CHAPTER 2

DESIGN APPROACHES

Everyone designs who devises courses
of action aimed at changing existing
situations into preferred ones.

Simon, H.A. The Sciences of the Artificial (3rd ed.).
Cambridge, MA: The MIT Press, 1981.

Keywords: assembly line, design, human behaviour, interactive and iterative design, line balancing, line layout, resource planning.

1. Introduction

> *The design profession seems to be more concerned with superficial styling. Styling has its place, after all, the best designs won't be bought if they don't have the look, however, for us, good design should concern itself with solving problems.* Victor Papanek 'Design for the real world '(1971).

Design is a fundamental and ubiquitous activity. Planning, scheduling, and most domains of engineering are, or can be categorised as, design problems. Any useful tool that can help designers would be widely applicable. Most of the current tools are based on a knowledge intensive view of the design process. Techniques like expert systems apart from problems involved with the acquisition of knowledge fail on new and/or poorly-understood applications, where there is insufficient knowledge to proceed, or difficulties in understanding the system. Design's nature makes it difficult to find a concise, comprehensive, and well-accepted definition. Attempts at defining design are usually biased by the author's background and range from the practice to the theoretical field.

In general, it is always preferable to carry out some process of simplification and analysis, to decompose the problem into separate small problems. This reduces the size of the problem allowing a more thorough study of several alternatives. Needless to say, the more we decompose the problem, the more we lose the interaction and vision on the whole problem. Thus, while simplifying the problem, generally we resolve another problem which is different from the one at hand.

Concurrent Engineering (CE) which also is known as *simultaneous engineering* allows an interaction among the different levels of the design of flexible manufacturing systems. Industrial practice of this approach is still being developed or is undergoing tests. Many authors define the term CE as '*a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to force the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements, etc.*'. Others define the CE as '*the process of forming and supporting multifunctional teams that set product and process parameters early in the design phase*' (Parsaei, 1993). According to Dean and Unal (Dean, 1992):

> '*Concurrent engineering is getting the right people together at the right time to identify and resolve design problems. Concurrent engineering is designing for assembly, availability, cost, customer satisfaction, maintainability, manageability, manufacturability, operability, performance, quality, risk, safety, schedule, social acceptability, and all other attributes of the product*'.

Manufacturing organisations are especially challenging, since they involve the performance of multiple activities; all must be planned, designed, co-ordinated, and executed by a team. Each member of the team must be competent in his own area, each person's work must help to achieve the overall objective of the team. Only an efficient and productive organisation can survive in today's competitive market. Because of this, designers and workers should be able to communicate with each other to understand problems and analyse the proposed solutions as well as their effects on the performance of the entire organisation.

Even if, thanks to a CE approach, communication problems between designers can be solved, assembly line design (ALD) problems are still very complex. This can be attributed to the non deterministic nature of information (Chow, 1990). It is not impossible to find solutions to this problem, however it is a difficult task to achieve a good integration. Effective communication and co-ordination among the diverse disciplines are key concepts in ensuring the success of the CE (Delchambre, 1996).

Design of manufacturing systems involves the design of products, processes and plant layout before physical construction. All theses modules interact at the different stages (De Lit, 1999). In assembly, the modules composing the CE concept are the following (see Figure 2.1):

Product analysis (PA) It proposes a first product design review, based on classical DFA rules (Boothroyd, 1992), a first decomposition of the product into subassemblies, and yields a precedence graph between the functional components (whose function is not specifically attachment) of the product.

Operating modes and techniques (OMT) It proposes an assembly technique (screwing, force fit, etc.) for each attachment liaison between the parts, and possible modes (manual, automated, robotic) for each operation (Marée, 1999). The time and cost of an operation are computed thanks to the information related to the chosen technique.

Line layout (LL) It assigns tasks to a set of stations, and decides on the position of the stations, conveyors.

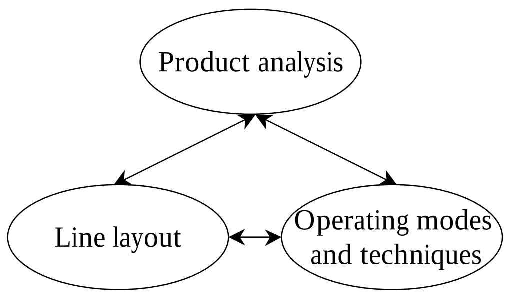

Figure 2.1. Flow chart of the CE.

Logical layout is related in the literature as the assembly line balancing (ALB) and the resource planning (RP) problems. The balancing, used especially for manual assembly line (MAL) aims to balance the workloads of stations. This approach is appropriate in manual assembly systems, since the primary concern is the distribution of tasks among stations, while keeping a desired production rate. For hybrid assembly line (HAL) (manual and automatic tasks) the RP helps the designer to find an assignment of tasks to stations, and an assignment of resources to each of them.

In this chapter we focus on design and particularly ALD problems. Section 2 explains why the design problem is difficult. In section 3 we briefly review related works on design methods. The design and search approach is presented in section 4. The gap between theory and practice in the case of ALD is discussed in section 5. An approach to decide about the quality of a solution is presented in section 6 while section 7 is devoted to the ALD evolution. Finally we draw conclusions and present some further works in section 8.

2. Why is the design problem difficult?

The main reason behind the difficulty of design tasks lies in the complexity of the mapping between function and structure. The specified function may be very complex and/or it may have to be realised using complex arrangements of a large number of interacting parts. Typically, the behaviour of each component is well known, difficulty lies in predicting how an assembly of such components will behave.

The design process is typically viewed as an iterative process which *"generate solutions and test; if not satisfactory, generate again"*. For instance, in mechanical engineering, a product or component design is evaluated under numerous interrelated criteria such as machinability, quality, reliability, structural integrity, assembly, maintenance and so on. Each criteria, while related to others is an area of expertise in its own right. Due to the difficulty of design problems, metaheuristic methods are often used to solve this kind of problems. Typically, only some aspects of the problem are considered, and one or more approximate solutions to the problem are sought-after using this restricted version. The resulting solutions are adjusted to propose acceptable designs and the best resulting solution is implemented.

Dealing at the same time with many items severely increases the complexity of systems to be designed. Indeed, since humans work in a sequential manner, they miss existing influence between the different components of the system. Although it is not difficult to develop a logical procedure for design, many problems may come from different sources. None of them has a simple solution. Indeed, generally designers deal with uncertainties, some information may be missing at the early stages of the design. Some available information may be subject to changes during the design or operation phase of the system, and operation phase of the system is subject to stochastic phenomena which are difficult to take into account. Finally, since most design works are team organisation, problems may arise due to poor communication between those responsible for different functions (Chow, 1990).

Traditional design tends to treat new products (goods, assembly line, etc.) as discrete objects that perform certain tasks or functions. Typically these are regarded as black boxes or sculptured objects aimed at making life easier. Designers of these products often prefer to consider only the object and its function, and either overlook the rest or unaware of the human considerations. We consider this to be an incomplete approach. Instead, the product designer should consider the relationship between the users and the objects, how these objects are integrated within their lives and what will be the role of these objects? The term 'object' or 'device' are unfortunate because our conditioning prevents us from thinking of them as more than things. While designing systems, we have to integrate the existing resources (technology, humans, etc.), that is one needs to be knowledgeable about these systems in existence firstly in terms of functions, performances and limitations. Again, the problem is how to integrate these multiple models (devices). The solution must address the problem of :

1. **Manageability** An important aspect is that the designer has to remain the master of the design process.

2. **Simplicity** The designer has a set of quick tools and a methodology to analyse several alternatives.

3. **Clarity** The designer must be able at any time to return to any alternative obtained before, this can be done only if all stages are clear to him.

We have been designing and acting as designers throughout our lives, indeed design solving is a natural human activity. The main source of confusion about design is that engineering design lacks sufficient scientific foundations. Design is a prescience phase and it must go through several stages before it constitutes a natural science. Thus, design is very subjective and depends on the background of the designer, two people may never agree on the quality of a given design. Until now many attempts have been made to standardise design (Parsaei, 1993) (Pahl, 1996).

Because of the wide range of expertise required to design systems, it is evident that generalists are more desirable than specialists. Too many people intervening in the same room become both unmanageable and *uneconomical*. Or, a significant percentage of the overall costs involved in the manufacturing of a product are committed to the design phase of the its life-cycle (Delchambre, 1996). This also leads to the need to decompose the system into meaningful subgroups with some interactions. Moreover, in order to minimise the sequentially iterative aspect of the design phase, CE has been widely adopted to help designers with DFA and DFM rules.

3. Design methods: state of the art

Many historical introductions to the design problem point out that Henry Ford was among the firsts to introduce the concept of '*designed for ...*'. He introduced many features which gave the model 'T' the competitive advantage. He designed the product so that it was easy to drive by virtually anyone. He devised the parts of the product to be interchangeable and easy to attach to other parts. He designed the interchangeable worker within the production system. He designed the movable production line. He designed the product for many different purposes. The combination of these sub-designs led to the supra-design of mass production, for which he is known (Kirton, 1994).

We frequently use the word 'design' as:

- Design is an activity that recognises the goals or purposes of products or systems.
- Design is an activity that shapes its objects–creates their forms, in accordance with the goals or purposes of those objects.
- Design is an activity that evaluates and determines the forms of its objects and makes their contents universally comprehensible.
- The product design process transforms abstract customer demands into specific product drawings.
- The product design process is a process of function allocation that identifies product purposes–such as functions, and allocates them to a structural product.
- The product design process manipulates information creatively.
- The product design process is a decision-making process.

In related works about design problem-solving we often find many types of design, including: *preliminary, conceptual, functional, innovative, creative, routine, embodiment, parametric, detailed, redesign, non-routine and configuration*.

Balkany (Balkany, 1993) classified design problems into three categories:

- those that have subtask ordering decided a priori,
- those that know the dependencies in advance, but order them during the design,
- those for which the dependencies between subtasks are both discovered and ordered during the design.

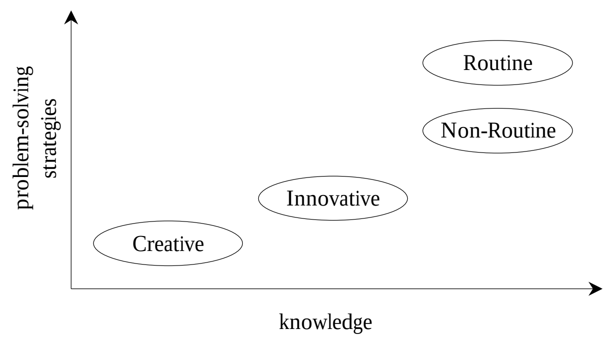

Figure 2.2. Tong's classification of design problems (Tong, 1992).

Many authors seem to classify design into *routine*, *innovative*, and *creative*, where each class is less known in advance by the designer. Tong (Tong, 1992) has classified the design process into five categories which are process dependent and product independent (see Figure 2.2).

1. **Routine design** We know in advance everything about the design process, including the knowledge needed. The solution may not be completely known in advance. Due to repetition of similar problem-solving, more and more design tasks are becoming routine. Since subtask ordering is decided a priori, routine designs are done more efficiently, and possibly with better results.

2. **Non-routine design** Are problems where a high level of experience is missing. The non-routine design belongs to the third category of Balkany classification (Balkany, 1993).

3. **Innovative design** Only the knowledge sources are known in advance.

4. **Creative design** Neither the knowledge sources nor the problem-solving strategies are known in advance.

5. **Redesign** Is concerned with changing prior design decisions. This includes modifying an existing design in response to changing requirements, and making changes to decisions already made during the design process. It can be a result of

unsatisfied constraints. Suggestions about suitable changes, can be either pre-stored or generated by analysing the situation.

In his taxonomy of design problems Dixon (Dixon, 1995), introduces other levels named *functional, phenomenological, embodiment, attribute, and parametric*. These levels depend on whether function, physical principles, general class of solution, type of object, or parameter values are decided at that level.

1. **Parametric design** The things being decided are values for a pre-specified set of attributes. This is a kind of iterative redesign (propose and revise method), where an initial and complete generated design is modified (one parameter value at a time). After each modification an evaluation leads to suggestions about which parameters to change next and in which direction. It is a kind of a hill-climbing optimisation approach, which can be controlled by designer knowledge to ensure that it keeps improving its solution and approaches a global optimum.

2. **Conceptual design** The kind of things being decided at that point are abstract (i.e., conceptual). It requires information from diverse sources in order to define the functional requirements, operating constraints, and evaluation criteria pertinent to accomplishing a prescribed goal. For instance, the design requirements can be satisfied by an object providing a particular function.

Dixon (Dixon, 1995) reported other design methods which can be classified into the following:

1. **Preliminary** Is considered as an extension of conceptual design. It contains more specification than the conceptual one, the type of the problem to solve is taken into account.

2. **Configuration** Is a restricted form of design, the components of the designed object can only come from a predefined set. They are selected and arranged together to satisfy some requirements. Depending on the complexity of the problem, the components may or may not need to have values provided for parameters.

3. **Functional** Hierarchy is useful to reduce search during configuration. Description of function and behaviour are useful during conceptual design, for criticism, and for reasoning about mechanisms.

4. **Embodiment** Takes an incomplete level of detail, such as the results of a conceptual design. It is used when adapting an existing design.

5. **Detailed** Finalises all detail of an embodiment design to a level sufficient for a system to take place.

Pahl and Beitz (Pahl, 1996) proposed another design model which can be described by a flow diagram comprising four main phases.

1. **Clarification of the task** This involves the collecting of information about the design requirements and the constraints on the design, and describing these in a specification.

2. **Conceptual design** This involves the establishment of the function to be included in the design, and identification and development of suitable solutions.

3. **Embodiment design** This conceptual solution is developed in more detail, problems are resolved and weak aspects eliminated.

4. **Detail design** The dimensions, tolerances, materials and individual components of the design are specified in detail for subsequent manufacture.

Dasgupta (Dasgupta, 1991) provides some historical as well as modern attempts to the above definitions. Parsaei and Sullivan provides an excellent set of articles which address a number of important issues within concurrent engineering (Parsaei, 1993). The various definitions agree, however, that design is concerned with the mapping of a specified function onto a structure or description of a structure. Usually, the designed structure also satisfies performance, resource, and constraints. In addition, most design theoreticians agree that the goal of design is to purposefully initiate change in some aspect of the world (Simon, 1981) (Tong, 1992). Unlike theories of the natural science, design is concerned with construction of artifacts.

Design is essentially a rational, logical, sequential process intended to solve problems:

> *"the process of constructing a description of an artifact that satisfies a (possibly informal) functional specification, meets certain performance criteria and resource limitations, is realisable in a given target technology, and satisfies criteria such as simplicity, testability, manufacturability, reusability, etc."* (Tong, 1992).

As most designers can be considered to be experts, knowledge-based systems created for design purpose can be considered to be expert systems. Initially, most of the expert systems research was concerned with diagnosis, and tools and techniques which help to build diagnostic systems. Now, design has become an important area to study. Expert systems technology has allowed many new practical applications. For example, in addition to systems that produce designs, systems can be built to check design decisions for conformance with standards or with company guidelines. Systems can be used to extract features, to select materials, to discover design flaws and suggest corrections, and to evaluate the manufacturability or constructability of the design (Björkman, 1991).

The use of computer-aided design, as well as the development of a computer-supported co-operative work environment for the design process, can improve the quality and speed of the design process. However, certain kinds of vital information, usually implicit in the process, are usually lost in large projects. This is why, designers have to use domain knowledge, past designs and well defined interaction with others.

Design has not always been a rational process; it is often a chaotic affair where consultation and consensus are scarcely evident. Design is not a total process. The work of participants in the process is often departmentalised, each one has its specific expertise. The expertise is so tight that each expert rapidly falls outside its boundaries. Participants always explore their ideas unilaterally, with one or another participant, through virtue of their 'expertise', imposing constraints upon all others. In this way, the craftsman has a veto on matters to do with skill or availability of materials, the engineer has a veto on technological considerations, and the manager alone could impose considerations of taste and finance. Such behaviour does not always lead to happy ends. Since the nature of design is equally as complex as that of technology, we believe that design must be shown as a shared activity. The design (problem-solving) process, must work by consultation and consensus. The process begins with the identification and analysis of a problem and proceeds through a structured sequence in which information is researched and ideas explored and evaluated until the 'optimum' solution to the problem is reached.

As we glance through a number of design methods presented in the literature, we can observe so many circles, arrows, paths, boxes, charts and diagrams (Parsaei, 1993) (Pahl, 1996). It seems that everyone has his own design process. *Ok, so we have one too!* Everyone has his own design method, there remains to find the applicability of such methods. Logical design processes do not and should not replace creativity.

4. Design and search approach

Designers use a broad range of experience to carry out their design; it is this experience and the associated information that distinguishes the novice designer from the expert one. Consciously or unconsciously, experienced designers apply their extensive knowledge base to resolve problems using requirements and criteria from past designs, by decomposing the problem and evaluating alternatives. Unfortunately, the design complexities may require knowledge beyond the direct experience of most practising engineers. All designers are novices in some context.

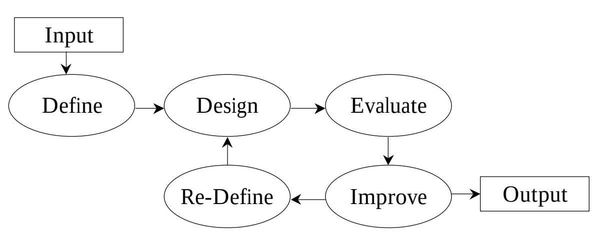

Figure 2.3. The design structure.

During the design process we propose a system that allows us to satisfy a set of purposes. The typical system contains processes, purposes, organisations, peoples, and behaviours. When humans are involved in the system to be designed, there are specific subsystems which must be considered. The associated considerations, such as safety, become a part of the set of purposes (requirements). Thus, design is the definition of forms (systems) to satisfy many desires.

Five distinct aspects of engineering tasks are defined (Figure 2.3). Each provides a particular function, and can be implemented in different ways using different techniques (expert systems, AI, etc.).

Definition
This phase (which is often *numerical*) permits designer to understand the properties of the design or of its sub-components. Abstraction (which supports the use of *analogical reasoning*) is used to discover the more general design the one at hand is an example of. Association is used to allow related concepts to be discovered. This might lead to a better understanding of which design plans or analysis methods to use. The **Re-define** phase allows designers to integrate new design knowledge into existing one.

Design
After dividing a design problem into smaller manageable sub-problems, the designer has to suggest from scratch or select (by retrieval) an appropriate working plan. Depending on the design state, a decision may be made to decide on what sort of method or analysis might be used. The obtained design (or a portion of it) has to be compared to a standard. A *verification* is done in case design requirements are used. Each time a conflict is detected (which can be a constraint violation, design agents disagreements about a design decision, etc.) a resolution procedure is required, which can be a retraction or a negotiation.

Evaluation
The analysis results (or some aspects of the design) are used to provide an *estimate* of quality or the degree to which it meets some design aims. The design values (estimation) must be *roughly right*, since they serve as a bridge to find features of the design that can be used for analysis. The fitness (suitability) of a given solution is a value that reflects its performance (i.e. how well a certain task is solved). A fitness landscape is the hyper-surface obtained by applying the fitness function to every point in the search space.

Improvement
By its nature a design is an iterative process. Thus, the designer has to learn from old experiences to improve resulting designs, or the design process, making it more efficient and more knowledgeable. The data resulting from the analysis provides each designer with a methodology to be followed and can be interpreted to allow evaluation. A serious interpretation maps data into concepts that are relevant for the design activity. *Negotiation* provides a way for a team of experts to arrive at a design which is acceptable for all parties.

Re-design
Modifies an existing design in response to conflict, poor evaluation, or changing requirements. In order to save time and effort in testing many combinations, *prediction* is often needed to determine the consequences of a design decision. A good

presentation of selected information about the current state of the design is important for assisting the human designer, since it helps to decide about the design's quality. The *patching* is often used to modify an existing design after flaws have been found in it. Some form of *backtracking* can be used to discard previous design decisions. For complex problems, the designer has to begin by a *simplification* of the problem, it can be carried out by abstraction (ignoring details or relaxing less important constraints).

Almost all search methods (Appendix 1), often use such design structure while seeking good design (product, assembly line, etc.). The difference resides in the way each of these design components (as well as its importance to designers) is dealt with.

5. Assembly line design : the gap between theory and practice

Each company using assembly as its strategic core activity, is faced with the problem of how to utilise and develop an assembly system in the most efficient way. The assembly activities performed within the assembly system do not only determine the final qualities of the products, but also affect quality, time-to-market, delivery, security, etc. Designing assembly systems in a systematic way, following a defined structure is very much in demand and can be very helpful. A precondition for this is a carefully planned design process.

In this study our emphasis is on design of manual and hybrid assembly line. Design begins by identifying a problem, a need or a change in need (an evolution of demand, products, etc.). Good design solutions usually satisfy criteria from many problem areas among others, such as: marketing, function, ergonomics, manufacturing processes, assembly and cost, etc.

Assembly of a product requires transformation of design ideas into reality, which ultimately results in a useful item. This is accomplished through the efficient completion of operations by a group of workers, machines, or robots. Managers and designers must carefully analyse different ideas regarding production of an item and then select the alternative which is the most cost-effective and feasible.

Advances in technology and changes in competition between companies have affected ALD. Introduction of new products and modifications in product design lead to frequent redesigns of the assembly system. This involves an increasing need for fast computer-aided design tools. We propose, in this section, a review (a simple fly-over) of several ALD approaches, and show the *gap* existing between these methodologies and the practical problems encountered in a real-world environment.

The operation research community has developed several algorithms to tackle the line balancing and the resource planning problem and several classifications of the logical line layout (LLL) problems were made in the past (Baybars, 1986) and (Scholl, 1999). The adaptation of such algorithms to real-world problems would yield very useful tools, since they are able to propose 'optimal' solutions to classical formulations of the ALB. Because of their combinatorial nature, the amount of information to take into account and the sometimes contradictory objectives to fulfil, ALB and RP applied to industrial problems are rather impossible to be solved (near) optimally by human. So, why existing methods are not applied to ALD problems?

Despite hundreds of projects on ALD, only a few of companies use published techniques to balance their assembly lines (Lucertini, 1998). One of the reasons is that the models usually adopted to solve the problem suffer from substantial loss of information. In fact, little work has been done to model the full range of practical ALD considerations. Most of the time, the ALB problems tackle linear assembly line, without separation into sub-lines. The common performance indices are the cycle time and the number of stations. In fact other factors may also heavily affect the system performances. Some of these, such as traffic problems, station space and transportation networks are often considered to be marginal in the design stage of the assembly line. This is why, until now, the developed algorithms are seldom used. In the following are cited some of the reasons which render the task difficult for academic methods to be applied to real-world problems.

5.1. Input data

Petit (Petit, 1999) mentioned a clear need for a object-oriented line design approach based on realistic input data. Almost all industrial approaches to design problems suffer more-or-less from the same drawback, which is the amount of data the designer has to introduce. On the other hand, existing academic algorithms, requiring little input data, cannot be applied to industrial problems–even if they get good results on test problems. This is because, despite their effectiveness and easiness of their use, they suffer from substantial loss of information, leading to solve fictitious problems rather than real (industrial) ones. There is, thus, a great need (and big challenge) to overlap the two philosophies, dealing with more real constraints of the design problem, rather than spending time with a non-sense *benchmarking* fight. Chapter 3 comes up with some new ideas on how to deal with such design problems.

5.2. Multiple objective

As many practical optimisation problems, the ALD must be formulated as a multiple objective problem rather than to aim to minimise the number of stations or the imbalance between stations. Efficient ALD methods should be able to deal with conflicting objectives or to take users preferences into account. They should be quick enough to allow the designer to test as many alternatives as possible (see Chapter 5).

5.3. Variability

Due to uncertainty in tasks duration, classical *deterministic* methods cannot be used to resolve industrial problems. Most ALD parameters that can be accurately estimated by engineers are available in terms of their average values. The only thing known is the mean process time, the average cycle time, the mean reliability of equipment. The line designer may try to reduce the variability, for instance, by introducing automation or improved work methods. Sometimes assigning a fast operator, in case of manual assembly line, to the operation with high variability may also help to increase line productivity. Methods like simple assembly line balancing (SALBP-1) (minimise the number of stations) may be discarded since such methods have to satisfy a hard constraint (stations process time must not exceed cycle time). However, in real-world assembly line the process time is not associated with high probability. Stochastic methods must be integrated to ALD approaches to deal with such problems. The accent should be put on the 'equal piles' methods (with the aim to minimise the imbalance between stations) (see Chapter 6).

5.4. Scheduling

Traditionally, the ALB and the variant ordering (for mixed-production) have been considered as two separate but related problems. Most research on assembly line sequencing considers scheduling problems after ALB. By separating the two problems, sub-optimal solutions are often obtained. In Chapter 8 is introduced a new concept called the *balance for operation* (BFO) to treat both problems simultaneously.

5.5. Layout

The design problem of organising an assembly system into workcenters (a set of linked stations) along a production plant is the well known facilities layout problem (logical and physical layout). The position of each workcenter is important, since it determines the costs of transportation and storage. Most research on ALD considers the physical layout problem after the logical layout. By separating the two problems, sub-optimal solutions are often obtained. Better solutions can be found by using the premises of the physical layout as input data for the logical layout and vice-versa. The main questions to consider are: which tasks should be grouped in the same workcenter, and how can we link the different sub-lines to achieve a good balancing? Chapter 9 introduces a new concept of workcenters and gives some useful responses to this important problem.

5.6. Iterative process and interactivity

In Chapter 10, the essential and distinct concepts adopted by the integrated ALD method are described, along with its step-by-step execution procedure.

6. About the quality of a design

An assembly line is composed of many individual components such as operators, stations, material handling systems, and so on. One of the main objectives of assembly systems designers is to increase the efficiency of the assembly line by maximising the ratio between throughput and required costs. Line performance is the outcome of interactions between these components. Performance evaluation involves generally two steps: (1) mathematical model, and (2) model solution. Because of the large number of these components it is difficult to find a simple model to describe a studied system. For this reason, a simulation method is frequently considered. The purpose of simulation is essentially to develop a mathematical model that resembles as closely as possible to the real-life decision situation, and then use a computer to solve the problem under various decision circumstances.

The design computing field is concerned with development of sophisticated tools for designers. First of all, it requires a better understanding of the design process in order to develop appropriate tools. A precise definition of input as well as output of the system is needed. While various optimisation techniques have been applied to engineering design problems, a class of realistic engineering design problems face a mixture of different difficulties, such as the number of design variables and objectives, etc. Indeed, the question is how to select the best configuration for an assembly line tacking into account factors such as balancing, throughput, resources, line cost, and so on? Modern design computing approaches cover several areas of interest including artificial intelligence, computer collaborative work and cognitive science.

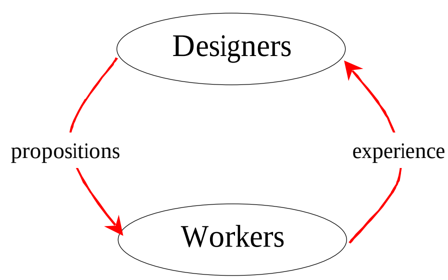

Figure 2.4. Interaction between designers and workers.

One of the classical questions about *human operator* is the how much it costs to hire such an operator, how skilled he is. No one asks about the difficulty of his (or her) tasks, how much time does the execution of the given task takes, etc. It is highly important in order to design assembly line to take into account operator knowledge– the person who really does the job, about the complexity of the tasks, the grouping of tasks preferences, the process time, all their experience on all the assembly methods. Thus, interactive and iterative methods have to be developed in order to introduce such knowledge to computer-aided design tools. The designers propose a set of assembly line alternatives, while operators give their experience and criticism of the proposed solutions (Figure 2.4). In Chapter 10 some features of our framework will be presented as well as the main drawbacks of the current design of assembly systems. The aim is to tighten the gap between *frequent talks* about human factors in assembly line and the actual reality of things. Most of the time social factors[1] go in the opposite direction to the company benefits, so *how to decide about the side and how to find a solution that compromises the two?*

7. Assembly line design evolution

> *"The fundamental problem is that designers are obliged to use current information to predict a future state that will not come about unless their predictions are correct. The final outcome of designing has to be assumed before the means of achieving it can be explored: the designers have to work backwards in time from an assumed effect upon the world to the beginning of a chain of events that will bring the effect about."* (Jones, 1970).

We have to remember that design and redesign are not accidents, but a mirror of their ages. Advances in technology and changes in the competition between the enterprises have affected ALD. The introduction of new products and the modifications in the product design yield frequent redesigns of the assembly system. Thus, with the increased diversified demand in production, more and more manufacturers use mixed-model assembly line. The design of the assembly line has to take into account the changes of demand and the evolution of products. In modern industry, batch or mixed-production approaches are used. In *batch production*, only one product is produced over a certain period, in *mixed production*, several variants of the product-family are produced all the time.

The problem seems to be simple like that, but this is not the case in real-world assembly line. This is why designers tend to *redesign* (rebalance) and *reuse existing assembly line* to produce different products (batches). It is certain that almost all industrialists tend to change as little as possible their existing assembly line. Each time designers have to redesign existing line (in a short time), approaches like '*pick and choose*' are used to find a possible (if it exists) design that fits the requirements. The results are bad in general, henceforth we think that the accent must be put on assembly line *recovery* methods, more than the design of new assembly line. Techniques that try to deal with the evolution of the architecture of assembly line over time are more asked for than methods that propose designs from *scratch*.

In the case of ALD, only a little research have been done on methods that help to improve existing designs. The aim is to enable a computer to create new designs, with some preliminary or existing designs being supplied. The evolution of complex assembly systems at the same time seems to be more complex, and needs more and more reflections. At least, thinking about the more simple problem can yield fruitful ideas on how to deal with the real-world design of complex installations. As constraints and preferences evolve with time, the progress of designs methods have to runs parallel to them.

---

[1] Design is no longer about designing shapes, forms and images, but about designing desires, tacking into account human factors.

8. Summary and further works

Despite a number of projects completed on ALD, academic algorithms are rarely yet used by industrial companies. This is because despite their effectiveness and the easiness of their use, they use little data and suffer from substantial loss of information leading to solve fictitious rather than industrial problems. Like many practical optimisation problems, the ALD must be formulated as a multiple objective problem rather than to aim to minimise the number of stations or the imbalance between the stations, etc. Efficient methods in line balancing and resource planning should be able to deal with conflicting objectives and take user's preferences into account. They should be quick enough to allow designers to test many alternatives.

Design is not an activity solely for engineers and designers but is a shared activity between those who design the systems and environments, those who make them (engineers, workers, etc.) and those who use them (customers). Computers have contributed to design for quite a while by providing analysis tools such the 'finite element' method, data bases of equipment and components, computer-aided drawing tools, and simulation packages, etc. We believe that computers could play a significant role in facilitating collaboration among the different participants– engineers, workers, customers, etc. One could envision a *framework* of several agents, where each agent could be viewed as a combination of a human and a computer that participate in a design process through a shared workspace.

There seem to be two extremes to the design process. The design satisfying process which uses constraints to narrow the design space to the final solution and the target based design optimisation process. Most design processes seem to use both the constraint and target concepts to some degree, although, they may be biased heavily towards one extreme or to another. The question is what is the *best combination*? *Multidisciplinary* search is a test bed for that determination. More and more due to frequents changes, we are constrained by time, thus the author thinks the acceptance of a given design will rely only on the *time* needed to do the job, rather than on the quality of the proposed design ... *only the future will tell us!*

9. References

(Balkany, 1993) Balkany A., Birmingham W.P. and Tommelein I.D., 'An analysis of several configuration design systems', AI EDAM, Academic Press, Vol. 7(1), pp. 1-17, 1993.

(Baybars, 1986) Baybars I., 'A survey of exact algorithms for the simple assembly line balancing', Management Science, Vol. 32, pp. 909-932, 1986.

(Björkman, 1991) Björkman M., Olofsson C., Lundström M., 'An approach to an expert system model for systematic design of flexible assembly systems', Proceedings of ICCIM'91, Singapore, 1991.

(Boothroyd, 1992) Boothroyd G., 'Assembly automation and product design', Marcel Decker Inc., New York, 1992.

(Chow, 1990) Chow W.-M. ‘Assembly line design - methodology and applications’, Marcel Dekker, New York, 1990.

(Dasgupta, 1991) Dasgupta S., ‘Design theory and computer science: processes and methodology of computer systems design’, Cambridge Tracts in Theoretical Computer Science, Vol. 15, 1991.

(De Lit, 1999) De Lit P., Rekiek B., Pellichero F., Delchambre A., Danloy J., Leroy A., Petit F., Marée J-F., Spineux A., and Raucent B., ‘A new philosophy of design of a product and its assembly line’, Proceedings of ISATP’99, Porto, Portugal, pp. 381-386, 1999.

(Dean, 1992) Dean E. B. and Unal R., ‘Elements of designing for cost’, presented at The AIAA Aerospace Design Conference, Irvine CA, AIAA-92-1057, 1992.

(Delchambre, 1996) Delchambre A., ‘CAD method for industrial assembly concurrent design of products equipment and control systems’, John Wiley & Sons Inc., Chichester, England, 1996.

(Dixon, 1995) Dixon J. R., ‘Knowledge-based systems for design’, Journal of Mechanical Design, Vol. 117, pp. 11-16, 1995.

(Jones, 1970) Jones J.C. , ‘Design methods and technology: seeds of human futures’, 1970.

(Kirton, 1994) Kirton J. and Brooks E., ‘Cells in industry: managing teams for profit’, McGraw-Hill, 1994.

(Lucertini, 1998) Lucertini M., Pacciarelli D., Pacifici A., ‘Modeling an assembly line for configuration and flow management,’ Computer Integrated Manufacturing systems, Vol. 11(1-2), pp. 15-24, 1998.

(Marée, 1999) Marée J.-F., Raucent B. and Spineux A., ‘Selection of assembly technique and equipment’, Proceedings of ISATP’99, Porto, Portugal, pp. 393-398, 1999.

(Nevins, 1989) Nevins J. L. and Withney D. E., ‘Concurrent design of products and processes’, Mc Graw-Hill, New York, 1989.

(Pahl, 1996) Pahl G. and Beitz W., ‘Engineering design: a systematic approach’, Springer-Verlag, Berlin Heidelberg, 1996.

(Parsaei, 1993) Parsaei, H. R. and W. G. Sullivan, ‘Concurrent engineering: contemporary issues and modern design tools’, Chapman and Hall, London, England, 1993.

(Petit, 1999) Petit F., ‘Interactive design of a product and its assembly system’, Ph.D. Thesis, Université Catholique de Louvain, 1999.

(Simon, 1981) Simon H.A., ‘The sciences of the artificial’, (3rd ed.), The MIT Press, Cambridge, MA, 1981.

(Scholl, 1999) Scholl A., ‘Balancing and sequencing of assembly lines’. Heidelberg Physica, 1999.

(Tong, 1992) Tong C. and Sriram D., ‘Artificial intelligence in engineering design’, Boston, MA: Academic Press, Inc., 1992.