Set-up Reduction for Lean Cells and Multi-Machine Situations

Dirk Van Goubergen
Ghent University, Department of Industrial Management,
Technologiepark 903, B-9052 Zwijnaarde, Belgium
WWW home page: http:// tw18v.ugent.be

Abstract. Set-up reduction is a key requirement nowadays for many lean implementations. Current set-up reduction methodologies, most of them based on Shingo's SMED, focus merely on simple one machine-one person situations, where as many value streams contain long multi-stage machine lines (e.g., in food industry) or multi-machine cells (e.g., in metal industry). In these situations, using SMED is not enough, one needs to look at reducing and optimizing all set-up activities across all available persons and machines. This paper presents a comprehensive approach for these situations (MMSUR) that yields very good results and that is easy to apply with any improvement team of operators. A real life case study will be used to illustrate the approach and the results.

1 Introduction

These last years many companies have embarked on a journey implementing Lean as their major business strategy for improving competitiveness. Due to these lean implementations, set-up reduction - reducing the downtime between producing the last product A and good products B on a machine or a line - has become even more important than before. This freed-up capacity can be used for producing more (on bottlenecks that are not meeting takt time) or for more flexibility [1].
First of all it is clear that set-ups are one of the main root causes of several out of the 7 classical types of waste: overproduction, inventory and waiting [2].
While implementing flow using value stream mapping, one is often confronted with these high inventories and long lead times due to long set-ups on upstream shared resources and in downstream mixed model pacemaker loops. Here is the concept of the interval (or EPEI= Every Part Every Interval) critical. The more often products of a product family can be scheduled (i.e. the smaller the interval), the smaller the lot sizes that can be produced, the shorter the production lead times and the lower the inventories (finished goods and WIP). A procedure is shown in [3] on how to

determine the future state EPEI for a mixed model cell by setting targets for set-up reduction.

2 Existing set-up reduction methodologies

2.1 Taxonomy of set-ups

In order to identify different types of set-ups and to characterize these situations in an unambiguous way, we propose following taxonomy. Two variables can be identified: the number of machines (X) and the number of persons (Y) that are performing the set-up on these machines. Hence every set-up can be characterized by a pair (X,Y).

2.2 Existing approaches for set-up reduction and their limitations.

Most existing publications on set-up reduction are based on the SMED system [4]. The main goal is to minimize what needs to be performed during the downtime. This is done in three steps [1]:
- SMED step 1: identifying what can be done while the machine is running (mostly organizational and method improvements)
- SMED step 2: moving set-up activities out of the downtime by technical solutions
- SMED step 3: minimizing and streamlining all remaining set-up activities

This approach is very straightforward and yields very good results in (1,1) and (N,1) situations. However in multi-person and multi-machine situations (1,M) and (N,M), a broader view is needed. It is not enough to apply SMED to each individual machine or person. There can be interaction between machines and between people. These situations are very common when dealing with long machine lines (present in many types of industry) and in lean mixed model cells involving multiple machines. Especially in these last ones, the lean principle of separating people and machines, results often in one person being responsible for several machines. Also there can be a varying number of operators in these cells (flexing in or out) in order to match the capacity with the demand (according to takt time). Existing literature does not deal with these situations.

3 An overall approach for multi-machine situations MMSUR

3.1 Introduction

Our proposed approach, named MMSUR - Multi Machine Set-Up Reduction - still uses the SMED system as the basic technique for looking at individual changeover activities as they are performed by an operator on a machine. But we need to take a look at the broader picture in order to have a better approach for identifying where to start in a multi machine situation and how to make the best use of the available operators in order to obtain the optimal set-up reduction of the whole cell or line.

We want to minimize the overall downtime of the cell or of the machine line. Note that we assume here that first a target for set-up reduction has been established before the start of the project (e.g., based on an EPEI calculation).

3.2 Steps of MMSUR

Figure 1 depicts an overview of the different steps of our methodology (13 steps). A key tool is the 'Multi-Activity Diagram'. This old industrial engineering tool (examples and background information can be found in [5]) is used in two ways (*Step 1*):

- The Machine Multi-Activity Diagram: A column is assigned to every machine/process step in a consecutive (logical) order. All activities are drawn as a block in the column of the machine on which they are performed, at the correct vertical position along the time axis. The Multi-Activity shows the overall downtime of the machine line as well as the waiting time of every machine (when no one is performing a set-up activity on this machine)
- The Person Multi-Activity Diagram shows who is doing what and when. All activities are blocks and every column corresponds with a person.

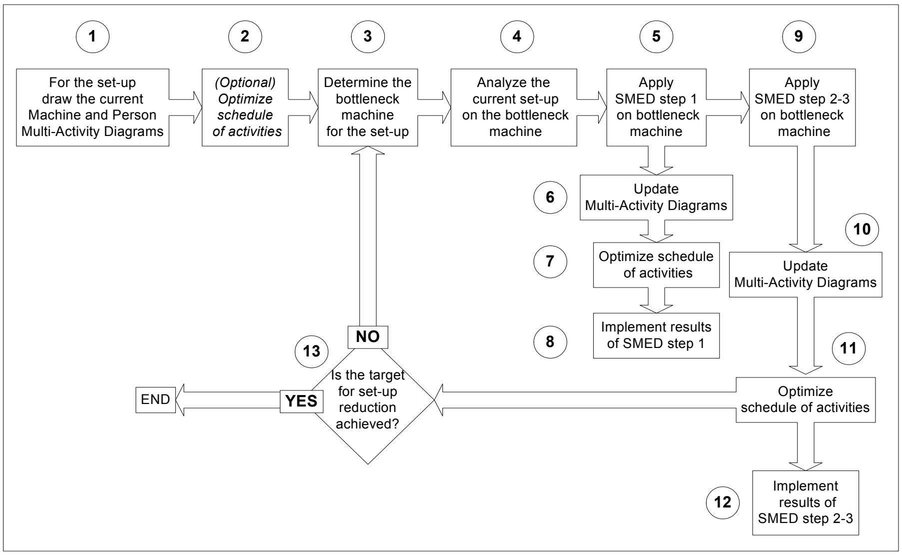

Fig. 1. MMSUR - Set-up reduction methodology for multi-machine situations

We will provide now additional information on the less self explanatory steps:
Step 2: The Multi-Activity Diagrams that were created in *Step 1* illustrate the current way of performing the set-up, before applying any set-up reduction techniques. However, this does not necessarily represent the optimal way of doing the set-up (given the current activities and available persons). At this point we can consider rescheduling and/or re-assigning the activities (blocks in the Multi-Activity Diagram) to the available persons by shifting the corresponding blocks (without

knowing all the details of the activities that occur inside every block). Hence, downtime may be reduced and/or work balance might be improved (more details on how to optimize the schedule will be given in Section 3.3). This step however is optional and will only be executed if there is clear evidence that a substantial downtime reduction can be achieved. If not, then it is better to immediately proceed to the next step in order to reduce set-up activities first, especially if it is clear that some quick wins can be achieved. An optimization of the activity schedule will follow afterwards on the improved situation.

Step 3: A lot of set-ups of multi-stage machine lines are rather complex because several workstations are involved with many (sometimes long) activities and because of the relationships between these activities on the different machines and between the different persons. Hence, it is in most cases advisable to deal with the set-up problem in small steps instead of tackling the whole problem at once. Therefore the approach that we propose in this Section is iterative. Set-up reduction techniques can be applied in an iterative way. In every iteration we identify in this step the bottleneck machine with regard to the set-up. This is the machine on which the most work needs to be performed. The activities performed on this machine are very likely to be part of the 'critical path' of the changeover. A reduction of the set-up time on this bottleneck will result in the best ratio effectiveness/effort for the improvement of the total downtime of the line.

Traditional set-up reduction techniques can now be applied to this bottleneck machine. Note however that after SMED step 1, improvements can already be implemented (as they will be rather organizational, method-related and low cost). In order to do this, the multi-activity diagrams need to be updated and an optimized schedule needs to be determined (*Steps 6-7*).

SMED step 2-3 (*Step 9*) will generate technical modifications in order to reduce the downtime; as they are not always easy to implement right away, an implementation plan is needed (*Step 12*).

After updating the multi-activity diagrams and optimizing the schedule of activities (*Step 10-11*), the new version of the machine multi-activity diagram will show the reduced overall downtime of the line or the cell, measured at the last machine. We can now compare this value with our initial set-up reduction target. If the desired reduction is obtained, we can choose to stop. If not, we need to start a new iteration and go to *Step 3* in order to determine the new bottleneck. In any case is the maximum number of iterations equal to the number the machines in the line.

When the total number of set-up activities on all machines in the cell or in the line is limited or when it is clear that SMED step 1 can already yield a substantial reduction, one can chose not to take the iterative approach, but to apply SMED to all machines at the same time. In that case it is not necessary to identify the set-up bottleneck; one needs to update the multi-activity diagrams only once.

3.3 Optimizing the schedule of activities in a qualitative, diagrammatic way

The machine multi-activity diagram shows the downtime of the cell or the line, with blocks indicating all activities that need to be performed. The primary objective is to schedule these blocks resulting in a minimal downtime; however we can identify secondary objectives:

- we want a balanced workload across all operators
- if there is slack (waiting time for an operator), it is preferable to have this grouped at the end of the changeover, so that this person can be used for another task
- we want to minimize the movements of the operators

There are some constraints such as a labor constraint (max. number of operators available) and sequence constraints among activities (precedence, concurrence, etc.). These have to be identified first, but in practice it suffices to have operators on the improvement team that are knowledgeable about the set-up activities.

Starting with a blank machine and person multi-activity template on a wall, the team can come up with a schedule (using post-it notes or paper pieces) as follows:

- locate the bottleneck machine with regard to the set-up and try to schedule all activities on this machine with leaving as little slack as possible, then schedule the other activities on the critical path (if applicable).
- Put the scheduled activities on the person multi-activity diagram
- Schedule the remaining activities on the machine multi-activity diagram taking into account all constraints; put them afterwards on the person multi-activity diagram to check the balance of the workload.
- The labor constraint and the movement constraint can be checked visually on the machine multi-activity diagram:
  - When drawing a horizontal line at any time point, no more blocks can be crossed than corresponding to the number of available persons
  - Connecting the blocks assigned to the same person results in a line; the more zigzagging (and less vertical), the more movement.
- Repeat the last two steps until an acceptable and feasible solution has been found.

4 Case application

4.1 Problem Description

In this Section we will describe the use and the results of our proposed methodology on a case study in food industry in Europe. This plant had a long machine line for manufacturing a product family of snack products. The process started with raw material and at the end of the line the packaged finished product came out. From a Value Stream Mapping point of view, this line was nothing more than a series of process boxes connected with FIFO lanes. A lean implementation in this situation should focus on two efforts: increasing the reliability of the line and increasing the flexibility (or decreasing the interval – EPEI). The main focus of this project was on the flexibility part, as initially the line produced all 6 flavors in one week (EPEI= 1 week) but marketing was planning on introducing additional flavors, adding up to 11 in total. The objective was to keep the interval one week.

Additionally, the market for this product family was growing fast, so any additional freed up capacity through downtime reduction was also important. The engineering department was, at the time of this project, working on building a second line.
Initially the set-up took about 2,5 hours and was conducted by 13 operators. With an hourly cost of all personnel of 500 €/hr and a net profit loss due to lost production of 2520 €/hr (due to the growing demand), it is straightforward to determine the total yearly cost of this downtime: 1,6 million € for 5 set-ups a week and 3,2 million € after introducing the new flavors.
The line consist of following machines/workstations: 22 baking ovens (in parallel), a vibrating conveyor, a (wet) coating machine, a drying oven, a cooling conveyor, a transport conveyor, a multi head weighing unit and a packaging machine. Hence this is a (8,13) set-up.
An improvement team was established, composed of operators, technical people and the production area manager. Engineering people were involved during the improvement process when needed.

4.2 Application of MMSUR – the results

As explained in the previous section, the first step is to make the machine multi-activity diagram of the set-up of the line. This way the bottleneck, being the machine that needs to be studied first, can be determined. In this case however, there was no standardized work method for the different operators, so it was not possible to draw the initial diagrams. We chose to study all machines at the same time based on a changeover recorded on video. All activities were drawn on the multi-activity diagrams and SMED step 1 was executed, resulting in a 60% downtime reduction. The remaining changeover time was 60 minutes, only using 11 operators. Figure 2 and 3 show the machine and person multi-activity diagrams before and after SMED step 1.

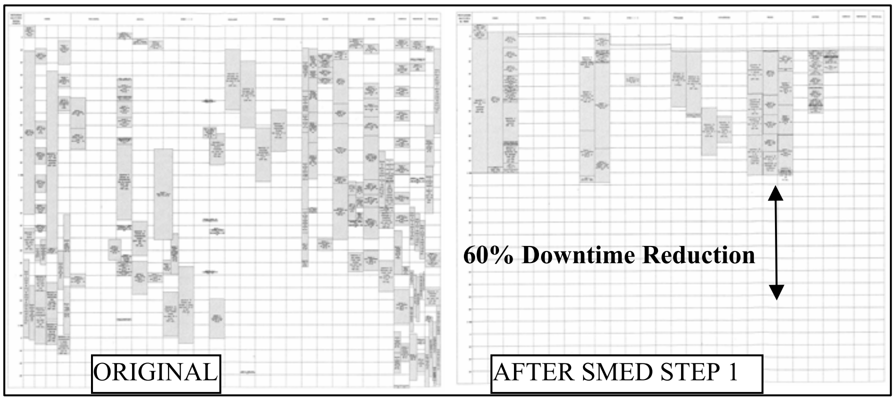

Fig. 2. Machine multi-activity diagram before and after SMED step 1

The new set-up method was immediately introduced and after a short learning period, the effective set-up time was a little more than 1 hour. In the meanwhile

MMSUR Step 9 (see Figure 1) was performed. The improvement team looked for technical SMED step 2-3 solutions, both multi-activity diagrams were updated again and all blocks were rescheduled (MMSUR Step 10-11) resulting in a set-up time of about 30 minutes (an overall reduction of 80% compared to the starting situation). Additionally the number of people needed for this set-up method was reduced to only 7 persons. An initial estimate of the cost of the technical proposals showed that it was only a fraction of the yearly downtime cost-reduction that could be obtained. Figure 4 depicts both multi-activity diagrams for this new situation

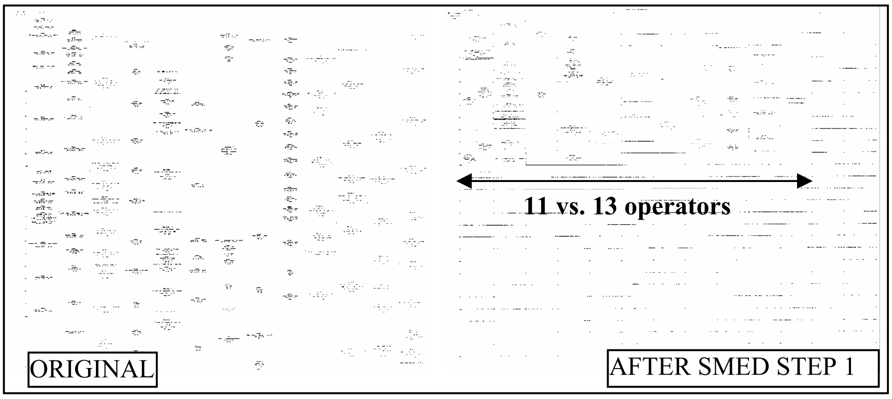

Fig. 3. Person multi-activity diagram before and after SMED step 1

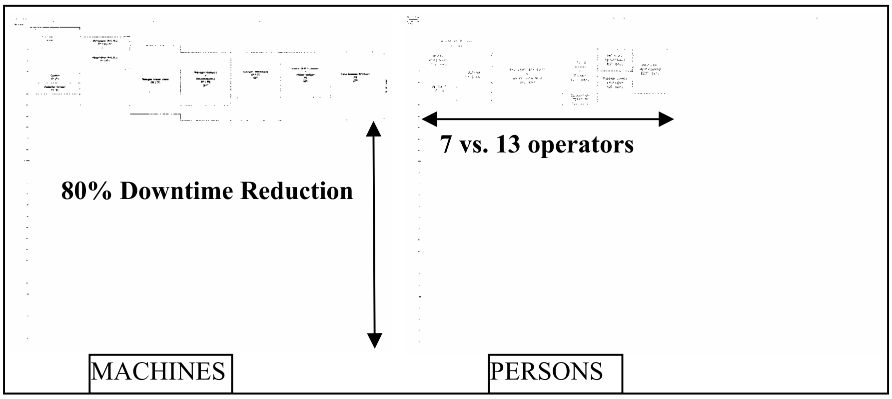

Fig. 4. Machine and Person multi-activity diagram after MMSUR.

4.3 Other applications of MMSUR

Besides the described case study, our methodology was also applied in other cases (on different multi machine situations in different types of industry). Some results:

- steel plant continuous caster (3,8): 72 to 30 minutes (60% reduction)

- steel galvanizing line (2,4): 450 to 100 minutes (78%)
- ice cream processing line (5,2) : 80 to 10 minutes (88%)
- lighting assembly cell (6,3): 390 to 25 minutes (ù)
- food extrusion line (7,2): 171 to 40 minutes (78%)

5 Critical evaluation of MMSUR and conclusion

Table 1 provides a critical evaluation of our proposed methodology MMSUR.

Table 1. Overview of a critical evaluation of MMSUR

Strong points	Weak points
• manual rescheduling of activity blocks gives good results with regard to the downtime optimization (most important objective) • hands-on and easy to use in practice • active participation of the members of the improvement team creates high level of acceptance and good implementation in practice • can handle large problems	• manual rescheduling of activity blocks gives no certainty about the optimality of all objectives, it is only qualitative approach; a mathematical model is needed for finding the optimal solution with regard to all objectives • can mean extensive work when evaluating different scenarios for making trade-offs (e.g., different number of persons vs. downtime)

Since multi-machine situations, as encountered in Lean cells and in machine lines were hardly considered in the existing approaches and literature for set-up reduction, we proposed in this paper MMSUR, a comprehensive methodology for set-up reduction in multi-machine situations.

Although the manual rescheduling procedure does not guarantee an optimal solution for all the different identified objectives, it does offer a practical approach with high levels of acceptance among the operators and very acceptable solutions, as illustrated in the described real life case study and other mentioned applications.

Besides set-up reduction problems, MMSUR can also be applied for other similar activities like maintenance activities, exchange of raw materials, etc. involving multiple machines and people and causing a downtime of a process.

References

1. Van Goubergen, D. and H. Van Landeghem, Rules for integrating fast changeover capabilities into new equipment design. *International Journal of Robotics and Computer Integrated Manufacturing*, 18: p. 205-214 (2002).

2. Prasad, B., A structured methodology to implement judiciously the right JIT tactics. *Production Planning and Control*, 6(6): p. 564-577 (1995).

3. Duggan, K., *Creating Mixed Model Value Streams*. (Productivity Press, New York , NY (USA) 2002).

4. Shingo, S., *A revolution in Manufacturing: the SMED system*. (Productivity Press, Cambridge, MA 1985).

5. Kanawaty, G., *Introduction to Work Study*. (International Labour Office, Geneva, 1992).