutely. Due to ever decreasing product lifecycles, increasing product diversity, unstable production plans, market globalization and numerous other factors, a company has to be as flexible and adaptable as the market itself.

1.1 Logistic Key Performance Indicators for Manufacturers

In order to attain and maintain a competitive edge it is necessary to constantly improve and revaluate products and production processes (see e.g., [Bull-92], [Port-92], [Port-93], [Warn-93], [Mert-96], [Milb-97]). Nevertheless, almost every advantage can be copied sooner or later. Therefore, a company has to become a moving target, developing new advantages at least as quickly as the old ones can
be copied. Selectively improving performance is thus generally not enough to sustainably fortify a company’s position. It generally provides only short-term improved results and instead of leading to a substantial change in competitive relations it at best gains time [Wild-98].

Sustainable advantages are only attainable when a strategic master plan is developed based on an analysis of corporate strengths and weaknesses and customer demands. Furthermore, it has to be built on coordinated measures and a comprehensive examination in order to not only be able to design and implement it, but to also be able to control it with regards to the desired success.

In addition to high quality standards and the price of products, the logistic factors delivery time and delivery reliability take on progressively more importance as possibilities with which a company can distinguish itself within the market (Fig. 1.1) ([Voig-90], [Kear-92], [Baum-93], [Gott-95]). Production, as the primary function for fulfilling orders, is thus increasingly called upon to improve effectiveness [Zahn-94]. The goal therefore, is to organize the entire material flow in the supply chain, from procuring raw materials and preliminary products, through the entire production process including all of the interim storage stages, up to supplying distributors or as the case may be, external customers in such a way that the firm can react to the market in the shortest time span. Since production logistics decisively influence these performance indicators, intense effort is invested both in research and in the industrial setting in order to expertly design and operate logistic systems.

The fundamental goal of production logistics can thus be formulated as the pursuit of greater delivery capability and reliability with the lowest possible logistic and production costs. Here, the logistic factor delivery capability, expresses the degree to which it is possible for a company, in consideration of the production situation, to commit to the customers preferred delivery date. Delivery reliability on

<table>
<thead>
<tr>
<th>purchase criteria</th>
<th>relative importance of purchase criteria</th>
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<tr>
<td></td>
<td>less important</td>
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<tr>
<td>product quality</td>
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<tr>
<td>price</td>
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<td>delivery reliability</td>
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<td>delivery time</td>
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<tr>
<td>flexibility</td>
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<tr>
<td>availability of information</td>
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<td>range of products</td>
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Fig. 1.1 Criteria for Purchasing Products (Siemens Inc.)
the other hand, depicts the extent to which the promised dates for the placed orders can be met. In addition to marketable production costs, delivery capability and delivery reliability are critical to a company’s long-term market success (Fig. 1.2).

Designing structures for products, production and purchasing which permit market geared delivery dates under suitably applied production planning strategies makes it possible not only to develop and ensure a greater delivery capability, but also to guarantee the company’s logistic process capability. When the targeted delivery capability based on the implemented structures is essentially possible, it is then the process controls’ job to fully develop the inventory management and operative control of the created logistic potential in order to achieve a greater logistic process reliability. The low throughput times, realizable due to the product and production structures, should be attained during the ongoing process and maintained at a stable level. As a result, a high delivery reliability will be continuously provided.

Finally, by designing and controlling the operating logistic processes the interactions between the performance and cost objectives should be constantly monitored so as to be able to ensure the production’s economic efficiency. In order to achieve marketable production costs it is necessary on the one hand, to strive for a maximal utilization of the available capacities and on the other hand, to reduce the storage and WIP levels as much as possible so that the costs of tied-up capital are minimized.

![Fig. 1.2 Logistic Key Performance Indicators for Production Firms (Gläßner, IFA)](image-url)
1.2 Dilemma of Operations Planning

The endeavor to strengthen targeted logistic key performance indicators (KPI) is complicated by existing conflicts between the objectives. The logistic objectives and requirements that need to be taken into consideration are neither consistent nor locally and temporally constant. Thus, a high level of work in process (WIP) is required to ensure a high level of utilization. However, a high WIP level results in longer throughput times. Nevertheless, high and based on experience, fluctuating throughput levels contradict high reliability. The tendency for these objectives to conflict is generally known as the ‘dilemma of operations planning’ [Gute-51]. Therefore, there is not just one target whose value has to be maximized or minimized, rather, the impact of the measures on each of the sub-goals has to be simultaneously considered. The fact that these sub-goals can be prioritized quite differently in the various stages of the production process makes the situation even more problematic.

Figure 1.3 depicts the objectives that are emphasized depending on the existing storage strategies and position of the observed processing step in relation to the customer order decoupling point: As long as the production is not conducted on the basis of concrete customer orders, the companies objectives i.e., maximal utilization and minimal WIP will be pursued, because these two objectives (even when contradictory) influence the economic efficiency of the production. The schedule reliability and throughput time are for the most part of secondary importance. Nonetheless, these parameters indirectly impact the storage goals. The poorer the schedule reliability is and the greater the throughput time for the related production is, the more stock there has to be in-store in order to attain a defined

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![Diagram](image_url)

Fig. 1.3  Weighting of the Logistic Objectives with Various Storage Strategies (based on Eidenmüller)
level of service. If production is driven by the customer, the relation between the prioritized objectives is turned around. The promised delivery times and dates are then clearly given more weight, because the customer is directly impacted by a failure to do so. Whether or not it is permissible to obtain shorter delivery times through poorer utilization of the respective production lines, can only be decided on an individual basis. The required extended capacities (machines and operators) quickly increase the unit cost. The customer then has to decide if and under what circumstances they are prepared to accept higher costs in exchange for shorter delivery times. If one also considers that all of the changes in the company’s environment can also impact the weighting of the objectives, then it becomes clear that there is no real ‘optimum’ on which a company can orient itself.

The uncertainties resulting from the above described problems often leads to the so-called ‘vicious cycle of production, planning and control’ (Fig. 1.4). Empirical decision theory shows that decision-makers predominantly try to tread the supposed ‘safer way’ [Knol-87]. This is particularly true, if they make a bad impression by not fulfilling routine jobs (e.g., through unsatisfactory level of delivery service) and are not offered any incentives for being prepared to take risks (e.g., maintaining lower storage levels). Material planners therefore, usually orient themselves not only on average throughput times, but from a risk point of view also consider the throughput times’ variance. If due to poor scheduling adherence the values for the lead time and throughput scheduling are now larger, then the orders arrive earlier than before in the production. The stock in front of the workstations then grows as do the queues. This means on average longer waiting times and thus longer order throughput times in conjunction with more widely distributed throughput times. As a result the schedule adherence is worse and the most

Fig. 1.4 Vicious Circle of PPC (Mather)
important contracts can only be completed by rush orders and costly special actions. The vicious cycle of PPC becomes a spiral of errors that only stabilizes when the throughput time reaches a very high level ([Math-77*], [Wien-97]).

In order to break such a vicious cycle and to make the dilemma of operations planning controllable through actively designing the processes and production it is necessary to qualitatively clarify and quantitatively describe the interdependencies between the logistic objectives as well as the possibilities for influencing them. Due to the diversity of processes in the field as well as external and internal influences these connections are not easily detected or described. It becomes increasingly clear that in order to cope with the design and control tasks, models that can be employed for describing and evaluating the processes have to be implemented. Only by applying an appropriate model is it possible to understand the complex operational sequences and their dependencies, and thus, to enable a continuous adjustment of the processes, even in the case of changing targets ([Hopp-96*], [Nyhu-96]).

1.3 Model Based Problem Solving Process

Previously, a model was primarily understood as a representation of reality. The term ‘model’ however, has been expanded in numerous fields of application. Models no longer exclusively facilitate understanding through visual means, instead they are also meant to help:

- make the primary situation and the forms which those problems may take understandable and comprehensible,
- uncover the causes and effects of the problems,
- deliver the basis of information required to derive measures,
- support specifically influencing or designing systems
- attain a fundamental understanding of a system’s static and dynamic performance.

Operational systems are almost exclusively modeled using mathematical models. Even when in individual cases iterative steps and loop-like repetitions occur within a few phases, the application of such models are generally characterized by the procedures depicted in Fig. 1.5.

The first step in a model application is to clearly and precisely describe the problem. Furthermore, the goal of the analysis has to be explicitly defined. Since the effort and expense required for modeling and interpreting increases disproportionately to the complexity, it is particularly important in both phases to minimize the complexity of the object of examination as well as the goals. It is therefore often wise to breakdown a large problem into smaller, manageable sub-problems.

Once the problem has been formulated, a suitable model has to be chosen and if necessary adapted. If no appropriate model exists, then a mathematical one has to be developed. Once the presentation of the problem has been transferred onto the
model, alternative solutions can then be subsequently derived and evaluated. During this process it should be kept in mind that no knowledge beyond that which was previously incorporated into designing the model and in choosing the conditions can be gained by using models. Moreover, the results of the model application can only be as good as the underlying data.

In this respect, the next step in applying the model is also particularly important: Both the model as well as the solution that was derived should be continuously examined, especially while the solution is being applied under real conditions. This is a step which all too often is not adequately considered. The model must reflect the real system’s behavior correctly and accurately enough. In addition to the technical precision and validity of the behavior (i.e., the model and the real system deliver comparable results) it is also particularly important to question the appropriateness of the cost-benefit ratio. The only way to guarantee that the model and the underlying parameters provide a sufficiently good basis for making decisions under changing conditions, is to examine it during the model use phase.

If in special cases no appropriate model exists, then the following basic requirements should be taken into consideration in the model design [Oert-77]:

- Direct Relationship with Reality: The model should illustrate the situation of interest for the actual targeted system as realistically as possible.
- Greater General Validity: The model should be applicable to a variety of real systems either directly or with minimal adaptation.
- Clear and Comprehensible Information: Based on the underlying objectives of the model application, the facts of interest should be simply but concisely presented. In particular, graphics or mathematical notation often depict information clearer than lists or tables.
- Limited to the Essentials: For practical reasons, it is important that the model is restricted to portraying and providing information only about the essential aspects of the real system.

Generally, in order to comply with these requirements the complex events found on the production floor, have to be strongly simplified by at least temporar-
ily factoring out many of the secondary aspects. Only through reducing (abandoning insignificant features) and idealizing (simplifying vital features) is it possible to develop straightforward models which can be mathematically formulated and then often transferred to other similar applications. Whether or not the simplifications are feasible can be verified during both the model validation phase and while the model is being applied.

If connections between the relevant events can be derived during the course of the modeling or the model application, which can be determined absolutely and repeatably under similar conditions and using similar methods, then the corresponding formulation can also be described as a law. The range of application for such a law increases to the extent that the formulation can be freed from special individual cases.

Models can be generally considered an abstract but very concentrated means of presenting descriptions of real or imagined systems. A common and at the same time typical property of all mathematical models is that they cannot in principle provide an absolutely true depiction of the original process, nor in the rule should they. Rather, they should be tailored to a specific application purpose and reproduce important characteristics relevant to it with sufficient accuracy. Therefore, a model can also only be chosen or judged from the perspective of its function. Figure 1.6 [Prof-77] shows the correlation between the effort required to develop and apply a model and the achievable model quality.

Accordingly, economical considerations also have to be integrated into the requirements for the exactness of the model. Generally speaking the more routine

![Fig. 1.6 Correlation between the Model Quality and the Amount of Effort Required for Development (Profos)](image-url)
1.4 Objectives of Production Logistics

In the following section, we assume that it is neither useful nor possible to completely describe the logistic processes within a complex production with one single model. It is therefore necessary to break the problem down. In order to do so, we will refer to the primary reference processes, which were defined by Kuhn [Kuhn-95]: production and testing, transportation, and storage and supply. Generally speaking these can be used to describe every production process from a logistic viewpoint.

The operational objectives depicted in Fig. 1.7 are derived from the logistic key performance indicators illustrated in Fig. 1.2. As can be seen, the objectives are contradictory and thus describe the specific problems which pertain to the individual reference processes.

Production is concerned with short throughput times and a high schedule reliability in order to on the one hand, fulfill customer demands and on the other hand, increase planning reliability. Furthermore, with shorter throughput times the risk of changes being made to orders in progress decreases. However, from a business perspective, it is preferred that the available production equipment is highly utilized and that there is the lowest possible WIP. In this way, the costs which are influenced by the production logistic can be minimized. It is thus obvious that whereas some of these sub-goals support one another, others contradict each other.

The objective for the stores has to be to keep the storage level and the related storage duration as low as possible given the store in/output. Nevertheless, at the same time a high level of delivery service has to be met for the areas requiring supplies by ensuring a minimal delivery delay. Thus, there are also competing objectives in the stores area. The objective output rate or utilization, which is critical for both production and testing as well as transportation, are generally not
determined for the storage processes unless the performance of inventory personal and facilities are being investigated.

The illustrated conflict between the objectives of the three reference processes is well-known, however up until now and particularly in the industry it has been only quantified with difficulty. Thus, conducting a targeted Logistic Positioning has been almost impossible. Previously, knowledge gained through experience has generally been relied upon in order to provide the market geared, target values for the necessary delivery times, existing work content/capacity structures etc. used in designing and operating the production processes. However, based alone on the complexity of the processes in the production and the interdependencies between the logistic objectives it is highly improbable that the best possible compromise can be found using this method. If while increasingly pursuing one of the sub-goals, another one is infringed upon (which is almost inevitable given the contradictions) then many companies fall back to the initial state. Thus it is quite common for companies to have actions to reduce inventory. Difficulties in fulfilling delivery obligations though often lead to the stock piling up again to the point which had originally initiated the inventory reduction sales (see [Jüne-88], [Eide-95]).

In order to break through this cycle, it is desirable to also be able to quantitatively represent the interdependencies between the logistic objectives and the possibilities for influencing them. Doing so allows various strategies to be pursued according to the operational and market situations. The Logistic Operating Curves, presented in the following, are useful for this purpose.

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**Fig. 1.7 Logistic Objectives for the Production Reference Processes**

<table>
<thead>
<tr>
<th>logistic objectives</th>
<th>production and testing</th>
<th>transport</th>
<th>storage and supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>schedule adherence</td>
<td>high schedule reliability</td>
<td>high schedule reliability</td>
<td>low delivery delay</td>
</tr>
<tr>
<td>throughput time</td>
<td>short throughput time</td>
<td>short transport throughput time</td>
<td>short storage time</td>
</tr>
<tr>
<td>output rate</td>
<td>high utilization</td>
<td>high utilization</td>
<td></td>
</tr>
<tr>
<td>inventory</td>
<td>low work in process</td>
<td>low work in process</td>
<td>low stock</td>
</tr>
<tr>
<td>costs</td>
<td>low costs per unit</td>
<td>low costs per transport operation</td>
<td>low storage costs</td>
</tr>
</tbody>
</table>

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1.5 Logistic Operating Curves – an Explanatory Model for Production Logistics

A Logistic Operating Curve visually represents the correlation between a specific parameter of interest (the objective or dependent variable) and an independent variable. Therefore, for every value of the independent variable – which can be changed by external conditions – at least one value can be determined for the objective.

In preparation for this description, it is first necessary to determine the independent variables and objectives based on these considerations. In principle it can be said that all of the previously mentioned logistic objectives can also be seen as an objective in a LOC. This however, is not the case for independent variables: The costs caused by the production logistics, result from a process but are in no way an independent variable that can be directly changed by external factors. This is also true for the schedule adherence, which occurs at the end of a process and can therefore be influenced only indirectly. The WIP, throughput time, and output rate however, remain as potential independent variables. All three of these can in principle be seen as both an independent variable and as a result.

In the following chapters we have chosen to use the WIP as the independent variable. This decision is supported by the fact that the WIP can be actively influenced through targeted control measures in all three reference processes i.e., it can be ensured that the input is temporarily greater, less than or equal to the output of the observed process. The remaining logistic objectives thus represent the dependent variables. Since the parameters WIP, throughput time and output rate can however be mathematically transformed into each other (see Chaps. 2 and 3), it is possible to declare one of the other parameters as an independent variable according to the particular problem.

In Fig. 1.8 the various LOC for the three reference processes are illustrated as schematic diagrams. The curve for production and testing shows that the throughput time of a production system mainly increases proportional to the growing WIP. The throughput time however, cannot fall short of a specific minimum which arises from the technology dependent operation time during the order processing and where applicable, the transportation time between two operations. Short throughput times are thus generally linked to a smaller variance of the throughput time. The greater planning certainty that results from this leads to a greater schedule reliability. Nevertheless, with the escalating WIP and throughput times, and as experience has shown the resulting increased throughput time variance, the planning reliability decreases. With a high WIP level, the Output Rate Operating Curve for a workstation is largely independent of the WIP. Should the WIP fall below a particular level though, there will be output losses due to a temporary lack of work materials.

Finally, the Cost Operating Curves (COC) make it possible to draw clear conclusions about the optimal costs of the operating sector. When the WIP level is low there is a loss of utilization which in turn increases the costs due to the higher
expenses related to the idle time of the available capacity. Higher WIP levels however, also give rise to greater stock related costs. The Output Rate and Throughput Time Operating Curves are often plotted together in one diagram and then referred to as Logistic Operating Curves ([Bech-84], [Nyhu-91], [Wien-93], [Wien-97]).

Since the Logistic Operating Curves for the transportation reference process generally behave very similar to the production and testing curves we will not explain them separately. The individual Transportation Operating Curves (TROC) are essentially influenced by the mode and number of employed transport means, the implementation strategy and the resulting percentage of double move or empty trips as well as the integration of the transport system in the organization of the process.

The LOC for the storage and supply reference processes represents the time an item or group of items spends in storage and is delayed in delivery as a function of the mean stock. These Logistic Operating Curves are also referred to as Storage Operating Curves (SOC) ([Gläs-95], [Nyhu-95]) and can be influenced by all the parameters that impact the behavior of the store input or output. In the Cost Operating Curve for this reference process, the value of the article as well as the costs of shortages are included.

The Logistic Operating Curves sketched here, very clearly illustrate the prevailing conflict between the goals of the logistic objectives for all three reference processes. The LOC make it possible to decide which characteristic needs to be weighted the most depending on the system specific boundary conditions and the

Fig. 1.8 Logistic Operating Curves for Production Reference Processes