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The Balancing of Mixed-Model Hybrid Assembly Lines with Genetic Algorithms

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With 95 Figures

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This book is dedicated to my parents,
to my wife Aaida, and
to my children Saad and Inas.

Dr B. Rekiek

Foreword

This new book 'Assembly Line Design' by Dr Brahim Rekiek and Professor Alain Delchambre is an important contribution in this domain. Its interest is in an integrated approach to the preliminary design of assembly lines (ALs). This approach is based on the grouping genetic algorithm (GGA), where the logical layout (LL) is designed to consider all the constraints and specificities of real-life manual and hybrid multi-product ALs. The LL is defined as the balancing and the resource planning. In addition, a new approach based on multi-objective GGAs is developed which includes the branch-and-cut algorithm combined with a multi-criteria decision-aid method. In this book, the logical and physical layouts are treated simultaneously. First, tasks (that perform activities) are grouped together in workcentres. Second, tasks are assigned to stations. The new concept of 'balance for operation' is introduced to deal with the changes during the operation phase of ALs. This concept permits one to treat balancing and scheduling at the design stage.

The authors have a great experience in practical AL design and balancing. Their scientific publications are well known and widely cited. Undeniably, this new book offer new vision and perspectives for development of industrial research and engineering methods for AL design. It provides a systematic analysis, efficient engineering concepts, and techniques to handle this design problem. It is a pleasure to foreword this excellent book as an important source for researcher, industrial engineer, faculty staff and graduate students in industrial engineering, management science, operations research and mechanical engineering.

Professor Alexandre Dolgui
Ecole des Mines de Saint Etienne, France
May, 2005

Preface

The design process is traditionally a time-consuming and an iterative business. First, a preliminary design is created, analysed, and then experimented to determine its quality. The process of search and evaluation is repeated until the design is viewed as being acceptable. Computer-aided design (CAD) software, simulation and analysis tools are widely used today. In contrast, automatic design techniques are less common. The recent success in design is due to the adaptive search techniques, in particular the genetic algorithms (GAs). GAs are powerful and broadly applicable stochastic search and optimisation techniques. They are the most widely known kind of evolutionary computation methods.

Assembly lines (ALs) are production systems composed of a succession of stations, connected by a conveyor, performing a set of tasks on the product passing through them. A production workshop can be set up following various topologies (*e.g.* lines, cells, combination of several lines, *etc.*) The line layout problem is composed of a logical and physical layout. The logical layout is defined as the AL balancing (ALB) and the resource planning (RP) problems. The ALB is used for manual ALs and it aims to balance loads of stations. For hybrid ALs (manual, robotic and automatic tasks), RP assigns resources to tasks and assigns tasks to stations. The physical layout determines the space requirements taking into account station dimensions, material storage, *etc.* The aim is to minimise the total cost of the line by integrating design (space, cost, *etc.*) and operation issues (cycle time, precedence, availability, *etc.*).

AL design (ALD) problems often have a complex structure due to multiple components (*e.g.* tooling, material handling facility, line efficiency, cost, imbalance, reliability, stations space, *etc.*). A number of design alternatives may exist. The problem can easily become unmanageable if the designer has to consider all these alternatives. Thus, many practical search and optimisation problems are considered as multiple objective problems (MOPs) and require a compromise among conflicting objectives. Since it is impossible to replace designers experience and creativity, it is important to support them with a set of tools to investigate and propose solutions. Using this information, the designer tests some alternatives and makes his decisions. Owing to the difficulty of ALD problems, metaheuristics are often used.

In applying GAs to solve MOPs one has to deal with the twin issues of searching a large and complex solution space and at the same time dealing with multiple and conflicting objectives. Selection of a solution from a set of possible solutions on the basis of several criteria is considered as a difficult task. Some methods reduce the problem to a mono-criterion one (weighted-sum approach). Other studies adopted the Pareto-based GA technique. The main drawback of Pareto approaches is the number of solutions the decision maker (DM) has to choose among them. The user cannot easily decide among more than a few solutions.

We present a new multiple objective grouping GA (MO-GGA) which is based on the GGA and multi-criteria decision-aid (MCDA) method called PROMETHEE II. The GA iteratively samples the trade-off surface (Pareto) while the MCDA method narrows the search. The choice of a solution over the others requires knowledge of the problem. It is the task of the DM to adjust the weights for guiding the algorithm to find good solutions. Optimising a set of objectives has the advantage of producing a single solution, without any further interaction by the DM.

In order to deal with line balancing, a new algorithm called 'equal piles' for ALs based on the so-called 'boundary stones' is introduced. The hard constraint is the fixed number of stations (piles) and the aim is to find the best balanced assembly system. In the case of the RP, the aim is to select equipment to carry out the assembly tasks. We present a new method which is based on the MO-GGA, the branch-and-cut algorithm followed by the MCDA method. To deal with the changes during operation phase of ALs, a new concept of balance for operations is introduced. The balancing of ALs is mostly uncoupled from the facility layout problem which yields sub-optimal line layouts. An iterative procedure is proposed to treat the two problems partially at the same time. First, tasks that perform similar activities are grouped together in a workcentre. Then, for each workcentre, tasks are assigned to stations. The main concern of this approach is the quality of the resulting line in terms of balancing and its suitability to the material flow requirements of the production system.

The last part of this book is dedicated to an integrated method of designing ALs. The software OptiLine is developed at the CAD/CAM Department of the Université Libre de Bruxelles, Belgium.

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Our thanks to Dr E. Falkenauer, General Manager of the Optimal Design company. He provided us a real-world case study illustrating the concepts described in this book. The case study has been optimised using the OptiLine software package which has been developed by Optimal Design.

The financial support of the Région Wallonne through a project entitled CISAL is acknowledged. My thanks to the Université Libre de Bruxelles, Belgium, especially to the staff of Service de Mécanique analytique et CFAO.

To our families with ultimate respect and gratitude for their continuous support. Many thanks also to the many interested readers of our research papers for some stimulating discussions at conferences, workshops and over the Internet.

Dr B. Rekiek
Professor A. Delchambre

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Part I Assembly Line Design Problems

Part III Assembly Line Layout

List of Abbreviations

AI	Artificial intelligence
AL	Assembly line
ALB	Assembly line balancing
ALD	Assembly line design
B&B	Branch and bound
B&C	Branch and cut
BD	Balance delay
BFO	Balance for operation
BPP	Bin packing problem
CAD	Computer aided-design
CE	Concurrent engineering
CISAL	Outils d'aide à la conception interactive des produits et de leur ligne d'assemblage
CM	Cellular manufacturing
COP	Combinatorial optimisation problem
CS	Capacity supply
DFA	Design for assembly
DM	Decision maker
DP	Dynamic programming
E	Line efficiency
EPALP	Equal piles for assembly line problem
ES	Evolutionary strategies
FABLE	Fast algorithm for balancing line effectively
FFD	First fit decreasing
FG	Functional group
GA	Genetic algorithm
GC	Goal chasing method
GGA	Grouping genetic algorithm
GT	Group technology
HAL	Hybrid assembly line
I	Line idle time

IB	Imbalance
ICA	Individual construction algorithm
JIT	Just in time
LL	Logical layout
LP	Linear programming
MAL	Manual assembly line
MCDA	Multi-criteria decision-aid
ML	Model launching
MOALBP	Multiple objective ALBP
MOB-ES	Multiple objective evolution strategy
MOEA	Multiple objective evolutionary algorithm
MOGLS	Multiple objective genetic local search
MOGA	Multiple objective genetic algorithm
MOGGA	Multiple objective grouping genetic algorithm
MOP	Multiple objective problem
MPAL	Multi product assembly line
MWkCALB	Multiple workcentres ALBP
NPGA	Niched pareto genetic algorithm
NSGA	Non-dominated sorting genetic algorithm
OGA	Ordering genetic algorithm
OMT	Operating modes and techniques
OV	Ordering variants
OX	Order crossover
PBX	Position based crossover
PG	Precedence graph
PL	Physical layout
PMX	Partially mapped crossover
PROMETHEE	Preference ranking organisation Method for Enrichment evaluations
PSGA	Problem space genetic algorithm
RD-MOGLS	Random directions multiple objective genetic local search
RP	Resource planning
RPW	Ranked positional weight
RRPW	Reversed ranked positional weight
RWS	Roulette wheel selection
SA	Simulated annealing
SALBP	Simple ALBP
SMCT	Scheduling method choice tool
SPAL	Simple assembly line balancing
SPEA	Strength pareto evolutionary algorithm
ST	Station time
SX	Smoothness index (SX)
TALB	Tree assembly line balancing
TS	Tabu search
TVR	Time variability ratio
VEGA	Schaffer's vector evaluated GA

1

Designing Assembly Lines

1.1 Introduction

Many attempts have been made in the last few years to investigate the use of *semi-automatic* methods of design as human design is time consuming. The term design implies a systematic planning processes prior to the execution of a plan in order to solve problems. Design is distinguished from other forms of planning by the level of precision used, expertise and care. It involves the consideration of many factors that may affect or be affected by the execution of a given plan. Many designers have the impression that the design is a 'cut-and-paste from old design' activities. This is not the case, as the *creativity* has a major role in design.

Assembly lines (ALs) are the most commonly used method in a mass production environment. They allow the assembly of products by workers with limited training and by dedicated machines and/or by robots. The main objective of assembly systems is to increase the efficiency of the line by maximising the ratio between throughput and cost. AL design (ALD) involves the design of products, processes and plant layout before the construction of the line itself. These different modules interact at the different stages of ALD [35]. The product analysis proposes a product design review based on the classical `design for assembly' (DFA) rules and precedence constraints between tasks. The operating modes and techniques module proposes an assembly technique and the possible modes (manual, automated, robotic) for each task. The line layout (LL) module assigns tasks to a set of stations and decides on the position of stations and the resources on the plant floor (Figure 1.1).

1.2 Assembly Line Design

The design of efficient assembly workshops is a problem of considerable industrial importance. ALs are production systems composed of a succession of

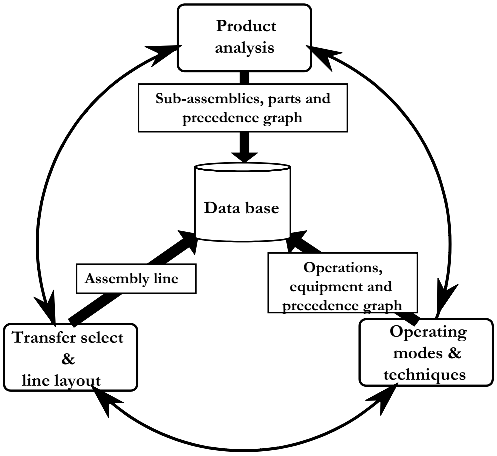

Figure 1.1. Methodology and information flow of the ALD [36]

stations performing a set of tasks on the product passing through them. The assembled product takes its shape gradually starting with one part (the base part), with the remaining parts being attached at the various stations which are visited by the product. A paced AL is a usual topology for medium and high production volumes [39]. In general, for simple products a single linear AL with possibly parallel stations can do the job. For complex products, the assembly system is mostly decomposed into sub-systems with their own cycle time, reliability, and stations requirements.

Many successful companies have adopted several working practices and tools known as concurrent engineering (CE) to improve their products' development. The main aim of CE is to integrate product and process development in order to reduce the design lead-time and to improve its quality and cost. The LL problem is known as logical and physical layout [39]. The elaboration of the *logical layout* of the line consists of distributing the tasks among stations along the line, while the *physical layout* decides on the disposition of stations, resources, conveyors, buffers, *etc.* on the shop floor. The logical LL is composed of *AL balancing* (ALB) and *resource planning* (RP) problems (Figure 1.2). The balancing used for manual ALs aims to balance the stations' workloads. For hybrid ALs (HALs) (where operations can be executed manually using robots or automated equipment) the RP assigns resources to tasks and tasks to stations. The objective is to minimise the total cost of the line by simultaneously integrating design (*e.g.* station space, cost, *etc.*), operation issues (*e.g.* cycle time, precedence constraints, availability, *etc.*) and designer desires (*e.g.* tasks complexity, *etc.*). Figure 1.3 shows the main features (blocks) of the concurrent ALD approach that will be discussed in detail in Chapter 10.

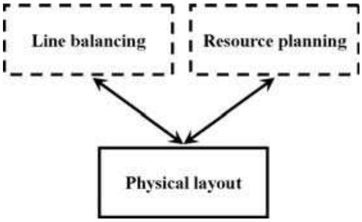

Figure 1.2. LL problem

A line design problem often has a complex structure due to multiple components (*e.g.* tooling, operators, material handling facilities, *etc.*). For a single product, a number of design alternatives may exist. The problem can easily become highly complicated if the designer has to consider all the possible combinations of these alternatives. Therefore, the problem must be solved with a structured approach. For a given product and a manufacturing environment, the design objective and constraints should be defined. A computer system which is inspired by nature (Darwinian evolution) is presented to design new ALs starting from a set of specifications. The designer system is *generic* (*i.e.* it has to be capable of evolving a wide range of different line designs with minimal reconfiguration by a designer).

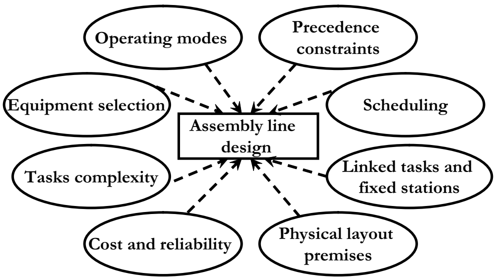

Figure 1.3. Concurrent design of an AL

1.3 Designing or Optimising?

The complexity of design is not due to the physical, material or procedural factors; rather, it depends on understanding a problem and making well-founded decisions. There are some general design steps that the designer has to follow [106]. These steps are: (1) formulating the problem to be solved, (2) breaking it down into sub-problems, (3) grouping ideas that must be discussed, (4) evaluating and redesigning (if needed) the current design, and finally (5) implementing the proposed model. In general terms, design is the process of