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Analysis of the Effects of Group Size and Learning on Manual Assembly Performance

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Abstract

On the basis of a prior experimental study, this paper performs a further analysis of the effects of group size (one to four workers) and learning (up to four repetitions per group) on manual assembly performance. More specifically, this paper aims to investigate the factors and the extent to which they affect reduced assembly time as a function of repetitions and reduced productivity per worker as a function of increasing group size. The ultimate aim of this study is to increase the understanding of how working in groups of different sizes develops through repetitions when workers are free to organize their work themselves. The results from the video-based analysis show that with a new, relatively complex product, instructions play a crucial role in learning and the losses caused by the inexperience of workers decrease rapidly through repetitions. Unequal temporal workloads between workers in larger groups increase idleness and cause a significant loss of productivity. The findings presented in this paper give insights for industrial managers when assigning workers to products in variable assembly production of highly customized products.

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Keywords: group size; learning; manual assembly; productivity; activity analysis

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1. Introduction

Effective manual assembly production needs skilled workforce and adjusting of worker resources with floor-level processes. At its best, the issues of worker training and coordination for specific products and tasks are addressed prior to actual production, such as in the context of automotive assembly lines [1–3]. Anticipating these issues becomes more challenging with increasing variation in product mix [4]. Further, when products are highly customized, besides learning new tasks, workers have to coordinate activities by themselves during the actual production (similar to self-directed worker groups [5, 6]), causing productivity losses. Referring to such production circumstances, this paper investigates how working in groups of different sizes develops through repetitions within a case assembly product. This is done by performing a further analysis of the experimental study by Peltokorpi and Niemi [7]. The case assembly product under study has, more than in previous studies, elements from real products in the mechanical engineering industry. The product was new and, in principle, relatively complex for 68 undergraduate students who participated in the experiments. The students were randomly assigned to one of groups the sizes of which varied from one to four workers (the sample sizes were $N = 9$ for one-, $N = 10$ for two-, $N = 9$ for three- and $N = 3$ for four-worker groups). The groups were free to organize the work themselves. The following paragraphs summarize the main results from the experimental study in question [7] that investigated the effects of group size and learning on manual assembly performance. Alongside this, for the present study, the aims of the more detailed and practical analysis are stated.

For each group size (one to four workers) the mean assembly time decreased at a decelerating rate as a function of repetitions (up to four repetitions per group). Learning took place rapidly and, across all group sizes, on average, a 45% decrease in assembly time was reached from the first to the second repetition, and the third repetition reduced it by 19%. Learning of the case assembly was uncommonly fast in comparison to what is typical of real industrial conditions. To gain further evidence of the effects, the present study aims to investigate more precisely

(1) the factors and the extent to which they affect the reduction of assembly time as a function of repetitions.

Generally, the mean productivity per worker decreased as a function of group size (in line with the statement by Steiner [8, p. 96]). In relation to a single worker, the productivity loss with two workers was approximately 8-17%, with three workers 12-33%, and with four workers 23-40%, depending on the repetition. On average, the productivity loss decreased as a function of repetitions. The workers preferred a two-worker group, especially in connection with helping with larger parts. Limited physical space and an inadequate number of subtasks for several workers were perceived as causes of a loss of coordination, especially in the four-worker groups. To gain further evidence of the effects, the present study aims to investigate more precisely

(2) the factors and the extent to which they affect the reduction of productivity per worker as a function of group size.

The rest of the paper is organized as follows. Next, the related literature is shortly reviewed. Then methods for investigating different factors and their effects on assembly performance are presented. The analysis presented and conducted in this paper is based on video evidence on worker activities during the assembly process (i.e., parts installation, necessary movements, reading instructions and having loss time). Then the results from the investigation are presented, analyzed, and discussed. Finally, conclusions are drawn, and managerial implications as well as aspects for further research are suggested.

2. Literature review

2.1. Coordination and learning of groups

The coordination of a group involves who among the members does what, when, where, and how [9]. In practice, several aspects should be taken into account when coordinating workers around the assembled product. These aspects include precedence constraints and the work contents of subtasks [10] as well as space around and physicality of the subtasks [1, 2]. How easy group coordination is depends on the number of workers, i.e. group size. The number of coordination links increases with increasing group size, resulting in difficulties and inefficiency in group working [8].

In general, a considerable increase in group size causes productivity losses as a consequence of increased workload imbalance among workers [8]. In group working, the efforts of individuals are combined in an additive or interactive manner [11]. Interaction requires both technical and social skills on the part of individuals [12] and may generate new ideas, solutions, and efforts [13]. Interaction among group members is thus vital to the success of group working on complex tasks. Nonetheless, large groups in particular may suffer from social loafing, in which a worker puts less effort into working [14].

Earlier studies on the coordination of group working on shared assembly tasks were mainly carried out in the context of automotive assembly lines, e.g. [1, 2]. These studies consider largely identical products and repetitive line production. In such conditions, work has a routine character and is standardized, thus indicating a high division of labor. When product variability increases for example as a result of the introduction of new products, use of self-directed work teams is beneficial [5]. In such teams, workers have autonomy to arrange work assignments and the ways of working [5] being responsible for a whole process by working together while planning and controlling their work [6].

Group learning process involves “the activities through which individuals acquire, share and combine knowledge through experience with one another” [15, p. 370]. For novice workers and worker groups, noteworthy is individuals’ capacity to learn and cognitive stimulation [13]. The model for individuals in [16] proposes that cognitive elements dominate learning during the early repetitions, whereas motor elements dominate when the number of repetitions becomes large. To become familiar with a new product and task, one needs to consider how the task information is presented within the instructions [17]. Traditional assembly instructions do not contain information for groups of workers on how to collaborate or divide the tasks [18]. Learning through repetition is linked with specialization, referring to the degree to which individuals perform a narrow range of tasks [19]. When group members are free to match themselves with subtasks, they tend to perform those tasks they can do most effectively [8], i.e. the tasks they specialize in.

Based on the literature review, there is a lack of empirical studies that give evidence on how working in groups of different sizes develops through repetitions when workers are free to organize their work themselves. Evidence on fundamental factors in group working would give insights for industrial managers when assigning workers to products in variable assembly production.

2.2. Methods for analyzing assembly work

Analysis of group coordination and learning in manual assembly work needs appropriate methods. To identify losses and improve productivity, assembly work can be divided into three types of activity, according to Monden [20]: non-value-adding (NVA), necessary but non-value-adding (NNVA), and value-adding (VA). NVA activities are pure waste involving unnecessary actions that should be eliminated. NNVA activities may be wasteful but are necessary within the current procedures. VA activities involve assembling parts. The seven wastes that originate from the Toyota Production System are overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion, and defects [20]. One practical way to find losses in NVA movements or transportation is material handling analysis, such as a spaghetti diagram [21]. The production area used can be recorded and a flow chart of the activities can be created, including distance moved, time taken, and people involved [22]. All the information on an assembly process can be gathered efficiently by a video-based activity analysis (e.g. [23]).

3. Methods

This section presents the methods to investigate the factors and the extent to which they affect reduced assembly time as a function of repetitions and reduced productivity per worker as a function of increasing group size.

Figure 1(a) shows the case assembly product, consisting of different types of parts (the pipe subassemblies (P), hoses (H), modules (M), plate (PL), and valve (V)) that are assembled in a steel frame. Figure 1(b) presents the precedence constraints of the parts and, more precisely, the most suitable assembly sequence (left to right) among the interconnected parts forming a subsystem. The assembly of these parts can partly overlap, while different subsystems can be assembled in parallel. In addition to the physical precedence constraints, the temporal work contents of different parts affect the ways in which groups of different sizes assemble the product.

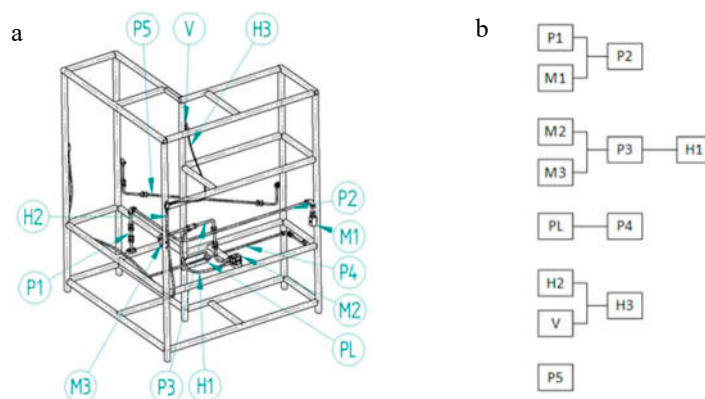


Fig. 1. (a) The case assembly product; (b) Precedence constraints of parts [7]

3.1. Video-based activity analysis

In the present study, the assembly process of each worker in each group and repetition was examined by means of a video-based activity analysis (similar to [23]) by using the AviX software (developed by Solme AB, Sweden). Examples of the timelines that were generated in the analysis are presented in Section 4.3, in Figure 6. In the analysis, different types of activities were specified as follows:

- Value-adding, VA;
 - installing of parts;
- Required, REQ;
 - necessary picking and handling of parts, small parts, and tools; necessary moving in the assembly cell;
- Instructions, INSTR;
 - looking at (reading) an assembly drawing; measuring the dimensions of parts and small parts;
- Losses, LOSS;
 - Wrong tools: taking and returning a tool that is inappropriate for installing the present part;
 - Faulty installing: installing a wrong part or the right one incorrectly so that a part has to be disassembled or reinstalled;
 - Dropping equipment: dropping tools, parts, or small parts;
 - Co-worker-related: inactivity caused by a co-worker such as congestion of workers or waiting for another worker's help or processing;
 - Familiarizing: observing and examining parts (except measuring dimensions), their assembly locations, and others' working; unnecessary handling of parts and small parts; unnecessary moving in the assembly cell;
 - Unexpected: any other unexpected event that interrupts the processing of a worker;
 - Idleness: inactivity resulting from there no longer being any (meaningful) task left for a worker at the end of the entire process.

In the list above, required activities and instructions correspond to NNVA and losses to NVA according to Monden [20]. Instructions are considered separately from the required activities because of their significance when assembling new products [17, 18]. Measuring dimensions is a very minor part of assembly time and is combined with instructions because it is closely related to reading an assembly drawing. The classification of the different types of losses is based on their importance and specificity, as well as on the possibility of distinguishing them from other losses or activities. In this study, losses are based on the physical activity (and inactivity) of workers. This also means that since the video material was muted before the analysis, communication and guidance among the workers were not taken into account. As shown in the above list, familiarizing covers a wide range of unnecessary activities and inactivity that is largely a consequence of the inexperience of a worker. These activities are considered together because they overlap and are

difficult to separate from each other in the assembly process. In general, the accuracy of activity analysis is subject to variation due to human conducting the analysis [24]. From the activities listed above, only value-adding (VA) and required (REQ) activities are connected to specific assembly parts, and others are considered independently of parts.

4. Results and discussion

4.1. Reduction of assembly time as a function of repetitions

Figure 2 presents different activities and the extent to which they affect assembly time as a function of group size and repetition. As Figure 2 shows, for each combination of group size and repetition, the share of the VA time of the total assembly time is the greatest, and, except for the 2W, 3W, and 4W groups with Rep 1, the share of REQ time is the second greatest. With Rep 1, the shares of INSTR and LOSS times from the total assembly time are significant (means of 23% and 18% across all group sizes). Thus, when a completely new product is being processed by novice workers and groups, losses occur to a great extent and the importance of instructions is obvious.

Rep 2 reduces the assembly time by 45% on average. This reduction is mostly explained by INSTR (a share of 39% of the total reduction) and LOSS (36%), followed by VA (16%) and REQ (9%). This order applies to each group size. When asked immediately after Rep 2, in the workers’ opinion, they learned quite much from Rep 1 (a mean 4.17 from all the workers on a 1-5 Likert scale, 4 = quite much, 5 = very much, Question: “I learned from the previous repetition” (Appendix 2 in [7]). It was also asked how learning occurred in the workers’ own performance or that of the group (open question). To sum up, less need for instructions was reported most widely over different group sizes. In addition, an improved assembly sequence was more common with single workers and two-worker groups, whereas the division of work or specializing in tasks were highlighted with three- and four-worker groups. First, these opinions show that, within smaller groups, there is more flexibility in the assembly sequence, which was also utilized. Second, within larger groups, there is potential in the better coordination of activities between the group members.

Rep 3 further reduces the assembly time by 19%. The reduction is mostly explained by LOSS (43%) and INSTR (31%), followed by REQ (15%) and VA (11%). It is noteworthy that INSTR accounts for most of the reduction with 1W, and the VA time even increases with 4W. After Rep 3, the workers felt that they learned neither much nor little from Rep 2 (mean 3.17, 3 = neither much nor little).

Rep 4 reduces the assembly time by 7% on average. With each group size, the REQ and INSTR times decrease. Instead, the VA time increases with 1W and 3W and the LOSS time with 3W and 4W. Increases in the VA times are, as observed by the experimenter, due to occasional problems when installing the large pipe parts, P2 and P5 (see Figure 1). According to an experimental study by Rohmert and Schlaich [25], problems with installation motions are one of the major reasons for individual differences in assembly performance. They also state that, rather than training, methods engineering would tackle these problems.

The above results show in practice what was proposed in the model in [16], that cognitive elements dominate learning during the early repetitions, whereas motor elements dominate with later repetitions.

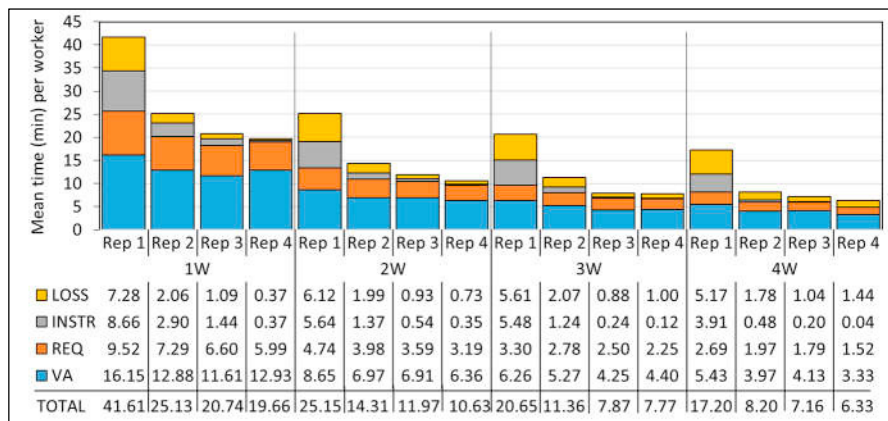


Fig. 2. Mean time (min) of different activities per worker as a function of group size (workers, W) and repetition (Rep).

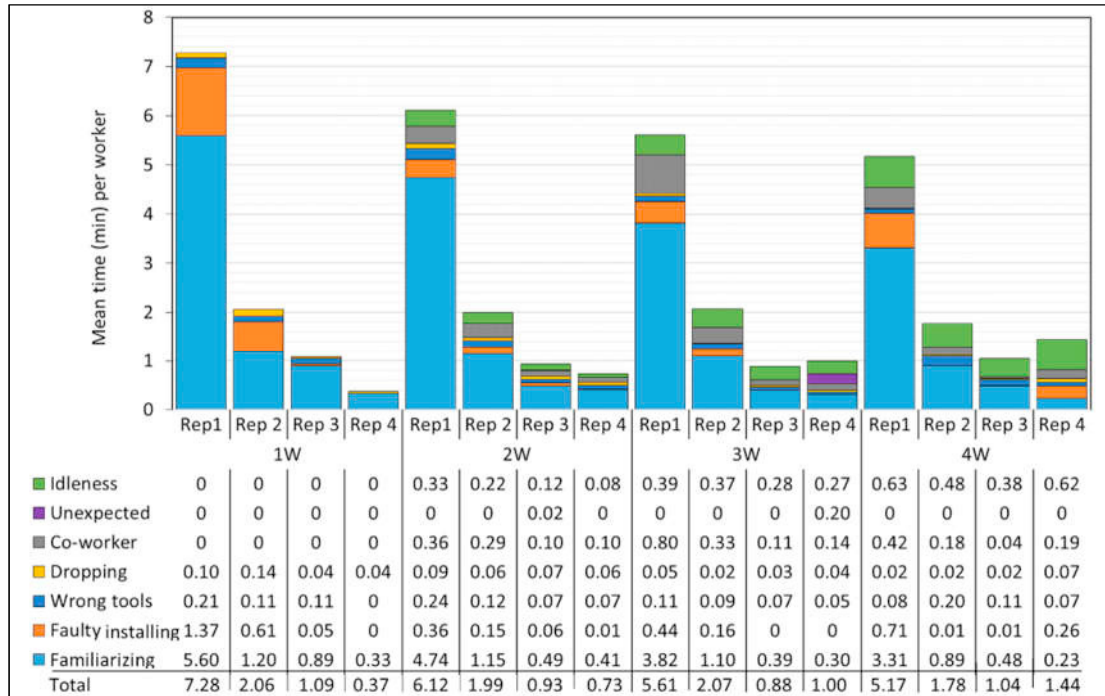


Fig. 3. Mean time (min) of different types of losses per worker as a function of group size (workers, W) and repetition (Rep).

4.1.1. Sources of losses

Figure 3 illustrates the extent to which different types of losses affect the LOSS time per worker as a function of group size and repetition. As Figure 3 shows, for each combination of group size and repetition, except for 4W with Rep 4, familiarizing is the greatest source of loss. As explained in Section 3.1, this loss type covers unnecessary activities which are mainly linked to the inexperience of a worker.

With Rep 1, across all group sizes, familiarizing explains on average 72% of the LOSS time and faulty installing (which is also linked to inexperience) 12%. Typically, inexperience appeared as observing and examining parts and their assembly locations. Rep 2 reduces the LOSS time by 67% on average, from which familiarizing explains 80% and faulty installing 12%. Rep 3 further reduces the LOSS time by 50% on average, from which familiarizing explains 52%. It is noteworthy that with 1W faulty installing explains the greatest proportion (58%) of the decrease and with other group sizes, co-worker-related losses the second greatest (18% each). With Rep 4, reduction of the LOSS time (66%) with 1W is significant and 78% of the reduction is explained by familiarizing. With 2W, the LOSS time decreases by only 20%. Instead, the LOSS time increases by 13% with 3W (mostly because of unexpected events) and by as much as 38% with 4W (mostly because of faulty installing and idleness).

To sum up Figure 3, inexperience-related losses (familiarizing and faulty installing) decrease rapidly, co-worker-related losses quite fast, and idleness slowly as a function of repetitions. Losses related to wrong tools, dropping equipment, and unexpected events are clearly minor. It is noteworthy that idleness remains a significant source of loss for 3W and especially for 4W groups with the latter repetitions. The results from the Pearson’s chi-squared test showed that, for each group size, repetition does not affect idle time significantly (for 1W, $p < 1.000$; for 2W, $p < 0.071$; for 3W, $p < 0.467$; and, for 4W, $p < 0.392$). Instead, for each group size, the effect of repetition on the total LOSS time is significant (for 1W, $p < 0.001$; for 2W, $p < 0.000$; for 3W, $p < 0.000$; and, for 4W, $p < 0.028$).

4.2. Reduction in productivity per worker as a function of group size

If group output does not increase in direct proportion to the number of additional workers, productivity (i.e. output per unit of time) per worker decreases (according to Steiner [8, p. 96]). In other words, to assemble a product, a larger

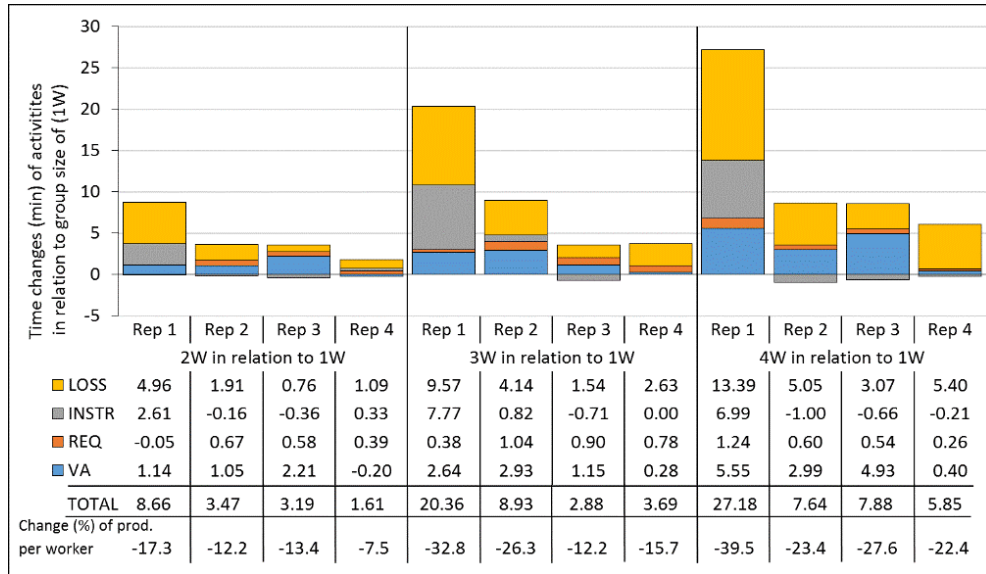


Fig. 4. Mean time changes of different activities with group sizes of two, three and four workers (W) in relation to single workers (1W) for each repetition (Rep). Changes (%) in mean productivity per worker with 2W, 3W and 4W in relation to 1W.

group will use more worker resources compared to a smaller one. Figure 4 shows the mean changes in the worker resources used (in minutes) in different activities with group sizes of two, three, and four in relation to single workers for each repetition. The changes (%) in mean productivity per worker are also presented.

According to Figure 4, in relation to single workers, the increase in the worker resources used (and the reduction of productivity per worker) with larger groups can be explained approximately as follows. With Rep 1, LOSS explains half of the change and INSTR one third; with Rep 2, LOSS explains half and VA one third; with Rep 3, VA explains half and LOSS one third, and with Rep 4, LOSS explains three quarters.

With each repetition, the LOSS time clearly increases as a function of group size. In general, the VA time increases moderately as a function of group size. As observed by the experimenter, this was due to wasted resources in assistance (i.e. workers assisting each other with subtasks) within larger groups. With Rep 1, larger groups (of three and four workers) used considerably more time with INSTR compared to smaller groups. It is obvious that when all the workers are novices, larger groups will waste more resources in order for the workers to gain experience. The time spent on reading instructions with large groups is also discussed in [18]. As a solution to this, they present a tool for dividing work and dedicated instructions for workers.

4.2.1. Sources of losses

Figure 5 presents the mean changes in the worker resources used (in minutes) in different types of loss with group sizes of two, three, and four in relation to single workers for each repetition. According to Figure 5, in relation to single workers, an increase in the LOSS time with larger groups in different repetitions is explained as follows. With Rep 1, on average, familiarizing explains 63% of the time change, followed by co-worker-related losses (17%) and idleness (14%). With Rep 2, familiarizing explains 46% of the time change, followed by idleness (27%) and co-worker (21%). With Rep 3, idleness explains 45%, followed by familiarizing (19%) and co-worker (18%). With Rep 4, idleness explains 31%, followed by familiarizing (26%) and co-worker (16%).

As Figure 5 shows, with Rep 1 and Rep 2, familiarizing clearly explain most of the LOSS time change, also increasing as a function of group size. Aligning with the INSTR time taken, this confirms that within a new product, large groups waste more worker resources as a result of the inexperience of the workers. Idleness clearly increases as a function of group size and explains most of the LOSS time change with the latter repetitions (Rep 3 and Rep 4). Pearson's chi-squared test showed that, for each repetition, the idle time differs significantly depending on the group

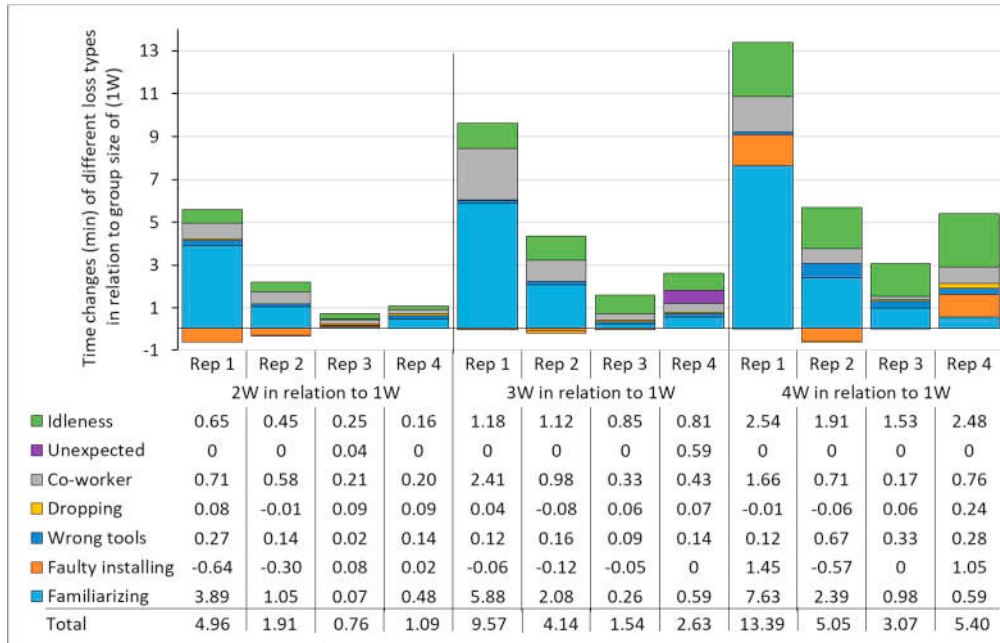


Fig. 5. Mean time changes of different loss types with group sizes of two, three and four workers (W) in relation to single workers (1W) for each repetition (Rep).

size. Idleness thus appears to be difficult to eliminate with larger groups. In practice, a worker is prone to idleness when completing his dedicated subtasks before a co-worker. The last sub-tasks are congested by other workers and a worker cannot contribute to processing or help with them. Further, workers in larger groups may prefer to be idle than to help others because, as stated in [8], in comparison to smaller groups, with larger groups “individuals are less willing to do their best”.

4.3. Examples of group working

The results above show how the groups spent time on different activities and how group working developed through the repetitions. As examples of advanced group working, Figure 6 presents the analyses of the best-performing groups (of two, three, and four workers) during the last (fourth) repetition. The figure illustrates the timelines of each worker when processing different parts (as in Figure 1), reading instructions (I), or having LOSS time (F = familiarizing, T = wrong tools, D = dropping equipment, C = co-worker related, and ID = idleness). For each part of the timeline, the shares of value-adding (green), required (yellow), and wasted (red) time are shown. Finally, the shares of these times of the entire assembly process are presented (the highest colored line).



Fig. 6. Examples of group performance in the best-performing groups of two, three and four workers (W) at the fourth repetition.

As Figure 6 shows, within the best two-worker group, the workers process extremely independently. Both workers clearly have their own, reasonably divided subsystems to process: for Worker 1, subsystems M2-M3-P3-H1 and H2-V-H3, and, for Worker 2, M1-P1-P2 and PL-P4 (see the case product in Figure 1). Assistance occurs only at the end, when one worker moves to work together with another with P5. Otherwise, that worker would have been idle for a longer period. Within the best three- and four-worker groups, idleness clearly occurs to a greater extent. In general, a two-worker group was the most preferred option among all the participants; see [7].

5. Conclusions

The present study examines the factors and the extent to which they affected reduced assembly time as a function of repetitions and reduced productivity per worker as a function of group size. What is special about the present case assembly is the fact that the groups of workers were free to organize the work themselves. The ultimate aim of this study is to increase the understanding of how working in groups of different sizes develops through repetitions when the coordination of workers processing a new product is not standardized.

The methods used to analyze the performance of group working and the findings provided in the analysis supplement earlier research on group working and learning. The following points compile the main findings from the examination and suggest their related practical and managerial implications.

1. When the case product was processed for the first time by novice workers and groups, a significant amount of time was spent on instructions and losses. Losses typically appeared as the observing and examination of parts and their assembly locations or as faulty installing. Learning took place quickly as soon as the process was repeated twice, and this was realized mostly as considerably less need for instructions and as less frequently occurring losses.

This finding highlights the importance of learning processes for workers with new products. Where production repeatedly requires new learning processes as a result of ever-changing products, inexperience will result in substantial costs. In this case, learning should be further speeded up by paying attention to the clarity and punctuality of the instructions, as well as to the identification of assembly parts and locations.

2. Compared to the smaller groups, the larger ones used more worker resources to assemble the product, thus resulting in reduced productivity per worker. During the first repetitions, this was due to the inexperience of the workers, which was realized as related losses and reading instructions.

This finding shows how the inexperience of workers reduces the efficiency of a group with increasing group size. In order to reduce the amount of information and speed up the specialization of workers in their dedicated tasks, instructions should be developed in a more worker-specific (dedicated) direction.

3. Despite increased experience in the last repetitions, the larger groups suffered from worker idleness. This was due to a lack of meaningful tasks and working space for several workers at the end of processing.

This finding exposes the challenges in the distribution of the workload between the workers with larger groups. An unequal temporal workload between the workers can be tackled through detailed planning of the assembly sequence and division of work. And where it still occurs, if it is possible and useful, workers should assist each other until the completion of the product. Otherwise, they should be moved to other jobs. Industry foremen should pay attention to these issues since they are ultimately responsible for the assignments and coordination of workers.

The findings of the present study show what the effects of learning and group size can be in an extreme case. They show the importance of planning instructions and coordination for groups of workers. These are challenging issues, especially with ever-changing products (caused by increasing customer needs) and changing groups of workers (caused by increasing flexibility and turnover of labor resources), which seem to be likely trends in future production.

For further research, typical sources of productivity losses with larger groups should be examined in a way that is even closer to real production conditions, and, if possible, also with professionals. In addition, more research is needed to develop effective instructions for worker groups at shared task. This line of research could utilize new technologies, such as mobile displays and augmented reality solutions.

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