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Published in:
23rd International Conference on Flexible Automation & Intelligent Manufacturing, 26-28 June 2013, Porto, Portugal

DOI:
[10.1007/978-3-319-00557-7_81](https://doi.org/10.1007/978-3-319-00557-7_81)

Published: 01/01/2013

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Peltokorpi, J., Laakso, S., Ratava, J., Lohtander, M., & Varis, J. (2013). Relationships of Factors in a Manual Assembly Line Environment. In A. Américo (Ed.), *23rd International Conference on Flexible Automation & Intelligent Manufacturing, 26-28 June 2013, Porto, Portugal* (pp. 985-996). SPRINGER.
https://doi.org/10.1007/978-3-319-00557-7_81

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Relationships of Factors in a Manual Assembly Line Environment

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ABSTRACT

This study makes a proposal and then presents the information required to describe operations and human resources management factors in a manual assembly line environment. This information is needed since the purpose of this study is to increase the understanding of the effects of the factors and their interrelationship on system performance. Because of the complex nature of the socio-technical assembly environment the present study focuses on task- and worker-related matters as a basis for conceptual-level analysis and factor connections flow. The study uses the Gephi software for analyzing factor clusters, occurrences and connections by means of a relationship network. As a result, the software produced four different factor clusters, each characterized by strong mutual relationships between the factors comprising them. Further, the results of this study help to identify the factors that are to be used in more thorough analysis, from assembly environment development up to semi-intelligent decision-making systems.

1. INTRODUCTION

The development and maintenance of a competitive manufacturing system is a widespread issue in global production markets. In order to achieve highly performing and profitable production the description of product and device resources and their interconnectedness should be the starting point for method comparison [1], the development of expenses [2], production planning [3, 4] and the performance of optimization [5]. According to Newness [2], budgeting in the design phase requires the presentation of factors relating to production and the product itself, as does process optimization.

There are at least two points of view on cost-effectiveness in the manufacturing context, namely cost-effective total product and cost-effective manufacture [6]. A typical response to decreasing cost-effectiveness in western countries is that companies concentrate on those actions that add the most value to the product they are able to with great efficiency. With a view to the present paper, such effectiveness potential has been seen in assembling mass customized products in varying production circumstances in which line design and the manual workforce play a major role. When assembly production is designed in such a way that the task-, system- and worker-related properties are taken into account throughout, a significantly higher degree of value added can be incorporated into a product, while minimum production costs and good employee satisfaction can also be maintained.

Many previous approaches to analyzing and developing the performances of manual assembly systems have been undertaken, advisedly or unknowingly, with inadequate information to handle a socio-technical system. Instead of the necessary and thorough understanding of the assembly environment, these academic studies or practical case studies from several disciplines mostly concentrate on separate subsystems or problems to be solved. Although the incremental improving of assembly processes can improve efficiency and productivity, in the longer term all the essential factors, both in the operations and human resources management fields, should be handled together. Therefore, when analytical methods are being selected the nature of the system must be taken into account. Furthermore, it is impossible to create an optimal technological design, as stated by Wang [7], unless the characteristics of the processes are known.

The purpose of this study is to increase understanding of the manual assembly line environment. As a research method the study makes a conceptual and relationship-level analysis of task- and worker-related factors in the

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proposed environment. Because of the complex nature of such a socio-technical system, the environment is described on a level that is suitable for examination. Then the information based on the literature is presented to describe the interrelationship effects of the factors. This information is needed for analyzing a highly-performing assembly production and for the further development of expert systems.

The rest of the paper is organized as follows. Chapter 2 deals with the traditional problems and methods when an assembly environment is being designed and analyzed. Chapter 3 proposes the assembly environment to be examined by defining the factors and explaining their effects on the other factors on the basis of the previous literature. Chapter 4 presents and analyzes the results as a relationship network generated by the Gephi software. Finally, Chapter 5 draws the conclusions.

2. METHODS FOR ANALYZING ASSEMBLY PROCESSES

Designing and analyzing manufacturing systems involves the handling of essential matters and the use of suitable methods. As an example, companies have traditionally integrated the master production scheduling and detailed capacity planning of production design. Production design, as well as all other design functions in manufacturing, including drafting, operation, and mechanics, should be increasingly combined under one overall system in order to improve profitability. Regardless of the development trend, it is inevitable that the portion of automatic and semi-intelligent systems will increase. The development of smarter systems requires several separate functions, practices, and disciplines to be gone through. This is used for designing systems that are capable of presenting the information people need at the right time and with suitable accuracy. In this chapter, the authors present the fields deemed the most central, required or in need of development in order to design intelligent systems for assembly operations.

Once a model for an assembly process is formulated, there may be multiple ways of attempting to find an optimal solution or analyze it as a function of its sub-processes. However, in order to get a broad understanding of the whole socio-technical system, the information on the factors and the effects of their interrelationships and all the loops in the entire process should be studied. From that point of view many previously studied processes, such as assembly task re-organizing, job scheduling, worker selection or assembly line balancing by means of workload or worker allocation can be seen as separate sub-processes or problems of the assembly environment. As an example of that, it has been proven by Rekiek et al. [8] that the assembly line balancing (ALB) problem itself is an NP-hard problem (non-deterministic polynomial-time hard), and in order to acquire an integrated solution from production design to highly performing production, it is but a single part of the environment. Therefore, solving the problem for complex assembly production will take large amounts of computation time if conventional means are used. Some of the solution methods may apply on multiple levels of the problem, whereas some may be unique to a specific part of the problem.

The exact formulation of the model of the assembly environment imposes specific requirements for the solving method to be applied. Most notably, solving, e.g., the ALB problem requires optimization in a discrete space. If measurements are used, care must be taken in data assimilation (model fitting), as all data must be considered noisy. All models are ultimately approximations, adding another source of imprecision to the system. Finally, in order for an appropriate method to solve the problem to be selected, the nature of the system must be taken into account.

The programming method must be able to deal with nonlinearities and discrete decisions in order to solve the problems in processes. As the assembly process is ultimately stochastic, many approaches use statistical and stochastic methods [9]. In addition, genetic algorithms and fuzzy logic are used. As a result of the discrete solution spaces, Multi-Attribute Decision-Making (MADM) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) may be used to select the correct combination. Other approaches may locally linearize the problem or use methods such as simulated annealing. Some approaches use an agent-based solution, such as in the study of Sabar et al. [10], though in general, branch-and-bound type solvers are used, e.g., for ALB problems.

Since the literature deals comprehensively with solving and analytical methods for problems and decision making the focus in this study is on a broader understanding and analysis of the assembly environment. Therefore the information that is needed and an analytical method that considers the factors involved with a suitable level of accuracy are proposed in the following chapters.

3. PROPOSED ASSEMBLY LINE ENVIRONMENT

Typically, when manual assembly performance is being examined the focus is on task- and worker-related matters. However, central issues in developing a socio-technical system are the goals the company has set and the way the system is to be managed in order to reach these goals. Hopp and Van Oyen [11] summarize that agile companies typically set such targets as reducing Work-In-Process (WIP), increasing throughput per time unit and maintaining a minimum product cycle time or good employee satisfaction. Whatever the target is, system decision makers are at the interface between operations and human resources management, an approach that was handled in a comprehensive study by Boudreau et al. [12]. According to this paper, managers in both fields in industry should know the value of their connection when working together. The paper also notes that authors in the research fields of both operations and human resources management mostly handle these aspects as separate subjects in separate communities of scholars.

The assembly system design in this conceptual study is a serial mixed model assembly line, in which several variations of the same base product are assembled in a single line as discussed in [9]. The customization of physically relatively large products with low-volume processes influences the variation in workload and processing times between the stations and makes it possible for workers to help others in teams [13]. Figure 1 introduces the different assembly line environment factors and their connections on a conceptual level on the basis of the literature and partly on the authors' own view.

Figure 1 Assembly line environment flow chart

In Figure 1, the operations management factors are shown against a dark gray background and human resources factors are shown against a light gray background. An arrow between the factors simply indicates a preceding factor affecting another. A factor against a changing dark gray and light gray background indicates that it can be characterized as both an operations and human resources factor in this context. The following paragraphs define the factors and explain their interconnections. First, work unit and task characteristics, then the system characteristics, followed by the individual characteristics, contribution and outcomes, and, finally operational costs are examined. Because of the nature of the environment, only directional effects are explained and the assessment of their magnitudes is omitted. Thus Figure 1 does not present any values or weights.

A *work unit* consists of a number of serial *tasks* and a group of *workers* in a line segment. Each task is performed at their own station by one primary worker. Although the tasks are mainly processed manually, the number of machines and the level of automation affect the work. Therefore, the *percentage of machine-paced work*, indicating the shares of tasks in which machines are pacing labor at work, affects the *learning rate* [14].

When the number of workers differs from the number of tasks, it also affects the *cycle time* for tasks. An increased work unit size (through increased numbers of tasks and workers) increases not only *production costs* but also *absenteeism* and *labor turnover* because of lower group cohesiveness, higher task specialization, and poorer communications [15]. Importantly, *job satisfaction* is connected to both absenteeism and labor turnover, the latter specifically through *worker resignations*.

The *learning rate* is determined as the speed of the decrease in the average time for a task when the task completions are doubled on the basis of Wright's learning curve [14]. In general, the learning rate depends on the task type, which comprises task characters (i.e., cycle time) and overall task complexity. This factor has a major influence on the task *processing rate* and also on individual *self-efficacy*, determined in [16].

Operationally, the cycle time is the average total time it takes a job to queue to and be processed at a workstation [17]. From a worker's point of view, the cycle time can be defined as a repeated work cycle [18]. A study in [19] reviewed that with a relatively short cycle time (2.5 to 5 minutes) the level of labor dissatisfaction in assembly work was the highest. By contrast, a cycle time of 15 to 20 minutes results in optimum job satisfaction as a result of the reduced machine pace and leaving room for individuals to make their own decisions at work. However, an advantage of a suitable short cycle time is its ability to keep an efficient, increased pace (processing rate) on the assembly line. [19] In production management, the cycle time has a connection to the *amount of WIP* (Work-In-Process) and *throughput*, according to Little's Law [17]. Another effect is that the longer the cycle time (greater task content for one worker) is, the higher the *training costs* are.

Since the system in this paper enables workers to cooperate by means of agile helping, *task cooperation efficiency* is defined as the ability of one worker to provide help to another. This ability is, on the one hand, based on task properties such as task space congestion or constraints in tools [20], but also on individual abilities such as *cooperation* and *task-related skills*. That cooperation efficiency affects the processing rate, and it is notable that when workers are accustomed to working together, it affects their individual skills. The system performance indicates how productive a work unit is in terms of system throughput, utilization of resources and efficiency. The *throughput* rate for the system is determined as the number of completed jobs leaving the system (work unit) in a unit of time [17]. As a clear measure for cost-effective production, throughput affects production costs. Moreover, throughput makes a general if somewhat ambiguous contribution to job satisfaction [21].

A paced assembly line (in which products move to the next station in a synchronized manner) is not suitable for a mixed model assembly system because of the varying processing times between the stations. In a mixed model system, varying cycle times are balanced by using work-in-process buffers between the stations. [22] Work-in-process (WIP) is the average "number of jobs within a system that are either undergoing processing or waiting in a queue for processing" [17]. The amount of WIP contributes to production costs because of the capital invested in temporary WIP inventories. The amount of WIP also affects the *idle time*, defined as the time when a worker cannot work because of blocking or starving [22]. Idle time increases production costs as a result of the non-value-adding time of a worker. However, an idle worker can help other stations, which here is denoted by the term *agile balancing*. An idle worker can be allocated to a bottleneck station in order to increase the efficiency of the whole line. A visible amount of WIP affects the working pace (processing rate) of an individual worker [12], assumedly through self-efficacy. The processing rate is determined as the number of completed items per time unit [23], thus contributing greatly to the cycle time.

The *system response* covers the ways in which the system re-organizes in order to maintain efficiency and good performance. A well-organized agile balancing is generally beneficial, though excess worker movement between stations, especially when setup times in the station they have moved to are taken into account, may increase production costs. In practice, temporary agile balancing can be characterized as individual *job enlargement*. Job enlargement means "widening the range of tasks performed" by a worker [24], which may increase the cycle time for a task. The increasing variety of work affects the individual processing rate through task-related skills, with learning (skilling) [14] and forgetting (deskilling) [25] effects. Job enlargement has a positive impact on *job autonomy and responsibility*.

The very basis of human resources management is the fact that individuals differ in what skills they possess, how fast they perform and many other characteristics [12]. When workers' base characteristics are being evaluated, the criteria can be classified into performance, social and mental factors. This classification was used in a study of the

worker placement problem in an industrial environment [26]. In this paper, the most relevant factors from these three categories are selected to determine individual base characteristics in the present assembly system.

Job-related experience is selected as a performance factor. It covers all the previous experience influencing the current job a worker has. This experience has an impact on performance through individual task-related skills [27]. The essential factors in a social context from [26] are selected as *professional knowledge and interests*. In this paper this term stands for the individual's professional know-how and interests in their current work. This fact contributes to *tenure length*, as reported in [28], which, in this paper, is supposed to occur through work motivation and job satisfaction. Job-related experience has a positive impact on professional knowledge and interests, which again affect task-related skills. Other social factors in this study are *cooperation skills*, meaning skills in "joint action" [24] taken by two workers and a *sense of responsibility*, describing awareness of one's obligations [24]. Both these social factors affect task cooperation efficiency. Moreover, a sense of responsibility contributes to job autonomy and responsibility and the level of absenteeism, as well as cooperation skills. Mental factors in workers' base characteristics are filled with self-confidence from [26], which means a belief in oneself or one's abilities [24]. Self-confidence basically affects self-efficacy with tasks.

Individual contribution to task covers the factors of individual abilities and performance of a given task. A skill is defined as "an ability that has been acquired by training" [24]. Task-related skills have a major impact on the individual processing rate as a result of the learning process described in [14]. These skills also have a negative effect on training costs. Task-related skills contribute to self-efficacy [24] and job autonomy and responsibility. Job autonomy means increased worker discretion and independence to schedule one's work and the ways work is done [29]. Job responsibility is simply defined as a given responsibility over work. Job autonomy and responsibility affect many factors, i.e., job-related experience, professional knowledge and interests, sense of responsibility, self-efficacy, and work motivation.

Self-efficacy is determined as beliefs in personal ability, skills, knowledge, previous task experience and completion of the task to be performed. Moreover, the motivation theory is also built from the aspects of these personal and situational factors. [24] First of all, good self-efficacy contributes positively to the processing rate. Another meaning is increased self-confidence. An *individual outcome* is characterized as a result or consequence of how a worker perceives his job or position with the current task. Motivation is "the driving force which causes us to achieve goals" [24]. Therefore a motivated worker performs better than a worker without any goals or targets and thus good motivation indicates an increased processing rate. Work motivation affects job satisfaction and self-efficacy [24]. Moreover, a motivated worker is more interested in working at the company and therefore may achieve a long tenure. By contrast, a worker with motivation problems is absent more often [30].

Job satisfaction indicates "the extent to which a worker's hopes, desires and expectations about the employment he is engaged in are fulfilled" [24]. In other words, job satisfaction embodies how contented a worker is in his job. This includes a sense of achievement, advancement, growth, recognition, and responsibility, as well as the work tasks [31]. Job satisfaction contributes to the processing rate, as well as the efficiency of the cooperation on an individual task. Continuous job dissatisfaction can lead to absenteeism and finally to the worker resigning from the job. Absenteeism itself is "a habitual pattern of absence from a duty or obligation" [24]. Temporary, when a worker is absent from work there may be a shortage of workers in a work unit. In the worst case absenteeism leads to *workers resigning or dismissal* from a job, which affects labor turnover.

Individual response describes the ways in which a worker's position in his current job is changed. When a change is needed, care should be taken to improve workers' tasks or working conditions through re-organization. Otherwise a worker's commitment to the job may decrease decisively. Job enlargement may be a solution to low job satisfaction, if dissatisfaction is caused by repetitiveness at work. [32] By contrast, a solution for low job satisfaction and work motivation resulting from work tasks not being challenging enough may be providing "a range of tasks and challenges of varying difficulties" by means of job enrichment [24]. A previous study in [33] connected job enrichment to positive personal and work outcomes. For example, new tasks, a decreased amount of control, special assignments, and increased authority were observed to lead to increased worker autonomy. The authors assume that special tasks influence the self-confidence of individuals through job enrichment. However, job enrichment increases training costs.

Labor turnover is the rate at which an employer gains and loses employees [24]. That turnover can be affected by any employee- or employer-driven reason that leads a worker to leave the job. Operationally, the turnover rate contributes to the training costs of new workers. Tenure length means the time a worker has held his current job position. It is assumed to contribute to work motivation and job satisfaction since a review study in [34] summarized that after a certain length of tenure labor turnover decreases. Tenure length also affects job autonomy and responsibility, as well as professional knowledge and interests [27].

Finally, operation costs include the costs of training and production. Training costs include training new workers or training current workers for new tasks. Production costs cover all the costs, direct or indirect, affected by the described assembly production itself. The costs of production can affect the numbers of worker dismissals for individual or for economic and productivity reasons.

4. RESULTS AND DISCUSSION

The factors and relationships discussed in Chapter 3 above were imported to the Gephi software suite presented in [35] to analyze the assembly environment being studied by means of a relationship network. Figure 2 below presents the self-organized network by visualizing factor clusters, occurrences and connections. The figure is followed by analysis and discussion of the results.

Figure 2: Relationship networks of manual assembly factors

In Figure 2 a thick line between factors indicates a two-directional effect, whereas a thin line indicates only a one-directional effect. Four different clusters of factors are identified in the assembly environment. These clusters consist of the factors with the strongest relationships together and are marked in similar colors, characterized as follows: white, light gray, gray, and dark gray. The size of the points and text reflect the number of connections between each factor in the system.

The white cluster consists of ca. 38% of the factors, covering all the factors from individual base characteristics and contribution to the task. In addition, work motivation and tenure length are involved in this cluster. Major factors here are work motivation, self-efficacy and task-related skills, as well as job autonomy and responsibility.

The light gray cluster covers about 24% of the factors. The factors in this cluster represent work unit characteristics, as well as job satisfaction affecting the factors of individual response. Job satisfaction has the largest point of the network (Figure 2), indicating the factor that occurred most frequently, with 15 incoming and outgoing connections in total. As mentioned, job satisfaction embodies the worker's contentment with his job, meaning, i.e., how the hopes, desires and expectations connected with the job are fulfilled [24]. On the basis of the figure above, it is a major connective factor in a socio-technical system in contributing to the operational and human resource processes and targets set for the present manual assembly system.

The gray cluster consists of ca. 21% of the factors covering all the operations management levels in the flow chart in Figure 1. The factors in this cluster are related to task challenges, processing speed, and the training costs and labor turnover rate. Major factors here are the cycle time and processing rate.

The factors in the dark gray cluster (ca. 17% of all the factors) consist of system performance factors, as well as agile balancing and production costs. A remarkable point about this cluster is that all the other factors affect the major factor, production costs.

According to the above analysis, the factors in the process flow levels of individual outcomes and individual contributions to tasks (Figure 1) have the most connections. One explanation for this is that in the upstream of the process flow chart human resources factors are slightly more widely represented than operations management factors. Although the factors and connections presented, found in the literature or partly based on the authors' view, can be interpreted in various ways, the generated network, however, increases the understanding of the assembly environment and also gives insights for further developments of suitable analytical methods.

5. CONCLUSIONS

This study made a conceptual-level analysis of operations and human resources management factors and the effects of their interrelationships in a manual assembly line environment. The proposed socio-technical system was studied in order to see how both these types of factors affect system performance from the operational and individual workers' points of view. Because of the extremely complex research field, only task- and worker-related base characteristics were used as starting points in the process flow. A literature review was conducted to find out the factors and their possible directional effects on each other. Because of the unique approach and selection of factors in the assembly environment, some of the effects were also based on the authors' own view. All the effects were imported to the Gephi software suite to analyze factor clusters and occurrences. Four different clusters were identified as a result of the analysis. The largest cluster represents individual base characteristics and contribution to the task. In addition, work motivation and tenure length are involved in this cluster. The second largest cluster represents work unit characteristics, as well as job satisfaction and the factors of the individual response. The other two clusters consist of operations management factors: the first connects system performance factors and agile balancing to production costs, and in the second the factors are related to task challenges, processing speed, training costs and labor turnover rate.

The results from the system that was studied show that the job satisfaction factor contributes most frequently to the other factors, being a major link between operations and human resources management processes and targets. Depending on the performance targets, different factor loops in the assembly process can be identified and thus taken into account during decision making and system development. This approach does not give automatic solutions to reach the targets, but helps to identify the factors that are to be used in more thorough analysis. Different expert systems can be further developed by examining the essential factors that influence specific assembly systems. In order to get more accurate results from such analyses, the parameter values have to be identified. Although literature and experts can be used in searching for values, ultimately empirical studies are needed for realistic parameters.

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