Jörg Niemann · Benedikt Reich · Carsten Stöhr

Lean Six Sigma

Methods for Production Optimization

Springer

Lean Six Sigma

Jörg Niemann · Benedikt Reich · Carsten Stöhr

Lean Six Sigma

Methods for Production Optimization

Springer

Jörg Niemann
Maschinenbau und Verfahrenstechnik
Hochschule Düsseldorf
Düsseldorf, Germany

Benedikt Reich
Düsseldorf, Germany

Carsten Stöhr
Düsseldorf, Germany

ISBN 978-3-662-68743-7 ISBN 978-3-662-68744-4 (eBook)
https://doi.org/10.1007/978-3-662-68744-4

Translation from the German language edition: "Lean Six Sigma" by Jörg Niemann © Der/die Herausgeber bzw. der/die Autor(en), exklusiv lizenziert durch Springer-Verlag GmbH, DE, ein Teil von Springer Nature 2021. Published by Springer Berlin Heidelberg. All Rights Reserved.

This Springer imprint is published by the registered company Springer-Verlag GmbH, DE, part of Springer Nature.
The registered company address is: Heidelberger Platz 3, 14197 Berlin, Germany

Paper in this product is recyclable.

Preface

The beginnings of Six Sigma can already be found in the 1980s, when the methods were developed and first used in the field of industrial production. In the meantime, however, Six Sigma has evolved from pure process control using statistical methods to a proven and effective concept for quality management. As part of a comprehensive customer orientation, Six Sigma is increasingly being combined with the approaches from Lean Management. The goal of optimization is then to synchronize one's own (production) processes as efficiently and waste-free as possible with customer requirements.

In this context, the authors have noticed that there is little freely accessible teaching material with practical exercise examples available for teachers and learners. With this work, we want to close this gap.

The Lean Six Sigma workshop therefore describes important practical methods and tools in the optimization of industrial production structures. In addition to the theoretical foundations, extensive "hands-on exercise material" with solutions is provided for each method to ensure application-oriented knowledge transfer.

The book is intended to support teachers and learners in particular in the preparation and implementation of training courses on the topic of Lean Six Sigma, which can then be practiced in depth and played out in a practical manner in group work. The playful application of theory over several rounds of play enables learners to use the methods in practice and apply the knowledge gained in an industrial environment.

The practical exercises were largely developed by ideas from students of industrial engineering at the Düsseldorf University of Applied Sciences. They are heartily thanked for this!

Düsseldorf, Germany — Jörg Niemann
October 2020

Contents

Glossary of Abbreviations

5S	Seiri, Seiton, Seiso, Seiketsu, Shitsuke
Auto-ID	Automatic Identification and Data Capture
AVD	Work distribution diagram
AZ	Daily Working Hours
C_p	Process capability
C_{pk}	Process capability with consideration of centering
CTC	Critical to Cost
CTQ	Critical to Quality
CTT	Critical to Time
DMAIC	Define-Measure-Analyze-Improve-Control Cycle
DoE	Design of Experiments
DPMO	Defects per Million Opportunities
DPO	Defects per Opportunities
DPU	Defects per Unit
EVA	Economic Value Added
FMEA	Failure Mode and Effects Analysis
FT	Factory days
GWA	Business value contribution
JIT	Just in Time
Jstk	Annual quantity
KT	Customer rhythm
KVP	Continuous Improvement Process
LSL	Lower specification limit
MSA	Measurement System Analysis
OEE	Overall Equipment Effectiveness, Total Plant Effectiveness
OSL	Upper specification limit
PDCA	Plan-Do-Check-Act Cycle
PPM	Parts per Million
PPS	Production planning and control system
QFD	Quality Function Deployment

REFA	Association for Work Studies and Business Organization
RFID	Radio Frequency Identification
RPZ	Risk Priority Number
SB	Safety Stock
SF	Safety factor
SIPOC	Supplier-Input-Process-Output Matrix
SMART	Specific-Measurable-Accepted-Realistic-Timed
SOP	Standard Operating Procedures
TK	Parts per Kanban
TPM	Total Productive Maintenance
V_d	Average consumption
V_{max}	Maximum consumption
VoC	Voice of The Customer
WBZ	Replacement time
WC	Working Capital
Wdh. Faktor	Repetition factor
WIP	Work in Progress

About the Authors

Jörg Niemann, has been a professor at Hochschule Düsseldorf since 2012, specializing in Industrial Engineering with a focus on Production in the Department of Mechanical and Process Engineering. He is the managing director of the interdisciplinary research institute and founder of the FLiX Research Center for Life Cycle Excellence. His expertise lies in Life Cycle Management and the assessment and optimization of production systems using Lean Six Sigma.

Benedikt Reich, M.Sc. mult., studied Industrial Engineering and Business Analytics. He was a long-time employee at the FLiX Research Center for Life Cycle Excellence at the Düsseldorf University of Applied Sciences.

Mr. Reich is currently Head of Digital Solutions Purchase to Pay at Henkel AG & Co. KGaA. His main areas of expertise are optimizing and digitizing purchasing processes.

Carsten Stöhr, M.Sc. mult., studied industrial engineering and business analytics. He was a long-standing member of the FLiX Research Center for Life Cycle Excellence at Düsseldorf University of Applied Sciences.

Mr. Stöhr works as a data analyst at L'Oréal Deutschland GmbH. He is responsible for consulting and developing reporting tools for the consumer goods division of the L'Oréal Group.

Furthermore, he is a lecturer at the Hochschule für Ökonomie und Management (FOM) in the fields of mathematics and computer science.

Introduction

1

1.1 Classification of the Book

All methods presented in this book serve to optimize processes within the company. But what significance and relevance do these methods have in terms of economic efficiency? Do the methods also result in an increase in company value? This question will be examined in more detail below. The creation of value in the company can be measured via the Economic Value Added (EVA.

As can be seen in Fig. 1.1, an economic value can only be created when the operating profit (Net Operating Profit After Taxes) covers the capital costs. The capital costs are in turn composed of the fixed assets and the Working Capital (WC) as well as the capital cost rate. The lever for increasing company value with the methods of production optimization lies in the area of Working Capital. Working Capital is defined as [1]:

$$WC = cash\ and\ cash\ equivalents + accounts\ receivable + inventory - current\ liabilities$$

Working Capital represents both a measure of liquidity, as current assets can usually be quickly converted into liquid funds (unlike fixed assets), and a measure of a company's financing needs. If the WC can be reduced, this leads to a reduction in financing needs and thus to an improvement in capital profitability and improved interest expenses. Based on the definition of WC, the lever of current assets can already be fixed, which can be optimized through operational excellence. The aim is to achieve continuous value enhancement through the application of Lean Management philosophy and the methods of production optimization, thereby strengthening the company sustainably [1, 2].

The WC is primarily determined by processes that affect inventories, receivables and liabilities. These processes are income management (Order-to-Cash), inventory management (Total-Supply-Chain) and expenditure management (Purchase-to-Pay). The focus below is on inventory management and the associated reduction of stocks. However, it

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_1

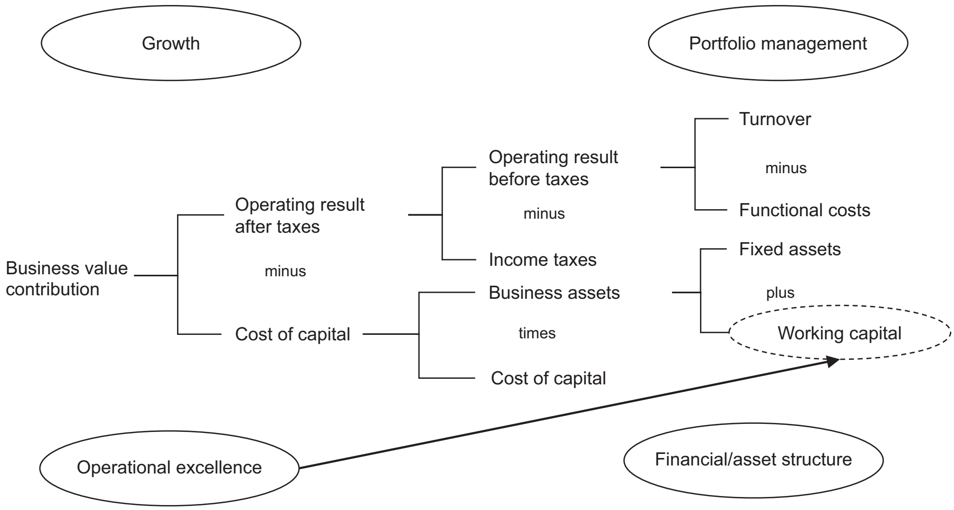


Fig. 1.1 Business value contribution [1]

should be considered that a holistic view of the three processes listed must always be taken to avoid isolated solutions. To minimize stocks, various intermediate goals can be formulated. For example, with the help of SMED, the setup time can be shortened or waste and scrap can be reduced by applying Poka Yoke. Also, existing transport routes, warehouses and processes can be optimized through a value stream analysis to achieve a reduction in stock [1].

In summary, it can be stated that suitable measures, some of which are presented in the book, have a high influence on the economic efficiency of the company. Thus, the inventory and consequently the Working Capital can be reduced. This results in the company's capital costs decreasing and the company value being increased.

The book is divided into individual self-contained chapters, each presenting methods for optimizing production structures.

Figure 1.2 illustrates the basic structure of the book. Kaizen, or the "change for the better", always operates within the tension or the target dimensions of improving lead time, the functional flexibility of the production system, and the enhancement of product quality. Lean Six Sigma provides tools and methods for this transformation to succeed. The following chapters of the book particularly address methods and tools that are most frequently used in industrial practice. Each chapter first explains the theoretical foundations, which are then to be tried out and practiced in practical "hands-on exercises". The tasks are designed for courses where the practical exercises can be carried out in small groups. For the trainer/course leader, templates for tables, work tasks, stencils, and suggested solutions are provided in the appendix of each chapter to support the practical implementation and guidance of the participants.

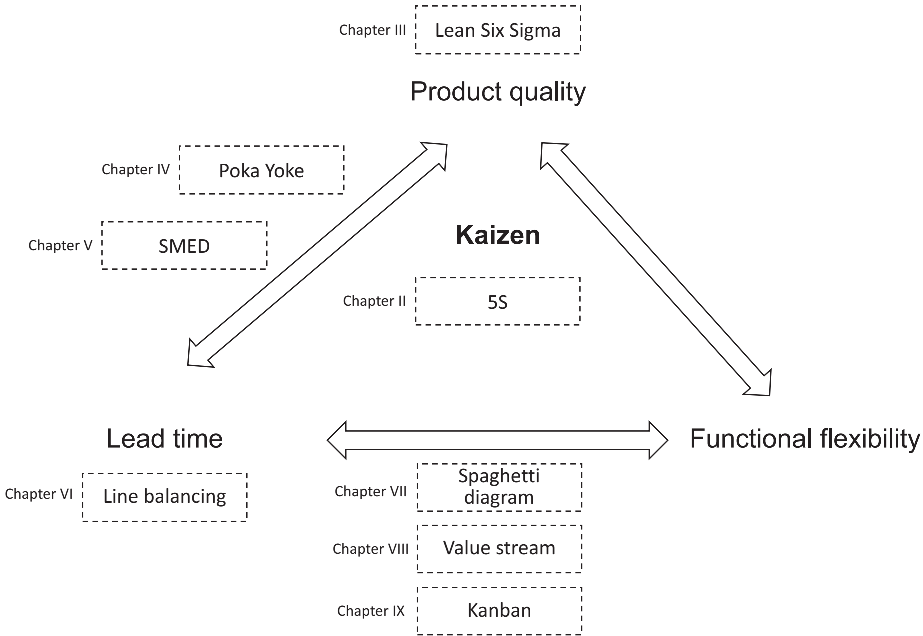


Fig. 1.2 The magic triangle of Kaizen

References

1. Klepzig H-J (2014) Working Capital und Cash Flow. Finanzströme durch Prozessmanagement optimieren, 3rd revised ed. Gabler, Wiesbaden
2. Keuper F, Sauter R (Eds) (2014) Unternehmenssteuerung in der produzierenden Industrie. Konzepte und best practices. Springer Gabler, Wiesbaden

2 5S—Seiri, Seiton, Seiso, Seiketsu, Shitsuke

2.1 Classification of the Method

5S is a Lean tool for systematically uncovering waste, named after the initial letters of five Japanese terms [1]. The term 5S is usually associated with a tidy and organized workplace and the assurance that this state is maintained [2].

However, it turns out (Fig. 2.1), that this representation of the goals of 5S is not appropriate, because 5S is more than a method for creating order. 5S is a foundation of every Lean management approach and a prerequisite for the application of the PDCA methodology [2–5].

2.2 Description of the Method

The 5S system, or also referred to as 5A in German technical literature [6], can be divided into the following components:

Seiri: Seiri (Sorting) describes the separation of necessary and unnecessary items at the workplace. Material that is no longer needed is removed from the workplace. This particularly refers to excessive circulating stocks as well as unnecessary, surplus and defective tools, unnecessary machines, faulty parts as well as unneeded papers and documents [1, 6]. The aim is to keep the workplace clear and avoid waste when searching for a tool. This also increases the quality by avoiding damage to the product through the use of the wrong tool [4].

Seiton: Seiton (Tidying up) describes the creation of a visible order that supports the process. This includes providing the work equipment in perfect condition and ergonomically within reach at a defined and standardized place [1]. It is useful to mark the places, as this way missing tools are noticed.

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_2

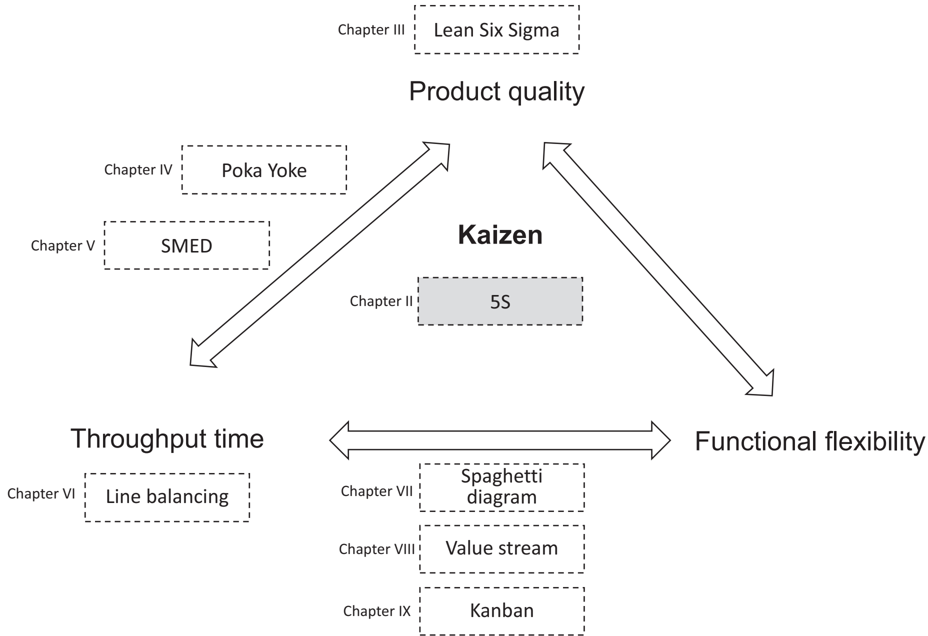


Fig. 2.1 5S in the tension field of Kaizen

Seiso: Seiso (Keeping the workplace clean) describes the general cleanliness of the workplace. Cleanliness allows errors to be detected more quickly and quality defects due to dirt and foreign bodies to be avoided [4]. Signs of wear and tear on the operating equipment become immediately apparent and unplanned machine stops and costly damage can be avoided. An orderly workplace therefore demonstrably leads to higher employee satisfaction [6].

Seiketsu: The Japanese term Seiketsu refers to the standardization of work processes in individual process steps [1]. New employees can be better trained through prior standardization of the activity. The aim is for work instructions and processes to become routine [6]. In the area of employee induction, Lean management follows a different approach than the classic view. In the classic view, the employee is provided with documents in addition to an induction, from which he can familiarize himself with standards. The Lean management view is that a new employee is trained until he can maintain the standard without documents. In the Western world, Seiketsu is often misunderstood in terms of employee induction. Seiketsu is not intended to ensure the fastest possible induction, but the highest possible quality of work and increased motivation of the employee. The standardization of the activity within the framework of the CIP [4].

Shitsuke: As part of Shitsuke (always apply and improve), employees and managers have to ensure that the achieved standards are not undercut. In addition, the continuous improvement process should be initiated [4], by having employees develop suggestions for eliminating Muda.

2.3 Workshop 1 "Kit Assembly"

In the following section, the above-explained 5S will be demonstrated in an interactive seminar through a simulation using a Lego kit. For this, it is necessary to complete three practice runs in groups, each containing minor changes, in order to develop the theoretical understanding in small steps and to illustrate the idea of optimization.

In each round, a Lego kit must be assembled according to the instructions and the required time must be measured. Once the first practice round is completed, the already assembled Lego kit must be passed on to the next group and an unknown new Lego kit must be assembled in the following practice round. The passing on after each individual practice round and the associated new kit at the beginning of each round is intended to better illustrate the optimization result, as this excludes a learning effect and the entire optimization of the 5S methodology can be credited.

2.3.1 Implementation

2.3.1.1 First Practice Run

1. Each group receives a box containing a mixed Lego kit. In addition to the kit, more – not needed – Lego bricks and paper snippets are added, which are supposed to simulate a disordered and unclean environment.
2. This kit must then be assembled according to the corresponding instructions (Fig. 2.2).
3. Furthermore, the required time must be measured using a stopwatch and entered into a table (Fig. 2.3).
4. Pass the kit on to the next group.

2.3.1.2 Second Practice Run

1. In this run, all groups receive a box with prepared partitions – simple cardboard is suitable here – to form 20 individual compartments.

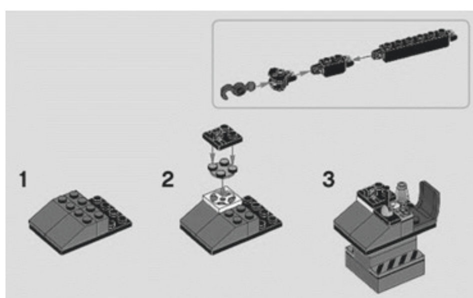


Fig. 2.2 LEGO® instructions

	Practice round 1	Practice round 2	Practice round 3
Lego kit 1			
Lego kit 2			
Lego kit 3			
Lego kit 4			

Fig. 2.3 Measurement table

2. The box can then be filled with the individual Lego parts as preferred by the respective group. This sorting can be done, for example, according to required work steps, colors, sizes, shape of the parts.
3. Now the assembly of the parts begins as well as the measurement of the required time.
4. The time must again be entered into the table and the Lego kit passed on to the next group.
5. Subsequently, the improvements should be discussed and further solutions developed.

2.3.2 Blank Templates

References

1. Gerberich T (2011) Lean oder MES in der Automobilzulieferindustrie. Ein Vorgehensmodell zur fallspezifischen Auswahl. Zugl.: Chemnitz, Techn. Univ., Diss., 2010, 1st ed. Gabler/Springer Fachmedien, Wiesbaden. https://doi.org/10.1007/978-3-8349-6754-1
2. Zollondz H-D (2013) Grundlagen Lean Management. Einführung in Geschichte, Begriffe, Systeme, Techniken sowie Gestaltungs- und Implementierungsansätze eines modernen Managementparadigmas. Oldenbourg (Edition Management), München. http://www.degruyter.com/search?f_0=isbnissn&q_0=9783486779042&searchTitles=true. Accessed 03 May 2021
3. Syska A (2006) Produktionsmanagement. Das A–Z wichtiger Methoden und Konzepte für die Produktion von heute. Gabler. https://books.google.de/books?id=WzRD_nyl8bcC. Accessed 03 May 2021
4. Gorecki P, Pautsch P (2014) Praxisbuch Lean Management. Der Weg zur operativen Excellence, 2nd revised ed. Hanser, München
5. Bartholomay C (2015) Kaizen. In: Dickmann P (Ed) Schlanker Materialfluss. Mit Lean Production, Kanban und Innovationen, 3rd ed. Springer Vieweg (VDI), Berlin, S 25–28
6. Menzel F (2009) Produktionsoptimierung mit KVP. Der kontinuierliche Verbesserungsprozess für gesteigerte Konkurrenzfähigkeit. mi-Wirtschaftsbuch FinanzBuch, München

3 Lean Six Sigma

3.1 Classification of the Method

Lean Six Sigma is a combination of the goals and techniques of Lean Management and the Six Sigma approach. It thus combines productivity-enhancing measures with quality-focused measures, forming a holistic approach whose goal is to achieve higher success through joint planning and enhancement of both sizes.

It shows that the demand for quality improvement (Fig. 3.1) and simultaneous cost reduction does not have to be a contradiction. Errors and waste are eliminated through a systematic and fact-based analysis of the processes. A targeted implementation of uniform measurement and project systematics increases customer satisfaction and company value [1–3].

3.2 Description of the Method

As already shown in the classification, Lean Six Sigma is the combination of techniques of the elements of Lean Management and Six Sigma. A core element is the DMAIC cycle which is divided into five phases and provides a structured analysis process for a defined problem. The phases are Define (D), Measure (M), Analyze (A), Improve (I), and Control (C). This cyclical structure also ensures continuous improvement. Various tools of Lean Management or Six Sigma can be used in each of these phases (Fig. 3.3). The individual phases will now be presented in detail.

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_3

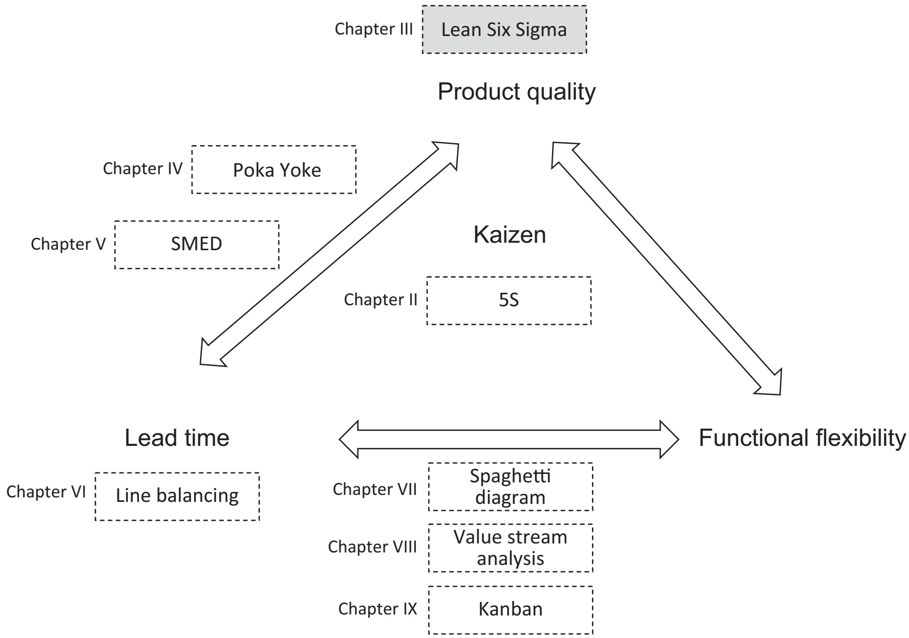


Fig. 3.1 Lean Six Sigma in the tension field of Kaizen

3.2.1 Define Phase

In the Define phase, the current situation is described and the goals and the problem are precisely defined. In addition, the schedule and project organization should be determined. A uniform understanding of the Lean Six Sigma project should be created within the entire team. Therefore, a detailed project contract should be created. An important step in this phase is also to define customer requirements, as these are essential for project success.

3.2.1.1 VOC

To define customer requirements, the first step is to capture the voice of the customer (Voice of The Customer). This represents a completely unfiltered statement. The aim is to make this statement measurable criteria up to the Project Ys, so that project success can be measured later (Fig. 3.2). The voice of the customer can be determined through market analyses or individual interviews.

The actual problem of the customer needs to be understood. This results in the customer need. Subsequently, the customer's requirements must be replaced with measurable output criteria. These are also called Critical to Quality (CTQ). This is a feature that has a direct influence on the success of the output (e.g., product). If the voice of the cus-

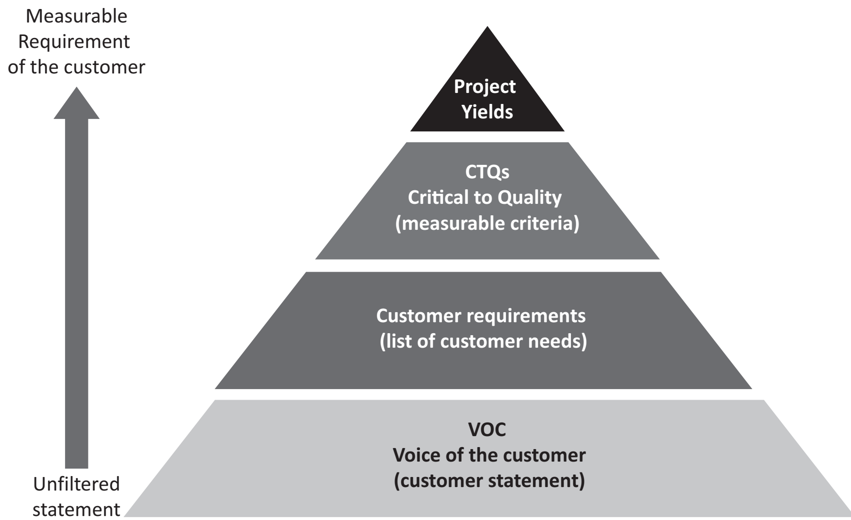


Fig. 3.2 Translation of the customer voice [4]

tomer is, for example, that it takes a very long time until an order release is made, a time can be defined that may occur at most until the release has taken place.

3.2.1.2 Project Contract

At the end of the Define Phase, all information should be recorded in a condensed form in a document. The company situation should be presented to legitimize the need for the project. In addition, a precisely defined problem statement must be included. This is essential for the later course of the project. Furthermore, a goal description should be included. This should be recorded according to the SMART (Specific, Measurable, Attainable, Relevant, Time bound) formula. The financial effect should also be defined, and the exact project team with responsibilities should be named.

3.2.2 Measure Phase

The main goal of the phase is to determine the current state. This serves as the basis for later process improvement. Critical measurement criteria must be selected and the relevant data determined to evaluate success in meeting customer requirements [5]. The quality of the data is crucial. This should be checked for its goodness with a measurement system analysis (MSA).

3.2.2.1 Measurement System Analysis

The collection of data for later analysis is carried out by trained individuals, based on clear instructions and within the framework of uniform methods, using defined measuring tools. This step is important as this procedure leads to a corresponding reliability of the system and the data obtained from it. Before a measurement system can be used, it must first be tested for reliability to rule out that the recorded data are not flawed. The subsequent phases build on this data, thus false conclusions can be accordingly ruled out. A measurement system analysis checks the following characteristics of a measurement system [4]:

- Accuracy (“accuracy”),
- Stability (“stability”),
- Repeatability (“repeatibility”) and
- Reproducibility (“reproducibility”).

In addition to the criteria mentioned above, it is also necessary to check the Resolution (resolution). The resolution refers to the smallest possible display difference of the measuring device. It should be less than or equal to 5 % of the Tolerance in order to record the quantity to be measured in sufficient detail [6]. An attributive measurement system analysis (MSA) is applied to discrete data. At least two appraisers and usually 30 numbered parts to be analyzed are required. Care should be taken to include both good parts and defective parts in the sample to be measured. Each appraiser must then measure all parts contained in the sample twice, in a random order. After the measurement results have been recorded, they are compared with the reference value. The goal of a good measurement system analysis is a 100 % match, although a limit value of at least 90 % may be sufficient [2].

3.2.2.2 Process Capability Analysis

The DPMO (Defects Per Million Opportunities) is a metric that describes the error rate and is considered from a company’s perspective. The DPMO is defined as [7]:

$$DPMO = \frac{number\ of\ defects}{number\ of\ units\ \times\ number\ of\ defect\ opportunities} \times 10^6$$

The DPO (Defects Per Opportunities) can also be calculated later on, as this metric is used to convert to the later Sigma level. This metric is defined as follows [7]:

$$DPO = \frac{number\ of\ defects}{number\ of\ units\ \times number\ of\ defect\ opportunities}$$

If an evaluation is to be carried out primarily from the customer’s perspective, the PPM (Parts Per Million) metric is used. It is defined as [8]:

$$PPM = \frac{number\ of\ defect\ units}{number\ of\ units}\ 10^6$$

If there is only one possibility of error—because there is only one characteristic—the DPMO and PPM metrics are the same. For meeting customer demand, it is not crucial whether a product has one or more defects, it is only important that the product is defect-free. Therefore, the PPM metric is a customer-driven metric and is used in the automotive industry as a requirement for suppliers. In contrast, the DPMO is used as an internal metric because it offers a better comparison between different complex systems. This results from the fact that the metric not only evaluates the number of defective units, but also relates these to the possibilities of error. This allows for fine-tuning. However, it should be noted that the error rate (DPMO) is the "softer" metric. This is because the denominator, due to the number of error possibilities, which results from the multiplication of the number of units and the possible number of errors per unit, will always be significantly larger than the denominator of the PPM. This, in turn, means that the overall metric is always smaller than the PPM. Therefore, for the actual evaluation of the quality level, the "sharper" metric—the PPM—is more suitable [8].

Not only with the determination and consideration of the DPMO and the PPM can a statement be made about the quality capability of the process. To get a more accurate assessment of the capability, the following process capability indices must be determined.

3.2.2.3 Process Capability Indices

The measure of process capability can be expressed with the metric c_p. This evaluates the reliability of a process to achieve the required goals. For this, the process spread is related to the tolerance. This metric is also described by Töpfer as the dispersion index.

The dispersion index characterizes the basic suitability of a process to deliver values with small dispersion in relation to the length of the tolerance interval. The metric can be calculated by [9, 10]:

$$c_p = \frac{\textit{specification width}}{\textit{process width}} = \frac{\textit{upper spec limit}\ (USL)\ -\textit{lower spec limit}\ (LSL)}{6\sigma}$$

The disadvantage of the dispersion index is that it does not reflect the position of the mean value. This can lead to the dispersion being kept within a narrow range (high c_p value), but the process is still not specification-compliant. A high c_p value is a necessary but not sufficient condition to achieve a high process sigma value. For this, an additional consideration of the process centering is required, which is described by the level index c_{pk} and thus represents the second metric for evaluating the process capability [2]. The metric can be calculated as follows [9, 10]:

$$c_{pk} = \min\left(\frac{USL-\mu}{3\sigma}; \frac{\mu-LSL}{3\sigma}\right)$$

This metric thus describes the position of the mean value within the tolerance. If a mean value shift of 1.5σ occurs, the level index changes, but the dispersion index does not. This deteriorates from a $c_{pk} = 2$ (without shift) to $c_{pk} = 1.5$ (with shift). This means that a c_{pk} value of at least 1.5 must be achieved to meet the requirement of Six Sigma [9, 10]. Once the required measurements have been determined, the next step is to analyze them in more detail.

3.2.2.4 Sigma Level

To determine the sigma level based on the determined metrics DPMO or DPO and PPM, the error rate is converted into the yield (Yield).

$$\Phi(z) = (1 - DPO) = (1 - 0,8889) = 0,1111$$

This corresponds to a yield of 11 %

To determine the sigma level, the calculated $\Phi(z)$ value can now be read off using the Z-table (Fig. 3.9).

The process sigma level is divided into Sigma Short Term and Sigma Long Term. The difference between a short-term process capability (Sigma Short Term) and the long-term process capability (Sigma Long Term) is based on the fact that the short-term value does not take into account external influences [4]. This means that in the long term, a process is less reliable because environmental influences or wear and tear are present. Therefore, a sigma of 1.5 is added to the Long Term, which expresses the shift due to unreliability. When determining via the DPMO, the table outputs the Sigma Long Term. However, when calculating via the Z-table of the normal distribution, the Sigma Short Term is determined [11].

3.2.3 Analysis

The objective of this phase can be described as follows.

Identify the root causes of the problem and then verify whether their resolution solves the process problem [5].

To do this, the measured data must be structured, evaluated, analyzed, and assessed [12]. This phase can be divided into two steps. First, the main influencing variables must be found and then the cause-effect relationships must be determined and represented. Qualitative and statistical methods can be used for this. At the end, the effects and causes on the target variable must be known in order to develop them in the next phase [8].

- Distribution diagrams,
- Cause-effect diagram,
- Pareto diagram,
- Flow diagrams,
- Control Charts,

- Regression analyses,
- Hypothesis test and
- Design of Experiment

3.2.3.1 Pareto diagram

The insights gained in the Measure phase can be graphically analyzed using a Pareto diagram. This is a bar chart in which the individual values are arranged and cumulated in size from left (largest value) to right (smallest value). This form of presentation allows the existing resources to be focused on the essential influencing variables. This form of analysis is based on the Pareto principle, according to which 80 % of the problems can be traced back to 20 % of the causes [13].

3.2.4 Improve

In this phase, a review and concretization of the impact forecasts should be carried out again, as the data basis was significantly improved in the previous phase. If the results achieved do not reach the defined target level, the cycle must be run through again [10].

The goal of this phase is to recognize, evaluate, and select solutions for successful optimization [5]. It must be determined how the process input variables and process parameters, taking into account the disturbance variables, are to be set. The activities of this phase also include testing the solution, checking its effectiveness, and the subsequent sustainable implementation using action and measure plans [8, 12]. However, the solution should be evaluated beforehand in terms of cost-benefit ratio, degree of difficulty, time required for implementation, and possible risks [14].

3.2.5 Control

The goal of the final phase is to stabilize the optimized process and check the pursued target level (Fig. 3.3) [10]. To monitor the process results and ensure them in the long term, a control system is needed that directly recognizes deviations and initiates appropriate corrective measures. This can be done through internal audits of the quality management or in the form of previously created test plans [12]. In addition to the control system, the cost savings should also be demonstrated by a before-and-after comparison, using the optimized rejects. If the results are satisfactory, the findings must be communicated throughout the company so that other projects can also benefit from them [5]. After the project is completed, further improvement activities should be implemented to thus directly enter the improvement process (CIP) [10].

Target	Six Sigma tools	Lean tools
DEFINE PHASE		
Identification of customer requirements and value creation from the customer's perspective, definition of a process plan	Project profile, VoC, QFD, Kano model	Value added analysis
Determining the financial impact and savings potential of the planned project		
Determining the requirements of all participants in the process under consideration	Stakeholder analysis	
Considering the influences and possibilities of the process with regard to its suppliers and customers	SIPOC	
Coordinating the planned changes with all parties involved and defining the communication structure	Communication plan	
MEASURE PHASE		
Mapping the current process, in particular value creation		Value stream analysis, cycle time diagram
Working out quality-critical influences	Quality tree (CTQ)	
Preparation and measurement of all required data	Data collection plan, sample survey	
Determination of the process capability and the current sigma level	Quality control chart, process capability analysis	

Target	Six Sigma tools	Lean tools
ANALYZE PHASE		
Carrying out the root cause analysis to determine process influences	FMEA, DoE, Brainstorming, Ishikawa diagram, hypothesis tests, regression analyses	Seven types of use, 5 times Why? (5W)
Comparison of process performance with best practice	Benchmarking	
IMPROVE PHASE		
Determination of suitable starting points for process improvement	Evaluate and select suitable tools	
Implementing improvement actions	Simulation, piloting	5S, SMED, Kanban, TPM
Installation of a continuous improvement routine		Kaizen (KVP)
CONTROL PHASE		
Long-term safeguarding of the results achieved	PDCA, quality plan, project repetition plan	SOP, Poka, Yoke

Fig. 3.3 Methods of the DMAIC cycle [3]

3.3 Workshop 2: “Precision Origami”

Required Materials

- Din-A4 sheets, possibly different colors
- Paper clip, possibly different colors
- Measuring template (appendix)

3.3.1 Implementation

The goal of the workshop is the creation of a "Precision Origami" (Fig. 3.5). As preparation, a SIPOC analysis was already carried out in the Define phase (Fig. 3.4), which describes the process flow. There, the individual production steps are stored and again illustrated in Fig. 3.5 to produce the final product. Figure 3.6 then shows the finished product, in which the clip should also be attached. It is important to ensure during production that, for example, a red clip is attached to a red product and a white one to a white product, etc.

3.3.2 Process Performance Analysis

The participants can divide themselves into groups of three and each group is given a certain number of sheets and paper clips. Then, within a given time of 5 min, each group must produce precision origami according to the scheme in Fig. 3.5. Subsequently, the quality of the produced parts (Fig. 3.7) is checked. The checks include whether

1) the clip is attached in the correct place and orientation,
2) the corner of the product is within the tolerance, made using the template shown in Fig. 3.6,
3) the sheet is heavily damaged.

As this is only a possible suggestion for quality defects, other defects such as damaged sheets/clips etc. can certainly be considered.

FLiX FORSCHUNGSSTELLE LIFE CYCLE EXCELLENCE

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMER
Product Line Manager	Output quantity	Accept of items	Finished products	Customer
Process Owner	Specifications	Take leaf	Missing parts	Waste disposal department
Supplier 1	Leaves	Fold center crease	Production data	Product line manager
Supplier 2	Staples	2. fold center crease		
		Place tip on center fold crease		
		Place the tip of the large side on the resulting crease		
		Fold the crease		
		Select clamp		
		Set clamp		
		Adjust clamp		

Fig. 3.4 SIPOC

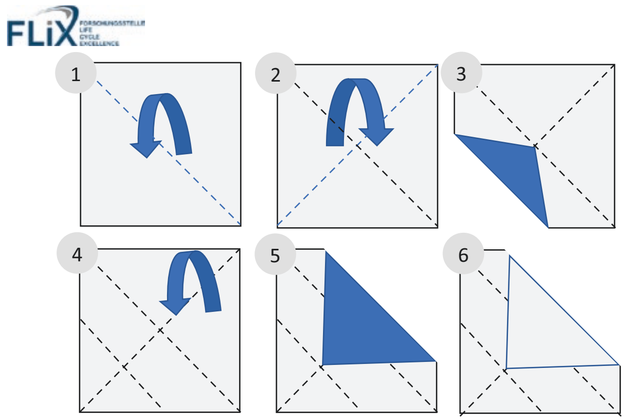
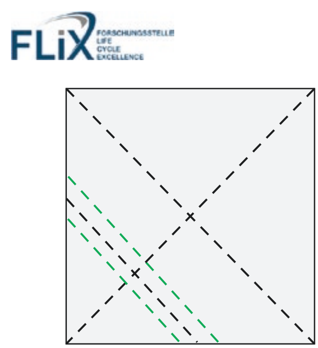


Fig. 3.5 Process flow

Fig. 3.6 Measuring template



The following tasks need to be completed:

1) Error evaluation using an error collection card for each group.
2) Use the total number of defective products **of all** groups to calculate the DPU and DPO metrics and also within the individual groups.
3) Determine the Sigma level (Long-Term and Short-Term value).
4) Create a Pareto diagram based on the error collection cards in the respective groups.
5) Develop optimization suggestions.

	Error collection card
Group: Error	Total number of parts produced:
number 1	Quantity
1	
2	
3	
Total number of errors	

Fig. 3.7 Error collection card

	Number of production groups	Total number of products	Total number of errors	Number of error characteristics / possibilities
	4	84	224	3

Fig. 3.8 Suggested solution error collection card

3.3.3 Appendix: Suggested Solution and Blank Templates

Task i–iii)

Based on the total error collection cards, the following errors (Fig. 3.8) have occurred.

$$DPU = \frac{Defects}{Units} = \frac{224}{84} = 2,6667$$

$$DPO = \frac{Defects}{Units \times Opportunities} = \frac{224}{84 \times 3} = 0,8889$$

$$\Phi(z) = (1 - DPO) = (1 - 0,8889) = 0,1111$$

Using the Z-table, the Sigma value can now be determined (Figs. 3.9 and 3.10).

z	0	0,01	0,02	0,03	0,04	0,05
0	0,50000	0,50399	0,50798	0,51197	0,51595	0,51994
0,1	0,53983	0,54380	0,54776	0,55172	0,55567	0,55962
0,2	0,57926	0,58317	0,58706	0,59095	0,59483	0,59871
0,3	0,61791	0,62172	0,62552	0,62930	0,63307	0,63683
0,4	0,65542	0,65910	0,66276	0,66640	0,67003	0,67364
0,5	0,69146	0,69497	0,69847	0,70194	0,70540	0,70884

Fig. 3.9 Z-table

	Number of groups	Total number of products	Total number of errors	Number of error characteristics /-possibilities	Sigma level Long Term	Sigma level short term
	4	84	224	3	0,54	2,04

Fig. 3.10 Suggested solution metrics

3.4 Workshop 3: "Vegetable Cutter"

In the course of a survey in a large-scale catering kitchen, it was found that the cutting results of the fruit, vegetables, or sliced sausage to be chopped vary greatly. The individual goods are cut into slices with an ordinary kitchen knife to cover bread slices for breakfast. A uniform thickness of the slices is desired, but so far this has only been achieved insufficiently. Customers complain either about slices that are too thick ("The sausage is then too thick for me and I don't like that.") or about slices that, due to too little slice thickness and poor execution of the cutting process, only result in incomplete or crooked slices. To increase customer satisfaction, a survey of customers regarding their quality requirements was conducted. With these data, the DMAIC cycle is now being carried out to improve the given process. The further results of the survey have been recorded in the DEFINE phase. Further conditions for the improvement project result from the specifications of the project sponsor (Fig. 3.11).

Required Materials

This requires a solution that can be reconstructed as simply as possible using the simplest means and that requires as little financial expenditure as possible. In the appendix, you will find forms and work instructions to carry out the process through the DMAIC phases.

Physical materials	Description
Cable ties	Min. 3 pieces
Sharp kitchen knife	Blade should not be too short, evenly ground
Popsicle sticks	Min. 3 pieces, wooden popsicle sticks or similar, e.g. Wooden skewers
Paper	z. e.g. A4 for notes and documentation, folded as a spacer if necessary
Glue (optional)	Instead of cable ties
Vegetables, fruit or	z. e.g. cucumber, sausage, apples
sausage Cutting board	As a base for experiments
Calipers	Alternatively, a folding rule can be used when using a long knife
Stopwatch	z. e.g. smartphone

Fig. 3.11 Required and approved materials for problem solving

3.4.1 Define Phase

The implementation of the phase is explained based on the contents of the project charter. A blank form as well as a document filled with all contents of the DEFINE phase is shown in Fig. 3.14.

Problem Statement

The problem in this project is the inconsistent slice thickness after the cutting process. Often slices are too thick or so thin that no whole slices can be handed over. The customers are directly affected by this problem, as they may not like the slices that are too thick or slices that are too thin are not suitable for covering and serving. The problem can be narrowed down to the actual cutting process, as this is where the inconsistent slice thicknesses occur.

Voice of The Customer

The primary goal of the project is to meet the customer's desire for consistently thin slices of food. As further conditions, the customers have stipulated that an ordinary kitchen knife must be used for the cut, as it is used in various locations and there is no space for large fixtures or cutting machines. Furthermore, the improvement solutions should not represent a major financial burden, as the budget is very limited. The process should also proceed as quickly as before and not generate increased cleaning efforts. With regard to the critical quality indicators, the customer requirements can now be converted into measurable sizes (QTC). For this purpose, the form for the VOC translation matrix in Fig. 3.12 can be used.

Customer requirement	Voice of the Customer	Critical to quality key figure
Little budget	Low improvement and project costs	Costs in €

Fig. 3.12 VOC translation matrix with Critical-to-Quality indicators

Goal Statement

On the one hand, the slice thickness (Critical to Quality) should not exceed 8 mm with a sufficient sigma level, as this is the highest value still acceptable to customers. Furthermore, the slice thickness should not fall below 1 mm, so that there is no risk of producing incomplete slices. The costs (Critical to Cost) should not exceed 2 €. The size of the improvement solution must fit into a storage space twice the size (Critical to Quality) of the kitchen knife. The duration (Critical-to-Time) including cleaning should not take longer than the current process (Fig. 3.12).

Time Frame

Due to the simplicity of the project, one week per DMAIC phase is scheduled as the time frame.

3.4.2 Measure Phase

With the information and quality metrics captured in the process charter, the current process can be examined in terms of the objective. For this purpose, a data collection plan was created in Fig. 3.13. Here it is determined which critical data (CTQ), when, how, where, and how often are collected. The duration of the cutting process of a whole cucumber is recorded. To determine the variation of inconsistent slice thickness, a sample of cutting processes on three whole cucumbers (150 slices) is measured and documented using a calibrated caliper. Based on this data, an initial process performance evaluation and determination of the sigma level are carried out.

Key figure and unit	Source	Time window	Sampling plan/grouping	Measuring method
What	Where?	When?	How often?	How?
costs in €	Expenses for material for testing	Over the entire duration of the project	All issues of the project were summarized	Cost accounting

Fig. 3.13 Data collection plan for the measurements

3.4.3 Analyze Phase

The project does not incur any costs (except labor and opportunity costs), as both the test object (cucumber) and the knife are already available in the kitchen. The dimensions of the knife in our example are 21.5 cm in length and 2 cm in maximum width. With this knowledge, the target specifications for the small transport size can be specified and included in the project charter as a target value. The process time in seconds showed no significant fluctuations over 15 % and was always within the usual process duration.

The measured values of the slice thicknesses can be appropriately displayed in a histogram to obtain the variation of the slice thicknesses around a mean value and to calculate the process performance parameters, as described in the theory part.

3.4.4 Improve Phase

To reduce the identified errors by positioning and guiding the blade, potential solutions were generated in the next step using a brainstorming session. A form for your own brainstorming is shown in Fig. 3.20.

3.4.5 Control Phase

At the end of the DMAIC cycle, all measurement results, documentation, and forms can now be handed over to the Process Owner. All critical quality metrics have been demonstrably achieved and the developed solution can now be applied. Aspects of change management should be considered, as the customer is not yet familiar with the "rustic" design and the changed cleaning process of the spacer. The data collection plan should be carried out at regular intervals to validate whether the distance of the spacer to the blade is still appropriate and has not been adjusted, as this would again cause process variations.

3.4.6 Appendix: Proposed Solution and Blank Templates

Proposed solution and blank form Project Charter (Figs. 3.14 and 3.15):

Proposed solution and blank VOC form (Fig. 3.16 and 3.17):

Proposed solution and blank Data Collection Plan form (Figs. 3.18 and 3.19):

Proposed solution Brainstorming (Fig. 3.20):

After conducting the brainstorming, the idea of a spacer (Fig. 3.21), which is attached to the knife and thus takes up little storage space in terms of the objectives, came up in addition to expensive and complicated measures. All ideas were reflected in terms of meeting all critical target specifications, but only the idea of the spacer could meet all criteria in theory. A spacer shown in the practical example can be realized inexpensively. The slice thicknesses should be more consistent due to the similar structure as with a planer or a stop. The identified approach should therefore first be tested in a pilot trial or when experimenting with a prototype.

By practicing a suitable cutting technique in conjunction with the prototypes of a spacer, the values could each be improved.

The spacer was attached slightly below the cutting edge, so that the knife can be applied without a cut having to be made already. The spacer is limited to a fixed distance from the blade, which defines the slice thickness. For larger distances, however, paper (possibly folded) can be inserted between the cable tie and wooden skewer to increase and adjust the targeted slice thickness. The maximum width of the device and knife is 2.8 cm, which meets the target specification for transport size. Only minor material values were expended.

3.5 Workshop 4: "Precision Throw"

A standard table tennis ball is repeatedly thrown by hand into an empty wastebasket from a distance of 1 m. In doing so, different and unpredictable effects occur. Not only does the table tennis ball bounce just in front of or behind the wastebasket at regular intervals, thus missing the target, but there is also a left or right spin in the flight behavior of the table tennis ball. The flight behavior of the table tennis ball also depends heavily on the person making the throw. Thus, different approaches to the throwing technique can emerge, which vary greatly due to factors such as experience, body size, or cognitive

Six Sigma Project Charter			
Project name	Cutting vegetables with a kitchen knife		
Process owner Project manager Black or Green Belt		Project sponsor Specialist department Completion	
1. Process/Product	Description of the actual process that is the target of the improvement		
2. Problem Statement	Where and when does the problem arise? What is the subject of the problem?		
3. Goal Statement/ Objective	When and to what extent should an improvement be achieved? What are critical quality indicators? What framework conditions must be observed?		
4. Voice of the Customer	Who is the customer of the product/process and what are their requirements?		
5. Business Case	Why is the problem relevant, why is the project being carried out?		
6. Time frame	When are the key milestones due?		
7. Team roles	Which team members are involved in the project and what skills do they bring to the table?		

Fig. 3.14 Blank project charter form

Six Sigma Project Charter			
Project name	Cutting vegetables with a kitchen knife		
Process owner Project manager Black or Green Belt		Project sponsor Specialist department Completion	
1. Process/Product	Description of the actual process that is the target of the improvement	In the kitchen, vegetables are cut with an even knife. Bread is topped with the vegetables.	
2. Problem Statement	Where and when does the problem arise? What is the subject of the problem?	The thickness of the cucumber slices is not uniform. Quality defects lead to customer annoyance. The different slice thicknesses are due to the cutting process.	
3. Goal Statement/ Objective	When and to what extent should an improvement be achieved? What are critical quality indicators? What framework conditions must be observed?	CTQ: slice thickness with sufficient safety between 2-8 mm CTC: Costs < 2€ CTT: No deviation in process duration > 15 %	
4. Voice of the Customer	Who is the customer of the product/process and what are their requirements?	-Optimal slice thickness -Low costs -Small dimensions -No extension of the process runtime	
5. Business Case	Why is the problem relevant, why is the project being carried out?	-Conflict avoidance with the customer -Perceived quality	
6. Time frame	When are the key milestones due?	Project start: Define Phase Measure Phase: Analyze Phase: Improve Phase: Control Phase:	
7. Team roles	Which team members are involved in the project and what skills do they have?	Team members and roles	

Fig. 3.15 Proposed project charter solution

Customer requirement	Voice of the Customer	Critical to quality key figure
Little budget	Low improvement and project costs	Cost in €
Small transport size As	Small product dimensions	Dimensions in mm
fast as possible	Short lead time	Process time in seconds

Fig. 3.16 Proposed VOC solution

Customer requirement	Voice of the Customer	Critical to quality key figure
Little budget	Low improvement and project costs	Costs in €

Fig. 3.17 Blank VOC form

abilities and thus have a significant influence on the successful placement of the table tennis ball in the wastebasket.

Required Materials

- 10 DIN-A4 sheets,
- Adhesive (e.g., super glue or hot glue gun),
- Scotch tape,
- 1 bottle cap,
- 1 table tennis ball,
- Scissors,
- Measuring tool (e.g., ruler),
- 1 rubber band.

Key figure and unit	Source	Time window	Sampling plan/grouping	Measuring method
What?	Where?	When?	How often?	How?
Slice thickness in mm	Distance between the top and bottom of a pane	After completion of the cutting processes	Process for cutting three cucumbers	Calibrated caliper gauge
Costs in €	Expenses for materials for testing	Over the entire duration of the project	All issues of the project were summarized	Cost accounting
Dimensions in mm	Maximum length and width of the knife	Before the start of the test series	One-time measurement	Calipers or folding rule
Process time in s	The process of slicing a cucumber	Start of the cutting process of a cucumber until the end of the process	Each of the three cucumbers	Stopwatch in the smartphone

Fig. 3.18 Proposed data collection plan solution

Key figure and unit	Source	Time window	Sampling plan/grouping	Measuring method
What?	Where?	When?	How often?	How?
costs in €	Expenses for material for testing	Over the entire duration of the project	All issues of the project were summarized	Cost accounting

Fig. 3.19 Blank data collection plan form

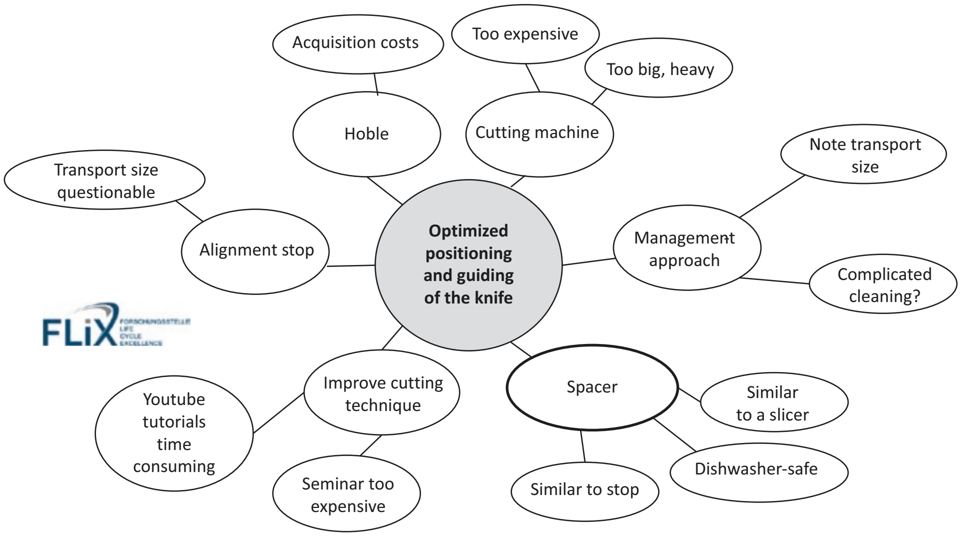


Fig. 3.20 Proposed brainstorming solution

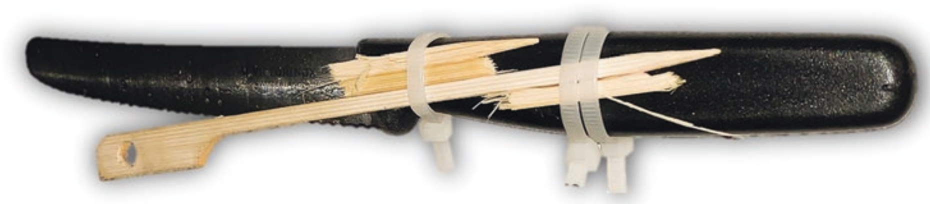


Fig. 3.21 First prototype of the spacer

3.5.1 Define Phase

The placement of the table tennis ball in the wastebasket should succeed from a distance of 1 m, regardless of the different characteristics of the participating individuals. The aim is to achieve the highest possible hit rate, which corresponds to the 6σ level and does not allow any conclusions about possible criteria such as experience, body size, or cognitive abilities of the participating individuals. The current process execution leaves too much room for error, endangering the target-oriented throw of the table tennis ball into the wastebasket. The hitting of the wastebasket depends heavily on the individual characteristics of the throwing person, which directly influences the flight curve of the table tennis ball. The transfer of the requirements into the project charter should not only represent the framework conditions, but also be used to show the most significant objectives using the SMART approach (Fig. 3.22).

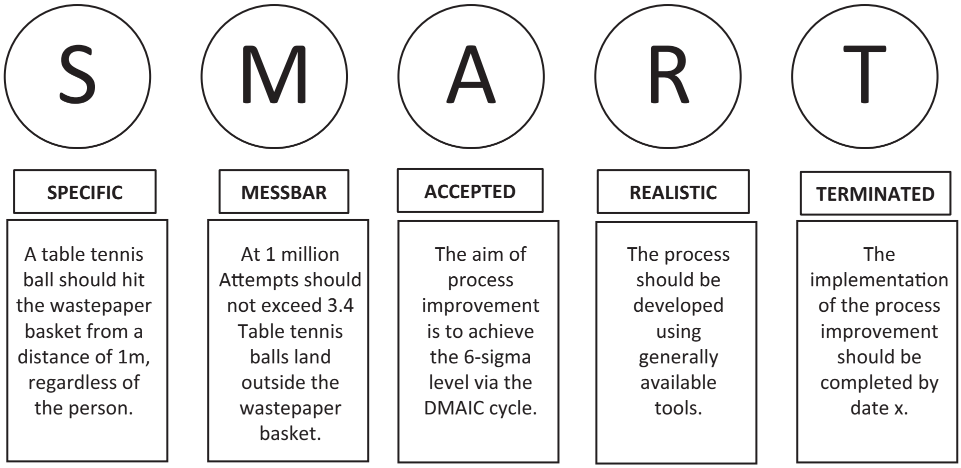


Fig. 3.22 Defined target criteria according to SMART

The goal statement thus includes the most essential aspects of improvement and also underlines the importance for successful implementation and the deadline to be met. In addition to achieving the 6σ level, achieving the best possible grade is also a high priority. The problem statement is primarily characterized by hitting the wastebasket from a distance of 1 m or the desired separation between the throwing process and the characteristics of the participating person. The miss rate should not exceed 3.4 misses per 1 million attempts. (Fig. 3.23). A proposed solution is attached in the appendix. The schedule also provides a visual or temporal orientation in calendar weeks. This allows the defined work steps to be delimited in time and at the same time gives the respective completion date.

Describing the initial situation and specifying the project scope round off the project charter. Here, by clarifying the student background and limiting the extent, the project task is fixed. In addition, a process improvement cooperation with the table tennis ball or wastebasket manufacturers and the dealers is categorically excluded. The focus is exclusively on the endeavor to achieve a sustainable throwing process optimization and to increase the hit rate.

To get an overview of the current process situation, a clear designation of the processes using SIPOC (Fig. 3.24) is required.

The suppliers have an equally significant influence on the specification or material properties of the table tennis ball or wastebasket. For example, dealers can have a significant impact on the product properties of the table tennis ball and the wastebasket through incorrect picking or storage methods. Therefore, the expected properties of the table tennis ball and the wastebasket are also among the inputs of the process execution. These are expanded by the throwing technique and the weather conditions. For example, wind conditions have a direct influence on the flight curve.

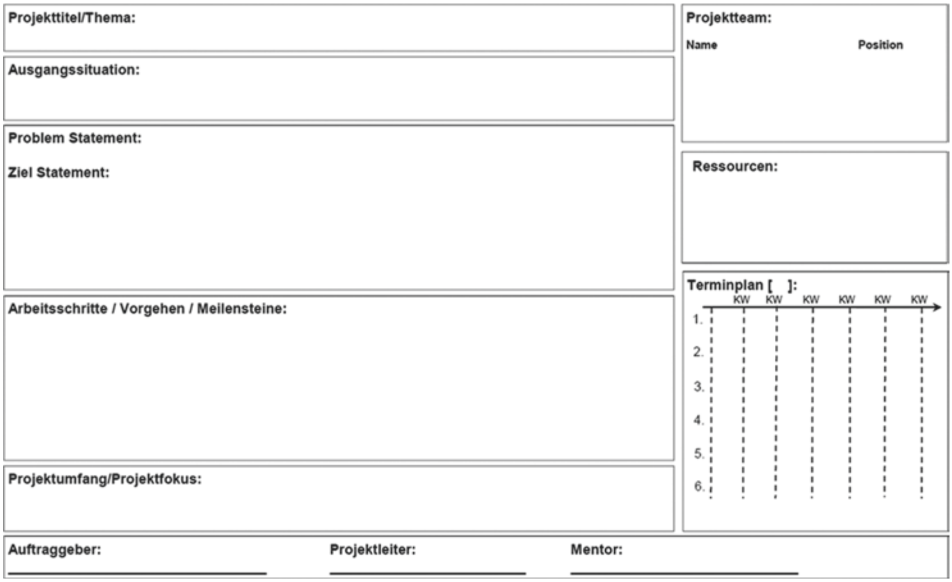


Fig. 3.23 Project charter—precision throw table tennis ball into wastebasket

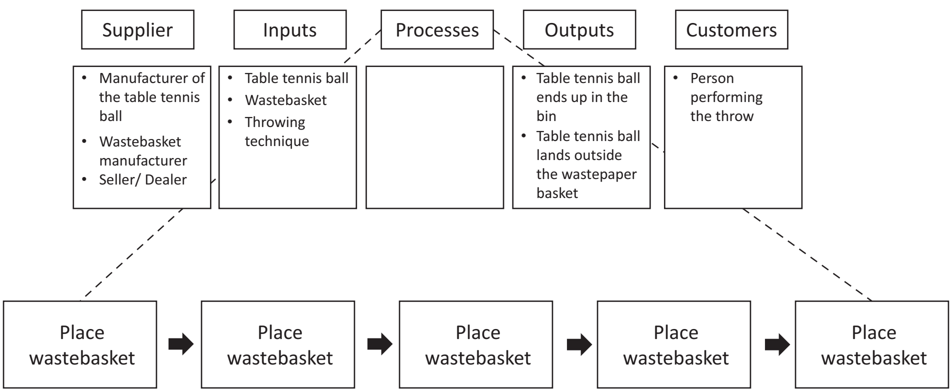


Fig. 3.24 Overview of the current process using SIPOC

The process flow can be reduced to five essential steps.

1. Placing the wastebasket on the ground, which has no inclination/slope.
2. Grabbing the table tennis ball: the palm of the hand is cleaned and neither sticky, moistened, or otherwise disadvantageously soiled.
3. Taking a distance of 1 m to the wastebasket.

4. Starting the aiming process.
5. Executing the throw.

The last two process executions are thus strongly dependent on the person, as, for example, the interpretation of the distance and the required force can vary from person to person. The exact hitting of the wastebasket or missing the wastebasket can thus be identified as the output of the process executions. In this case, the thrower takes on the role of the customer. He aims to ensure the successful placement of the table tennis ball while adhering to the processes to be carried out.

3.5.2 Measure Phase

The evaluated measurement data in the Measure Phase should enable a revealing identification of the problem extent to be eliminated. Here, the placement of the table tennis ball in the wastebasket is to be seen as an unchangeable size. In addition, the throwing distance of 1 m to be maintained and the wastebasket dimensions, which are mainly characterized by the wastebasket height of 36 cm and the wastebasket diagonal of 28 cm, must be taken into account. To measure the hit or miss rate as accurately as possible, it is advisable to use a cardboard device that records the impact of the table tennis ball.

The cardboard device coated with flour serves the purpose of capturing the impact of the table tennis ball (Fig. 3.25a,c). The trail left by the table tennis ball serves as a reference point for distance determination. Thus, using a measuring device, the distance between the impact point of the table tennis ball and the center, marked with a *black cross* in Fig. 3.25b,c, can be measured in cm. In addition to the possible deviation to the center, the lower and upper specification limits can also be determined.

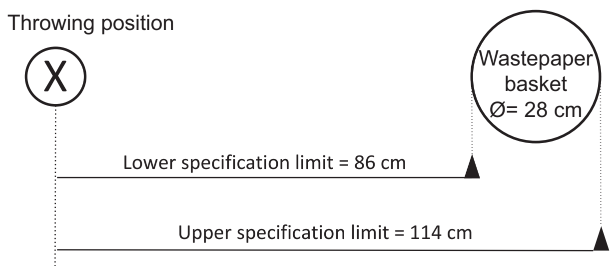
The lower specification limit is thus 86 cm away from the throwing position. The upper specification limit, on the other hand, is 114 cm away from the throwing position (Fig. 3.26). For a more reliable interpretation, however, the number of throws must be increased and the documentation care improved. Here, the data collection sheet (attached as a blank form in the appendix) should enable a clean listing of the throwing processes. The number of throwing processes is set at 100 throwing processes to make a more accurate statement about the process.

The data collection sheet summarizes the attempts made, the respective throwing results, and the respective distance achieved. The most important key data are also listed at the top right edge to be able to immediately classify the distance achieved in the throwing attempt. The results of the data collection sheet can then be evaluated using a histogram.

Using the DPO or PPM calculation from the theory, the current Six Sigma value can be calculated in the next step.

Fig. 3.25a–c Recording device for deviation determination

Fig. 3.26 Throwing position, wastebasket, and specification limits



3.5.3 Analyze Phase

To describe the interaction between the miss rate and the possible causes, the use of the Ishikawa diagram is suitable. By dividing the causes into the classes environment, material, human, and method, the most significant causes should be listed (solution proposal in the appendix).

3.5.4 Improve Phase

The process improvements are now derived from the analysis. It is advisable to control or eliminate the causes induced by humans and the methodology, possibly through standardization in the form of a device. The errors induced by the material could be reduced by a material test using a small scale and a measuring device before the throw. In addition, sufficient lighting conditions and the selection of a wind-free zone should be ensured.

The development of a catapult device and the experiment in a closed room could help to significantly increase the hit rate. Instructions for construction are included in the appendix.

3.5.5 Control Phase

In order to apply the developed process improvement methods sustainably and standardized, continuous process documentation must be introduced. One of the most important factors in fixing the process steps is maintaining the distance to the wastebasket. The distance of 1 m can be determined using a ruler and marked. The second important factor is the attachment of the rubber band. It should be noted that a distance of 3 cm must be maintained between the outermost edge of the catapult ramp and the bonding point of the rubber band. In the next step, the catapult ramp must be pulled down to the stop. The data sheet can be used again to check the process performance. The continuous recalculation of the DPO and PPM allows the improvement to be continuously checked and consolidated.

3.5.6 Appendix: Suggested Solution and Blank Templates

Suggested solution to the Ishikawa Diagram (Fig. 3.27).

Methodological causes include incorrectly chosen throwing processes or inappropriate “running up”. In the human class, the lack of a fine feeling for the necessary throwing force, body size, dirty or sticky hands, and a misjudgment of the distance to the wastebasket play a major role. Deviating material properties of the table tennis ball, mainly characterized by weight and volume, also influence the course of the throw. Poor lighting conditions, an unpredictable gust of wind, and barriers that are in the throwing path or near the thrower directly interfere with the throwing process.

Suggested solution and blank form Project Charter (Fig. 3.28).

Blank form Data Collection Sheet (Experiment Series 1–50) (Fig. 3.29).

Blank form Data Collection Sheet (Experiment Series 51–100) (Fig. 3.30).

Construction instructions for the catapult (Fig. 3.31).

By rolling up the blank papers and then taping them with adhesive tape, the paper rolls gain their stability. A total of 6 x 21 cm, 2 x 15 cm and 3 x 10.5 cm long paper rolls are needed. The adhesive spots are characterized by the *blue dotted markings*. The rubber attachment point must be placed in the middle. The lever movement allows a 4 cm long paper roll, attached under the rubber attachment point. The developed catapult device significantly increases the hit rate.

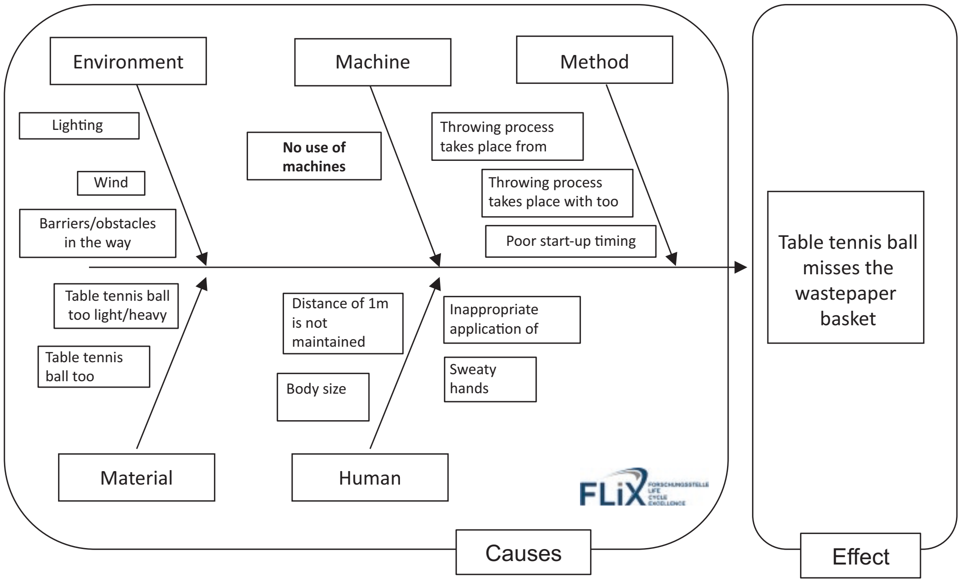


Fig. 3.27 Suggested solution Ishikawa diagram

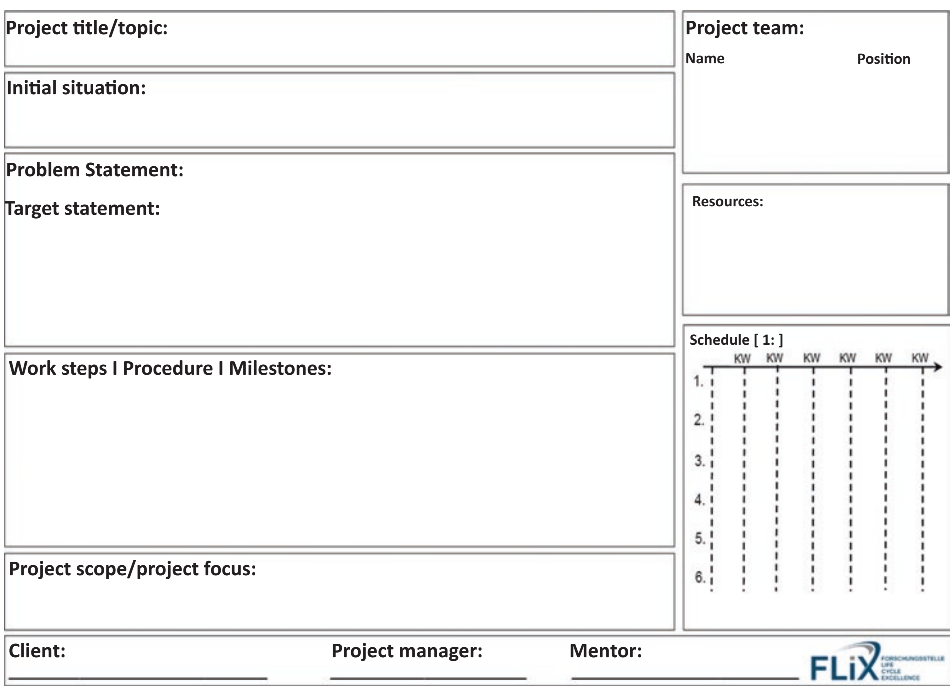


Fig. 3.28 Blank form project charter

Data collection sheet Project: Distance throw Recorder:_______________	Target value:_______ Lower Specification limit:_________ Upper Specification limit:_________ _

Wu rf #	Mee ting he	Deviation	Wu rf #	Mee ting he	Deviation	Wu rf #	Mee ting he	Deviation	Litter #	Hits	Deviation
1			14			27			40		
2			15			28			41		
3			16			29			42		
4			17			30			43		
5			18			31			44		
6			19			32			45		
7			20			33			46		
8			21			34			47		
9			22			35			48		
10			23			36			49		
11			24			37			50		
12			25			38					
13			26			39					

Fig. 3.29 Blank form data collection sheet 1

Data collection sheet Project: Distance throw Recorder:_______________									Target value:_______ Lower Specification limit:_________ Upper Specification limit:_________ _		
Wu rf #	Mee ting he	Deviation	Wu rf #	Mee ting he	Deviation	Wu rf #	Mee ting he	Deviation	Litter #	Hits	Deviation
51			64			77			90		
52			65			78			91		
53			66			79			92		
54			67			80			93		
55			68			81			94		
56			69			82			95		
57			70			83			96		
58			71			84			97		
59			72			85			98		
60			73			86			99		
61			74			87			100		
62			75			88			FLiX FORSCHUNGSSTELLE LIFE CYCLE EXCELLENCE		
63			76			89					

Fig. 3.30 Blank form data collection sheet 2

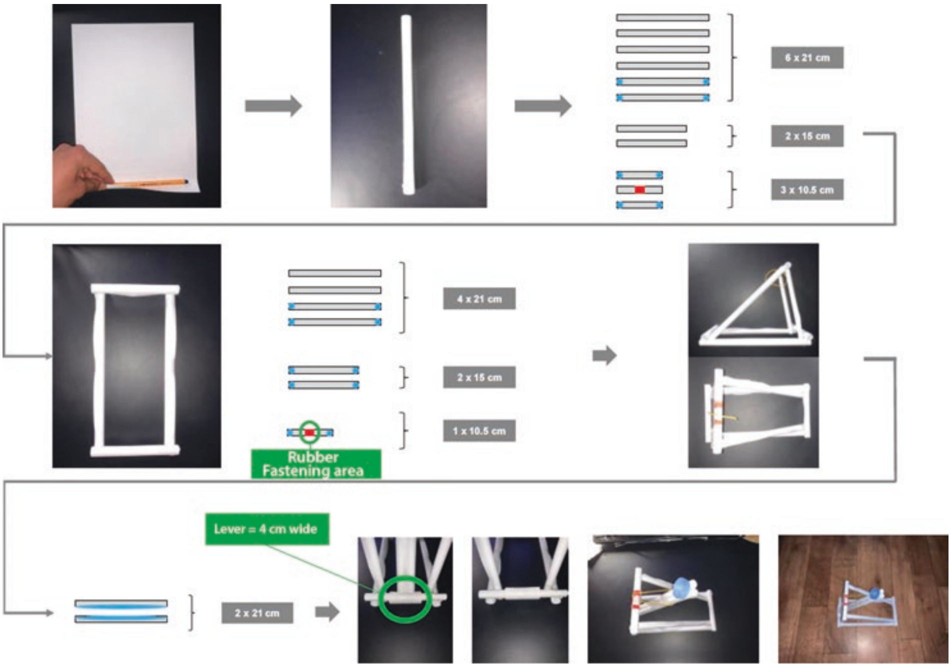


Fig. 3.31 Catapult construction instructions

3.6 Workshop 5: "Spaghetti Dispenser"

In this workshop, a reliable process is to be developed to remove a defined portion of spaghetti from a standard plastic packaging. Because depending on how the packaging is manually torn open or, for example, cut open with scissors, the size of the amount of spillage (Fig. 3.32) varies.

In the practical part, the basic principles and tools of Six Sigma and the DMAIC cycle presented in the theory are to be applied practically using a simplified example. For this, the required materials are first listed and the practical example is presented (Fig. 3.33). Subsequently, the practical problem is to be made more process-reliable using the phases of the DMAIC cycle with a tool. It can also be seen that the size of the outline can vary greatly without precise specifications and accordingly high different quantities per packaging are dispensed solely due to the opening.

Required Materials

The core of the practical example is the spaghetti, of which at least one package is needed, but several packages allow for slight variance in execution (e.g., different tearing of the package). All other materials can be assigned to the following three functions:

Fig. 3.32 Outline of packaging when opening and varying amount of spillage

Fig. 3.33 Overview of required materials

- Objects for measurement: kitchen scale and a large glass or similar containers, stopwatch;
- Objects for the process-optimizing tool: Large reusable bottle (preferably high length), nut-nougat cream lid, cardboard (e.g., inside of the nut-nougat cream lid), thumbtack, and adhesive tape;
- Objects for developing the tool: scissors, knife, pen, and a measuring tape.

3.6.1 Define Phase

To narrow down the process in this simplified workshop, the amount between one “tilt” of a standard packaging and the single tilt with the support of the tool to be developed is to be compared. With the help of the DMAIC cycle, the presented practical example is to be improved process-wise and, for example, the process variations are to be reduced with a tool to be developed.

First, the framework of the project is recorded and precisely defined in the Project Charter. In addition to the key data such as the project title, project number, location, etc., the exact problem definition and the project goal are formulated. In addition, the benefits, a rough milestone plan, and the project team are defined in the Project Charter.

The project goal is to increase the process capability. However, to further specify and make this measurable, an exact target quantity in grams and a customer specification range are defined. An average amount of pasta per person is 55–75 g. In this project, the target value is therefore set at 70 g and a specification limit of +/− 5 g.

In a further step, the process to be examined is divided into five subprocess steps as part of the SIPOC analysis (Fig. 3.34).

The process to be optimized starts with opening the pasta packaging and ends with either putting the pasta into the cooking pot or closing and storing the pasta packaging. However, the focus of the workshop is on the undefined amount of removal and the readjustment, which can lead to high process variations.

In addition to breaking down the process steps, the SIPOC analysis can also determine the supplier (e.g., the buyer) or the customer (e.g., the cook) as well as the associated inputs and outputs, which are relevant in the following for determining customer requirements and the derived Critical-to-Quality (CtQ).

3.6.2 Measure Phase

At the beginning of the Measure phase, the Quality Function Deployment (QFD) should be applied to filter and refine the output criteria in terms of customer needs. The aim here is to identify the relevant quality characteristics that will be measured in the further course of the phase and then sustainably improved within the framework of the DMAIC cycle.

Supplier	Input	Process	Output	Customer
Buyer	Purchased pasta packaging	Open the pasta packaging	Opened pasta packaging	Kitchen
Kitchen help	Opened pasta packaging	Tipping pasta packaging	Undefined amount of pasta	help Cook
Kitchen help	Undefined amount of pasta	Readjustment of the quantity	Subjectively correct amount of pasta	Cook
	Subjectively correct amount of pasta	Put the pasta in the saucepan	Pasta in a saucepan	kitchen
Kitchen help	Opened pasta packaging	Close and stow the pasta packaging	Closed and stowed pasta	assistant

Fig. 3.34 SIPOC analysis for spaghetti removal

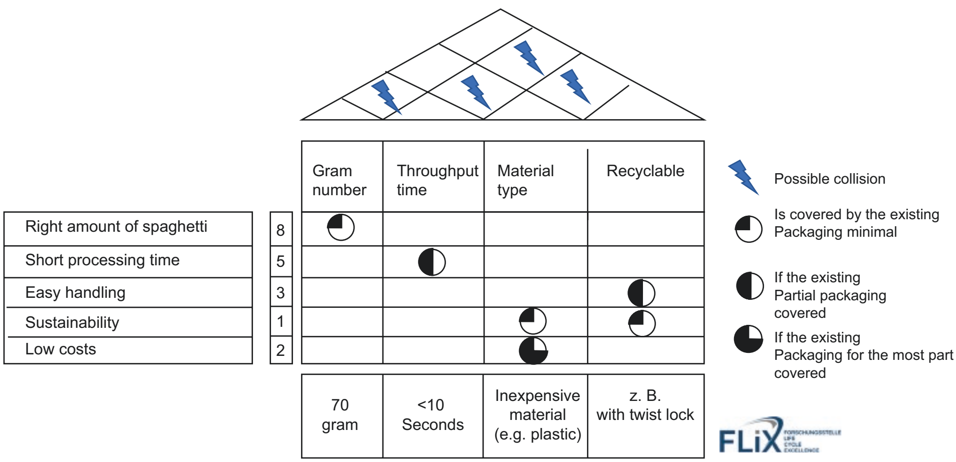


Fig. 3.35 QFDt using the practical example

Fig. 3.35 shows the House of Quality within the framework of Quality Function Deployment, applied to the practical problem. The *differently colored fields* represent different functions in the form:

- *Green:* Customer requirements such as the correct amount of spaghetti and the shortest possible processing time;
- *Yellow:* Weighting of the customer requirement;
- *Purple:* Quality-critical characteristics for meeting customer requirements;

- *Gray:* Target values for the quality characteristics;
- *Orange:* Relationship matrix, which indicates the degree of fulfillment of customer requirements by the quality-critical characteristics;
- *Blue:* Interactions among the characteristics.

To understand the QFD, the form is exemplified by the customer requirement for the correct amount of spaghetti. This has the highest weighting as the main requirement in the practical problem and is influenced by the characteristic of the gram number. A target value of 70 g per withdrawal was set, which is only fulfilled to a small degree according to the relationship matrix. In the roof of the House of Quality, there is a possible collision for the characteristic of the gram number with the throughput time, as the correct amount often requires time-consuming readjustment. Analogously, the form can also be read for the other customer requirements. It becomes apparent that the relevant requirements are not met in the process with the conventional packaging.

After the customer requirements have been identified and weighted using QFD and related to the relevant characteristics, these can now be measured in the main part of the Measure phase. It is important that not as many criteria as possible, but the right output criteria are measured. Of high importance is especially to get the right amount of spaghetti and possibly also the processing time. Therefore, the gram amount will be focused on during the measuring process first.

During the measuring process, the spaghetti is tipped out of the packaging with a push. The amount that is pushed out of the packaging during this tipping can then be weighed in a container (e.g., a large glass or a measuring cup) on a kitchen scale. The kitchen scale must be set in advance so that the weight of the container is not included in the gram number of the measurement. A blank form and a suggested solution can be found in the appendix.

In another measurement attempt, an additional parameter is examined: the throughput time. For this purpose, the time required to achieve the required target quantity by readjustment is measured using a stopwatch. To further delimit the process to be measured, an already opened spaghetti package should be taken and the time should be stopped from the moment of tipping until the correct amount of spaghetti is displayed in the measuring container on the kitchen scale.

Fig. 3.36 shows the measurement of the throughput time. Here too, it becomes clear that the assumed target duration of less than 10 seconds is not achieved with the existing packaging.

As can be seen from the measurements of the gram number and the throughput time, the required target values are not achieved in both cases and a high scatter is noticeable. The process capability is therefore not given under the defined conditions and should be analyzed and improved in the long term. However, the sigma level will only be calculated for the gram number as the central quality characteristic in the following.

Measurements	Processing time (in seconds)
1	27
2	24
3	33
4	13
5	17
Mean value	23
Standard deviation	8
Target duration	>10
Measuring instruments: kitchen scales, container for spaghetti, stopwatch	
Delimitation process: Start = tilting the pack End = correct number of grams in the container on the kitchen scales & remaining quantity back in the packaging	

Fig. 3.36 Measurement of throughput time

3.6.3 Analyze Phase

The data collected in the Measure Phase should be examined in the Analyze Phase for causes of process quality reduction. The Ishikawa Diagram helps to identify and evaluate possible influencing factors based on the six M. Fig. 3.37 shows the Ishikawa Diagram related to the question "Why is the variation in the amount of spaghetti when tipping particularly high?". The influence from the categories machine and nature can be neglected here, as no potential causes of error result from this in the practical problem. Possible error influences arise from the measurement, for example if the kitchen scale is incorrectly calibrated and the weight of the measuring container is incorrectly included. The material of the packaging can also lead to a sequence of errors in the question under investigation, as the packaging easily tears. With regard to the methods, a more precise specification for opening the packaging would have to be available in order to create a smaller measurement scatter. However, the main cause in the practical example is the human factor, as this exerts a different force when tipping and the inclination when tipping can vary greatly, so that the variation in the amount of spaghetti is very high.

Another method of the Analyze Phase is the already introduced FMEA, which further specifies the possible influencing factors from the Ishikawa Diagram and categorizes them with a Risk Priority Number (RPN). A crucial difference is that the sources of error are also prioritized by the RPN according to importance, detection probability and occurrence probability. A proposed solution and a blank form can be found in the appendix.

3.6.4 Improve-Phase

Human inaccuracy and a lack of methodology were identified as the main causes of error based on the Ishikawa diagram and the FMEA. These need to be improved in the Improve phase.

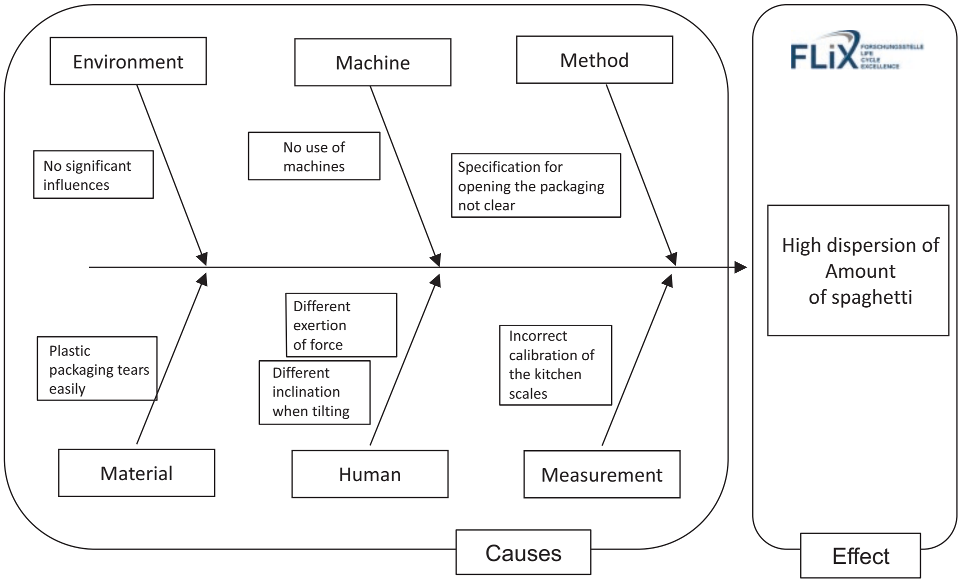


Fig. 3.37 Ishikawa diagram using the example of spaghetti removal

In the exemplary FMEA form, the development of a device or tool was already determined as a countermeasure for possible errors. The Poka-Yoke approach was considered in the development of the tool. Since the Poka-Yoke method also aims to eliminate randomly occurring errors, which often arise from human actions as a source of influence, it is suitable for the present practical problem. The goal is therefore to develop a tool for spaghetti removal that does not allow human inaccuracy in the first place, so that strong process scattering cannot occur. Various creativity techniques can be used to develop this tool (e.g., brainstorming). According to the task of this work, only common household items should be used in the development of the tool. As a result, the prototype was created, which is shown in Fig. 3.38.

Here, a plastic bottle was cut open and used as a container for the spaghetti, which can hold about three times the amount of the usual 500 g package. The heart of the tool is the head glued on with adhesive tape, which is supposed to regulate the amount of spaghetti ejected. For this purpose, the lid of a nut-nougat jar was used, as it fits well onto the cut end of the bottle in terms of geometry and is made of a more stable plastic that does not deform when tipping due to the spaghetti. To enable a process-safe exit quantity of the spaghetti, a hole was first cut in the middle of the lid, which corresponds approximately to the circumference of 70 g of spaghetti. However, in order for the same amount to always be able to exit, the container had to always be completely filled. As an iterative improvement, another lid was therefore used, in which the hole was cut out elongated at the edge of the lid.

In addition, Fig. 3.38 also shows the lid closure. With the help of a piece of cardboard (e.g., contained in the nut-nougat lid) and a thumbtack, a kind of turntable can be integrated on the lid, which allows the tool to be opened and closed. Thus, the spaghetti should also be able to be stored quickly and easily closed with this.

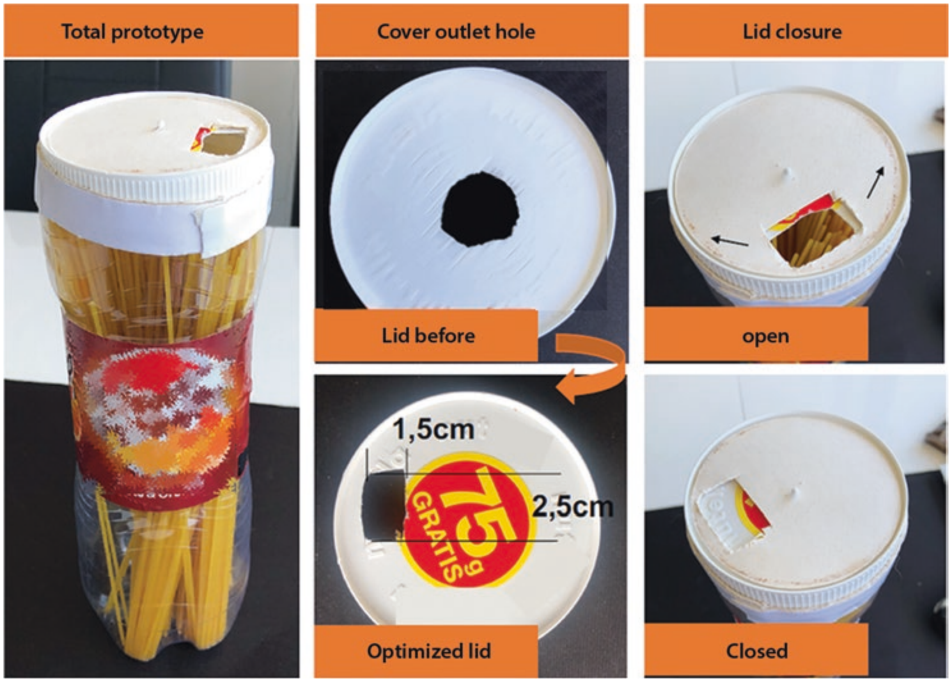


Fig. 3.38 Prototype for process improvement

The firmly defined hole in the dimensionally stable lid should always allow the same amount of spaghetti to exit when tipping the container, so that inaccuracies due to human actions have no influence on the quantity. The harder material also does not tear compared to the previously used spaghetti packaging, thus preventing a potential source of error. To check the effectiveness of the tool, a measurement process is carried out again, in which both the gram number of the exiting spaghetti and the throughput time of the process are measured.

When comparing the mean values and standard deviations between the measurements with the tool and the commercially available packaging, it becomes clear that the process capability could be greatly increased. As before, the C_p and C_{pk} values were calculated for this series of measurements, leading to a higher sigma level (in our example, just under 2σ). The mean values correspond to the defined target values and are within the permissible specification limits. Thus, the customer requirements are met.

3.6.5 Control-Phase

After the process has been defined, measured, analyzed, and effectively improved in the previous phases of the DMAIC cycle, the last phase is about the sustainability of the process. It must therefore be ensured that the newly developed tool is actually always used and that in the long term the spaghetti is not taken directly from the commercially available packaging again.

For long-term compliance with the improved process, a visualized procedure instruction is useful, for example. The process documentation of the optimized state with the newly gained knowledge and a before-and-after description also contributes to the process being adhered to in the long term.

If other or new process quality reductions occur in the long term, which negatively influence the result and the process capability, the DMAIC cycle can be run through again to iteratively eliminate these influences. Otherwise, at the end of this phase, the process is handed back to the process owner and the project is completed.

3.6.6 Appendix: Suggested Solution and Blank Templates

Proposed Solution for Project Charter **(Fig. 3.39)**

Project charter

Project title/topic	**Process improvement for spaghetti output quantity**		
Area/location	Düsseldorf	Project date Start	
Project number	12345	Project completion date (planned)	
Project manager	Mr. D		

Exact problem definition:	*What exactly is dos problem?*
The quantity of spaghetti that falls out when "tipping" from the packaging is not process-reliable and is highly scattered, meaning that no defined portion can be removed.	

Project goal	*What is to be achieved?*
Increase process capability and reduce the variation in the amount of waste. The defined portion should be 70 grams. The customer specification limits are +/- 5 grams.	

Monetary benefit	Milestones	Start	End	Status
20 per year due to optimized process and thus reduced spaghetti consumption (less waste)	Kickoff			✓
	Phase DEFINE			✓
Additional benefits	Phase MEASURE			✓
Easier handling, time saving, better storage support	Phase ANALYZE			✓
Prerequisite / ancillary conditions	Phase IMPROVE			✓
Development of the aid only permitted with standard household items.	Phase CONTROL			✓

Project team		
Name	Role	Agreed time availability
Mr. A	Project manager	6h/ week
Mrs. B	Video editing	once 2 h
Mr. C	Supervisor / Consultant	3 h/week

Fig. 3.39 Proposed solution for project charter

Blank Form for Project Charter **(Fig. 3.40)**

Project charter			
Project title/topic	**Process improvement for spaghetti output quantity**		
Area/location		Project date Start	
Project number		Project completion date (planned)	
Project manager			

Exact problem definition:	*What exactly is the problem?*

Project goal	*What is to be achieved?*

Monetary benefit	Milestones	Start	End	Status
	Kickoff			
	Phase DEFINE			✓
Additional benefits	Phase MEASURE			✓
	Phase ANALYZE			✓
Prerequisite / secondary conditions	Phase IMPROVE			✓
	Phase CONTROL			✓

Project team		
Name	Role	Agreed time availability

Fig. 3.40 Blank form for project charter

Proposed Solution and Blank Form for Measurement Implementation
Proposed Solution for Measuring Throughput Time **(Fig. 3.41)**

For the measurement, three different spaghetti packages were used, each opened differently. This leads to different measurement scopes or different averages between the packages. Overall, the measurements show an average of 114 g with a standard deviation of 49 g. The target quantity of 70 g and the assumed specification limits for the customer of +/−5 g are thus not achieved. Based on the average μ and the standard deviation σ as well as the upper and lower specification limit, the C_p value and the C_{pk} value can be calculated, and the sigma level could then be determined from a table. However, due to

	Measurements	Single discharge of the quantity in grams	
		Standard	Optimized
Packaging 1	1	49	66
	2	65	66
	3	32	71
	4	87	70
	5	56	70
Packaging 2	6	168	66
	7	190	73
	8	160	67
	9	176	71
	10	142	74
Packaging 3	11	119	68
	12	98	70
	13	132	69
	14	138	72
	15	105	70
	Mean value	114	70
	Standard deviation	49	3
	Cp	0,034	0,0658
	Cpk	-0,266	0,597
	Sigma level	n.d. (<1 Sigma)	approx. 2 Sigma
	Target quantity	70	70
	USP/OSP	+- 5	+- 5
Measuring instruments: Kitchen scales, container for spaghetti, stopwatch			

Fig. 3.41 Proposed solution for throughput time

the very low values, no sigma level can be determined in this example, as even the lowest level of the 1σ level only starts at a C_p value of 0.33.

***Blank Form for Measuring Throughput Time* (Figs. 3.42 and 3.43)**

***Blank Form for QFD* Analysis (Fig. 3.44)**

***Proposed solution for the FMEA* analysis (Fig. 3.45)**

The example shows that errors resulting from different inclinations or force exertion during tilting are particularly highly prioritized and therefore urgently need a corrective action. For other errors with a lower RPZ, a corrective action can sometimes be dispensed with, as resources would otherwise be wasted. Depending on the project and company, the threshold for the RPZ that should lead to corrective actions can be chosen differently.

***Blank form for the FMEA* analysis (Fig. 3.46)**

	Measurements	Single discharge of the quantity in grams	
		Standard	**Optimized**
Packaging 1	1		
	2		
	3		
	4		
	5		
Packaging 2	6		
	7		
	8		
	9		
	10		
Packaging 3	11		
	12		
	13		
	14		
	15		
	Mean value		
	Standard deviation		
	Cp		
	Cpk		
	Sigma level		
	Target quantity	70	70
	USP/OSP	+- 5	+- 5

Measuring instruments: kitchen scales, container for spaghetti, stopwatch

Fig. 3.42 Blank form for measuring throughput time

Calculation of c_p value	Calculation of c_{pk} value	Sigma level calculation
$= \frac{OSG - USG}{6\sigma}$	$= Min\,(\frac{\mu - USG}{3\sigma}\,;\,\frac{OSG - \mu}{3\sigma})$	Determined using C_p from table

Fig. 3.43 Calculation formulas Six Sigma

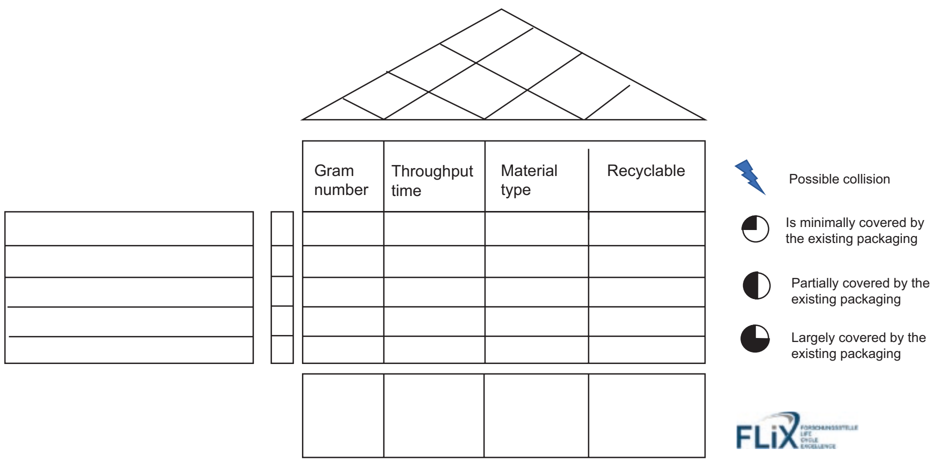


Fig. 3.44 Blank form for QFD analysis

FMEA

ERROR POSSIBILITY AND INFLUENCE ANALYSIS

Design FMEA: ☐
Process FMEA ☑

Product name	Product number
Spaghetti removal	1234
Model/system/production	Technical change status
-	0

Created by (name/	Responsible	Created	Revised	Effort (in h)
				2

Element/ Function	Possible error consequences	Meaning	Possible error/ malfunction	Possible causes of errors	Current status: Avoidance measures	Appearance	Discovery measures	Discovery	RPZ Risk priority number	Recommended remedial measures	Responsi-bility/ Deadline	Improved condition: Measures taken	Meaning	Appeara	Discovery	RPZ Risk priority number
1																
1.1																
	Undefined quantity of spaghetti	8	Below. Inclination when tilting	Human in accuracy	currently none	9	Check with kitchen scales	2	144	Development of a device	24.06.2020	Use of the aid	8	2	2	32
	Undefined quantity of spaghetti	8	Bottom. Exertion of force	Human in accuracy	currently none	9	Check with kitchen scales	2	144	Development of a device	24.06.2020	Use of the aid	8	2	2	32
	Undefined quantity of spaghetti	8	when tilting Torn packaging	Inexpensive packaging material	currently none	3	Visual inspection	4	96	Newly developed device with twist lock	24.06.2020	Dimensionally stable lid	8	1	2	64
	Undefined quantity of spaghetti	8	Packaging opened unevenly	no specification	currently none	6	Visual inspection	3	144	Development of a device	24.06.2020	Defined outlet quantity for aids	8	1	2	48
	Undefined quantity of spaghetti	8	Incorrect weight display	Incorrect setting for kitchen scales	currently none	2	Check whether kitchen scales are set to 0	2	32	not necessary	24.06.2020	currently none				0
1.2																
	Extended processing time	5	Spaghetti back into the packaging = time-consuming	Dimensionally unstable packaging material	currently none	7	currently none	3	105	Development of a device	24.06.2020	Use of the aid (no readjustment necessary)	5	2	3	45

Fig. 3.45 Proposed solution FMEA analysis

FMEA	FAILURE MODE AND EFFECTS ANALYSIS Design FMEA: ☐ Process FMEA ☐	Product name		Product number		
		Model/system/production		Technical change status		
		Created by (name/	Responsible	Created	Revised	Effort (in h)

Element/ Function	Possible error consequences	Meaning	Possible error/ malfunction	Possible causes of errors	Current status: Avoidance measures	Appearance	Discovery measures	Discovery	RPZ Risk priority number	Recommended remedial measures	Responsi-bility/ Deadline	Improved condition: Measures taken	Meaning	Appearance	Discovery	RPZ Risk priority number
1																
1.1																
1.2																

Fig. 3.46 Blank form FMEA analysis

3.7 Workshop 6: "T-Shirt Folding Board"

A daily process is the folding of clothes. Challenges can be posed by special T-shirts and sweaters, as they are difficult to fold precisely. This not only results in wrinkled clothing, but also a messy appearance in the wardrobe. With the DMAIC process, a reliable process should be developed with which T-shirts can always be folded and stored in the same dimensions.

Required Materials

- Cardboard:
  - 5 parts: (80 × 20, 80 × 20, 30 × 25, 30 × 25, 20 × 25),
  - Middle part (30 × 25 cm),
  - Upper part (30 × 25 cm),
  - Lower part (20 × 25 cm),
  - Right side part (80 × 20 cm),
  - Left side part (80 × 20 cm).
- Adhesive tape, scissors and/or cutter knife, folding rule,
- Pen (markings), optionally five different colored pens.

The two side parts can also be made from two different parts if no cardboard of 80 cm length is available.

3.7.1 Define Phase

The SMART approach should be used to define the goals.

- **S**pecific: concrete naming of the process in which the problem occurs.
- **M**easurable: The problem must contain at least one operational measurement size.
- **A**greed: Same understanding of goals and problems by champion and team.
- **R**ealistic: Project goal is achievable within a defined period.
- **T**imed: A defined schedule for achieving the goal.

The clothing should be evenly folded, i.e., have the same dimensions when folded, so that it can be stacked neatly on top of each other. The dimensions of 30 cm × 25 cm with a tolerance of one centimeter each have been defined as the goal for this.

3.7.2 Measure Phase

In the Measure phase, it must now be defined how exactly the process result can be measured. The edges of the folded garment are selected as the measurement size. Because if these are straight and the same length for each garment, this would mean a neatly folded garment. The result can simply be measured using a yardstick to be able to assess to what extent the process result varies. For this purpose, a total of 20 tops are folded and measured by hand. A simple recording form is used to record the results. This is attached in the appendix as a proposed solution as well as a blank form.

In conclusion of the Measure phase, it can be noted that the current manual process does not particularly well meet the requirements and results in a large variation of the folding results.

3.7.3 Analyze Phase

The Analyze phase is now about analyzing the collected measurements. Each aspect must be examined so that the main causes can be derived from this information. This can create a basis from which an improvement can be worked out in the Improve phase.

With the help of a process analysis, the folding process is broken down into its individual parts to identify potential causes. The folding process can be divided into 5 steps, which are then examined for potential sources of error. A proposed solution and a blank form are attached in the appendix for this analysis. As a result, the potential sources of error that led to this process result become apparent.

3.7.4 Improve Phase

After the causes of the problem have been identified, the Improve phase is now about generating a solution, refining it, and implementing it. The so-called Poka-Yoke principle can be considered for this. The preventive approach of implementing a new method so that errors in folding clothes cannot occur in the first place would be an effective solution to avoid errors.

Approaches for an improved mechanism emerge from the Analyze phase. The solution must ensure that the sleeves are always folded straight at the same position. This also applies to folding lengthwise.

From these prerequisites, the idea of a folding board was developed, with which the garments can always be folded to the same dimensions. This can be relatively easily realized via cardboard cutouts that are connected with adhesive tape. The center part of the folding board can be defined as 30 cm × 25 cm according to the target specification (Define phase).

In order to be able to fold larger garments as well, the folding board has dimensions of 80 cm × 65 cm. Accordingly, the two foldable side parts of the board have dimensions of 80 cm × 20 cm. All individual parts were attached to the center part with conventional adhesive tape. The construction instructions for the folding board are in the appendix.

In order to be able to fold the garments to the desired dimensions of 30 cm × 25 cm, two folding processes in length are required for a total length of the T-shirts and sweaters. The sequence of the individual folding steps is shown in the appendix.

A potential source of error remains that the garment is placed crooked and uneven on the folding board at the beginning of the process. To counteract this, colored markings were drawn on both side parts. This way, it can be immediately recognized if the T-shirt is not correctly placed on the board.

After the T-shirts have been folded using the folding board according to this process, they have the desired dimensions of 30 cm × 25 cm. In our example, the dimensions of all garments after folding with the folding board were within the required tolerance.

3.7.5 Control Phase

In order to establish the process sustainably, the measurements must be repeated and documented at random, but at regular intervals.

L \ B	20	20,5	21	21,5	22	22,5	23	23,5	24	24,5	25	25,5	26	26,5	27	27,5	28	28,5	29	29,5	30
25														1							
25,5																					
26								1								1					
26,5			1																		
27																					1
27,5			1														1				
28																					
28,5					1																
29										1			1								
29,5																			1		
30											1										
30,5													1								
31				1				1													
31,5												1			1						
32						1															
32,5																					
33,5																			1		
34																					
34,5																					
35																	1				

Fig. 3.47 Proposed solution fold

L \ B	20	20,5	21	21,5	22	22,5	23	23,5	24	24,5	25	25,5	26	26,5	27	27,5	28	28,5	29	29,5	30
25																					
25,5																					
26																					
26,5																					
27																					
27,5																					
28																					
28,5																					
29																					
29,5																					
30																					
30,5																					
31																					
31,5																					
32																					
32,5																					
33,5																					
34																					
34,5																					
35																					

Fig. 3.48 Blank form folds

3.7.6 Appendix: Proposed Solution and Blank Templates

Proposed Solution for Capturing the Folds **(Fig. 3.47)**

Blank Form for Capturing the **Folds (Fig. 3.48)**

Proposed Solution for Capturing the Folding Process **(Fig. 3.49)**

***Blank Form for Capturing the Folding Process* (Fig. 3.50)**

***Folding Board Construction Instructions* (Fig. 3.51)**

Dimensions and Measurements (Fig. 3.52)

	Action	Possible errors
1.	Put down the T-shirt	• Not laid down correctly
2.	Fold over the right sleeve	• Sleeves folded back askew • Sleeves too wide/short folded inwards
3.	Fold down the left sleeve	• Sleeves folded back askew • Sleeves too wide/short folded inwards
4.	Fold the T-shirt lengthwise	• T-shirt folded askew • T-shirt folded to different lengths • T-shirt partially folded 1x and partially folded 2x lengthwise
5.	Place T-shirt on finished stack	• Placed at an angle on the stack so that the T-shirt slips

Fig. 3.49 Proposed solution folding process

	Action	Possible errors
1.		
2.		
3.		
4.		
5.		

Fig. 3.50 Blank form folding process

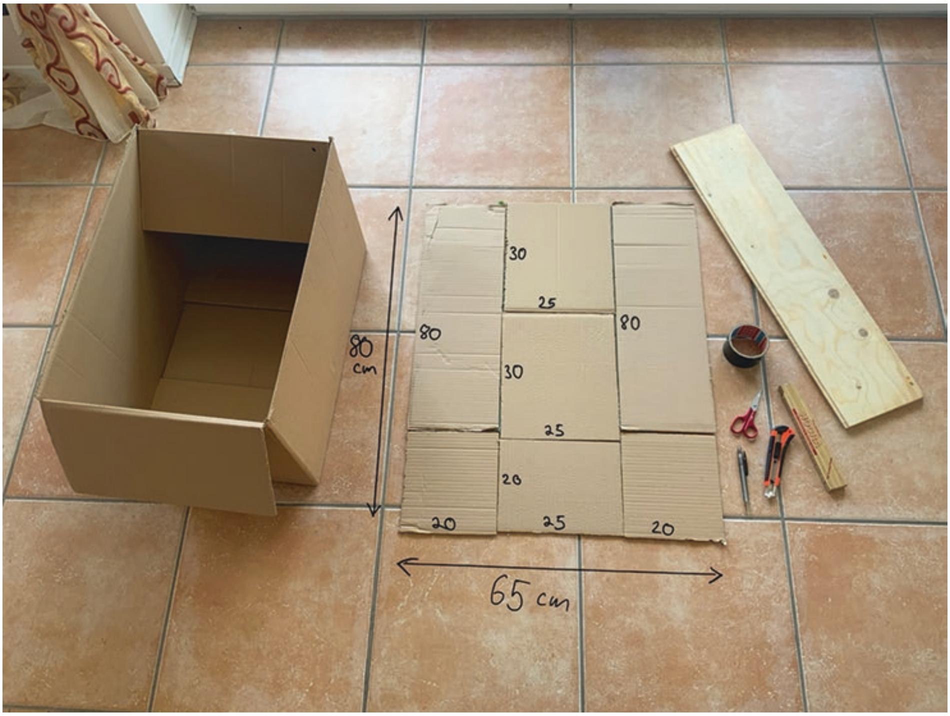


Fig. 3.51 Construction instructions folding board

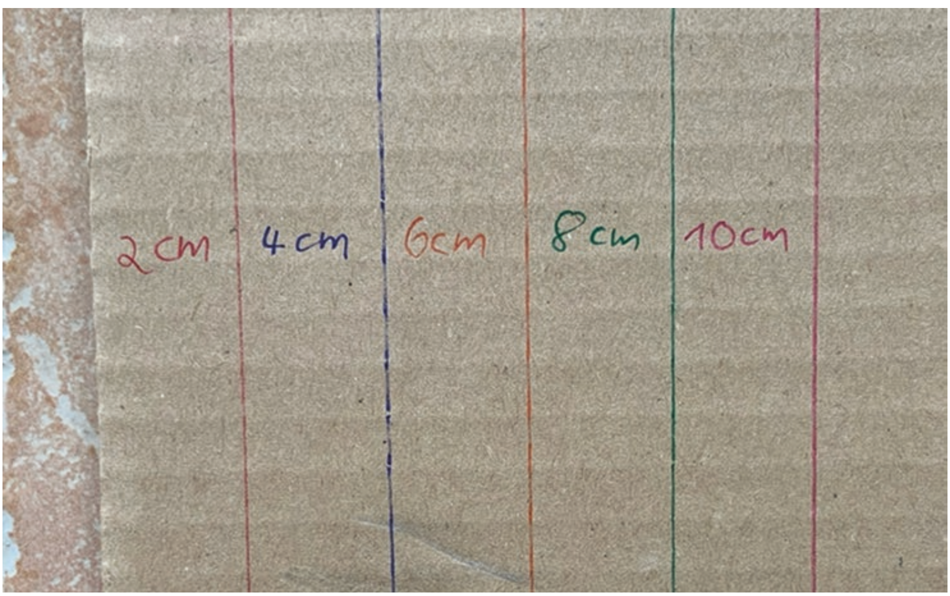


Fig. 3.52 Markings folding board

Folding Instructions for the T-Shirts on the Folding Board

Step 1:

Align the T-shirt along the top edge and the side markings

Step 2:

Fold down right side

Step 3: Fold down the left side

Step 4: Fold down the lower part

Step 5: Fold over the top half

Step 6: The T-shirt can be placed on the finished

Stacks are placed

DONE

References

1. Mollenhauer J-P, Lunau S (Ed) (2007) Design for Six Sigma+Lean Toolset. Innovationen erfolgreich realisieren. Springer (VDI-Buch), Berlin
2. Lunau S, Meran R, John A, Staudter C, Roenpage O (Hrsg) (2014) Six Sigma + Lean Toolset. Mindset zur erfolgreichen Umsetzung von Verbesserungsprojekten, 5th ed. Springer Gabler, Berlin
3. Waurick T (2014) Prozessreorganisation mit Lean Six Sigma. Eine empirische Analyse. Springer Gabler, Wiesbaden
4. Toutenburg H, Knöfel P (2009) Six Sigma. Methoden und Statistik für die Praxis, 2nd improved and expanded ed. Springer, Berlin
5. Dahm MH, Haindl C (2011) Lean Management und Six Sigma. Qualität und Wirtschaftlichkeit in der Wettbewerbsstrategie, 2nd newly edited amd expanded ed. Schmidt, Berlin
6. Wälder K, Wälder O (2013) Statistische Methoden der Qualitätssicherung. Praktische Anwendung mit MINITAB und JMP. Hanser (Praxisreihe Qualitätswissen), München
7. Broecheler K, Schönberger C (2004) Six Sigma für den Mittelstand. Weniger Fehler, zufriedene Kunden und mehr Profit. Campus, Frankfurt a. M.
8. Wappis J, Jung B (2013) Null-Fehler-Management. Umsetzung von Six Sigma; [extra mit kostenlosem E-Book], 4th revised and expanded ed. Hanser (Praxisreihe Qualitätswissen), München
9. Schipp B, Töpfer A (2003) Statistische Anforderungen des Six Sigma Konzepts. In: Töpfer A (Ed) Six Sigma. Konzeption und Erfolgsbeispiele. Springer, Berlin, S 150–159
10. Töpfer A (2003) Six Sigma als Projektmanagement für höhere Kundenzufriedenheit und bessere Unternehmensergebnisse. In: Töpfer A (Ed) Six Sigma. Konzeption und Erfolgsbeispiele. Springer, Berlin, S 38–85
11. Staudter C, Mollenhauer J-P, Meran R, Roenpage O, von Hugo O, Hamalides A (2009) Design for Six Sigma + Lean Toolset (Lunau S (Ed). Springer, Berlin
12. Jochem R, Geers D, Herklotz H, Giebel M (Hrsg) (2015) Six Sigma leicht gemacht. Ein Lehrbuch mit Musterprojekt für den Praxiserfolg, 2nd fully revised ed. Symposion, Düsseldorf
13. Buchholz L (2013) Strategisches controlling. Grundlagen – Instrumente – Konzepte, 2nd ed. Springer Gabler, Wiesbaden
14. Schmutte AM (2015) Six Sigma im Business-Excellence-Prozess. In: Gundlach C, Klietmann M, Becker R (Hrsg) Six Sigma leicht gemacht. Fehler vermeiden, Prozesse verbessern, Kosten senken; [Praxishandbuch Six Sigma], 2nd updated and expanded ed. Symposion Publ, Düsseldorf, S 71–100

Poka Yoke

4

4.1 Classification of the Method

By enforcing the One-Piece-Flow and the desire to be able to produce flawlessly, it is necessary to make the manufacturing processes more reliable and to reduce errors. The goal of the Poka-Yoke method is to prevent errors in assembly in particular through an appropriate process design. The method follows the principle of error source prevention—since no errors can occur without an error source.

Together with the production evolution towards Lean Management, the Poka-Yoke method was invented in Japan in 1961 by Shigeo Shingo. Shigeo Shingo was a quality engineer at Toyota who coined Poka Yoke through the term Poka Yoke [1]. Baka Yoke translates as "foolproof" and quickly spread in organizations like the Arakawa Body Company.

An employee of the Arakawa Body Company, who was told that her workplace was "foolproof", found the term derogatory and the term was renamed Poka Yoke "avoidance of unintentional errors" [2].

Lean Management is characterized by Kaizen and the avoidance of "Muda" (Waste). Figure 4.1 shows the three essential drivers for successful production—it can be seen that Poka Yoke is classified in terms of product quality compared to other process optimization methods [3]. The essential factors for successful production listed in Fig. 4.1 do condition each other, but are not negatively correlated. While it is possible to improve the quality of products by accepting a longer throughput time, both factors can also be optimized equally through the use of the right methods and an appropriate management approach. Furthermore, Poka Yoke can contribute to increased throughput time through the approach of error source prevention, as potential rework becomes obsolete.

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_4

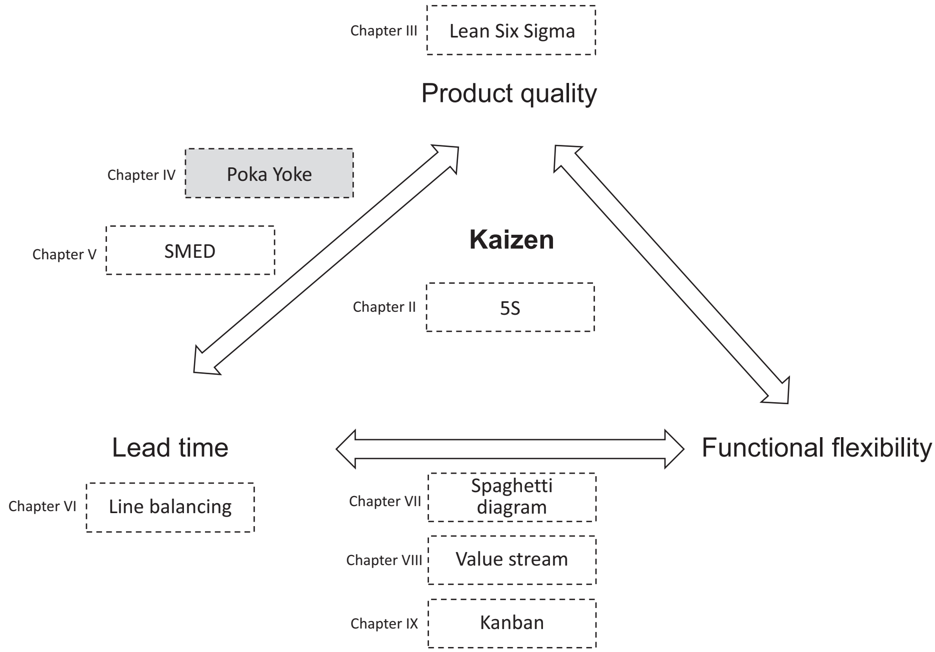


Fig. 4.1 Poka Yoke in the tension field of Kaizen

4.2 Description of the Method

The Zero-Error-Production aimed at by Shigeo Shingo through the application of Poka Yoke is based on a basic idea with three components [4]:

1. ***Cause Analysis:***
   In the cause analysis, the process is checked in advance for possible incorrect actions and not resulting errors for their causes. Due to the analysis of the actions with regard to errors, a higher avoidance of errors is possible.
2. ***100% Inspection:***
   Through the implementation of the Poka Yoke, all parts in a process are checked for certain potential incorrect actions, or the process is designed in such a way that the incorrect action does not occur. Due to the simplicity of the facilities, it is also economically possible to check each individual part and not just a sample.
3. ***Immediate Corrective Actions:***
   Because the system is designed in such a way that errors are not allowed, the initiation of necessary corrective measures takes place immediately. Furthermore, Wildemann divides Poka Yoke into three subsystems, which allow the discovery and reporting of incorrect actions to follow one another in time [5].

4.2.1 Detection Mechanism

The testing method serves to describe the time and place of error and cause detection. Within the detection mechanisms, the causes for the incorrect actions must also be determined in the context of an error source check. The basic principle of the error source check is to prevent, for example, a wrong or defective/faulty material from reaching a work step.

For this purpose, checks with direct and indirect feedback are suitable. In the case of direct feedback (self-control), the employee actively recognizes the incorrect action and can correct it. For example, a component can be dimensioned in such a way that it can only be assembled in one orientation, or screws are to be dimensioned in such a way that they differ both in length and in diameter.

In the case of indirect feedback (subsequent control), the next process step cannot be carried out before the error has been corrected. An example of this would be that the weight or dimensions of a workpiece are checked by a worker.

4.2.2 Trigger Mechanism

Trigger mechanisms ensure the detection of errors within the framework of a target-actual comparison. In this process, the characteristics and details of the error are described by a contact method, a fixed value method, and a sequence of steps method.

In the contact method, the error is usually detected via geometric properties, e.g., by sensors that can detect deviations in weight, temperature, or position, but also time.

The fixed value method describes the testing for errors upon reaching a certain number of partial work steps. The partial work steps can be controlled, for example, by mechanical or electronic counting devices. For instance, forgotten parts can be determined in assembly by the number of parts.

With the sequence of steps approach, incorrect actions are detected through a control of movement or action sequences, and if necessary, a regulatory mechanism is initiated. A common example of a sequence of steps approach is cash withdrawal at an ATM. Here, the money is only made available to the customer after they have removed their card. In the industrial environment, the possibility of material removal for a work order only after the previous insertion of a Kanban card is another example.

4.2.3 Regulatory Mechanism

The regulatory mechanism shows how the production system reacts due to errors or incorrect actions. This function is divided into an intervention and steering method and a warning approach. The intervention and steering method intervenes directly in the system when an error or an incorrect action is detected and would—for example in industrial production—block the production. In the case of the intervention method, this is to be subsumed under the hard Poka-Yoke methods. If the system does not intervene despite an error, but the error is clearly communicated by the system (e.g., through an acoustic, haptic and/or optical signal), this regulatory mechanism is defined as a warning approach. An example of a haptic signal is a vibration.

For successful quality improvement, every element of the Poka-Yoke system must be used in the implementation of the quality improvement measure. Comparable to the creativity technique of the morphological matrix, the Poka-Yoke system matrix is also used. The solution finding of Poka Yoke is oriented towards the avoidance of incorrect actions. For this, the specific process is analyzed by applying the Poka-Yoke system matrix (Fig. 4.2). By using creativity techniques, solutions for the causes of errors can be found in a targeted manner. Prioritization for possible changes can be done by weighting the errors via the Poka-Yoke priority number. The Poka-Yoke priority number is calculated as follows:

$$\begin{gathered} \textit{Poka-Yoke-Priority Number} = \\ \textit{Probability of an Error Occurring} \times \textit{Significance of the Error} \\ \times \textit{Effort to correct Error} \end{gathered}$$

Errors with a high priority number are treated as a priority. If there is a high effort to correct an error, this is weighted by a numerically high correction effort. Overall, the Poka-Yoke system learns over the entire product life cycle and Poka-Yoke measures address different levels of the product development cycle accordingly (Fig. 4.3). Furthermore, an earlier avoidance of a cause of error is advantageous, but errors increasingly occur as the product life cycle progresses.

For the analysis of activities, error probabilities play a significant role. Figure 4.4 shows relevant types of error actions for certain activities within a production.

Elimination of error sources		
Detection mechanism	***Release mechanism***	***Regulatory mechanism***
Error source check – root cause analysis	Contact method – physical quantity	Intervention and control method
Exam with direct feedback – Self-check	Fixed value method – Number of partial work steps	Warning approach
Inspection with indirect feedback – follow-up inspection	Step sequence method – standard movement sequences	

Fig. 4.2 Poka-Yoke system matrix

Product development cycle	Poka Yoke description	Contents	Development and influence of Poka Yoke
Development/Construction	Product-oriented Poka Yoke	Identify theoretical mistakes and prevent them through constructive measures	Influence on the Error causes
Production planning	Process-oriented Poka Yoke	Recognize and prevent possible mistakes	
Production/assembly	Error-oriented Poka Yoke	Avoid known mistakes	
Application/Service	No Poka Yoke application, only root cause analysis	Identify further errors and implement poka-yoke measures at a deeper level	Development of Poka Yoke solutions

Fig. 4.3 Development and influence within the product life cycle

4.3 Workshop 7: “Reading and Puzzling”

The susceptibility to errors of a task requiring care is to be illustrated using the reading card attached in the appendix. The task is to correctly determine the number of the letter “e” within the illustration. If this task is to be solved within a certain time, the susceptibility to errors increases, all other things being equal. This again makes it clear that the human factor represents a high source of error. Furthermore, it is questionable whether it is possible to establish a routine within this task.

The avoidance of errors through appropriate process design is to be illustrated by assembling a puzzle. However, the process example “Puzzle” (appendix) is characterized by the fact that all parts fit together—so also parts that do not belong together; this greatly increases the number of potential errors. To document the process optimization, the time, the problems that occurred, the number of errors, and suggestions for optimization are documented (template blank form documentation).

For the first optimization of the process, a template with numbers could be created, for example, and the puzzle pieces could also be numbered so that the pieces can be placed in the corresponding fields. To ensure the correct positioning of the parts, either the numbers themselves or corresponding parts can be used.

Activity	Type of activity	Example	Mishandling/error rate per activity/task
A Simplest activity / task	Reading/ Reasoning	Failure to react to signal board	0.0001
		Incorrect reading of an alphanumeric character	0.0002
		Incorrect reading of a five-letter word with good resolution	0.0003
	Physical/ manual activity	Failure to switch off (power) supply during electrical work	0.0001
B Simple Routine activity / task	Read Conclude	Incorrect reading of a checklist or digital display	0.001
		Read analog display incorrectly	0.005
		Read ten-digit number incorrectly	0.006
	Physical/ manual activity	Multi-position switch wrong positions	0.001
C Routine activity / task with Due diligence requirement	Read Conclude	Incorrect recording of information or incorrect reading of a diagram	0.01
		Solve a simple math problem incorrectly	0.01-0.03
		Calculate a simple equation incorrectly	0.02
		Incorrect reading of a five-letter word with poor resolution	0.03
		Incorrectly typing ten digits into a calculator	0.05
		Incorrect dialing of ten digits	0.06
	Physical/ manual activity	Insert plug the wrong way round	0.01
		Failure to reset a valve after related tasks	0.01
		Incorrect insertion of an individual part	0.02
D Complex non-routine activity / tasks	Reading/ Reasoning	Failure to carry out an appliance check when changing shifts	0.1
		General reading (for greater stress)	0.25
		Failure to recognize an incorrect position of a shut-off valve	0.5
		Failure to recognize improper status during on-the-fly inspection	0.1

Fig. 4.4 Human error/mistake rates [6]

A second optimization can be achieved by implementing a self-check. In this case, the typical cutouts of a puzzle are added to the parts, in addition to the template and the numbers, so that the process (in se) ensures that the parts are correctly combined with each other—since another combination is not possible (suggestion in the appendix). In addition, the reliability of the process can be further increased by standardizing the order in which the parts are provided. In this case, the process quality is greatly increased by the possibility of finding a routine.

Appendix: Suggested Solution and Blank Templates

Reading card solution suggestion

c	l	z	e	u	e	z	e	u
e	b	v	o	e	f	c	j	e
c	j	e	c	e	b	e	c	e
e	b	o	i	e	i	s	i	i
f	j	b	e	e	e	f	j	e
a	e	c	e	f	e	i	e	e
b	c	e	f	i	e	e	e	f
z	e	o	f	e	b	v	o	f
v	c	e	f	e	j	e	c	o
e	o	i	i	e	e	i	e	c
a	d	o	f	e	e	b	d	e
b	c	e	f	f	e	j	c	e
l	z	e	u	e	f	e	o	f
c	l	a	d	o	e	f	i	e
e	b	i	e	e	i	e	o	f
c	j	d	o	f	e	e	c	e
e	e	c	e	f	o	i	e	j
l	z	e	e	u	d	e	f	e
e	b	f	z	e	w	i	i	e
c	z	e	d	d	o	o	f	e

Blank reading card form

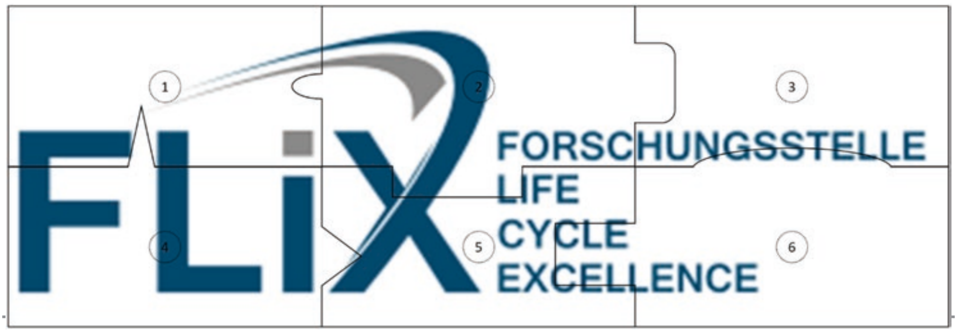
c	l	z	e	u	e	z	e	u
e	b	v	o	e	f	c	j	e
c	j	e	c	e	b	e	c	e
e	b	o	i	e	i	s	i	i
f	j	b	e	e	e	f	j	e
a	e	c	e	f	e	i	e	e
b	c	e	f	i	e	e	e	f
z	e	o	f	e	b	v	o	f
v	c	e	f	e	j	e	c	o
e	o	i	i	e	e	i	e	c
a	d	o	f	e	e	b	d	e
b	c	e	f	f	e	j	c	e
l	z	e	u	e	f	e	o	f
c	l	a	d	o	e	f	i	e
e	b	i	e	e	i	e	o	f
c	j	d	o	f	e	e	c	e
e	e	c	e	f	o	i	e	j
l	z	e	e	u	d	e	f	e
e	b	f	z	e	w	i	i	e
c	z	e	d	d	o	o	f	e

Blank documentation form

FLiX	1. Passage	2. Throughput (optimization)	3. Throughput (optimization)
Problems encountered			
Puzzle solved?			
Time required			
Number of errors			
Optimization proposal			

Blank puzzle form

Puzzle process improvement



References

1. Wisner JD (2016) Operations management. A supply chain process approach. Sage, Los Angeles
2. Shingo S (1986) Zero quality control. Source inspection and its poka yoke system. Productivity Pr, Stamford. http://www.loc.gov/catdir/enhancements/fy0801/85063497-d.html. Accessed 03 May 2021
3. Zollondz H-D (2013) Grundlagen Lean Management. Einführung in Geschichte, Begriffe, Systeme, Techniken sowie Gestaltungs- und Implementierungsansätze eines modernen Managementparadigmas. Oldenbourg (Edition Management), München. http://www.degruyter.com/search?f_0=isbnissn&q_0=9783486779042&searchTitles=true. Accessed 03 May 2021
4. Kamiske GF, Brauer J-P (2008) Qualitätsmanagement von A bis Z. Erläuterungen moderner Begriffe des Qualitätsmanagements, 6th ed. Hanser, München
5. Wildemann H (2013) Logistik Prozessmanagement [Organisation und Methoden], 6th edited ed. TCW, Transfer-Centrum-Verl. (TCW, 19), München
6. Sondermann JP (2013) Poka Yoke. Prinzip und Techniken für Null-Fehler-Prozesse. Hanser, München. http://www.hanser-elibrary.com/action/showBook?doi=10.3139/9783446437616. Accessed 03 May 2021

5 SMED

5.1 Classification of the Method

Due to the ongoing industrialization and the shift from a seller's to a buyer's market, customers increasingly expect a larger number of different products. In order to be able to meet customer wishes flexibly and fairly, batch sizes must be systematically reduced. This usually involves frequent retooling. In order for the entire production system to remain efficient, it is necessary to keep the setup processes as short as possible. The SMED method "Single Minute Exchange of Die" can be used for this purpose—waste is reduced through the use of organizational and technical measures, and production time and overall plant efficiency are increased (Fig. 5.1).

The idea of shortening setup times or minimizing any kind of waste comes from the Toyota Production System. Toyota pursues the goal of a One Piece Flow. In contrast, the batch size can be increased to shorten the proportionate setup time to value-adding time. However, this leads to inflexible production and to the dilemma of high batch size according to Gutenberg. Gutenberg describes that a high batch size usually leads to high inventory levels, a large number of rush orders and inflexible production. Furthermore, the inventories conceal any inadequacies within the production [1].

According to REFA, setup refers to the activities of setting up the operating resources of a work system (e.g., machine, production site, individual plant or plant line) for a specific work process (e.g., tool change) [2]. Thus, the setup time is the time between the last good part of a batch and the first good part of a subsequent batch. The setup time is defined as the sum of the basic setup time, the setup recovery time and the setup distribution time. The basic setup time describes the employee's work effort for the actual setup activity and the setup distribution time the waiting time that the employee spends during setup without recovery.

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_5

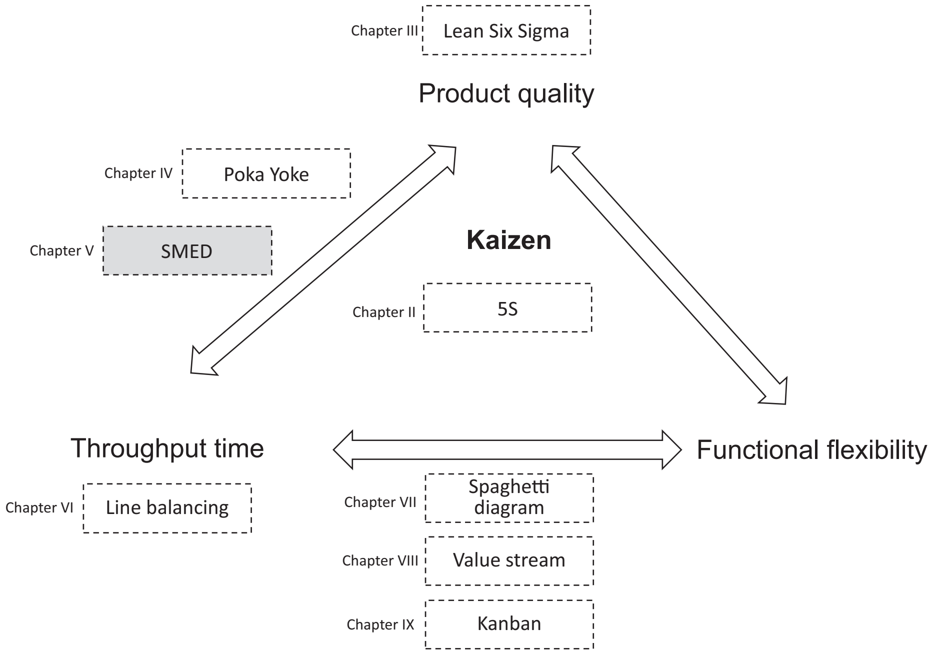


Fig. 5.1 SMED in the tension field of Kaizen

The SMED method, however, does not focus on shortening setup times per se, but on transforming internal setup processes into external setup processes. The difference between internal and external setup processes is that the process of service provision is stopped during internal setup processes and not during external setup processes. From this approach, it is possible through SMED to expand capacities, accelerate the process and optimize productivity. A capacity expansion can take place within a service by having more activities of the service process taken over by the customer.

Today, SMED forms the basis for the Total-Productive-Maintenance approach, as the risk of machine failure is to be minimized and the speed of maintenance increased through the use of autonomous maintenance.

5.2 Description of the Method

A proper implementation of the SMED method is achieved by applying the Deming Cycle, as used in the Kaizen approach. This allows the teams working on the problem to work in a structured and goal-oriented manner. Therefore, it is appropriate to first describe the Deming Cycle and then condense it in the SMED. The Deming Cycle is basically divided into four areas, which include a total of eight tasks [3]:

- Plan,
- Do,
- Check,
- Act.

Plan: First, it is necessary to map the current process in order to be able to analyze it afterwards. In this process, information is collected and evaluated. The analysis identifies potential improvements from which objectives are derived. After describing the potentials and objectives, the process of the optimization project is planned, i.e., methods for implementing the optimization measures are determined. Generally, the time required for the planning phase is very high.

Do: The Do phase describes a pilot phase in which the planned is implemented in a protected area.

Check: The new process flow is checked for errors during the Check stage. If defects occur, it is necessary to identify and eliminate the causes. Another component of the Check stage is the determination of the achievement of the desired goals by the new process.

Act: The last part of the cycle is dedicated to the release of the new process. In this process, the new process becomes the standard and seamlessly replaces the previous, old process.

The application of the PDCA cycle (Fig. 5.2) is not mandatory for every improvement measure, as small improvements can be implemented in a very short time without prior planning.

After applying a PDCA cycle, it transitions into an SDCA cycle; the described standardization is implemented (S), practiced in day-to-day business (D), checked (C), and completed (A).

At its core, the PDCA cycle is a scientific mindset, as it underlies scientific research. This is described in Fig. 5.3. The SMED method adds specific activities to the Deming cycle in the context of problem analysis and the subsequent derivation of solution approaches. Within the planning phase, there are the specific task steps of SMED. These can be applied either horizontally for each element (e.g., each activity

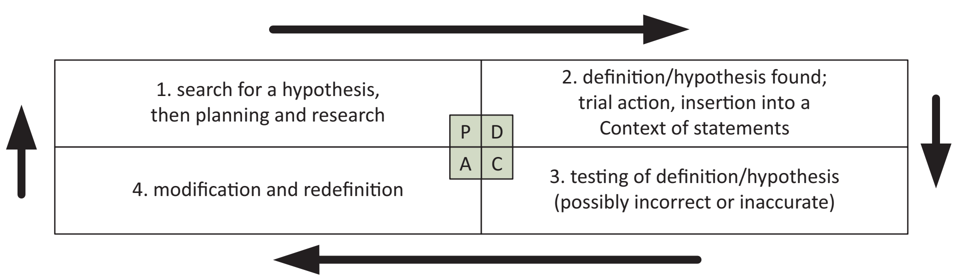


Fig. 5.2 PDCA cycle [3]

	Activity	SMED-specific content
I. Plan	1. Select topic	
	2. Set a goal	
	3. Investigate the problem	
		a. Classification into internal and external actions
	4. Develop solutions	
		b. Convert internal actions into external actions
		c. Shortening internal and external actions
II. Do	5. Create action plan	
	6. Implement action plan	
III. Check	7. Measure effects	
IV. Act	8. Standardization and guaranteeing the result	

Fig. 5.3 Deming cycle with activities and SMED-specific contents

of the process the first step, then the second, etc.) or vertically (steps one to three for the respective activity).

5.2.1 Planning Phase

1. ***Choose a topic***
   When choosing a topic, the process to be considered is first determined. If it is a production process in which the throughput time is to be improved, the process should be analyzed in terms of the times incurred. These results of the analysis should be visualized, for example, by using the Pareto diagram.
2. ***Set a goal***
   After the elements to be optimized have been selected, a target value can be defined and the period of optimization determined. Since well-formulated and achievable goals are essential for project success, the SMART criteria are suitable for this. SMART shows the requirement for the description of goals. Accordingly, these should be **s**pecific, **m**easurable, **a**cceptable, **r**ealistic, and **t**ime-bound. A goal is specific and measurable when it can be clearly determined which element should be optimized and when this is measurable. This is absolutely necessary for checking the achievement of objectives. A goal is acceptable when all team members can identify with it.

3. ***Investigate the problem***
   The aim of the analysis is to divide the actions into external and internal setup tasks. Internal actions are carried out when the process of service provision does not continue due to setup operations. External actions, on the other hand, are characterized by the fact that they are carried out in parallel with machine use. A tabular representation helps in comparing internal and external setup operations (Fig. 5.4).

In order for all team members to suggest solutions at the same level and later decide on the most optimal solution path, it is necessary that each member has a similar basic knowledge. Various possibilities are available for this: Video recordings are generally suitable, especially for the analysis of complex setup processes. Furthermore, when analyzing a process with several setup operations, creating a flowchart can contribute meaningfully to the description of the problem. The prioritization of the analysis of individual activities can be done by evaluating the Pareto diagram or chronologically according to process steps.

4. ***Develop solutions***

   The goal of this phase is:
   a. to transform internal actions into external actions and
   b. shortening of internal and external actions.

By transforming internal actions into external actions, a large gain in production time can be achieved. Therefore, all setup operations that can be carried out in parallel with service provision should also be carried out in parallel. Since a transformation of the service provision into external operations is not always possible, the internal setup operations should be kept as short as possible. The solutions for this can be developed using

Internal action	External action
☐ …	☐ …
☐ …	☐ …
☐ …	☐ …
	☐ …

Fig. 5.4 Illustration of internal and external actions

different methods, such as creativity techniques. Other approaches can be the standardization of functions or visualizations at workplaces.

5.2.2 Do Phase

5. ***Create action plan***
   After the planning phase has been completed and the analysis is finished, the team creates an action plan in which responsibilities, deadlines, and budgets are defined.
6. ***Implement action plan***
   The team implements the measures of the action plan. Both progress and quality need to be controlled, documented, and if necessary, measures initiated.

5.2.3 Check Phase

7. ***Measure effects***
   After all activities created in the action plan have been implemented, the team checks through appropriate measurements whether the desired effects have actually occurred. This allows the degree of goal achievement to be specified. Deviations in the realized improvements can—if necessary—be corrected by a new iteration of the DEMING cycle. Special attention should be paid to the implementation of the planned measures during the new iteration.

5.2.4 Act Phase

8. ***Standardization and assurance of the result***
   The purpose and goal of the last step of the improvement cycle is to define a standard for the respective process. For the standard to be successfully implemented within the process, appropriate training for the employees may need to be carried out. Audits of the work method ensure the long-term guarantee of the improvement of the overall process.

5.3 Workshop 8: "Coffee Production"

The practical example of "coffee production" is used to explain the application of the SMED method.

5.3.1 Implementation

The following is required for this practical example:

1. A coffee pad machine,
2. Water,
3. Coffee pads,
4. Milk,
5. Sugar,
6. Spoon,
7. Ten cups,
8. Stopwatch,
9. If necessary, a trash can.

Goal: Ten cups of coffee should be produced.

Figure 5.5 shows the entire process flow so that the ten cups of coffee can be brewed. The overall process consists of three different sub-processes.

5.3.2 SMED Analysis

As part of the plan phase, the object of analysis is first determined—in this case, the production process of ten cups of coffee. This should be done with the aim of reducing the throughput time by 35 % and thus increasing the economic efficiency of the process.

As a rule, it makes sense to visually represent the process as the first step of analysis. In particular, the activities and the required times should be written down. A flowchart or—for more complex processes—a value stream analysis is suitable for this. In addition to Figs. 5.5 and 5.6 shows the individual activities of the summarized work steps.

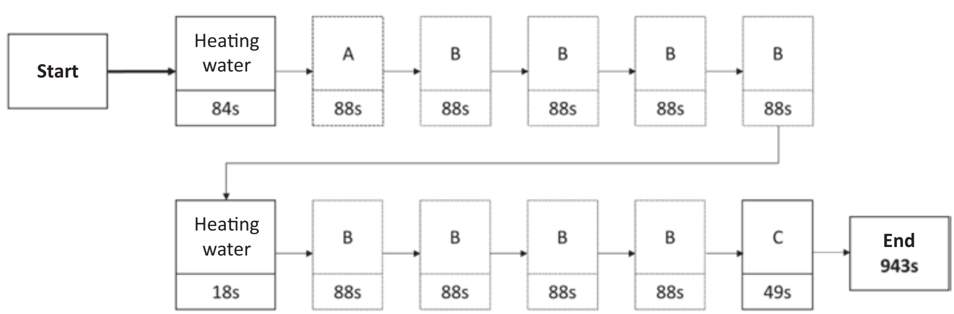


Fig. 5.5 Process flow of coffee brewing

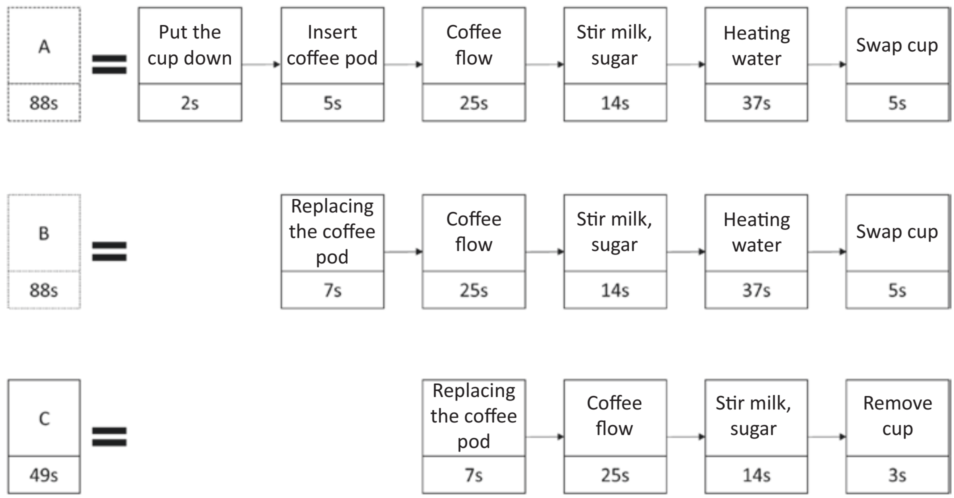


Fig. 5.6 Micro process steps of coffee brewing

The process of coffee brewing can be clearly represented using the Pareto diagram. In this representation, the times required for a process are listed in ascending order (Fig. 5.7).

Overall, it is evident that the elements "heating the water" and "coffee flow" take up the most time. The action of "filling the water tank" seems to take the least time in comparison. The method suggests that the longest process times should be analyzed first—however, it should be noted from practice that any process improvement is beneficial.

In the next two steps of the Deming cycle, the three phases of the SMED analysis are considered. The first step is to divide the setup operations into internal and external setup operations. For the example of coffee production, these are shown in the appendix.

After the setup operations have been divided (Fig. 5.4), creating an awareness of the process flow, the aim is to convert as many internal setup operations into external setup operations as possible. To achieve this, an action to be analyzed is first determined—the results of the Pareto diagram should be taken into account. The setup operation to be changed from an internal to an external one is analyzed using different techniques. Creativity techniques, such as brainstorming or brainwriting, are particularly suitable. By using the morphological matrix, various solution methods can be combined for multi-faceted tasks. For very complex problems, the synectics method can lead to alternative solutions. To ensure structured and goal-oriented work with all solution techniques, it is advisable to involve a moderator (especially when using the synectics method). Furthermore, visualizations at the workplace, such as those used in the 5S method, can significantly contribute to reducing setup times.

In every problem-solving process, proposals are developed that vary in complexity and effectiveness in their application. A benefit-effort matrix is suitable for classifying

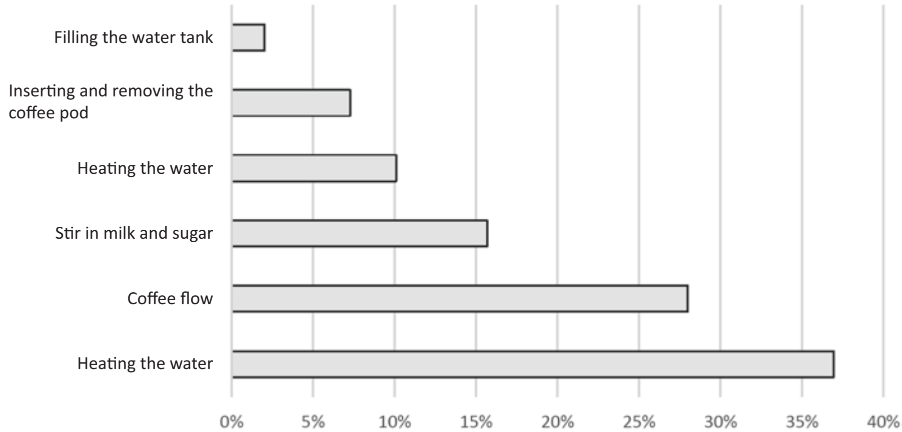


Fig. 5.7 Pareto representation of process times

the solution proposals. For the example of coffee production, the benefit-effort matrix is shown in the appendix.

The benefit-effort matrix shows that the improvement ideas are evaluated differently. The solution of the double coffee pod holder can be considered particularly attractive, whereas the installation of a larger water tank is to be rated as unattractive, as the effort is not in a reasonable proportion to the benefit. These findings are consolidated in the next step in an action plan (solution proposal in the appendix).

After all measures from the action plan have been implemented, the process improvement must be measured and it must be ensured that the goals have been achieved. If deviations are noticeable, it makes sense to first check the implementation of the action plan before the Deming cycle is reconsidered. The new coffee production process is shown in Fig. 5.8.

In Figs. 5.8 and 5.9, it can be seen that a large number of processes have been parallelized and thus internal setup operations can be carried out in parallel. For example, the coffee pod is inserted while the water is heating, or the cups are filled with milk and sugar. Overall, the process was reduced from 943 to 510 s—this corresponds to a time saving of 54 %. Thus, the initially described goal of reducing the total process time by 35 % has been achieved.

The determined measures are directly implemented in the example of coffee production. In practice, it is advisable to adapt the measures within a protected framework to ensure continuous process quality, and only transfer them to the actual process when errors can be ruled out and the changes have been tested. It is also important to ensure standardization of the changes made. Methods such as 5S are suitable for this.

Since an optimized process time affects the total cost of the process, these are considered in a greatly simplified cost calculation. Here, Fig. 5.10 shows the costs for the manufacturing process for coffee production before the application of the SMED method.

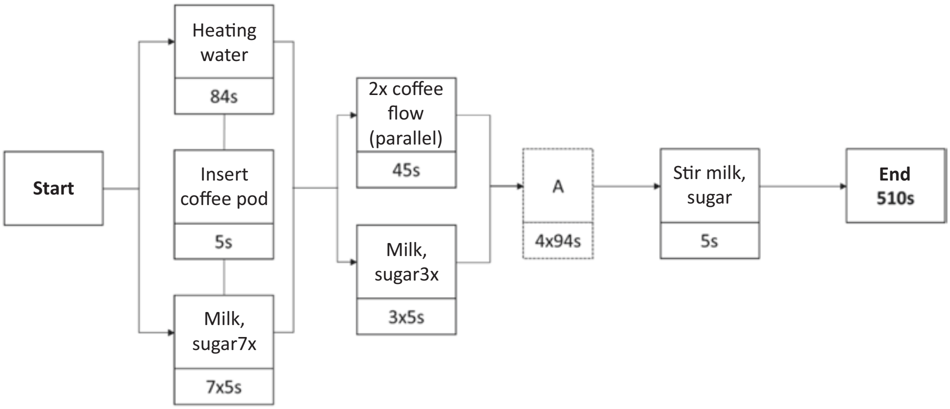


Fig. 5.8 New process representation of coffee production process

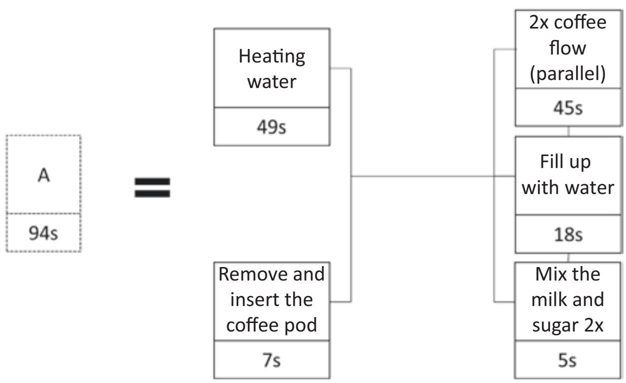


Fig. 5.9 Subprocess A of the revised coffee production process

The costs after process optimization are shown in Fig. 5.11. The used repetition factor (Rep. Factor) indicates how often the quantity or the manufacturing position are used in the process. This results in a manufacturing price of 3.96 EUR for ten cups of coffee before and after the application of the SMED method of 3.24 EUR. It should be added that the key figures must always be considered in their context—a decreasing efficiency can also be justified by a shortening of the value creation process, which is to be assessed positively if the quality remains the same.

In summary, Fig. 5.12 presents the changes in efficiency, material costs, manufacturing costs, and production costs.

Here, the high change in manufacturing costs is only influenced by the reduction in manufacturing costs. The application of the SMED method shows here that 18 % of the manufacturing costs can be significantly reduced by optimizing the manufacturing process.

Standard throughput	Relative Costs	Quantity	Time	Unit/rev. Factor	Cost (10 cups)
Direct material costs					
Water [EUR/l]	0.86	0.15	-	10	1.29
Coffee pod [EUR/pc]	0.08	1	-	10	0.8
Milk [EUR/cup]	0.02	1	-	10	0.2
Sugar [EUR/cup]	0.01	1	-	10	0.1
Material costs [EUR]					**2.39**
Direct production costs					
Electricity (1st heating)	0.1	-	1.4	1	0.14
Electricity (2nd-10th heating)	0.1	-	0.68	9	0.56
Current flow	0.1	-	0.42	10	0.42
Current idle	0.1	-	0.45	10	0.45
Production costs [EUR]					**1.57**
Production costs (10 cups) [EUR]					**3.96**
Production costs/pc. [EUR]					**0.40**
Running time [min]	15.68				
Value-added time [min]	4.2				
Downtime [min]	0				
Efficiency	**26.79 %**				

Fig. 5.10 Cost calculation before application of the SMED method

5.3.3 Solution proposal and blank templates

SMED solution proposal

Internal action	External action
☐ Heating up the water ☐ Add milk, sugar and stir ☐ Insert coffee pod ☐ Filling the water tank	

FLiX Standard throughput	Relative Costs	Quantity	Time	Unit/rev. Factor	Cost (10 cups)
Direct material costs					
Water [EUR/l])	0.86	0.15	-	10	1.29
Coffee pod [EUR/pc]	0.08	1	-	10	0.8
Milk [EUR/cup]	0.02	1	-	10	0.2
Sugar [EUR/cup]	0.01	1	-	10	0.1
Material costs [EUR]					**2.39**
Direct production costs					
Electricity (1st heating)	0.1	-	1.4	1	0.14
Electricity (2nd-10th heating)	0.1	-	0.68	4	0.27
Current flow	0.1	-	0.75	5	0.38
Current idle	0.1	-	0.12	5	0.06
Production costs [EUR]					**0.85**
Production costs (10 cups) [EUR]					**3.24**
Production costs/pc. [EUR]					**0.32**
Running time [min]	8.47				
Value-added time [min]	3.75				
Downtime [min]	0				
Efficiency	**44.27 %**				

Fig. 5.11 Cost calculation after application of the SMED method

Changes	Before	Afterwards	Pro rata
Efficiency	26.79 %	44.27 %	65.29 %
Material costs	2.39	2.39	0.00 %
Production costs	1.57	0.85	-45.98 %
Production costs	3.96	3.24	-18.22 %

Fig. 5.12 Comparison of the changes

Blank SMED form

Internal action	External action
☐ Heating up the water ☐ Add milk, sugar and stir ☐ Insert coffee pod ☐ Filling the water tank	

Solution proposal benefit-effort matrix

large effect	▪ Double coffee pod holder	▪ more staff
small effect	▪ Use of two coffee pod holders ▪ Use Kettle ▪ larger pack of coffee pods	▪ larger water tank
	easy	difficult

Blank benefit-effort matrix form

large effect		
small effect		
	easy	difficult

Solution proposal action plan

Measure	Effect
Use of a double coffee pod holder	enables two cups of coffee to be prepared at the same time
Use of a kettle	enables the second heating process to be minimized
Use of two coffee pod holders	enables parallel use and simultaneous filling

Blank action plan form

Blank form action plan for coffee production

Measure	Effect

References

1. Gutenberg E (1983) Grundlagen der Betriebswirtschaftslehre. Die Produktion (3), 24th ed. Springer, Berlin
2. Böhrs H (1967) Wirtschaften mit der Zeit als Kernstück der REFA-Lehre. In: Böhrs H (Ed) Arbeitsstudien in der Betriebswirtschaft. Gabler, Wiesbaden, S 13–48
3. Zollondz H-D (2013) Grundlagen Lean Management. Einführung in Geschichte, Begriffe, Systeme, Techniken sowie Gestaltungs- und Implementierungsansätze eines modernen Managementparadigmas. Oldenbourg (Edition Management), München

Line Balancing

6

6.1 Classification of the Method

In order to withstand cost pressure in manufacturing, measures are necessary to efficiently utilize and operate the lines. Therefore, one goal must be to eliminate conflicts such as bottlenecks or underutilizations or waiting times in manufacturing. A bottleneck (or also Bottleneck) usually occurs at the workstation where the processing of the process steps (the workload) takes the longest. The so-called "Work-In-Progress (WIP) inventory" is created by processing the process steps at this station. It includes all goods that are still in the processing phase. Conversely, unused times (idle times) occur at workstations with a lower temporal workload, as these workstations always have to wait for further assignment of work by the upstream workstations with longer process times. The idle time then refers to the time when a unit is unproductive or unused (but ready for operation). This is exactly where the method of Line Balancing comes into play.

The goal of Line Balancing is to optimize the value chain and eliminate waste [1]. In terms of production, Line Balancing aims to trim the production chain to flow production in One-Piece-Flow (single production) and to the TPS-typical pull principle [2]. In German, Line Balancing stands for cycle timing, so Line Balancing is essentially nothing more than aligning the cycle times of all workstations in the process to the customer demand to be achieved. Simply put: If you have to produce a part every 20 s to meet customer demand, then each individual station in the production chain—ideally One-Piece-Flow—should also only need 20 s.

Line Balancing thus serves to optimally utilize human and machine resources based on customer demand [1]. The practical goal of the method is therefore to determine the number of workstations and to assign the various tasks to the workstations in such a way that a uniform temporal workload per station is created, in order to achieve a synchronized flow of parts between the workstations or the associated units (see Fig. 6.1).

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_6

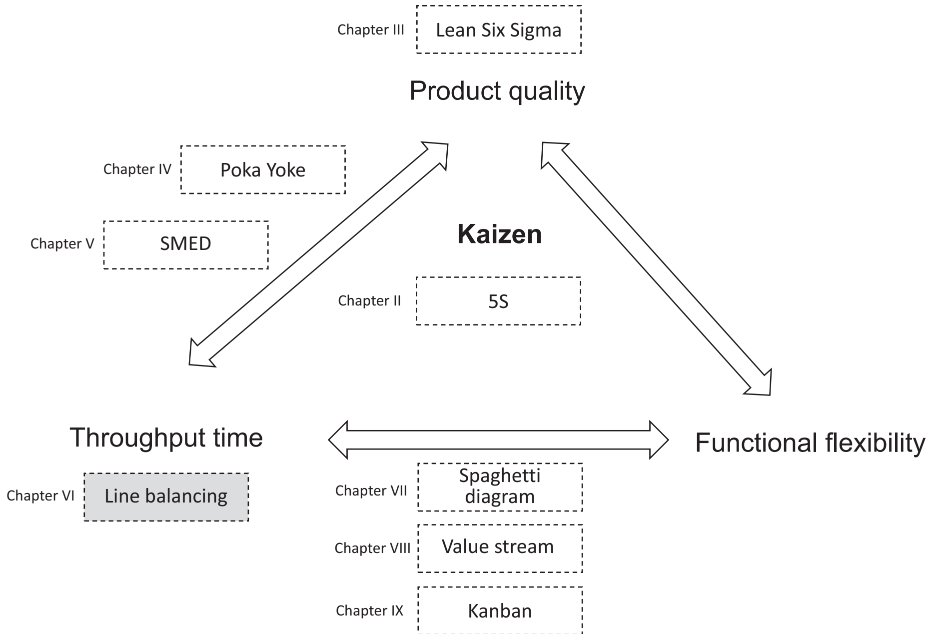


Fig. 6.1 Line Balancing in the field of tension of Kaizen

The even flow then also means that the idle times of the stations and the "Work-In-Progress inventory" are minimized.

Line Balancing has its origins in the Toyota Production System (TPS) and is also located in the Lean sector. A primary assignment of this method can be seen in connection with specialized Lean Six Sigma tools for improving series production. Another special feature of this method is that optimizations are primarily carried out through mathematical analyses. Therefore, some current users trace the orientation of this tool back to M.E. Salveson, who is considered one of the pioneers for the development of mathematically specialized Lean Six Sigma tools due to his research. His considerations on the problem of the "assembly line balancing problem" were groundbreaking for the development of the Line Balancing method [3]. Today it has a more central importance in the context of the Toyota production systems, whose methods include Line Balancing as well as other mathematically oriented Six Sigma methods, which include, among others, Just in Time, Total Productive Maintenance [4].

6.2 Description of the Method

Line Balancing refers to the smoothing of very irregular production orders in terms of quantity and temporal sequence from the existing customer orders [5]. The main concern of line balancing is to balance the individual workstations in production so that no sta-

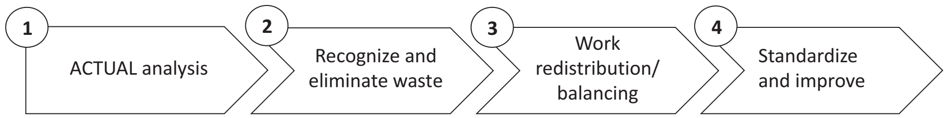


Fig. 6.2 Line-Balancing procedure

tion becomes a bottleneck, leading to high Work-In-Progress inventory and increasing idle time. The following general procedure according to Fig. 6.2 is suggested.

Before starting with line balancing measures, it is necessary to capture the current, non-optimized production process (Step 1, actual analysis).

Only then will the two essential measures for line balancing begin. On the one hand, waste in the sense of the 7 (or 8) types of waste must be recognized and ideally eliminated. In addition, work redistribution (cycling) is then carried out to adapt all workstations to the required customer demand. In a final step, it is recommended to standardize the implemented improvements/changes to ensure the sustainability of the measures [1].

6.2.1 Actual Analysis

To analyze the actual situation, it is necessary to analyze the value chain or process chain [6]. This includes the temporal recording of cycle times per activity, the number of activities at each workstation, and the number of workstations. The own Overall Equipment Effectiveness (OEE) must be known. In addition, customer demand is also absolutely necessary. These terms are explained in the following [1].

6.2.1.1 Activities

Activities refer to all the steps an employee needs to perform his work. This includes active work, but also, for example, walking distances. Therefore, every single action must be recorded in terms of time. Accordingly, all activities are divided into three categories [7]:

- value-adding activities (e.g., turning, welding, screwing),
- necessary but non-value-adding activities (e.g., set-up, emptying containers),
- non-value-adding activities (e.g., waiting, searching, rework).

The correct time recording per activity is done per manufactured single piece. For example, a housing must be screwed for each finished product, and this activity takes 30 s.

6.2.1.2 Customer Cycle

$$\mathit{Customer\ cycle} = \frac{\mathit{production\ time}}{\mathit{customer\ order\ quantity}}$$

The customer cycle is the ratio between the available production time and the customer order quantity. The customer cycle thus represents the time limit for each process. If the time is above the customer cycle, a bottleneck occurs. If the time is below the customer cycle, the opposite results. More is produced than the customer needs, leading to overproduction [1].

6.2.1.3 OEE – Overall Equipment Effectiveness

$$OEE\ [\%] = Availability\ [\%] \times Performance\ [\%] \times Quality\ [\%]$$

The OEE reflects a key figure that combines the number of units, speed, production time, and quality. As a key figure, the OEE (Overall Equipment Effectiveness, Total Plant Effectiveness) provides information about the total losses and makes them visible to the employees. In order to work with the OEE, the optimum for the plant must be defined beforehand. This must run without interruption, must not lose any quality, and must always work at the highest possible speed. With this target value, the degree achieved by the real plant can be compared and thus the effectiveness can be determined [8].

6.2.1.4 Cycle and Takt Time

The actual analysis is particularly about the correct time recording of the individual cycle and takt times. Takt time is understood as the time for a single activity per part at a workstation. The cycle time describes the time in which a finished part leaves the work system or a workstation. It thus describes the complete run per part.

In Line Balancing, it is about determining the required cycle time. The required cycle time is the necessary customer takt to meet the customer demand, considering the own total plant effectiveness (OEE).

$$Required\ cycle\ time\ = customer\ takt \times OEE$$

A customer takt of, for example, 100 s means that a finished part must leave the work system every 100 s in order to be able to meet the customer demand. In practice, however, no plant runs continuously without loss and at full effectiveness, so the OEE must be taken into account in the calculation to compensate for the "loss factors". In this way, the required cycle time can be determined in order to still be able to maintain the customer takt. To compensate for the losses over time, the actual required cycle time is always lower, since an OEE of 100 % is almost impossible in the real environment and thus losses always have to be compensated [1].

6.2.2 Presentation of Analysis Results

6.2.2.1 Work Distribution Diagram

The work distribution diagram (AVD) is suitable for displaying the times of individual work processes at the workstations. A column with the individual tasks is displayed for each workstation. The tasks are then color-coded into value-adding (green), non-value-adding (red), necessary (yellow), and periodic tasks (blue). Figure 6.3 graphically illustrates the structure of a work distribution diagram.

In Fig. 6.3, the *upper dashed line* corresponds to the Customer Takt and the *lower line* to the required Cycle Time. It can be seen that some stations are significantly above the required times and some are even below. The goal of Line Balancing is to adjust the workload per station to the required cycle time, but at least below the customer takt.

6.2.2.2 Operation List

The operation list is a tabular enumeration of operations of the entire work process [9]. It contains all operations listed in the Project Structure Plan. Each operation is assigned a letter. In addition, a predecessor is determined for each operation, i.e., the previous activity that is the prerequisite for the start of the respective operation must be determined. Furthermore, a duration is assigned to each operation. The operation list forms the basis of a network plan. It clarifies parallel work aspects and the overlap between work packages or time intervals [9]. The following Fig. 6.4 shows this graph.

6.2.2.3 Network Planning Technique

After breaking down the manufacturing process into various process steps or operations and listing these operations in the Operation List, the network planning technique follows.

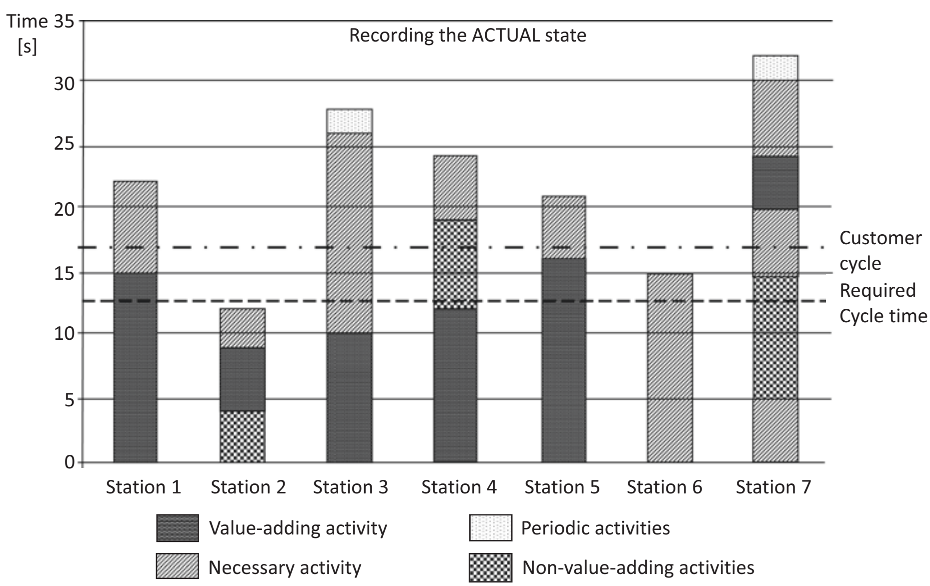


Fig. 6.3 Example of a Work distribution diagram

Fig. 6.4 Example of an operation list

Process	Activity	Time [min]	Predecessor
A	Process 1	4	-
B	Process 2	8	A
C	Process 3	10	A
D	Process 4	2	A, B

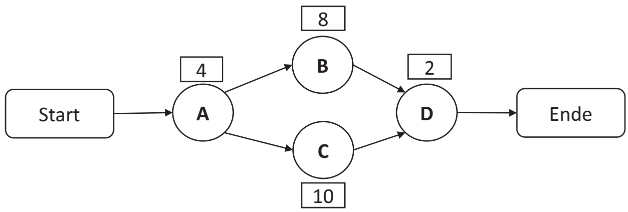


Fig. 6.5 Example of a network plan

Here, *circles* are labeled with letters that are supposed to represent the operations. These are then connected with *arrows* depending on the order. A *rectangle* with the corresponding duration is then drawn on each *circle* or operation. The network planning technique describes the temporal and final chaining of actions. It illustrates the order and duration of these operations. Figure 6.5 shows a Network Plan:

6.3 Workshop 9: "Aircraft Manufacturing"

Building blocks are used as manufacturing material for the simulation of aircraft manufacturing. Figure 6.6 shows the aircraft manufacturing of Group A. It consists of six stations:

The arrangement of the stations shown in Fig. 6.6 also represents the individual seating positions of the participants. A table is needed for each station. These should be set up with sufficient distance from each other so that the individual aircraft components can be transported safely to the following stations.

To simplify the simulation, a two-piece flow was chosen instead of a one-piece flow. This means that always two assemblies are manufactured and only after the completion of the second assembly both assemblies are transported to the next station at the same time.

The simulation is designed for 20–22 people. Ten to eleven people are needed per production line. With the exception of quality, one person is responsible for assembly and one for time recording at each station. The quality station is only manned by one person if there are more than ten people in this production line. The work instructions for all workstations are located in the appendix.

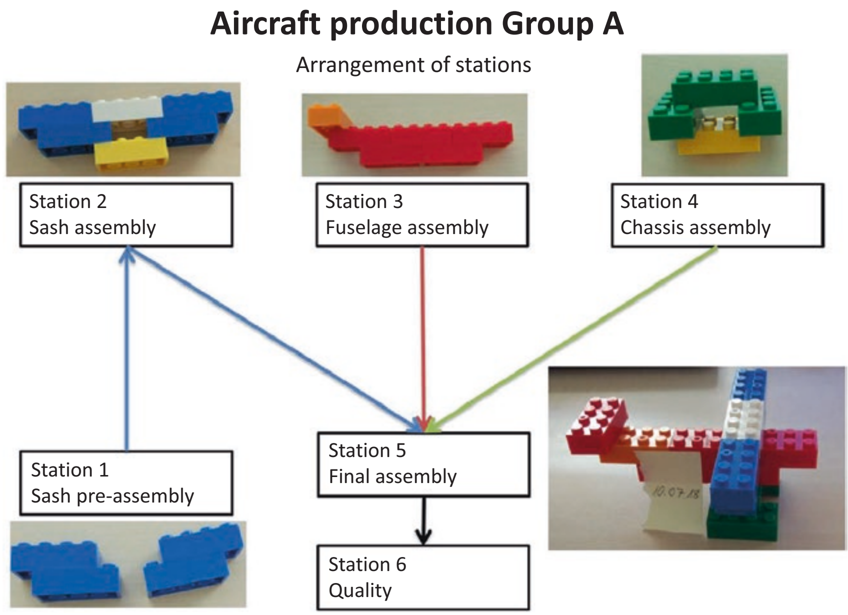


Fig. 6.6 Group Task Aircraft manufacturing

Time Recording
For an evaluation, the times of the individual work steps are needed in addition to the assembly:

1. Remove bricks from the brick tower (prepare parts),
2. Assembly of the individual components,
3. Round trip when transporting the finished components to the next station.

Five times are measured and entered into the displayed worksheet (Fig. 6.7). It is recommended to start the time measurement only after a few parts have been produced. This prevents times from being measured while the line is filling up.

6.3.1 Production Round 1

Duration
The first simulation lasts five minutes. If a station no longer has any material to process, it remains quiet and waits until the other stations are finished or the time has expired.

	1	2	3	4	5	∅
Prepare building blocks						
Assemble building blocks						
Transport route						

Fig. 6.7 Excerpt from the time recording worksheet

Station 1 Wing Pre-Assembly

Eight blue bricks are taken from the tower and two pieces are stacked on top of each other. It should be noted that one row always remains free. Afterwards, four parts are passed on to the wing assembly.

Station 2 Wing Assembly

At station 2, four parts of the wing pre-assembly, two white and two yellow bricks, are needed. Two wing parts from the pre-assembly are each built with a white stone, which serves as a carrier. Finally, the yellow stone is attached from below. This serves as transport protection. After that, the finished wings are handed over to the final assembly.

Station 3 Fuselage Assembly

For the fuselage of the airplane, twelve red or orange bricks are taken from the tower. Two bricks form the base and three more are attached offset from above, leaving two rows on the left and right. Finally, the tail wing is attached to one end. It is important that the tail wing is centrally attached, as can be seen in Fig. 6.6.

Station 4 Landing Gear Assembly

Station 4 is responsible for the landing gear. A total of six green and two yellow bricks are used for assembly. A green brick is placed on top of two other green bricks, so that the top brick is only attached to the bottom ones with one row on the left and right. For transport protection, the yellow brick is attached parallel to the top green brick at the bottom. After the landing gears have been completed, they are handed over to the final assembly.

Station 5 Final Assembly

At the final assembly, all delivered parts are assembled. For this, all bricks used for transport security are first removed. Then the wing is placed on the fuselage in such a way that 3 rows are still free on the right. Afterwards, the landing gear is attached to the fuselage from below parallel to the wing. Finally, a labeled Post-it with the date of completion is attached to the right of the fuselage. For the final check, the finished airplane is handed over to quality control.

Station 6 Quality (optional)

Quality ensures that only flawless airplanes are handed over to the customer. For this, it checks whether each brick is in the right position, the Post-it is sticking in the right place and it is correctly labeled. If this is not the case, the airplane goes into the rejects. If the airplane is flawless, it can be handed over to the customer.

Work instructions with pictures are available for each station in the appendix. The work steps are identical for both groups, only the brick colors differ.

6.3.1.1 Execution of the First Production Round

During the five-minute simulation round, the participants had the task of producing as much as possible at each station, i.e., to "push". Stress and chaos were noticeable shortly after the start of the first simulation.

6.3.1.2 Round 1: Evaluation

After the time has elapsed, the finished airplanes and the rejects are counted in both groups. The results can be visualized in a diagram. Figure 6.8 shows an exemplary evaluation.

In our game situation, Group A produced a total of six airplanes, two of which were rejects. Group B achieved a slightly better result with seven airplanes and no reject parts. A brief survey of all participants showed that the greatest difficulties were the high pressure, the transport, and the preparation of the parts. This is also evident in the actual

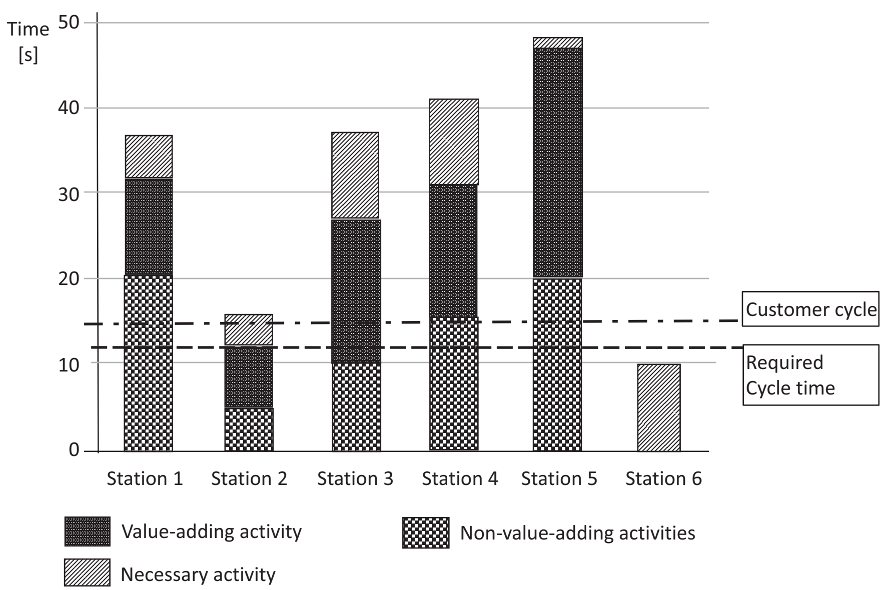


Fig. 6.8 Exemplary evaluation of the assembly task

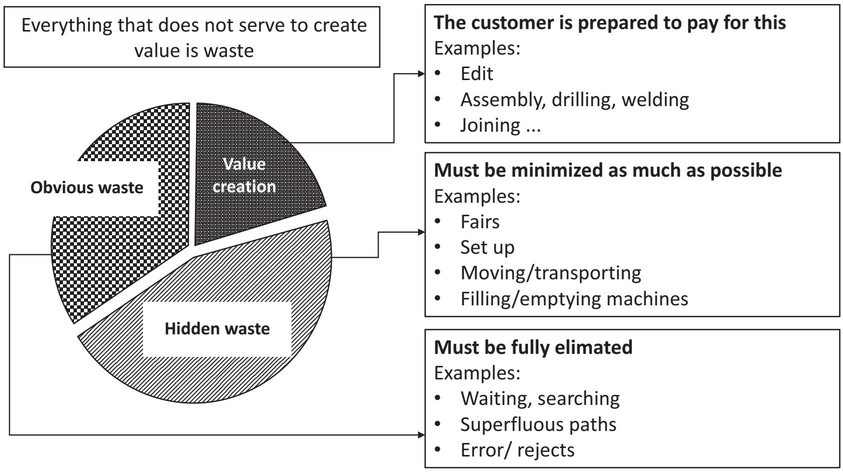


Fig. 6.9 Value creation and waste

evaluation, where the waste (lighter blocks) at the stations takes up more time than the value creation (darker block).

6.3.1.3 Round 1: Waste Analysis

As mentioned before, the individual activities at the stations are divided into value creation, hidden waste, and obvious waste (Fig. 6.9). Hidden waste means that this work step is necessary to carry out value-adding activities, such as the setup of a machine or the transport of components to the next station. So the aim is to minimize hidden waste. Obvious waste, on the other hand, is not needed to carry out value-adding activities, so obvious waste should be completely eliminated. Examples of obvious waste are searching for tools or waiting for materials. Everything else is called value creation, i.e., increasing the value of the product. An example of this is attaching a wing to the fuselage of an airplane.

In addition to the distinction between hidden and obvious waste, waste can also be differentiated by types. The so-called seven types of waste are:

- Overproduction,
- Inventory,
- Transport,
- Rejects,
- unnecessary paths,
- waiting,
- unsuitable processes and
- (unused knowledge).

Various types of waste are also clearly visible in the simulation. The high inventories at the stations are a result of overproduction. Transport and unsuitable processes (transport stone or preparation of the building blocks) are other types of waste that have occurred. The next step is to minimize the hidden waste and eliminate the obvious waste.

6.3.1.4 Round 1: Implementing Improvements

Initially, the focus is on minimizing hidden waste. In the case of the simulation, these were:

- Transport (long distances from one station to the next) and
- unsuitable processes (preparation of the building blocks and labeling of the Post-its at station 5).

As a solution to the first problem, the "stations" (tables) are placed closer together. This eliminates the need to stand up and walk to the next station, greatly reducing transport time. The individual building blocks no longer need to be dismantled from the block for the next rounds, but are individually in a container at the workplace, which shortens the preparation time. The Post-its are pre-printed and no longer need to be labeled by hand.

The obvious waste of the simulation is an unsuitable process (attaching and removing the transport block). By shortening the transport routes, no transport block is necessary anymore, thus this waste has been eliminated.

To reduce the mentioned stocks in front of the stations, the waste of overproduction must be addressed. The "Push system" has been converted to a "Pull system". The upstream process may only produce if the intermediate warehouse is not full. To convey this information, a Kanban system is implemented. This system serves to give the command to produce to the upstream process. So, in the simulation, if the buffer between station 1 and station 5 is full, station 1 is not allowed to produce anymore.

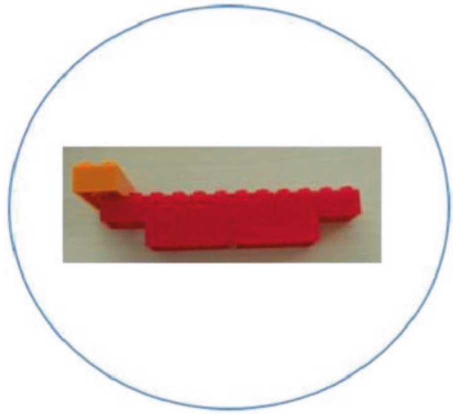
6.3.2 Production Round 2

6.3.2.1 Execution of the Second Production Round

Like the first round, the simulation of the second round also has a time of five minutes planned. The work order is also to produce as many airplanes as possible.

In contrast to round 1, the tables or stations are closer together, the transport parts no longer need to be used, the building blocks no longer need to be detached (prepared) from the block. Furthermore, the Post-its are already labeled and a "Pull system" has been introduced with the help of a Kanban buffer. Figure 6.10 shows one of the buffers, which are now double—due to the Two Piece Flows—in front of each station. In this case, it is the buffer in front of station 5 (final assembly) for station 3 (fuselage assembly).

Fig. 6.10 Kanban buffer



6.3.2.2 Round 2: Evaluation

Already through the waste analysis and the associated measures, a significant performance increase can be achieved. In our game situation, after round 2, Group A had produced eleven and Group B seventeen airplanes. It was already noticeable during the simulation that there was much more structure in the respective processes. Unnecessary running back and forth could be eliminated as waste by pushing the tables together. The elimination of transport routes also made it possible to dispense with transport parts, which also led to a time saving. The effort of detaching the building block from the tower could be eliminated by color sorting and sorting into containers. The pre-made Post-its lead to a further time saving. The introduction of a pull system with the help of buffers was intended to prevent overproduction of parts. However, this quickly led to the respective stations having to wait until a part was taken from the buffer again and production could continue.

6.3.2.3 Round 2: Waste Analysis

The results of the time measurements of the respective stations yielded the following results:

As can be seen in Fig. 6.11, the wastes were eliminated. Compared to the first simulation, the time of the respective assemblies could be reduced or even halved. In the survey of the participants, it was found that the respective assemblies had to wait for the final assembly, thus creating excessive waiting time. This statement is confirmed by the diagram. Since station 5, the final assembly, takes the longest, the other operations (1–4) have to wait. This waiting time of operations 1–4 is measured from the end of the construction time of the respective operation until the point when an aircraft has been assembled. Station 6 quality still consists only of hidden waste, as quality control does not represent value creation. As key data, an OEE of 80 % and a customer cycle of 15 s were initially set. The resulting required cycle time was not met in either the first or the second simulation. In order to be able to meet the customer cycle, the work of the

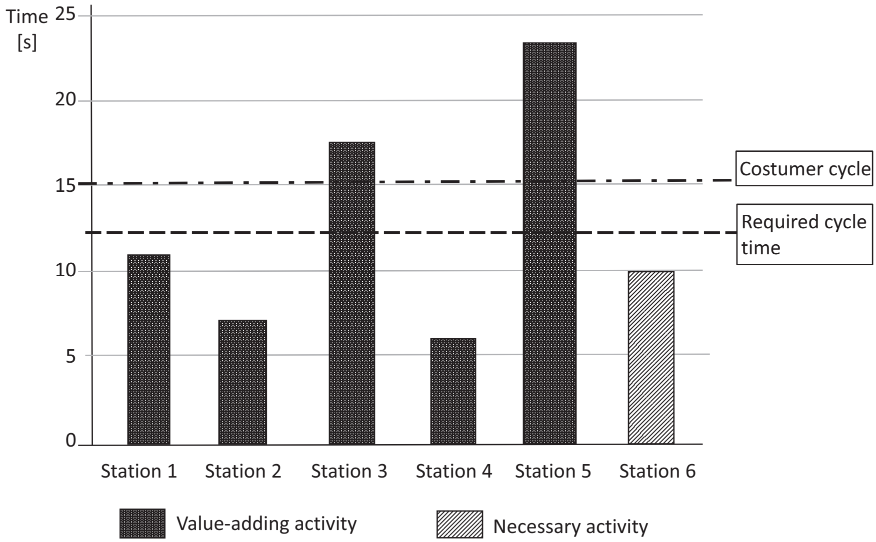


Fig. 6.11 Evaluation second simulation

respective operations must be redistributed. This redistribution of work is now explained in the following.

6.3.2.4 Round 2: Implementing Improvements

The goal of the work redistribution is to shift the individual operation steps in such a way that the respective operations take as long as possible. This is intended to minimize or even completely eliminate unnecessary waiting times. Because the entire production system is only as fast as the slowest station/operation. In addition, this should ensure that the specified customer cycle is adhered to. The more balanced the respective stations work in terms of time, the more efficiently the overall system functions. An even distribution of workloads on the stations then results in buffer storage and waiting times being reduced or even completely eliminated. Figure 6.12 graphically represents this ideal state:

In Fig. 6.12, the target state after a work redistribution can be seen. Even here, more improvements could be made to align the process times and minimize waiting times and thus optimize the process and meet customer requirements.

6.3.3 Production Round 3

6.3.3.1 Implementation of the third production round

Here too, the theory should be put into practice again. The groups should now consider for ten minutes how the work steps can be distributed so that each station has as equal

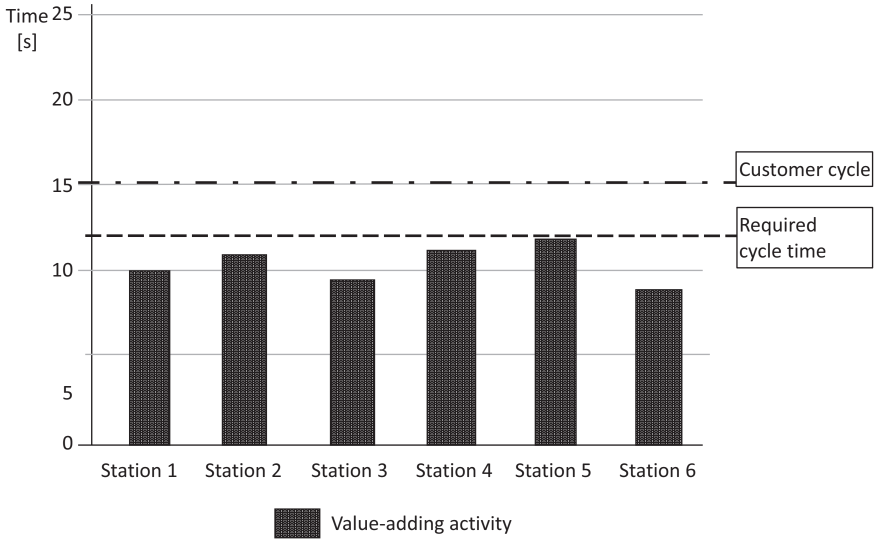


Fig. 6.12 Example of a target state after work redistribution

a cycle time as possible. The conditions remain similar to the second run. The building blocks are loose and sorted in a container, the post-its are already pre-printed. Production continues according to the Two-Piece-Flow and the tables remain assembled, so the transport parts continue to be eliminated. In addition, there is the requirement that fewer employees can be used, but none can be added. The airplane may not be changed as a whole. However, which station inserts which part can be freely decided. In the previous simulations, the customer cycle could not be maintained. To check the redistribution of work, the first airplane is now removed after 24 s and all others are removed after twelve seconds (required cycle time). If this timing cannot be maintained, it is considered a failure.

The final step is to establish the improvements gained as a new standard and anchor them in the company.

During the third simulation, the groups have time in advance to think about and try out suitable work redistribution measures in order to maintain a given cycle time of 12 s/airplane.

In our example, Group B conducted their simulation with four employees, while Group A conducted the simulation with five employees.

6.3.3.2 Round 3: Evaluation

After the third simulation, the airplanes produced and the scrap are also counted for both groups.

A subsequent survey of the approach of the individual groups showed that similar improvement measures were implemented, leading to a more pleasant working environment with sometimes high utilization of individual employees.

In our example, both groups each produced 20 airplanes, of which 2 were each rated as scrap. The approach was to optimize underutilized workplaces to the extent that the system can be managed with fewer employees. This was done, for example, by merging the less busy stations 2 (wing assembly) and 4 (landing gear assembly). Furthermore, employees were detached from the system by both groups, so that employees with lower utilization could take on additional supporting activities. The redistribution of work content resulted in a relatively even employee utilization. This was solved, among other things, by having station 4 (landing gear assembly) take over the attachment of the tail wing from station 3 (fuselage assembly). Station 6 (quality) was dissolved by both groups. It was noteworthy that both groups, despite different numbers of employees, adhered to the specified cycle time and achieved high employee utilization without major waste.

6.3.4 Documenting Improvements

In order to permanently secure the results achieved, the changes must be documented and transferred as a new standard into the work descriptions. Without documenting the standard and continuous training, the performance increases achieved would fizzle out over time. Furthermore, the target state developed should be regularly checked and adjusted if necessary in the future.

The continuous improvement process (CIP) is an efficient method to improve and optimize new or existing production processes in the long term. The goal of the CIP is to reduce waste and costs. A goal achieved is always further improved, as there is no perfect solution, but there is always potential for improvement. The basis for successful improvement are clear goals, the involvement of all employees, good communication between them, transparency, sustainability, and time.

6.3.5 Blank Templates (Fig. 6.13)

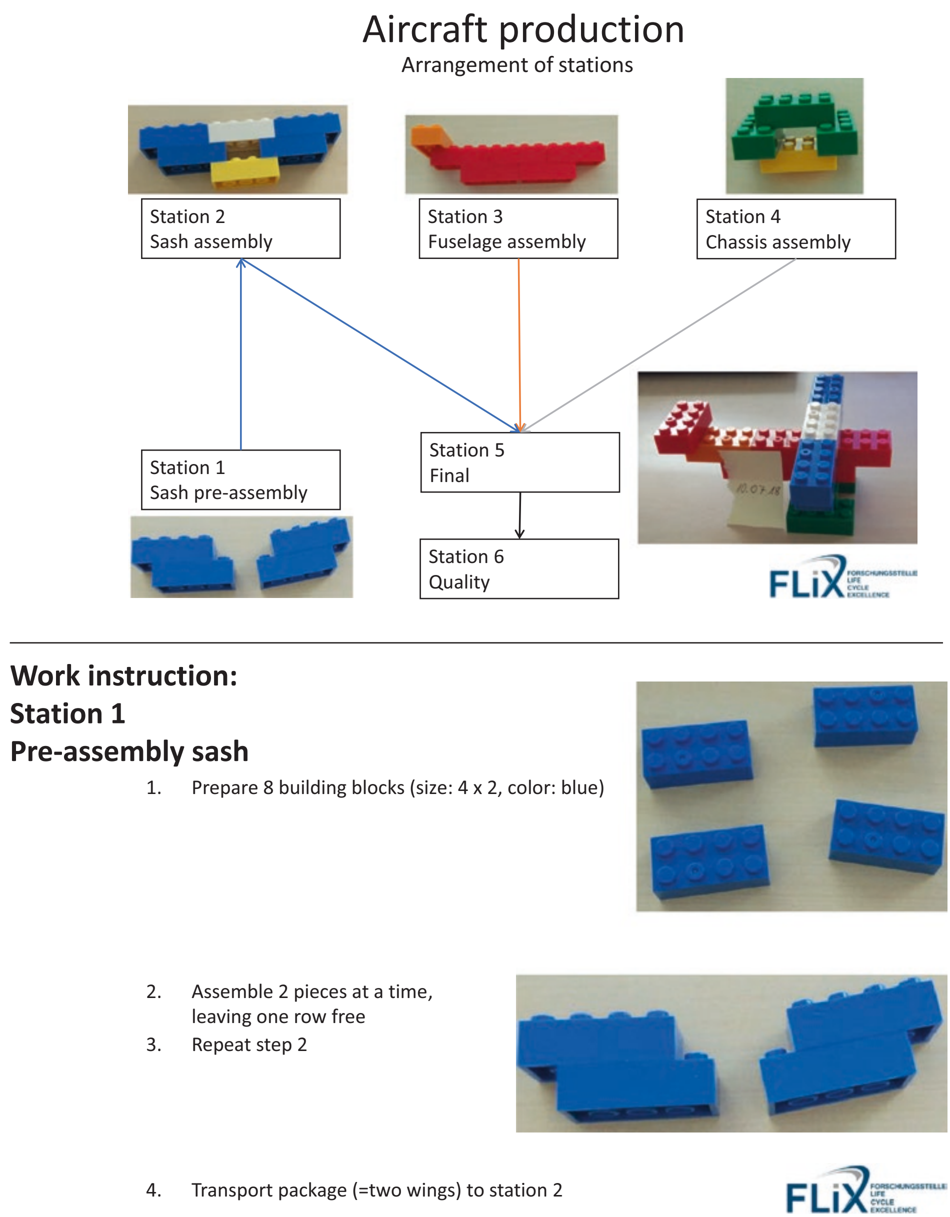
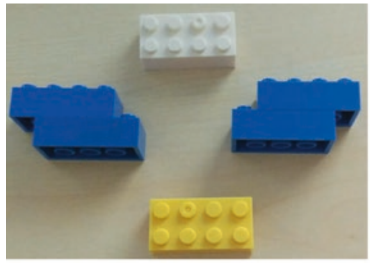
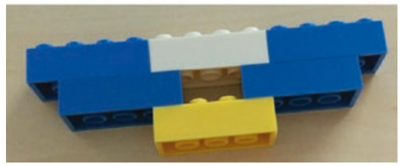


Fig. 6.13 Work instructions Line Balancing

Work instruction:
Station 2 (Group A)
Assembling sashes



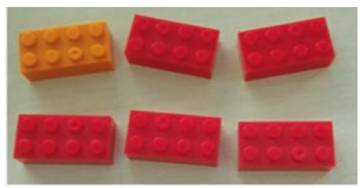
1. 4 parts from prefabrication,
   Prepare 2 building blocks (size: 4x2, color: white), 2 building blocks (size: 4x2, color: yellow)



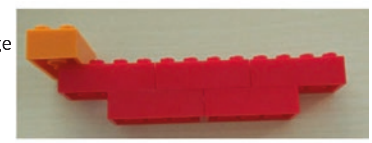
2. Assemble the individual parts of station 1 with the single white building block
3. Attach transport protection (yellow component) at the height of the connecting lego
4. Repeat steps 2 and 3

5. Transport package to station 5

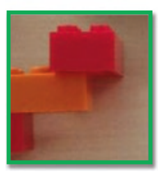
Work instruction:
Station 3 (Group A)
Fuselage assembly



1. Prepare 12 building blocks (size: 4x2, color: red or orange)



2. Assemble 5 building blocks so that the fuselage is created Attach the rear wing



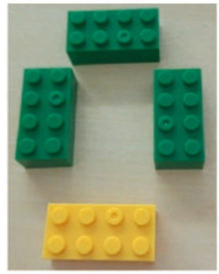
3. Ensure that the rear wing is fitted correctly

4. Repeat steps 2 and 3

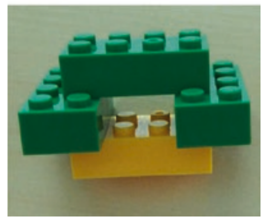
5. Transport package to station 5

Fig. 6.13 (continued)

Work instruction:
Station 4 (Group A)
Chassis assembly

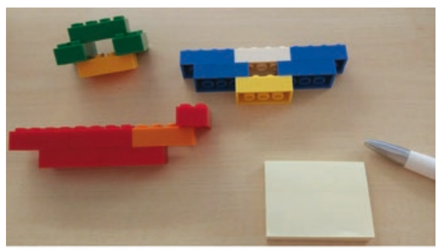


1. Prepare 6 building blocks (size: 4x2, color: green), 2 building blocks (size 4x2, color: yellow)

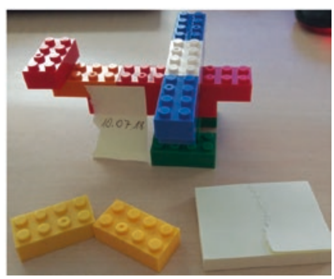


2. Assemble 3 pieces to chassis, attach transport module
3. Repeat step 2
4. Transport package to station 5

Work instruction:
Station 5 (Group A)
Final assembly



1. Prepare packages from stations 2, 3 and 4
   Prepare Post-it and pencil
2. Remove transport legos
3. Mount the wing on the fuselage so that 3 rows of nubs remain free from the front

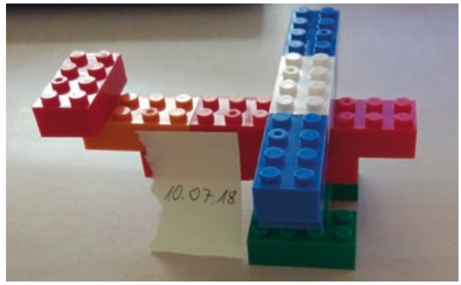


4. Mount the landing gear at the height of the wing
5. Label the Post-it with the current date and attach it to the fuselage (left-hand side when viewed from the front)

Fig. 6.13 (continued)

Work instruction:
Quality (Group A)

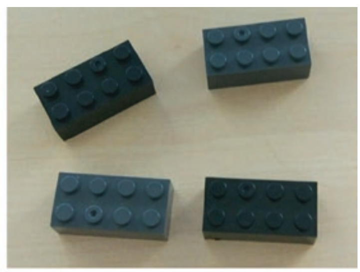
1. Checking the colors
   (Wings: blue outside and white inside,
   fuselage: red or orange, undercarriage: green)



2. Check that the rear wing is fitted correctly
   (one row of studs free-standing)
3. Check that the aerofoil is fitted correctly
   (leave 3 rows of studs free from the front)
4. Check that the running gear is mounted correctly
   (at the height of the wings)
5. Check that the Post-it is mounted correctly
   (left side when viewed from the front)
   and that the date is correct

Work instruction:
Station 1 (Group B)
Pre-assembly of sash

1. Prepare 8 building blocks (size: 4x2, color: black or grey)



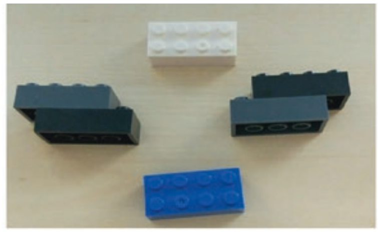
2. Assemble 2 pieces at a time, leaving one row free
3. Repeat step 2

4. Transport 4th package (=two wings) to station 2

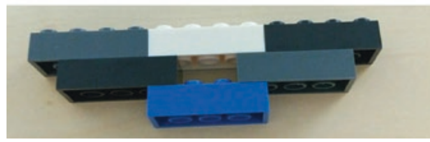
Fig. 6.13 (continued)

Work instruction:
Station 2 (Group B)
Assembling sashes

1. 4 parts from prefabrication,
   2 building blocks (size: 4x2, color: white),
   Prepare 2 building blocks (size: 4x2, color: blue)



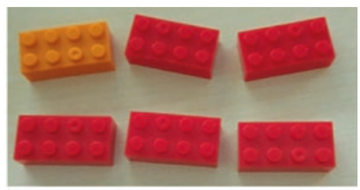
2. Assemble the two parts of station 1 with the single white building block
3. Attach the transport protection (blue component) at the height of the connecting lego
4. Repeat steps 2 and 3



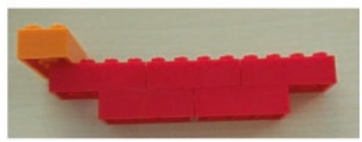
5. Transport package to station 5

Work instruction:
Station 3 (Group B)
Fuselage assembly

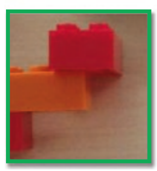
1. Prepare 12 building blocks (size: 4 × 2, color: red or orange)



2. Assemble 5 building blocks to create the fuselage Attach the rear wing



3. Ensure that the rear floor is properly mounted
4. Repeat steps 2 and 3

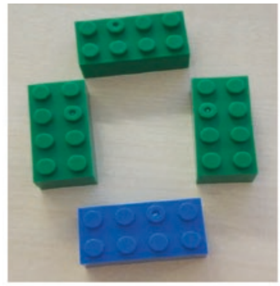


5. Transport package to station 5

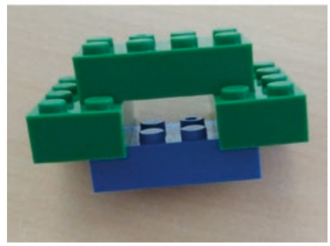
Fig. 6.13 (continued)

Work instruction:
Station 4 (Group B)
Chassis assembly

1. Prepare 6 building blocks (size: 4x2, color: green), 2 building blocks (size 4x2, color: blue)



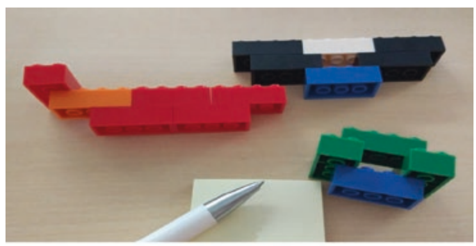
2. Assemble 3 pieces to chassis, attach transport module



3. Repeat step 2

4. Transport package to station 5

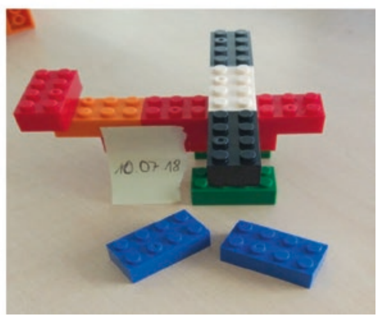
Work instruction:
Station 5 (Group B)
Final assembly



1. Prepare packages from stations 2, 3 and 4 Prepare Post -it and pencil

2. Remove transport legos

3. Mount the wing on the fuselage so that 3 rows of nubs remain free from the front



4. Mount the landing gear at the height of the wing

5. Label the Post -it with the current date and attach it to the fuselage (left side when viewed from the front)

Fig. 6.13 (continued)

Work instruction: Quality (Group B)

1. Checking the colors
   (Wings: black or gray outside and white inside, fuselage: red or orange, landing gear: green)
2. 2. Check that the rear wing is fitted correctly
   (one row of studs free-standing)
3. 3. Check the correct assembly of the wing
   (leave 3 rows of nubs free from the front)
4. Check that the landing gear is mounted correctly
   (at the height of the wings)
5. Check that the Post-it is mounted correctly
   (left side when viewed from the front)
   and that the date is correct

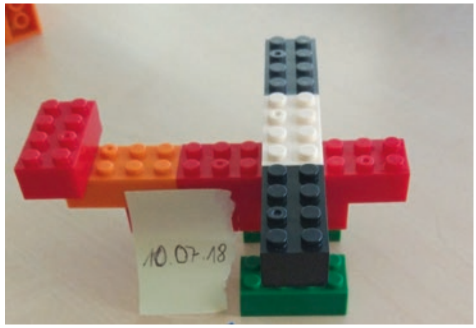


Fig. 6.13 (continued)

6.4 Workshop 10: "Paper Airplane Production"

Work order: The assembly of a paper airplane is to be carried out. For this purpose, the work steps are summarized into the four workstations, according to Fig. 6.14, and divided:

The necessary materials per group are:

- Airplane templates (see attachments),
- Multi-colored fineliner pens,
- a pair of scissors.

In a shift of 15 min, 13 planes should be manufactured according to the given customer demand. This corresponds to a cycle time of 69 s.

In analogy to the previous workshop, the production of the paper airplanes should then be optimized in three simulation rounds. The procedure of the first round is shown below. Templates for the paper airplane and the individual work steps for each processing station can be found in the appendix.

6.4.1 Execution of the First Assembly Round

The four workstations should each carry out the following work steps:

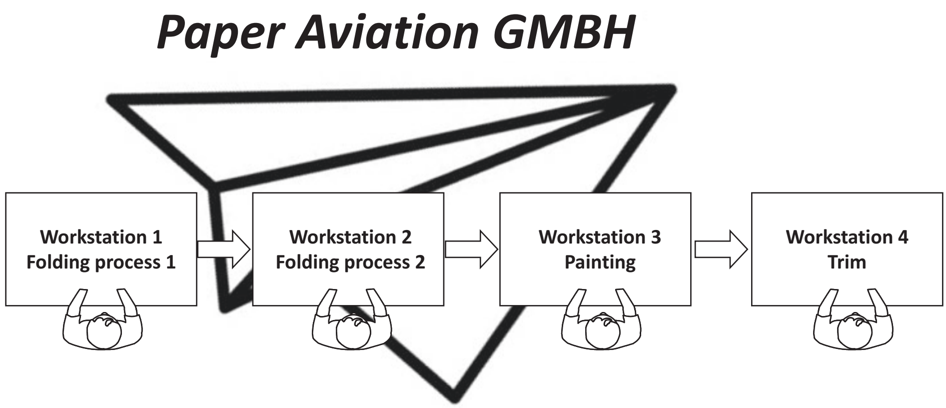


Fig. 6.14 Assembly of the paper airplanes

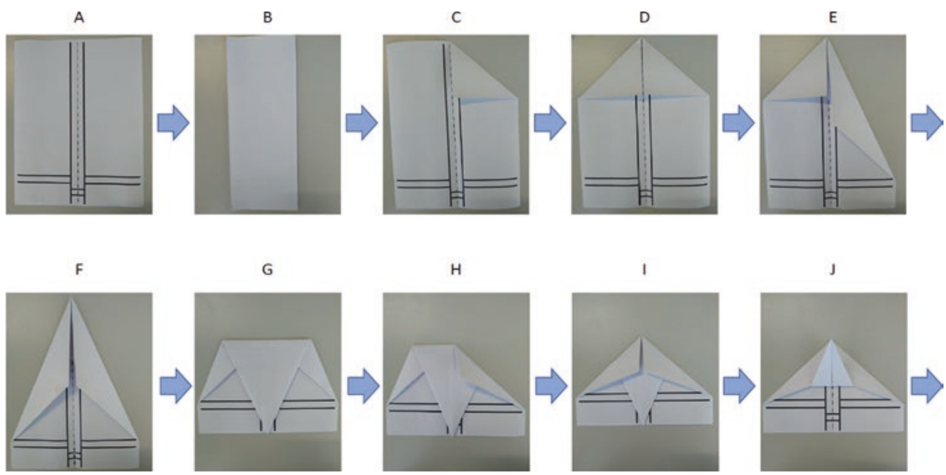


Fig. 6.15 Individual work steps for workstation 1

Workstation 1: Folding 1

In the folding process 1, the paper airplane gets its pointed profile shape.

The starting point is the use of the folding template of the paper airplane (work step A) from the appendix.

Execution of work steps A–J according to Fig. 6.15.

After completion of work step J, hand over the plane to workstation 2.

Workstation 2: Folding 2

In the folding process 2, the wings of the airplane are folded into a square profile shape.

The starting point is the paper airplane handed over from workstation 1.

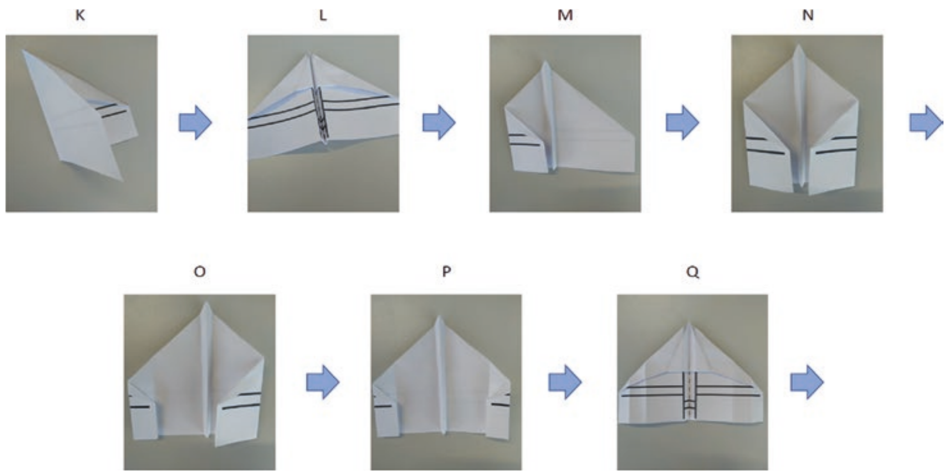


Fig. 6.16 Individual work steps for workstation 2

Execution of work steps K–Q according to Fig. 6.16.
After completion of work step Q, hand over the plane to workstation 3.

Workstation 3: Painting
In the painting process, the paper airplane gets its external appearance. For this purpose, the marked segments (already indicated in the template) are painted with felt-tip pens.
The starting point is the paper airplane handed over from workstation 2.
Execution of work steps R–X according to Fig. 6.17.
After completion of work step Q, hand over the plane to workstation 3.

Workstation 4: Trimming
In the last workstation, supporting profiles are cut into the wings and fuselage in the trimming process.
The starting point is the paper airplane handed over from workstation 3.
Execution of work steps Y–Ü according to Fig. 6.18.
After completion of work step Ü, the plane is completed and can be handed over to the “exit hangar”.

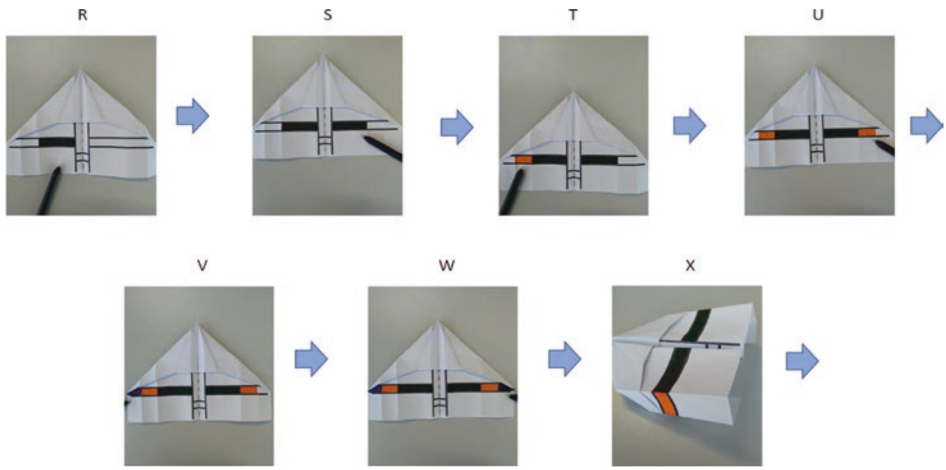


Fig. 6.17 Individual work steps for workstation 3

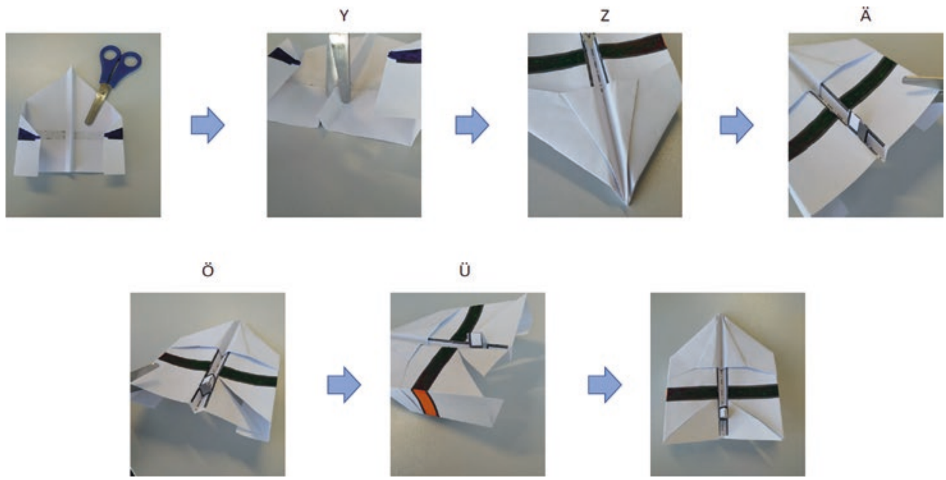


Fig. 6.18 Individual work steps for workstation 4

6.4.2 Improvement Approaches and Observations

The following are some exemplary observations and improvement approaches listed from the feedback of the workshop participants:

- stressful workflows,
- backlogged work processes,
- insufficient utilization,
- partially slow work steps,
- unbalanced task distribution,
- time-consuming painting process,
- unevenly distributed requirements.

For the individual observations, improvement suggestions should be developed by brainstorming in the groups, which will then be implemented in one or two further rounds. The respective process results are always recorded and evaluated and discussed after each round.

6.4.3 Blank Templates (Figs. 6.19 and 6.20)

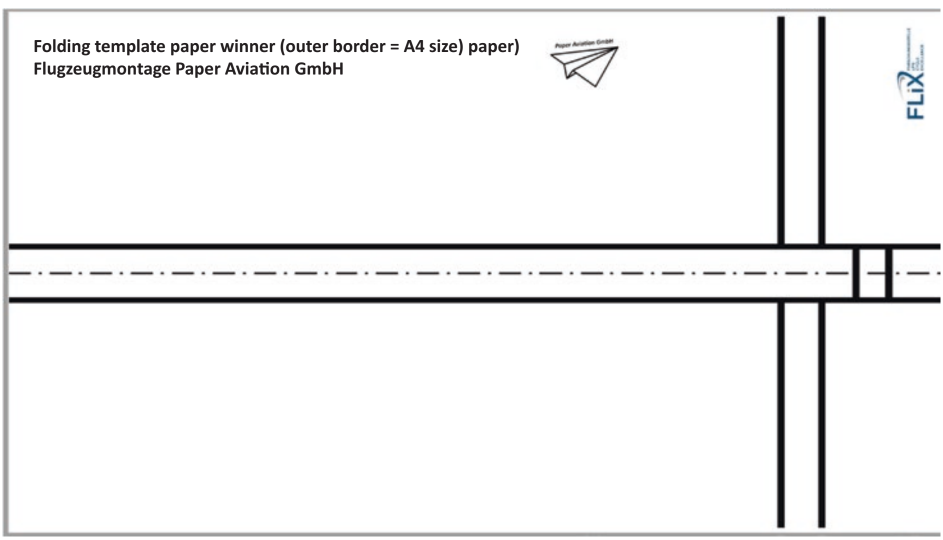


Fig. 6.19 Paper airplane folding template

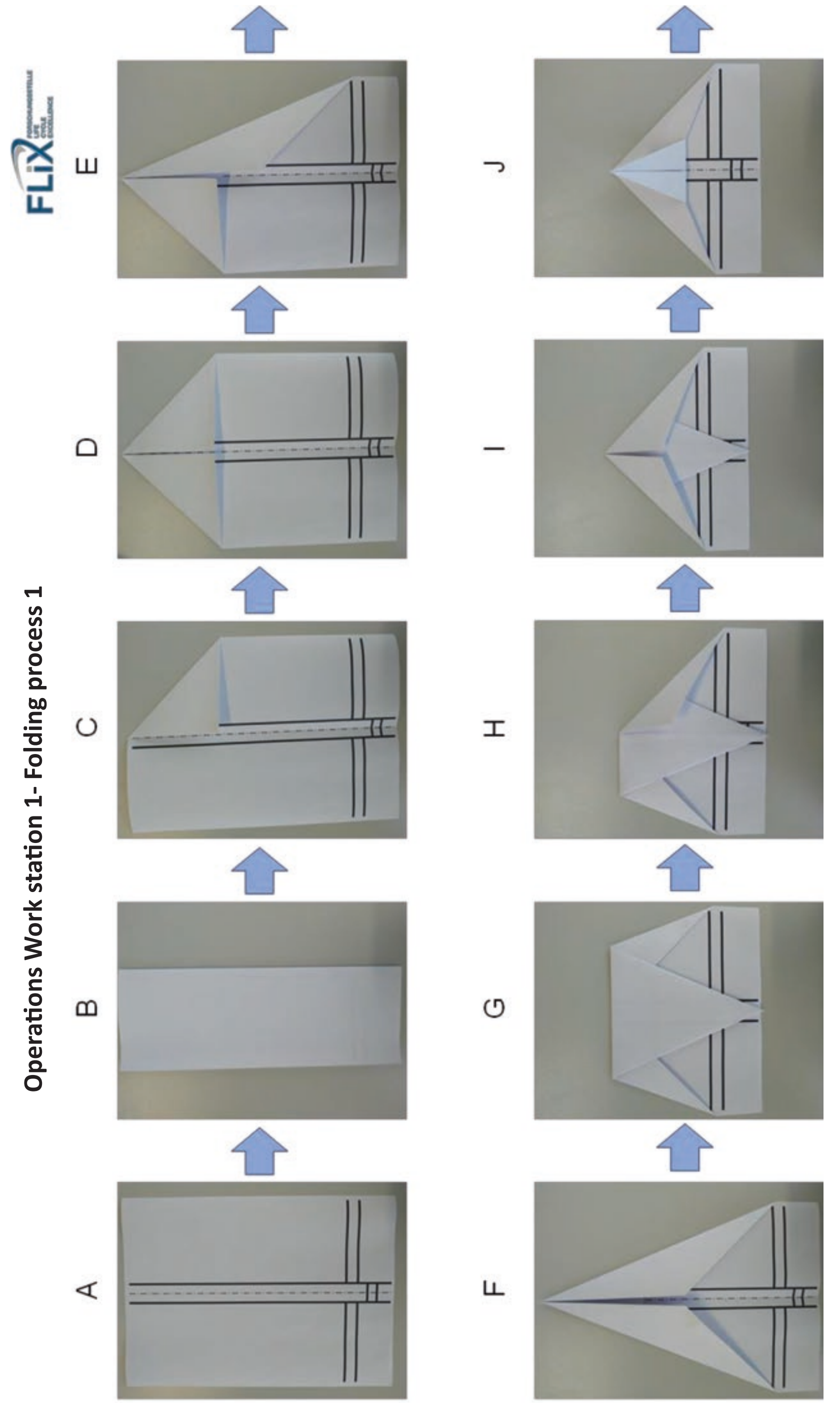


Fig. 6.20 Paper airplane work instructions

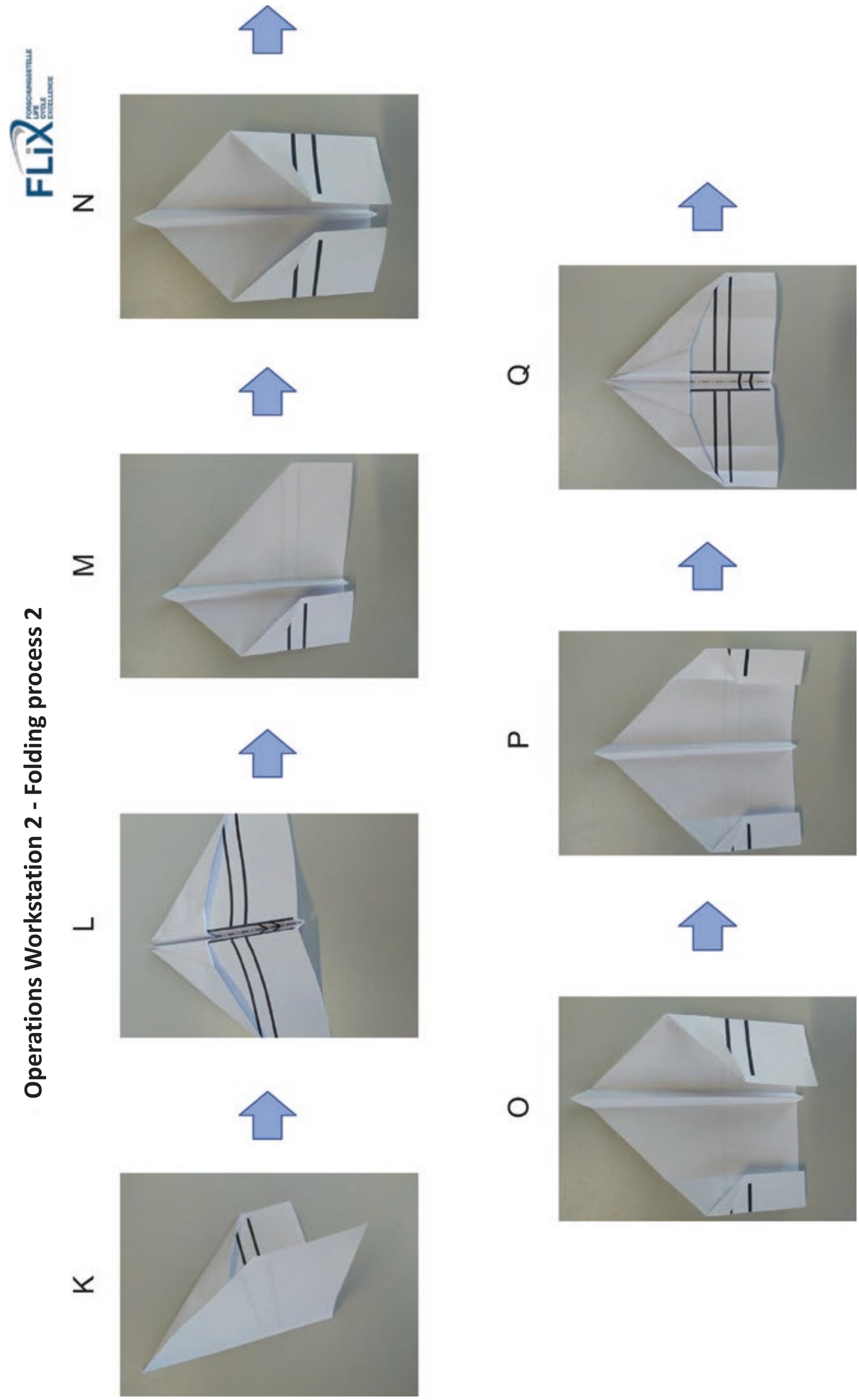


Fig. 6.20 (continued)

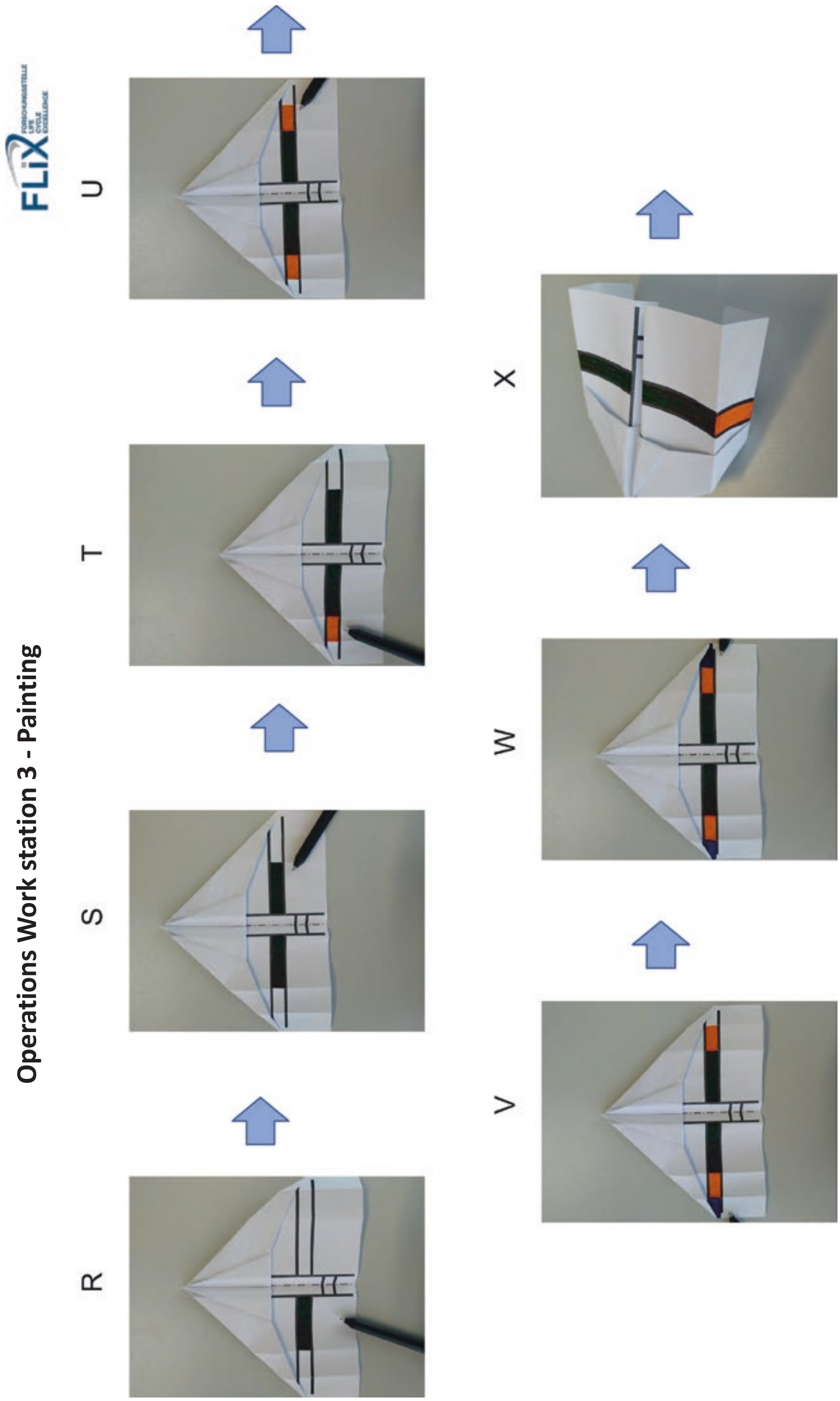


Fig. 6.20 (continued)

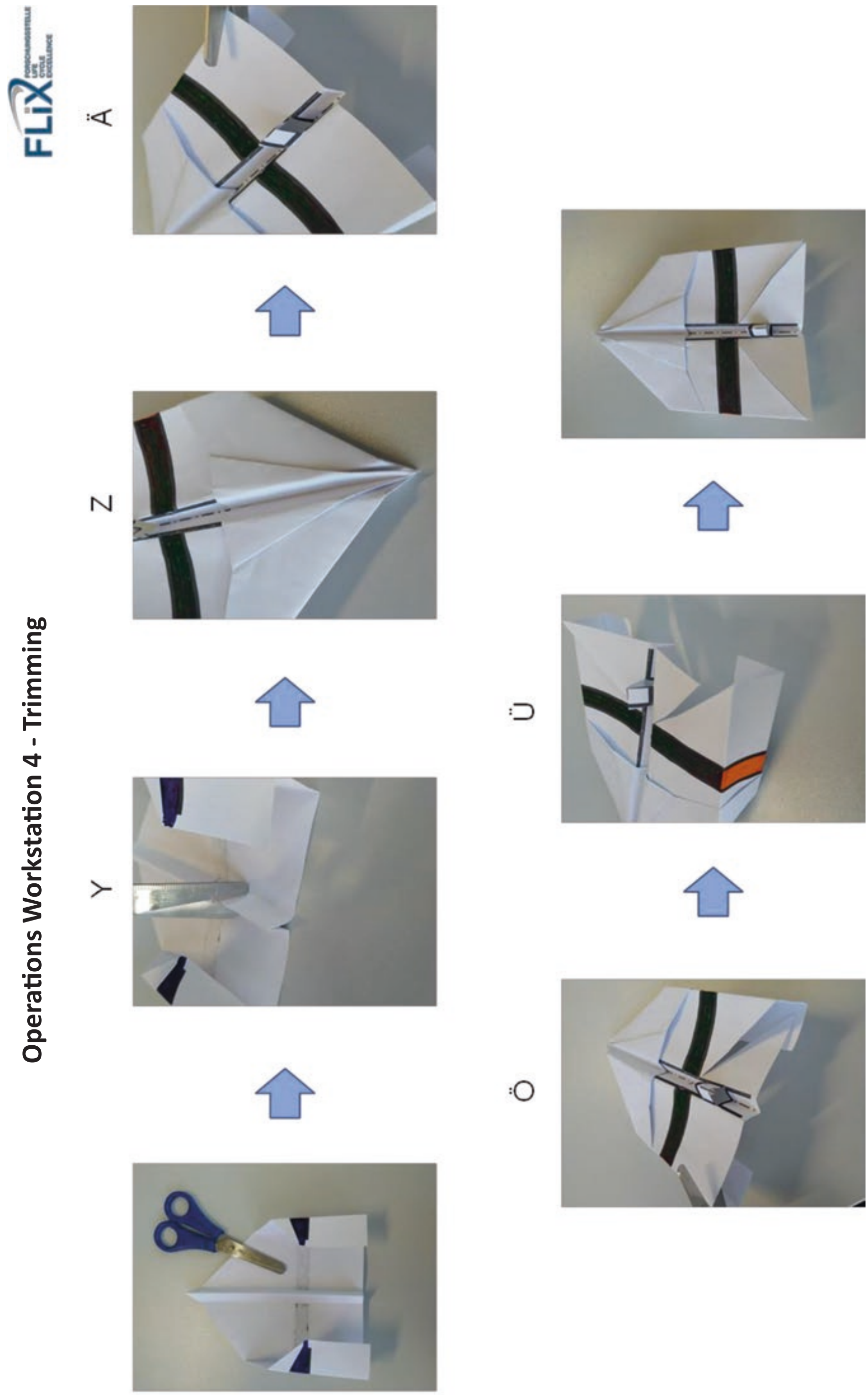


Fig. 6.20 (continued)

References

1. Bertagnolli F (2018) Lean Management. Einführung und Vertiefung in die japanische Management Philosophie. Springer Gabler, Wiesbaden
2. Becker T (2018) Prozesse und Produktion in Supply Chain optimieren, 3rd ed. Springer Vieweg, Berlin
3. Salveson ME (1955) The assembly line balancing problem. J Ind Eng 6(3):18–25
4. The Implementers GmbH (2019) Toyota production system definition (29 July 2019). http://www.the-implementers.de/TPS00.htm#Line_Balancing. Accessed 29 July 2019
5. Blum C (2017) (Management Circle AG) Von Nivellierung und Heijunka: Wichtige Grundpfeiler im Produktionsprozess in acht Schritten, Management Circle AG, 07 September 2017. https://www.management-circle.de/blog/nivellierung-und-heijunka-wichtige-grundpfeiler-im-produktionsprozess-in-acht-schritten/. Accessed 03 May 2021
6. Klevers T (2007) Wertstrom-Mapping und Wertstrom-Design – Verschwendung erkennen – Wertschöpfung steigern. mi-Wirtschaftsbuch, München
7. Gottmann J (2016) Produktionscontrolling – Wertströme und Kosten optimieren. Springer Gabler, Wiesbaden
8. Focke M, Steinbeck J (2018) Steigerung der Anlagenproduktivität durch OEE-Management. Definitionen, Vorgehen und Methoden – von manuell bis Industrie 4.0. Springer Gabler, Wiesbaden
9. Walder F-P, Patzak G (2013) Qualitätsmanagement und Projektmanagement. Springer, Wien

Spaghetti Diagram

7

7.1 Classification of the Method

To analyze and illustrate waste ("Muda") in an existing process, in addition to the value stream analysis, the so-called spaghetti diagram (also spaghetti chart) can be used. The spaghetti diagram is part of the tools for process analysis [1].

Thus, the diagram is used to represent material flows in order to eliminate the types of waste "transport" and "movement" and thus create a process that is as lean as possible. The method primarily supports the goal of reducing throughput times and thus also increases the functional flexibility of the production system (Fig. 7.1).

7.2 Description of the Method

The starting point in process analysis using the spaghetti diagram is the layout of the work area. Therefore, it is important to define a clearly selected area for analysis. Once a sketch of the floor plan has been created, the process can be observed. Here too, a so-called "Gemba Walk"—a Japanese term meaning "the real place"—is suitable for capturing the process. The objects of observation can be the distances covered by the employees, but also the paths of the materials within the production process or even the flow of documents within a process. The application of this process analysis creates a high level of transparency within the existing process. This reveals efficiency losses due to the distances covered by the employees, but also losses caused by a suboptimal layout. The distances covered are drawn into the diagram by lines in the existing layout. The efficiency loss is thus usually made visible by very tangled lines in the diagram. These unproductive sequences must then be eliminated using various measures [1–3].

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_7

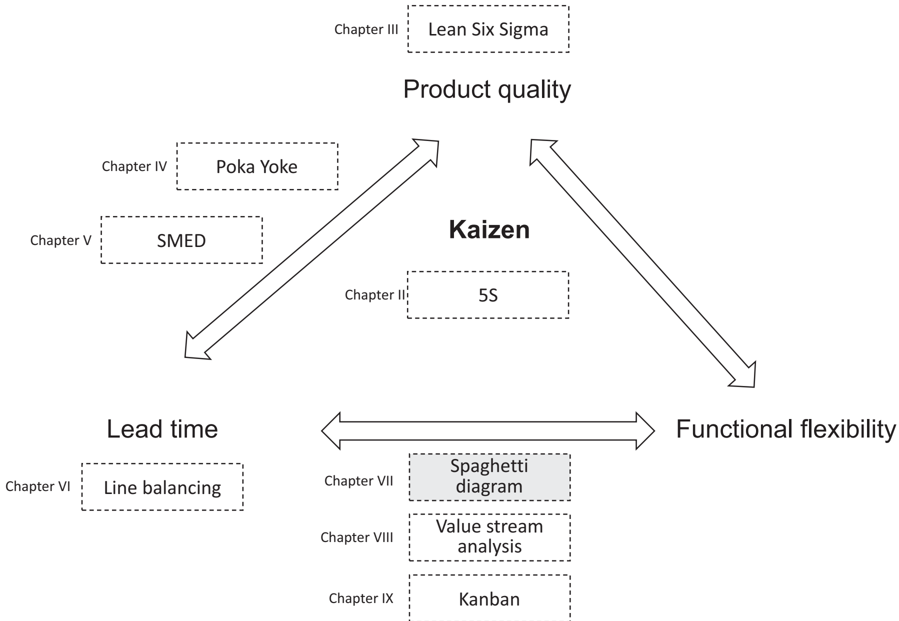


Fig. 7.1 The spaghetti diagram in the field of tension of Kaizen

7.3 Application of the Spaghetti Diagram

The following six steps are required to visualize the spaghetti diagram and efficiency losses (Fig. 7.2).

1) **Definition of the local dimension—Define:** In the first step, a work area to be analyzed should be defined. Care should be taken to ensure that the process to be considered has a clear start and end point and that this is ideally located in a clearly defined work area. If a slightly larger work area is chosen, which extends over several halls, for example, it makes sense to divide the diagram into two individual diagrams, as it otherwise becomes too complex. Once the work area is defined, the layout can be recorded. It is advisable to work as true to scale as possible. Existing drawings of the floor plans (e.g., factory layout) should be used for this. Furthermore, it is always necessary to conduct a walk-through on site (Gemba). Only here can the exact dimensions be checked and any changes that were not listed in the drawing be uncovered. The scale drawing allows not only the conclusion in which area the efficiency losses occur, but also allows an exact measurement [2].
2) **Definition of the temporal dimension—Define:** After the location has been defined, it is necessary to determine the temporal dimension. This should also be precisely defined in advance. The observation period must be chosen so that a clear statement

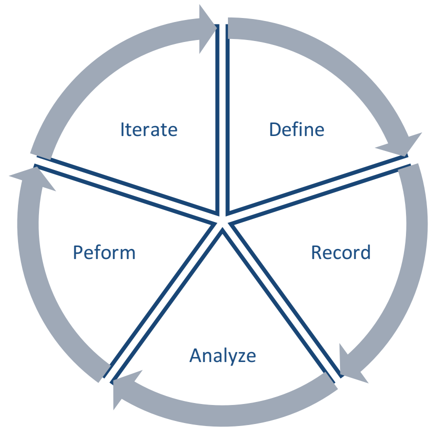


Fig. 7.2 Application steps spaghetti diagram

about the process can be made in the analysis. If the observation period is too short, not enough information is recorded and therefore no reliable statement about the efficiency of the process is possible. Furthermore, in production companies that operate in shift work, it is necessary to extend the observation period to the various shifts. Different colors can be chosen to draw the lines, so that it is recognizable in the analysis which paths were taken by which shift. This opens up the possibility of comparing the two groups in the analysis, in order to eliminate possible efficiency losses between them [2].

3) **Determination of the observation object—Define:** Furthermore, in this step, the object to be analyzed must also be defined. For example, should a material be analyzed through the respective process steps or should the paths of the employees be recorded? The previous definition of the observation object is intended to reduce the later complexity.
4) **Drawing of the process flow—Record**: Once the temporal and spatial dimensions are defined, the layout is created and the observation object is defined, the drawing of the paths taken into the layout can begin. It is important to draw all the paths taken into the diagram exactly. Even if paths are taken twice, they must be recorded in the diagram. This may seem confusing, but it is essential for the later evaluation and uncovering of waste.
5) **Evaluation of the spaghetti diagram—Analyze:** The scale layout allows a qualitative as well as quantitative assessment of the current process flow and its efficiency in the evaluation. One sign of waste occurring within the process can be the distance traveled, which is determined by the quantitative analysis. For this, the distances drawn into the layout are read off due to the scale drawing. Another method to identify waste is the qualitative evaluation. This is done based on the lines drawn into the layout. An indicator is a high frequency of lines, long path lines, and frequent crossing of lines. If the visual evaluation shows a very tangled diagram, this is often a sign of a high degree of waste [2].

6) **Define measures—Perform**: After the diagram has been evaluated quantitatively and qualitatively, measures must be defined to free the process from waste and thus design a process that is as efficient as possible. A table can be used for this, in which the measures to be carried out are prioritized. It is often advisable to classify the measures according to their integration effort and to implement the so-called "quick-wins" directly. If changes to the layout are also planned, these should be implemented at a later point in time and possibly re-evaluated after a further analysis, after the "quick-wins" have been implemented.
7) **Repetition—Iterate:** The last step is to conduct another recording of the process to check the implemented measures. Even with this repeated process recording, it is advisable to record it to scale. This allows the measures taken to be evaluated quantitatively and the increase in efficiency to be clearly measured. The step of repeated recording is particularly important, as often an improvement of the process on one side can lead to a deterioration on the other side.

7.4 Advantages and Disadvantages of the Spaghetti Diagram

The biggest advantage of the diagram is that no prior knowledge is required. The user can start recording immediately after drawing the layout. Furthermore, no prior knowledge is required for the evaluation. The diagram simply shows where waste occurs. This is also another major advantage of the diagram. It visualizes the process and, above all, its execution for the user in the best possible way. This way, waste can be eliminated directly in the process and, if necessary, faulty executions of the process (e.g., incorrect routes) can be eliminated. Another advantage that the Spaghetti Diagram offers is the focus on the two types of waste "Transport" and "Motion". These two types of waste can be specifically eliminated. A major disadvantage of this diagram is the quickly occurring lack of clarity. If larger processes are analyzed or many routes have to be covered within the process, the diagram can often be difficult to evaluate. Therefore, the Define phase is a very important step to clearly delineate the process to be considered and its object of observation, thus reducing the lack of clarity to a minimum [3].

7.5 Workshop 11: "Post office"

In a post center, various letters have to be packed in envelopes and prepared for shipping. For this, the letters have to pass through several workstations in the post office, where the necessary operations are carried out until shipping. The Spaghetti Diagram is to be used to examine the layout of the office or the arrangement of the workstations for possible inefficiencies. The production of the letters is to be simulated in order to visualize the workflows and record them with the Spaghetti Diagram.

The following is required for this practical example:

1. Layout: Production—Sending letters (Chap. 8),
2. Measuring device (tape measure),
3. Pen and
4. Layout evaluation table.

7.5.1 Preparation

The individual stations must now be set up according to the given layout (template in the appendix). Afterwards, the distances between the individual workstations should be measured with the tape measure in order to also carry out a quantitative analysis later. These distances should be entered directly into the evaluation table (template in the appendix).

Furthermore, form pairs to create the Spaghetti Diagram. This way, the group members can discuss the findings later. Also, designate another person to perform the simulation of the process, so that the routes are clearly visible for the defined period of time.

7.5.2 Conducting the Workshop

In the following, a Spaghetti Diagram is to be created based on the layout. The procedure should follow the listed sequence. The time specification is variable and should be defined in subtask (ii). Print out the layout for the participants so that the routes can be drawn in directly. This is a very small example, but it is intended to convey the idea and application of the Spaghetti Diagram to the participants.

1) Define: Define the time dimension and the object of observation. The spatial dimension is already given by the task.
2) Record: Now draw the covered distances in the existing layout. Transfer the recorded information to the evaluation table.
3) Analyze: Now evaluate the drawn routes quantitatively and qualitatively and discuss them with the groups.
4) Perform: What measures can you take to make the process more efficient? Discuss these with the groups.

7.5.3 Solution Proposal and Blank Templates

1) **Define:** The spatial dimension is already given with the production of the letters and the layout. The object of observation is the material flow of the letters. These are collected in a box to a respective batch size of 5 and passed on to the next station. The

temporal dimension—the observation period—is defined as 15 min. During this time, all paths taken in the layout should be drawn.

2) **Record**: (Evaluation table in the appendix)
3) **Analyze**: The qualitative analysis shows that the distances between the individual stations are sometimes very long and therefore a lot of working time is lost in the form of transport. Furthermore, it becomes clear that the employees use different paths between the stations. The quantitative analysis supports this evaluation. It becomes clear that the Folding/Packing and Packing/Labeling stations together already account for a distance of 76 meters and thus two-thirds of the total distance. A large part of the time is spent on transport at these process steps, thus representing the greatest inefficiency.
4) **Perform**: The evaluation shows that the two transport routes between the respective processes contain a lot of waste. It is therefore necessary to analyze the layout and make changes if possible to minimize the transport distance and time.

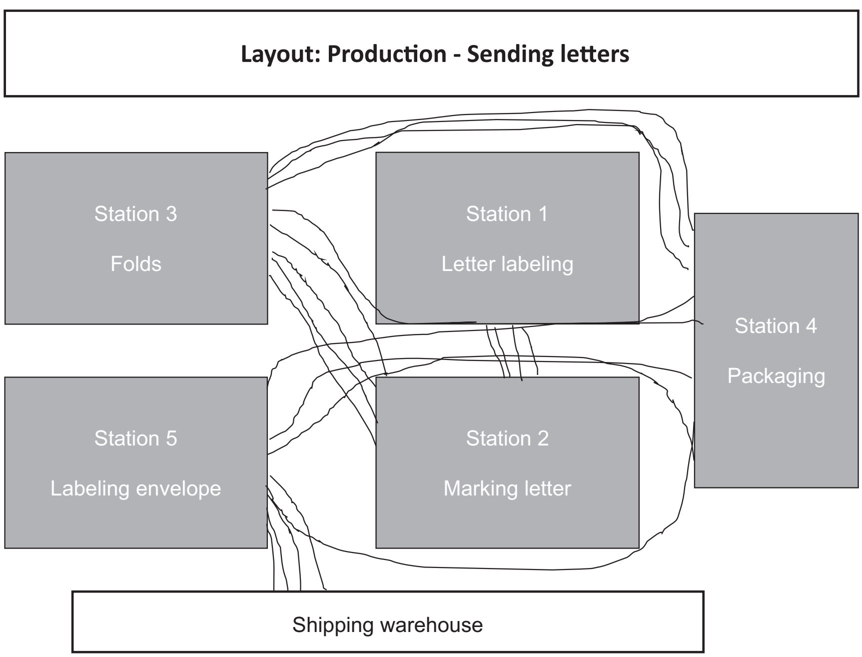


Fig. 7.3 Solution proposal spaghetti diagram

Solution Proposal Layout with Spaghetti Diagram **(Fig. 7.3)**

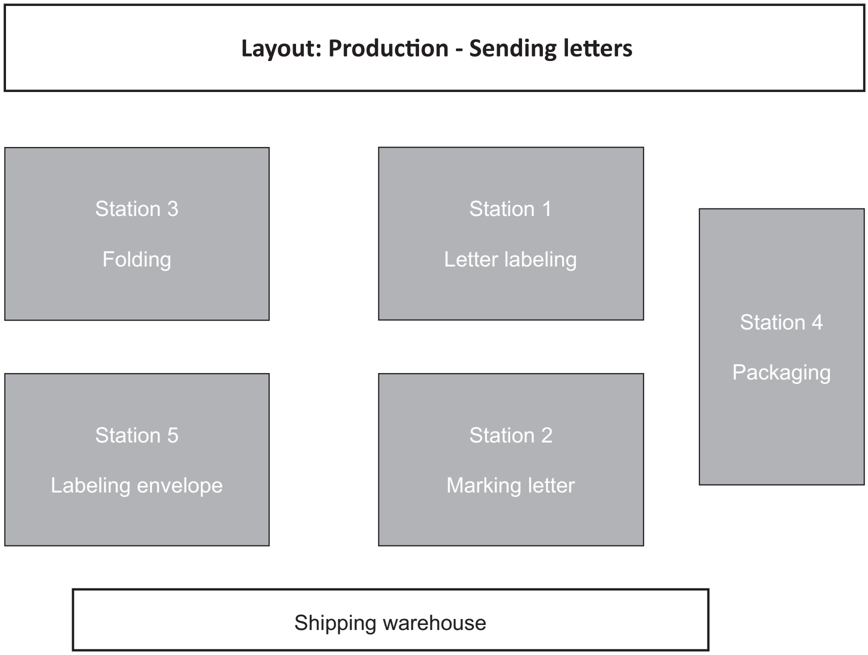


Fig. 7.4 Blank layout form

Blank Layout Form **(Fig. 7.4)**

Process: Sending letters Observation period: 15 minutes			Date: DD.MM.YYYY	
From station	By station	Distance	Number of paths	Total distance
Labeling	Marking	3	4	12
Marking	Folds	7	4	28
Folds	Packing	10	4	40
Packing	Labeling	9	4	36
Labeling	Shipping warehouse	2	4	8
			Total distance	124

Fig. 7.5 Solution proposal evaluation of sending letters

Solution Proposal Evaluation Record **(Fig. 7.5)**

FLiX FORSCHUNGSSTELLE LIFE CYCLE EXCELLENCE Process: Observation period:			Date:	
From station	To station	Distance	Number of paths	Total distance
Labeling	Marking	10	4	40
			Total distance	

Fig. 7.6 Blank form for evaluation of sending letters

Blank Evaluation Record Form **(Fig. 7.6)**

References

1. Thonemann U (2011) Operations Management. Konzepte, Methoden und Anwendungen, 2nd updated ed. Pearson Studium (Wi – Wirtschaft), München
2. Hofmann M (2020) Prozessoptimierung als ganzheitlicher Ansatz. Mit konkreten Praxisbeispielen für effiziente Arbeitsabläufe, 1st ed. Springer Gabler, Wiesbaden
3. Schewe S, Herbig N (2015) Lean Administration. Methoden zur Prozessvisualisierung und -optimierung, Tätigkeitsanalyse, Kennzahlen und Office Management. Books on Demand, Norderstedt

8 Value Stream Analysis

8.1 Classification of the Method

The value stream analysis is a method that has its roots in the Toyota Production System (TPS). The method means seeing the whole in order to improve the whole. The focus here is on the whole, meaning that analysis should also be carried out outside of production in order to gain a holistic understanding of the situation and opportunities for improvement. Thus, value stream analysis can enable a holistic transparent representation of the processes, with the aim of eliminating waste and thus significantly improving the responsiveness of production as well as increasing the profitability and efficiency [1–3].

Value stream analysis therefore primarily focuses on optimizing throughput times while simultaneously increasing the flexibility of the production system in the manufacture of different products according to customer specifications (Fig. 8.1).

8.2 Description of the Method

When creating a value stream analysis, it is necessary to start with a categorization of the prevailing products. If possible, a product or a product family should be chosen that needs to be analyzed in the production process. This should be followed by a customer demand analysis, which can be carried out based on the sales figures of the past fiscal year. In the next step, the actual value stream recording in production can begin, after which potential improvements can be analyzed (Fig. 8.2) [4].

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_8

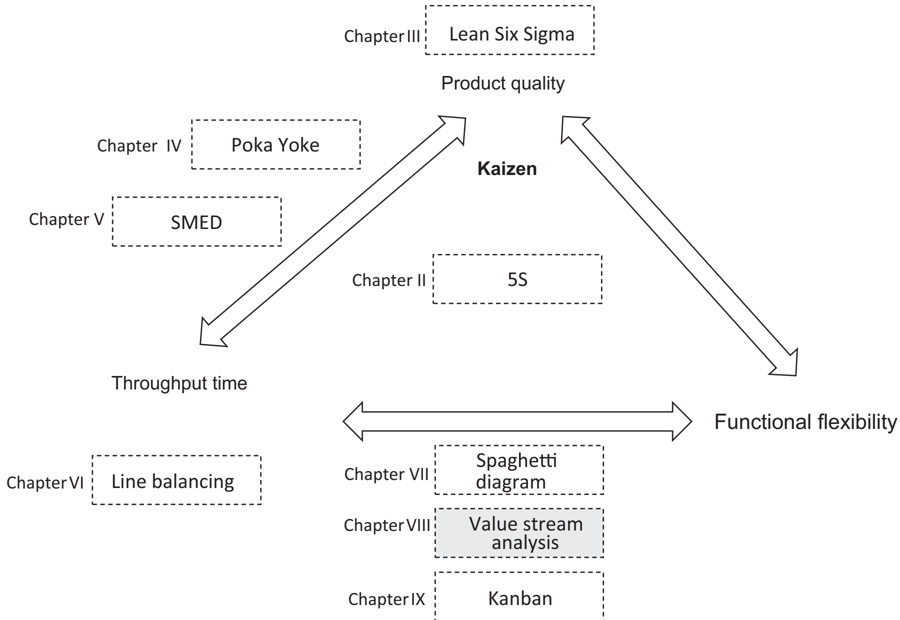
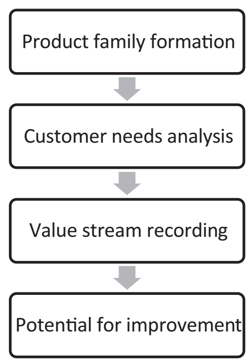


Fig. 8.1 Value stream analysis in the field of tension of Kaizen

Fig. 8.2 Steps in a value stream analysis [4]



8.2.1 Product Family Formation

Before starting with the value stream analysis, it must first be determined which product is to be analyzed. A value stream is always a link of the processes for exactly one product. If many different products, which take different paths through production, were drawn into a value stream analysis, this would lead to an overlay of connections in which nothing can be recognized anymore. To prevent this, the subdivision of the product spectrum according to production-relevant similar criteria must begin. This results in the product families. These are a segment that is separated from the factory and analyzed. To create such product families, the use of a product family matrix or the evaluation based on the production process/product family similarity is recommended [1].

8.2.2 Customer Needs Analysis

The overarching goal of value stream analysis is to orient production towards the customer demand. For this, the customer perspective must be adopted in the analysis. This means that after defining the product families, the customer must be analyzed. The customer cycle helps in aligning the production rhythm and sales rhythm. The cycle brings the market feeling into production and makes the production rhythm transparent. The cycle time should always exactly match the customer cycle, as too high a time leads to non-fulfillment of customer demand and too short a time leads to overproduction. The customer cycle is the beat that is dictated by the market and with which production should work as best as possible [4]. The customer cycle can be calculated as follows [4]:[1]

$$Customer\ Cycle = \frac{available\ time\ for\ production\ per\ year}{customer\ demand\ per\ year}$$

The calculated customer cycle and the resulting transparent production rhythm assume that there is not a high fluctuation in demand. If demand fluctuations occur, this places high demands on the flexibility of production. Flexibility can often only be achieved by decoupling production from the customer cycle by creating stocks. However, it is also possible to initiate upstream measures. For example, sales can influence ordering behavior through quantity and time-limited discounts [4].

8.2.3 Value Stream Recording

The first step should be to start recording the material flow. The process is generally carried out upstream. Therefore, the recording starts with the customer and continues in the opposite direction to the actual material flow. The second step is to record the information flow. This should start at the customer order acceptance, as this represents the direct interface to the customer [5]. How the information and material flow should be represented within the Value Stream Analysis is shown in the appendix.

[1] KT: Customer cycle [min/piece].
FT: Factory days [days/year].
AZ: Daily working time [min].
JStk: Annual quantity [pieces/year].

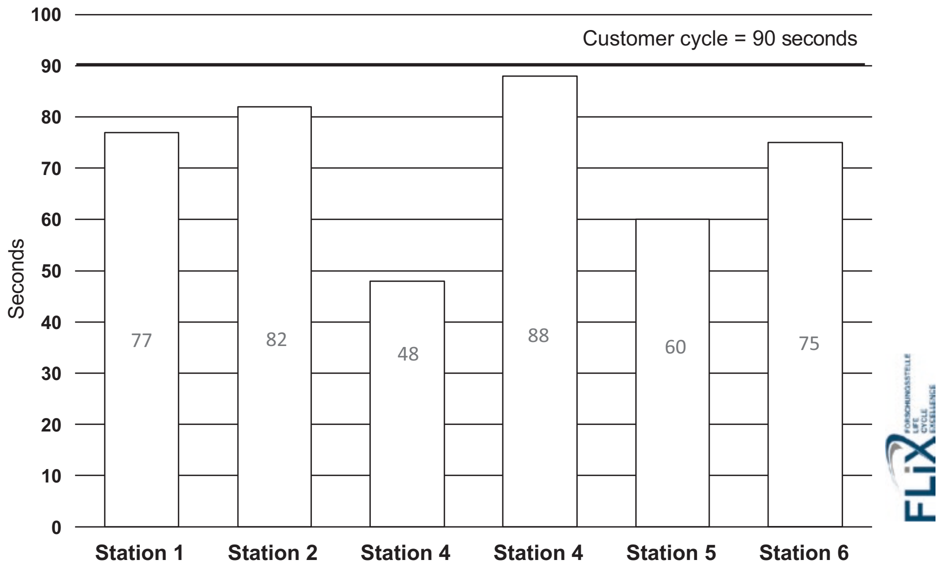


Fig. 8.3 Cycle coordination diagram [4]

The recorded times are entered on the jump line, which is located under the drawing. This line consists of two levels. The upper level is used to describe the material flow using the storage range, and the lower level is used to describe the process using the processing time. At the end of the timeline, the total throughput time and the sum of the processing times are entered. The timeline allows an evaluation regarding the maximum achievable and the actual existing throughput time. A large distance from the actual to the theoretical throughput time leads to high inventories, which often cause problems with the logistical target specifications (delivery time, deadline compliance). If the throughput time is considered in relation to the processing time, a statement can be made about how much of the processing time the object under consideration has spent in the production system. This value serves as an assessment of the extent to which flow production has already been implemented [4, 6].

A second analysis, the cycle-oriented view, allows an assessment of the Degree of Coordination of the production units. The Cycle Coordination Diagram can be used as a tool here (Fig. 8.3) This allows the difference between the theoretical cycles and the actual cycle times to be represented. The Cycle Time of a process indicates the time requirement per piece and thus the capacitive performance of this process. The smaller the cycle time, the greater the capacity. Thus, the capacity offer can be represented by the cycle times, using a bar chart, over the entire Value Stream. In addition, the Customer Cycle can also be entered to visualize where capacities may be lacking and where they are sufficiently available. The largest bar in the diagram is the bottleneck of the line, as it determines the maximum possible output. The diagram results in a Capacity Profile of the value stream [4, 7].

8.2.4 Potential Analysis

In the potential analysis, waste in the value stream should be made visible and eliminated. Wastes are activities that do not contribute to the value enhancement of the product. From the Toyota Production System and according to Taiichi Ohno, wastes can be divided into seven categories. These are [8–10]:

- **Waste due to overproduction:** This means that the quantity produced exceeds the quantity demanded. Overproduction is one of the most serious wastes as it conditions the others. Overproduction can, for example, result from too high batch sizes.
- **Waste due to inventories:** High inventories lead to increased capital commitment and an increase in storage or parking space. Furthermore, high inventories conceal problems that are prevalent in production. This can, for example, be caused by a wrong production strategy or lack of overview/transparency within production and the associated poor control possibility.
- **Waste due to transport:** Transport often arises due to spatial separation of successive production steps or due to necessary intermediate storage due to downtimes. Causes include a poor layout, among other things.
- **Waste due to movement:** This is caused by unnecessary distances covered by the employee. This can be caused by poor ergonomics at the workplace and the associated frequent rotation of the body or by a secondary activity, such as placing a container.
- **Waste due to waiting times:** Waiting times often arise due to lack of material and machine downtimes. These often cause an uneven degree of utilization of employees in upstream or downstream process steps. A common reason is also poor takt time of the processes, which can be made visible in the takt alignment diagram.
- **Waste due to the production process:** These are wastes that can, for example, be caused by too long setup or travel distances. But also the setup time counts as non-value adding activities to the wastes within the production process.
- **Waste due to errors:** These are faulty parts that may have to be reworked in an additional step or completely removed from the production process.

8.3 Workshop 12: "Mail Dispatch"

The practical example "mail dispatch" is intended to simulate the application of the value stream analysis as an example.

The following is required for this practical example:

1. Din-A4 sheets,
2. Envelopes,
3. Pen,
4. Ruler and
5. Stopwatch.

8.3.1 Preparation

Groups of seven participants each should set up the following stations according to Fig. 8.4, each of which should be manned by one person. Each station should contain exactly one process step and be set up on a separate table. The transport between the individual process steps is taken over by a single person ("logistician") and ends with station 5. Another person takes over the time recording and notes the time required for each individual station.

Process Description—Station 1

- Write the number of the letter being processed (e.g., #1 for the first letter) in the upper right corner of the paper, followed by "inner" to mark the inside of the letter.
- Availability: 95 %; Setup time: 0.8 s

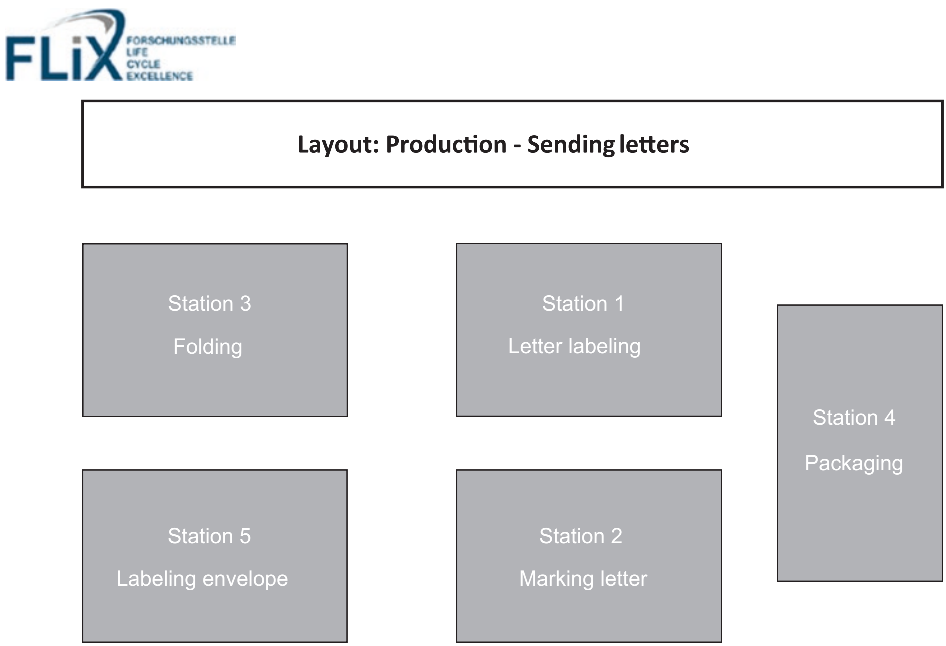


Fig. 8.4 Layout of the stations

Process Description—Station 2

- Measure 9.3 cm on both long sides of the letter paper and mark them so that there are markings at 9.3 cm and 18.6 cm respectively.
- Availability: 89 %; Setup time: 1.8 s

Process Description—Station 3

- Now fold the lower third of the letter paper to the middle. Turn the paper over so that the folded side is on top, and now fold the lower side upwards. Now the inside should be readable again on top of the letter.
- Availability: 87 %; Setup time: 0.6 s

Process Description—Station 4

- Take the folded letter and put it in the envelope. Then fold the envelope so that the letter can no longer fall out (no need to glue).
- Availability: 96 %; Setup time: 1.2 s

Process Description—Station 5

- Label the envelope in the upper right corner with the number (# X) and note the respective time that must be read on the stopwatch underneath.
- Availability: 81 %; Setup time: 0.9 s; Quality: All parts that are recorded as scrap are noted exclusively at this process step.

Information Flow

- The Production Planning and Control System (PPS) informs production about the daily quantity to be produced based on customer demand. The PPS receives the customer demand quarterly by email. Based on this information, the supplier receives a monthly overview of the weekly deliveries required.

Material Flow

- The customer is supplied weekly based on his demand for 10 letters. The required raw materials are also received by production weekly. The material flow within production runs according to the process steps given above. Assume cycle times of 2 s per process step.

8.3.2 Implementation

A production is carried out over a total duration of 10 min. As soon as this has elapsed, the production is immediately stopped and the products that have not yet completed process step 5, thus all parts that are at the stations, are counted as scrap (Work in Progress). Furthermore, a batch size of 5 is produced (i.e., as soon as 5 products have passed through process step 1, the logistician picks them up and transports them to process step

2). The logistician is responsible for the transport between the respective process steps. A proposed solution to the respective task parts can be found in the appendix.

1) Start the production of the letters based on the throughput description and the assigned layout.
2) The actual analysis begins with the drawing of the value stream. Record the entire material and information flow and represent it using a hand drawing. Also use the given values for availability, setup time, cycle time and the customer demand.
3) Now discuss the existing value stream based on the different types of waste such as
   a. Transport,
   b. Overproduction/Inventory,
   c. Errors/Rework and
   d. Waiting time
4) and mark these on your created value stream drawing with the relevant symbol.
5) Consider how the respective wastes can be eliminated/reduced and implement these. Afterwards, play another round with the improvements you have made.

8.3.3 Suggested Solution

Task 2 (Fig. 8.5)

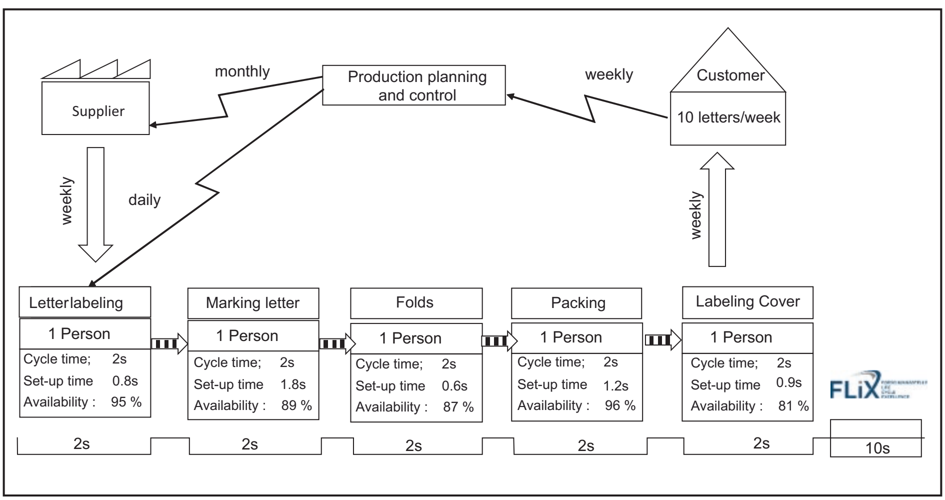


Fig. 8.5 Suggested solution value stream

Task 3 and 4

a. Transport—Due to the arrangement of the stations, the logistician has a long transport route to supply the respective processes with materials.
   - Optimization: Arrangement of processes according to the process sequence. This may eliminate the need for the logistician, who can then support another process.

b. Overproduction/Inventory—Since the information flow between production and PPS only runs via sales, the customer demand is unknown and production is carried out for stock. This leads to high capital commitment costs.
   - Optimization: Improvement of the information flow between PPS and production. Various scenarios are conceivable here, such as the introduction of a Kanban system or monthly planning that is broken down into a weekly production plan known to each process.

c. Errors—Since the workday ends after 10 min and the parts that are still in "Work in Progress" status are no longer usable the next workday, they are disposed of as quality errors.

d. Waiting time—Production in a batch size of 5 leads to high waiting times at the beginning of some processes until production starts.
   - Optimization: If a Kanban system is introduced and the processes are arranged in the order of work, a one-piece flow can be introduced. This results in less waiting time. The pacemaker process can be supported and thus optimized with the help of the logistician.

References

1. Koch S (2015) Einführung in das Management von Geschäftsprozessen. Six Sigma, Kaizen und TQM. Springer, Berlin. https://books.google.de/books?id=GbRnBwAAQBAJ. Accessed 03 May 2021
2. Syska A (2006) Produktionsmanagement. Das A–Z wichtiger Methoden und Konzepte für die Produktion von heute. Gabler. https://books.google.de/books?id=WzRD_nyl8bcC. Accessed 03 May 2021
3. Doliwa S (2014) Anwendung des Wertstromdesigns in einem metallverarbeitenden Unternehmen. Eine Fallstudie. Bachelor + Master Publishing. https://books.google.de/books?id=1naQAwAAQBAJ. Accessed 03 May 2021
4. Erlach K (2010) Wertstromdesign. Der Weg zur schlanken Fabrik, 2nd ed. and expanded ed. Springer (VDI-Buch), Berlin. http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10408765. Accessed 03 May 2021
5. Hartel DH (2009) Consulting und Projektmanagement in Industrieunternehmen. Praxisleitfaden mit Fallstudien. de Gruyter Oldenbourg, München. http://www.degruyter.com/search?f_0=isbnissn&q_0=9783486845402&searchTitles=true. Accessed 03 May 2021
6. Pfeffer M (2014) Bewertung von Wertströmen. Kosten-Nutzen-Betrachtung von Optimierungsszenarien. Springer Fachmedien, Wiesbaden. https://doi.org/10.1007/978-3-658-02128-3

7. Dickmann P, Hirsch J (2015) Materialfluss- und Wertstromanalyse sowie Wertstromdesign und andere Darstellungen der Materialströme. In: Dickmann P (Ed) Schlanker Materialfluss. Mit Lean Production, Kanban und Innovationen, 3rd ed. Springer Vieweg (VDI), Berlin, S 385–416
8. Bullinger HJ, Spath D, Warnecke HJ, Westkämper E (2009) Handbuch Unternehmensorganisation. Strategien, Planung, Umsetzung. Springer, Berlin. https://books.google.de/books?id=LtwfBAAAQBAJ. Accessed 03 May 2021
9. Reitz A (2008) Lean TPM. In: 12 Schritten zum schlanken Managementsystem; effektive Prozesse für alle Unternehmensbereiche; gesteigerte Wettbewerbsfähigkeit durch KVP; Erfolge messen mit der Lean-TPM-Scorecard. mi-Fachverlag. https://books.google.de/books?id=0Qh_Lg5foWkC. Accessed 03 May 2021
10. Liker JK (2006) Der Toyota-Weg. 14 Managementprinzipien des weltweit erfolgreichsten Automobilkonzerns. FinanzBuch. https://books.google.de/books?id=w-SrGHj800cC. Accessed 03 May 2021

Kanban

9

9.1 Classification of the Method

Muda describes any activity that consumes resources but does not create value, therefore the goal of any efficiency increase of a process is to minimize Muda. In manufacturing processes, the Just-In-Time manufacturing (JIT manufacturing) is desirable. This requires that the right parts in a flow process must be available at the right time, in the required quantity, at the right place [1]. This can be ensured with the help of a Kanban system (Fig. 9.1).

The system is now a globally used control method. The reason for this popularity lies in the reduction of complexity, low susceptibility to interference as well as decentralization and the associated reduced control effort within production [2]. It ensures that production runs smoothly in the sense of lean management with minimal throughput times and high production flexibility [3].

9.2 Description of the Methodology

The Kanban system was developed by Ohno in 1950. It is the oldest principle of coordinated, self-regulating work systems. The Kanban system is often described in literature as the supermarket principle. As soon as a product is taken from the shelf, the resulting gap must be filled again. This view can also be transferred to production. If a part is consumed by a process, a gap is created. The upstream process must then ensure that the gap is filled as quickly as possible. This creates a clearly recognizable customer-supplier relationship [4].

The basic model of the Kanban control in parts production consists of a linear arrangement of workstations to a Kanban line. Each workstation has a buffer in the form

J. Niemann et al., *Lean Six Sigma*, https://doi.org/10.1007/978-3-662-68744-4_9

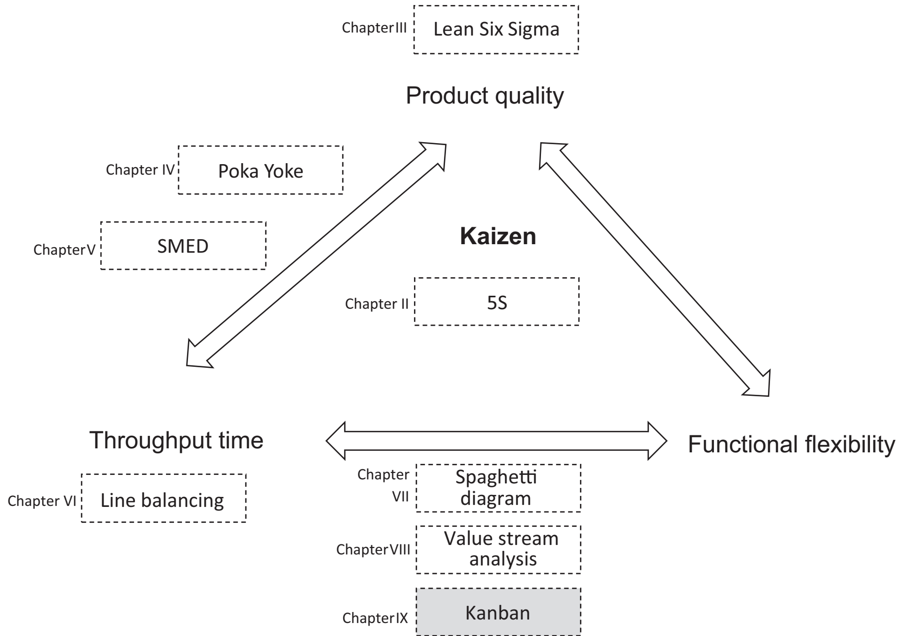


Fig. 9.1 Kanban in the field of tension of Kaizen

of an outbound store. The information flow runs backwards along the Kanban line. When a customer order is received, this information is passed on to the first process where the raw material is located. The material flow, on the other hand, runs forward until the required product, demanded by the customer order, is completed. When an order is received, it can be served in the first step from the finished goods warehouse. The gap that arises there must be filled according to the supermarket principle and thus triggers a production order to the upstream workstation. The activities of generating and consuming the parts are continued until the first process of the chain [4].

The difference to the Push system is that in the Kanban (=Pull system) only the removed quantity is refilled. The Kanban cards serve the information flow between the individual control loops. The following two basic types of Kanban can be distinguished (Fig. 9.2):

- The Production Kanban circulates exclusively between the source and the Buffer storage. The cards contain data regarding the containers, the transport routes (from the source to the sink), the delivery time as well as the parts information [4]. They trigger production orders at the source [5].
- The Transport Kanban, on the other hand, circulates between the source and Buffer storage. It triggers a transport of parts to supply the consuming point from the buffer storage. If the supplier is also included in the Kanban system, the Kanban card takes over the function of the order form [5].

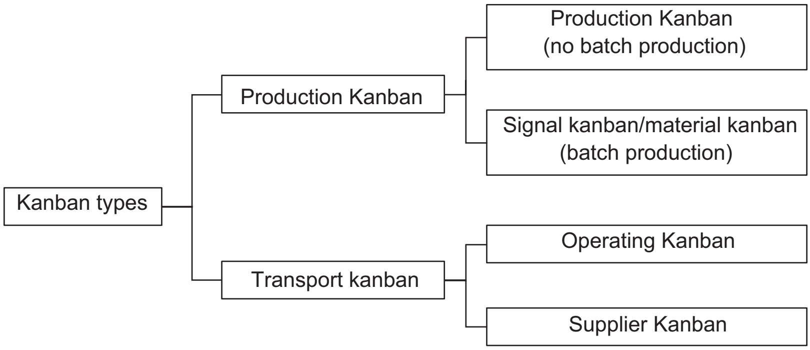


Fig. 9.2 Types of Kanban [5]

In addition, the Kanban model can be distinguished into a 1-card system and a 2-card system.

9.2.1 1-Card System

The basic model of the Kanban consists of a 1-card system. This is particularly suitable when the distance between two consecutive processing stations is so small that the output warehouse of the first process can be merged with the input warehouse of the following one. In the system, there is only one card that takes on two functions. On the one hand, transport and on the other hand, production. If a workstation removes a full container from the upstream buffer storage, the production kanban card attached to the container is passed on to the upstream process or placed in a collection box located in the buffer storage. The cards from the collection box must then be collected by an employee. The card triggers a production order and the removed quantity, with the corresponding card, is refilled in the buffer. This restores the initial state [6].

However, the 1-card system can also be modified and represented as a 2-card system.

9.2.2 2-Card System

The 2-card system is mostly used when a container has to be fetched from a far-off place or when the transport quantity of containers differs from the quantity of the production order [4]. Here, the cards are differentiated into transport and production kanban (Fig. 9.3) [7].

If a place has consumed a container, it must be refilled from the preceding buffer storage. The starting point of consideration here is the consumer, the so-called sink. As soon as a container has been emptied, the employee removes a transport kanban from the des-

Fig. 9.3 Production Kanban

<table>
<tr><td>Process
Number: 3</td><td colspan="3">Storage location no. 3: painted stickers</td></tr>
<tr><td>Part no.</td><td>003</td><td colspan="2">Model type: Sticker 002</td></tr>
<tr><td>Part designation</td><td>Paper with prepared stickers</td><td rowspan="3">Appearance
</td><td rowspan="3">Process: (work step)

Cutting stickers</td></tr>
<tr><td>Container</td><td>Mesh box</td></tr>
<tr><td>Container capacity</td><td>5</td></tr>
</table>

ignated collection box and goes with the empty container and the card to the buffer storage. There, he places the container in the designated place. In the next step, the employee removes a full container. Before the container can be transported to the sink, he must exchange the production kanban attached to the full container with the carried transport kanban and pay attention to the match of the information on both cards. The removed transport kanban must now be placed in the collection box provided at the buffer storage. An employee of the source collects the cards from the collection box at short time intervals, which then triggers the production. The empty containers are transported to the source and are filled as a result of the production order and then provided in the buffer storage [5]. The transport kanban regulates the information flow and the production kanban the material flow [4].

9.2.3 Conditions for a Kanban System

For a manual Kanban System to work successfully, several aspects must be considered and adhered to. It is particularly important to define a high quality standard and to maintain this standard through suitable quality assurance measures, as it must be prevented that faulty parts enter the Kanban container and are transported to the next process. Another aspect that must be considered is that production may only be carried out due to a demand from the upstream process. This means that production should only be initiated by receiving a Kanban Card. In addition, only the exact quantity that is requested according to the card should be produced to avoid overproduction. The last important condition that should prevail for the system to work successfully is that the entire production must work in a standardized and stable manner. If there are frequent machine failures during production, this can result in the subsequent processes no longer being able to be supplied according to their needs. Thus, production can come to a complete standstill [3]. The prerequisites can be summarized as follows [8].

- The material flow must correspond to the flow principle in order to avoid strong demand fluctuations. If these cannot be prevented, this leads to high demand peaks that cannot be covered by the Kanban containers and the material flow breaks off.

- In order to produce economically with a high variety of variants, short setup times are essential.
- A high level of quality control is necessary to avoid delivering faulty parts to the downstream process, so that no supply gaps occur due to the low stocks [4].
- It is recommended to produce variants or similar products that have a similar sequence of processing steps in order to keep the setup effort low [4].

However, the manual Kanban also has some disadvantages. Methods are necessary to control the circulation quantity of the Kanban Cards due to disturbances. In addition, manual bookings in the Material-Requirement-Planning-(MRP-)System must be carried out in addition to the cards used in production [2]. These disadvantages can be avoided by using electronic Kanban.

9.2.4 E-Kanban

It has already emerged that there are some deficiencies in traditional Kanban with regard to transparency, material booking and the lack of connection to the IT system [9]. The rapidly developing information and communication technology offers very good conditions for the Kanban System. Information can be transmitted digitally. For this purpose, physical Kanban Cards are still used, but they contain a barcode. By scanning this code, the data can be read out and transferred to the system for recording incoming and outgoing parts. The reproduction is controlled by the stock in the system [10]. In addition, the economic efficiency of the container sizes can be checked [11]. The principle is identical to the reorder point system known from procurement planning [10]. With an E-Kanban board, the information regarding the quantity of empty or full containers in circulation can be viewed digitally in the internal network through terminals located in the company. With the IT connection of the Kanban, a simpler supplier connection can also be implemented. As soon as a container in the system is set to the status empty, an order is sent. When a full container is accepted, it can be scanned and thus directly registered in the system. If the data is updated daily, this results in enormous advantages for the supplier and the company. The supplier can use the data to precisely analyze consumer behavior, which in turn leads to shorter replenishment times [12]. The advantage of the E-Kanban system is a (almost) paperless and faster flow of information. By registering the current stocks in the system and the resulting accurate material consumption booking, Kanban orders can be better prioritized depending on the order situation. In addition, scanning the barcodes provides accurate documentation of the parts and therefore also a very good possibility of product tracking [9], which is becoming increasingly important in today's times. The E-Kanban can be used using other techniques for automatic identification and data capture (Auto-ID) such as "Radio Frequency Identification" (RFID).

9.2.5 Signal Kanban—Kanban Board

A variant of the Kanban system is the formation of batch sizes and the resulting bundling of orders. The idea is not to trigger production as soon as an empty container arrives, but to wait until a critical amount of orders is reached. The most common way to implement this is the traffic light system. A board is divided into three different zones: a green, yellow, and red area. Each part gets a column, which starts with red at the bottom and ends with green at the top. Incoming Kanban cards are pinned to the board. When enough cards are collected to reach the green area, production begins. If the cards are only in the yellow area, in the middle, it is up to individual decision whether the order should be executed depending on the workload. It is important to note that a sufficient quantity of full containers must be kept in the buffer storage to serve the incoming orders. This in turn requires storage space equivalent to the bundled batches, and can therefore only be used if there is a small number of different end products. The advantage of the Kanban board is the visualization of the control impulses of the material flow and the transparency thus created [4].

9.2.6 Visualization in the Kanban System

Visualization in the production principle is an important component. It enables self-control and presents the services provided well for the employees. This allows them to directly identify with their performance. It serves as motivation to achieve the defined goals, as well as the process of continuous improvement (CIP) [13].

Increased transparency prevents *waste*, increases productivity, and enhances the competitiveness of the company.

The flow of information provided to the employee has a tremendous impact on job satisfaction. Visualization helps align the actions, thinking, and behavior of employees with the company's defined goals [13].

9.2.7 Dimensioning

The central question for the design of a Kanban system is:

How many Kanbans, i.e., control elements, must be put into circulation to achieve reliable material availability? [14]

The number of cards depends on several parameters. There is the quantity of parts or the content per Kanban, and the replenishment quantity. It must be clearly defined whether a single production or a collection in batches takes place. Other aspects are the replenishment time and a necessary safety stock [14]. The inventory should be large at the introduction of the system and can then be reduced step by step, e.g., in the sense of Kaizen [4]. This increased inventory in the initial phase, however, ensures that the unproductivity of one's own company and the suppliers can be compensated [3]. Then, a safety factor should be included in the design of the system. However, in the sense of the Lean concept, this is a waste and should be reduced to 1 as quickly as possible. The last parameter is the initial inventory. This represents the starting size and is always reached when production has not produced for a longer period of time [14]. The number of Kanbans can be calculated as follows [14]:[1]

$$K = \frac{WBZ \times V_D}{TK} \times SF + \frac{SB}{TK}$$

In case of fluctuating consumption, the average consumption V_D should be replaced by a value for the maximum consumption V_{max} to gain additional security in the design. Before the system can be introduced, it should be tested through a simulation [14].

9.2.8 Summary

In summary, it can be stated that the Kanban system and the resulting self-regulation of production significantly reduce planning and control effort. In addition, the responsiveness of production can be greatly increased [9]. A high supply security of the material can be guaranteed with minimal stocks. Furthermore, the Kanban system is a simple, easily understandable system that shows a high level of employee involvement [15]. If there is a disruption at the workplace or with the operating resources, this usually leads directly to a standstill in production. In addition, strong demand fluctuations cannot be compensated by the Kanban system [15].

9.3 Workshop 13: "Sticker"

The functionality of a Kanban system is to be exemplified by the production simulation "Sticker", thus giving the course participants a better understanding.

The following is required for this practical example:

1. Din-A4 sheets,
2. FLIX template "Arrow",
3. FLIX template "Rectangle",
4. Template Kanban card,
5. Pen,

[1] RT = Replenishment time; SS = Safety stock.
SF = Safety factor; PK = Parts per Kanban.
V_D = Average consumption.

6. Ruler,
7. Scissors and
8. Stopwatch.

9.3.1 Preparation

For this practical simulation, groups of four should be formed, with three group members each performing a work step and one group member taking over logistics. The workstations are distributed over three different tables and intermediate storage areas should be set up in front of station 1 “Preparing stickers” and station 2 “Drawing stickers”, as well as a shipping warehouse behind station 3.

After the production layout has been set up, the templates should be pre-produced in the next step in order to use them in the later production process. In addition, two Kanban cards should be printed and filled out from the provided template. The container capacity must not be changed and must be set to five. The templates can be found in the appendix.

Process Description—Station 1 “Preparing Stickers”

- Start production by placing the FLIX template “Rectangle” on the DIN-A4 paper and tracing the contour with a pen.
- Then place the DIN-A4 paper on the intermediate storage in front of station 2.

Process Description—Station 2 “Drawing Stickers”

- In this production step, place the FLIX template “Arrow” on the DIN-A4 paper and trace the contour with a pen.
- Then place the DIN-A4 paper on the intermediate storage in front of station 3.

Process Description—Station 3 Cutting Stickers

- In the last process step, the sticker should now be cut out. To do this, cut out the drawn rectangle and the arrow.
- The finished sticker can be placed in the shipping warehouse in the last step.

Process Description—Logistician

- The logistician is responsible for replenishment control and transports the manufactured intermediate parts, which are stored in the wire mesh boxes, to the next workstation. The wire mesh boxes have a maximum quantity, which can be taken from the Kanban card.

9.3.2 Implementation

Production continues until a total quantity of 15 stickers is reached. As soon as these 15 are stored in the shipping warehouse, the time is immediately stopped and used as a reference time for the passage of variant 2. Furthermore, it is necessary for each employee to record their own working time. This working time can then later be related to the total production duration to determine the productive working time of each employee.

9.3.2.1 Variant 1

First, there is an employee at each production unit who carries out the corresponding production step, this means that one worker prepares the stickers, records the stickers, and cuts the stickers.

Production is centrally controlled—i.e., one employee determines when which production unit produces. All workers remain at the assigned stations.

The maximum storage capacity is ten parts in all intermediate warehouses. The goods receipt and dispatch warehouses have a capacity of 15 units.

9.3.2.2 Variant 2

Production is no longer centrally controlled, but decentralized via a Kanban system. Here, there are two Kanban containers in each intermediate warehouse. Production is controlled decentrally via the pull principle, which means that the downstream step determines when the upstream step begins production. This is controlled, as described above, via the Kanban card.

The workers can support the other stations if they are not processing a production order.

The maximum storage capacity is two containers, i.e., ten parts in all intermediate warehouses. The goods receipt and dispatch warehouses have a capacity of 15 units.

9.3.3 Task

- Start production according to variant 1 and note the productive time per employee as well as the total time required for the production of the 15 stickers.
- Now carry out the production according to variant 2 and also note the productive time per employee as well as the total time required.
- Discuss the results of the simulation based on variant 1 and variant 2. What influence did the production control based on Kanban have, especially considering the recorded times?
- Also discuss whether production control using Kanban is suitable for this process.
- What other measures and concepts are there to implement this process more efficiently?

9.3.4 Blank Templates (Figs. 9.4 and 9.5)

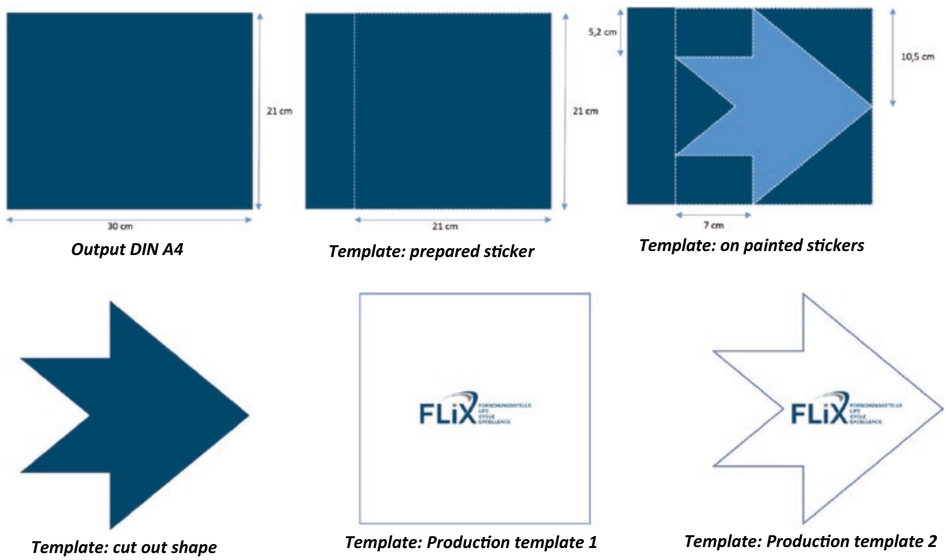


Fig. 9.4 Kanban production template

FLiX FORSCHUNGSSTELLE LIFE CYCLE EXCELLENCE	Variant		1Variant 2	
	Productive time	Total time	Productive time	Total time
Station 1 / Employee 1				
Station 2 / Employee 2				
Station 3 / Employee 3				
Total				

Fig. 9.5 Blank Kanban evaluation form

References

1. Zollondz H-D (2013) Grundlagen Lean Management. Einführung in Geschichte, Begriffe, Systeme, Techniken sowie Gestaltungs- und Implementierungsansätze eines modernen Managementparadigmas. Oldenbourg (Edition Management), München
2. Dickmann P (2015) Grundlegende Steuerungsverfahren. In: Dickmann P (Hrsg) Schlanker Materialfluss. Mit Lean Production, Kanban und Innovationen, 3rd ed. Springer Vieweg, Berlin, S 196–203
3. Louis RS, Reiter D (2000) Effiziente Materialfluss-Steuerung mit Kanban und MRPII. Verl. Moderne Industrie, Landsberg/Lech
4. Vahrenkamp R, Siepermann C (2008) Produktionsmanagement, 6th revised ed. de Gruyter, München
5. Schulte G (2001) Material- und Logistikmanagement, 2nd substantially expanded and verb ed. Oldenbourg, München
6. Tegel A (2012) Analyse und Optimierung der Produktionsglättung für Mehrprodukt-Fließlinien. Eine Studie zum Lean-Production-Konzept. Gabler (Produktion und Logistik), Wiesbaden
7. Regber H, Zimmermann K (2013) Changemanagement in der Produktion. Prozesse effizient verbessern im Team, 3rd ed. mi-Wirtschaftsbuch, München
8. Bleher N (2014) Produktionssysteme erfolgreich einführen. Univ., Diss. – Hohenheim, 2013. Springer Gabler, Wiesbaden
9. Kletti J, Schumacher J (2014) Die perfekte Produktion. Manufacturing Excellence durch Short Interval Technology (SIT), 2nd ed. Springer Vieweg, Berlin
10. Hausladen I (2016) IT-gestützte Logistik. Systeme – Prozesse – Anwendungen, 3rd ed. Springer Gabler, Wiesbaden
11. Gudehus T (2010) Logistik. Grundlagen – Strategien – Anwendungen, 4th updated ed. Springer, Berlin
12. Heiserich O-E, Helbig K, Ullmann W (2011) Logistik. Eine praxisorientierte Einführung, 4th fully revised and expanded ed. Gabler/Springer Fachmedien, Wiesbaden
13. Bullinger H-J, Spath D, Warnecke H-J, Westkämper E (2009) Handbuch Unternehmensorganisation. Strategien, Planung, Umsetzung, 3rd ed. Springer, Berlin
14. Klevers T (2009) Wertstrom-Mapping und Wertstrom-Design. Verschwendung erkennen – Wertschöpfung steigern, 1st ed. mi-Wirtschaftsbuch, München
15. Kamiske GF (2015) Handbuch QM-Methoden. Die richtige Methode auswählen und erfolgreich umsetzen, 3rd updated and expanded ed. Hanser, München