PROJECT IRP

„Creation of English Study Supports for Selected Subjects of the Follow-up Master Study in the Quality Management Study Field“

IRP/2015/104

MODERN MANAGEMENT APPROACHES

Study supports

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STUDY INSTRUCTIONS

You have received a study support for the combined study containing the main topics covered by the course of the „Modern Management Approaches“ taught in the 2nd semester of the follow-up master's degree of the study programme of Quality Management study field at the Faculty of Metallurgy and Material Engineering.

Course objective and learning outputs

The main course objective is to offer students the complex overview of the aspects of the application and methodology of the modern management and understanding of the importance of various managerial approaches and paradigms in the process of the innovative management development.

Knowledge outputs:

- a student should be knowledgeable in the large variety of management approaches and methodical aspects;
- a student will obtain knowledge about differences between particular managerial concepts;
- a student will gain detailed information about principles, methods and methodology of the selected managerial approaches implementation (Lean production, Six Sigma, Agile, Leagile approach, Mass customization, Product personalisation).

Skills outputs:

- a student will be able to apply his knowledge for the innovative development of the managerial system in the manufacturing or nonmanufacturing organizations.

Who is the course intended for

The course is included in the follow-up master's study of the field of study of Quality Management, but it can be studied by an applicant from any other field of study, provided that he/she meets the required prerequisites.
This study support is divided into chapters, which logically divide the studied matter, but are not equally comprehensive. The estimated study time of the chapters may vary considerably, which is why large chapters are further divided into numbered sub-chapters and they correspond to the structure described below.

Method of communication with the educator

This matter is presented to students within the frame of their lectures and practical exercises, where they practically learn the topic discussed during the theoretical lectures. But selected topics suppose self-learning and elaboration of the written seminar works discussed with the lecturer during the consultations and via internet.

STRUCTURE OF THE CHAPTERS

Time to study

The time necessary to study the subject matter is given at the beginning of every chapter. The time is approximate and can serve as a rough guide for the study layout of the entire subject. The time may seem too long to some people or, on the contrary, too short to other ones. There are students who have never encountered this issue and, on the other hand, those who already have extensive experience in this field.

Goal

There are defined objectives given for you to achieve after reading the chapter and studying the topics - concrete skills, knowledge.

Lecture

This part is the actual presentation of the studied subject matter, the introduction of new terms, their definitions and explanation of the principles of the studied subject matter. All is accompanied by pictures, tables, solved examples.

Time to reflection

You will encounter questions and problems within the study of the chapters that should be thought over for the sake of mastering the subject matter. Do not continue reading until you have thought everything over well.

Tasks

Solve defined tasks and use practical examples of the application of the presented theoretical knowledge to better understand the discussed subject matter.

Summary of terms

The main terms you should learn are repeated at the end of the chapter. If you still do not understand any of the terms, go back to them again.

Questions

There are several theoretical questions to verify that you have fully and well mastered the subject matter of the chapter.

Key to solutions

You will find the solution key to the tasks at the end of every chapter.

References

There is a list of the used reference sources, from which you can draw additional information on the issue in question, at the very end of every chapter.

The author of this educational material wishes you a successful and pleasant study using this textbook.

Prof. Ing. Darja Noskievičová, CSc.

CONTENTS

1. BASIS OF MANAGEMENT

Time to study

480 min

Goal

after studying this chapter

- you will understand the importance of management;
- you will learn what management is;
- you will know what the key functions of management are;
- you will understand the link between management functions and decision making;
- you will know what the diference between efficiency and effectiveness is.

Lecture

1.1 Preface

At the beginning – the first task:

In the following pictures you can find the results of the human activity throughout centuries, different civilizations, various parts of the world and diverse kinds of activities (including the biggest or highest buildings or other objects unique in the world).

Define what common aspect enabled to accomplish such results?

Mammoth hunting

Source: [1]

Stonehenge (2600-2400 BC)

Source: [2]

Egypt pyramids

Source: [3

Eastern Isles

Source: [4]

Ayuthaya – Thailand 14st century

Source: [5]

Machu Picchu – Peru (15th-16th Century)

Source: [6]

Hagia Sophia – Constantinopol (6th centrury)

Source: [7]

The Roman aqueduct

Source:[8]

Pugam – Myanmar (Barma) 1044-1287

Source: [9]

Roman legions

Source: [10]

Prague – Praque castle

Source: [11]

St Peter's Basilica

Source:[12]

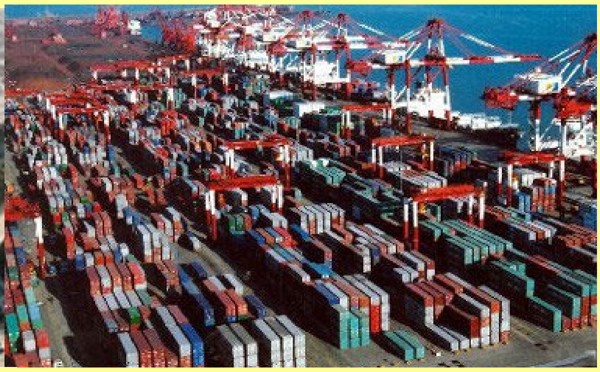
Trans-siberian magistral

Source:[13]

Atlanta crossing

Source: [14]

Shanghai port



Source: [15]

Maglev (603 km/hour)

Source: [16]

Atlanta airport

Source: [17]

China – Three Gorges

Source: [18]

Burdž Dubai – 818 m

Source: [19]

Mall - Dubai

Source: [20]

Shanghai town (24 mil)

Source: [21]

Rocket ship Atlantis

Source: [22]

Satellite Astra

Source: [23]

Fig. 1.1 – 1.23 Results of the human activity through centuries

Answer is really simple: the common aspects that anbled to accomplish such marvellous result are:

Planning, Organizing, Directing, Controlling = Management

1.2 Basic definitions

The birth of the main principles of management is connected with the birth of civilization when people started to live in groups and first sought to improve their lot of life to survive in the existing environment. These attempts led to the division of labour.

Definition of the division of labour

The division of labour is the form of cooperation of various participants in the process (individuals, firms, regions…) specialized in the parts of this process that must be coordinated and integrated (managed) to accomplish the common goal.

Definition of management

Management is the proces of setting and accomplishing goals through the use and coordination of human, technological and financial resources withing the context of the environment [24].

- *Management is the proces of setting and accomplishing goals*

Every organization exists and operates to fulfill some purpose: to manufacture some product, to offer some service to customers. To achieve such overal goal, the organization must break it down into a set of objectives that have to be accomplished.

- *Management uses and coordinates human, technological and financial resources*

To achieve set goals, managers must bring together people, materials, money, technology. It includes determining the necessary quantity and quality of resources, their finding and managing so that the goals would be met in the best possible way (limitedness of resources).

- *Management operates within the context of the particular environment*

Above all, such environment includes demands of customers, competition, the state of economy, political, social and technological factors.

1.3 Basic functions of management

Management is realized through four main functions: planning, organizing, directing, and controlling [24].

1. ***Planning*** is the proces of analyzing the environment, setting objectives a designing the courses of actions to achieve them.
2. ***Organizing*** means identifing the work to be done, dividing it into parts, assigning these parts to specific individuals or groups (for instance departments of organization), and coordinating particular efforts to achieve the goals with the available technological and financial resources.
3. ***Directing*** (core of the human resource management) means focusing human skills, time and energy on the planned goals. It involves staffing, communicating, motivating and coordinating groups.
4. ***Controlling*** is setting performance standards based on overal goals, comparing actual performance to these standards (the performance measurement) and taking appropriate corrective actions. To measure performance, two basic aspects must be assessed: efficiency (are things done right?) and effectiveness (are the right things done?).

1.4 Efficiency and effectiveness

Efficiency is the best possible use of all resources (scarcity of resources) – products are manufactured at the lowest possible cost.

Effectiveness means the accomplishment of proper goals (a producer manufactures a product that is required by customers).

It is possible to be efficient yet ineffective at the same time and also to be effective and inefficient simultaneously. Managers must balance efficiency and effectiveness.

1.5 Management as a decision making process

Planning, organizing, directing and controlling are realized through the decision making proces.

Management decision making is a proces o identifying a problem or opportunity, developing alternative ways to address it, and selecting the best alternative.

The core of the management proces is summarized in the Fig. 1.24.

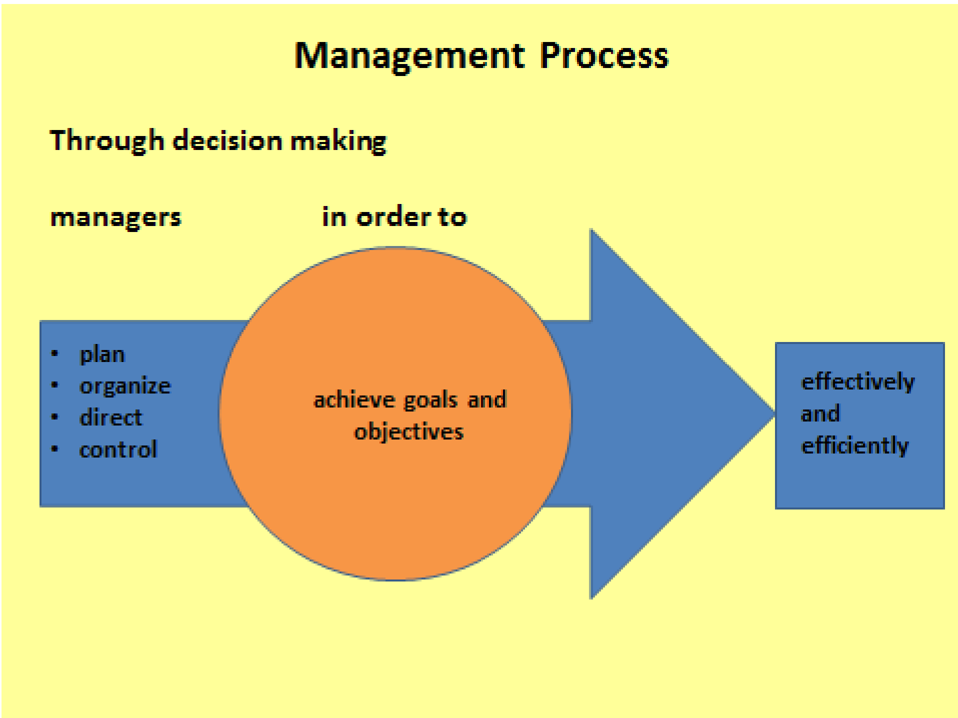


Fig. 1.24 The management proces [23]

Time to reflection

- Try to define examples of the situation when the proces is effective but not efficient, and vice versa.
- What was the historical development of the division of labour?

Task

- Study in more detail the contents of the management functions and give examples of their realization.

Summary of terms

- Controlling
- Decision-making
- Directing
- Division of labour
- Effectivity
- Efficiency
- Management
- Management functions
- Organizing
- Planning

Questions

- What is management?
- Why is it so important?

- What are the main management functions?
- Explain the management process as a decision making proces.
- What is planning?
- What is organizing?
- What is directing?
- What is controlling?
- What is effectiveness and efficiency of the process? Give several examples.
- How to balance these two aspects?

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2. MANAGEMENT EVOLUTION

Time to study

480 min

Goal

after studying this chapter

- you will understand the development of manufacturing,
- you will reveal the consequences of this development,
- you will understand the circumstances of chaging the manufacturing paradigms,
- you will be familiar with various managerial theories, paradigms, and approaches,
- you will understand the differences between various managerial paradigms and approaches,
- you will be able to formulate advantages and disadvantages of different managerial paradigms and approaches,
- you will understand the necessity of the managerial paradigm shift.

Lecture

2.1 Managerial theories and approaches

The birth and evolution of the modern management as a specific management activity and scientific discipline relate to the second phase of the industrial revolution at the turn of the 19th century.

Most researchers divide the evolution of management into four phases:

Phase 1 – the end of the 1900s – the 1930s

Phase 2 – the 1940s – the 1970s

Phase 3 – the 1980s – the end of the 20th century

Phase 4 – the 21st century

The beginning of Phase 2 relates to the world economy crisis in the 1930s and the oil crises in the 1970s announcing the age of discontinuity are considered to be the turning point of Phase 2 and 3.

A summary of the main theories and approaches to management through these phases can be seen on Fig. 2.1.

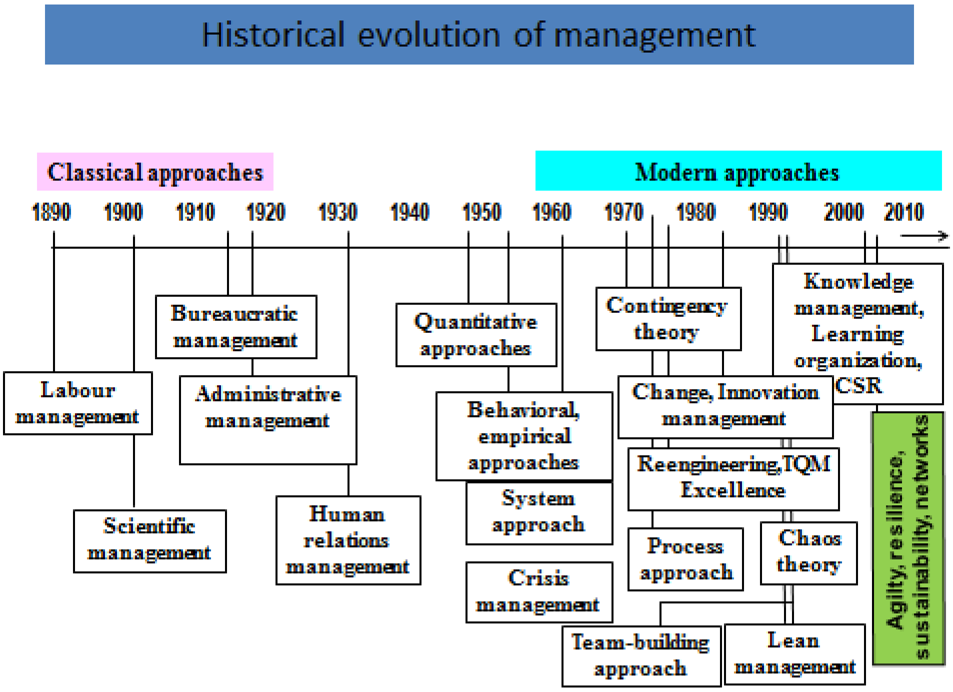

Fig. 2.1 Evolution of management

Since the beginning of the production of products a services, a competition has been accompanying it. To face a competition, people tried to develop various technological and managerial paradigms and models. The technological models have been enabling human society to develop advanced technologies. The managerial ones have been anabling to adopt various styles of managing organizations to manufacture products and offer services. Until the era of the industrial revolution, these models were developed very slowly (people used simple technological models and for centuries, they were adopting so called craftsmanship production paradigm as a managerial model). The quick development of the first and 2nd industrial revolution largely accelerated by the application of machines and electric power enabled people to produce large quantities of products consuming comparatively less time. This led to the situation when a single man or family was not able to realize the whole production process and not all people had talent and knowledge to manufacture every product offered by the firm. Struggling to find solution for these problems, the management guru

Taylor, who emerged at the beginning of the 20th century, proposed his scientific management principles [1]. In response to these principles, large organizations with large number of empleyees and high quantum of resources were established and divided into departments; the division of labour and deep specialization started to be a motor of achieving higher productivity and profits. Since this theory offered solution of challenges evocated by the industrial revolution, the Taylor´s principles were formalized and developed by other scientists (Fayol, Gantt, Gilberth [1]). During the 20^{th} century, the production paradigm based on the Taylor´s principles enabling manufacturing large quantities of products was called “mass production”. We can say that the first entrepreneur, who truly integrated an entire production process combining the ideas of interchangeable parts, production lines, and work standardization, was H. Ford [1]. By the middle of the 20^{th} century this paradigm has been increasingly adopted by many organizations. But with the growth of competition during the 1970s linked to the oil crisis and invasion of the Japanese products of the high quality and low price into the world market, it was evident that the mass production and its detection-based approach to the quality are not able to succeed in such competition. The Japanese prevention-based approaches based on the employee involvement-oriented continuous quality improvement approach and ideas of TQM (total quality management) originated in the 1950s, recommended by the quality gurus (Deming, Juran, Ishikawa, Feignbaum, Taguchi [2]) gradually penetrated into the practice of organizations. The quality was adopted as the competition weapon. Organizations began to involve all levels of employees and departments into continuous quality improvement regarded as the responsibility of all employees, all departments, and functions of the organization. But continuing competition revealed that TQM alone would not support the producers to face the stronger and stronger competition. TQM provided only very broad guidelines for management. Guidelines so abstract and general that only the most gifted leaders were able to unite together a successful deployment strategy for TQM. In spite of the fact that organizations that succeeded in successfully implementing TQM reaped substantial rewards, the low probability of success deterred many organizations from trying to apply TQM. Instead, over million organizations opted for quality management standard ISO 9000 (the first initial version was published in 1987; revised versions were issued in 2000 and 2008). On the contrary to TQM, ISO provides clear criteria and a guarantee that meeting these criteria will result in recognition. However, ISO 9000 promises not world-class performance levels, but “standard” performance. Organizations striving for being the best in competition accept the Six Sigma methodology developed by Motorola engineers and managers [3], who had a single goal in mind: to make their businesses as successful as possible (Six Sigma is often defined as a dynamic, problem-solving program). Compared to TQM, Six Sigma makes it easier for organizations to succeed by providing a clear roadmap for success. As a direct effect of the Japanese competitiveness in 1980s, efficiency of the processes started to be looked for more intensively through Japanese approach again called Toyota production system (TPS) – the system designed to resolve problems of the mass production in the higher variety production, focused on the elimination of waste in all processes through the continual improvement [4]. The Toyota production system or just-in-time (JIT) system has been developed to offer better flexibility via the concept of pull system. JIT production depends on actual customer demand activating the release of orders into the system to meet this demand. The JIT philosophy emphasizes making the right products in the right amount at the right time. JIT leads to eliminating excess inventory, shortening the production lead-time and increasing quality in both products and customer service. Various consultants in the west began to try to introduce their versions of the TPS under westernized names such as World Class Manufacturing, Continuous Flow Manufacturing, or Stock-Less Production.

Its world-wide application came with the Womack book "The Machine That Changed the World" published in the 1990s [5]. In this publication, the author consolidated tools and techniques used in the Toyota production system and called it Lean Manufacturing (some experts called it the lean manufacturing paradigm). Lean manufacturing enables to drive the cost of production down and achieve process flexibility in order to produce high quality products in greater variety. Lean manufacturing can be considered a comprehensive philosophy where employees continue to strive for improvement to eliminate all non-value added activities.

However at the end of the 20th century, when excess of supply over demand, limitations of the resources, and quickly changing customer requirements unprecedently sharpened the competition, rather than focus on internal structure and processes alone, competitive advantage started to tend to quick change capabilities. The practice showed that lean production in its traditional form lacks the robustness to absorb shocks in a dynamic turbulent environment. Although JIT or lean manufacturing has a significant impact to improve the production efficiency, its system performance measures are limited to steady-state conditions. Only cost and quality are no longer sufficient for customer retention and loyality or for a sustainable competitive advantage.

In the 21st century, due to the highly fluctuating market demand and the frequent change of product designs mentioned above, to stay competitive in this global market, manufacturing companies must possess a new kind of manufacturing system that can be very responsive (responsive manufacturing systems) to volatile global markets, and to be agile, sustainable and resilient. Agile manufacturing can be defined as the “capability of reacting to unpredictable market changes in a cost-effective way, simultaneously prospering from the uncertainty“ [6]. As contrast to the mass production, where goods are produced to stock and sell, agile manufacturing produces to order [7]. This is accomplished by the continuous process improvement, waste elimination and rapidly introducing product innovation in response to market changes [8]. As it can be seen from the last sentence, the agile incorporates some lean thoughts. Therefore, some experts reccommend to merge lean and agile and this approach is called leagile.

2.2 Production paradigms

In this subchapter, various production paradigms will be described.

Definitions of paradigm

- It is a way we see the world – not in terms of our visual sense of sight, but in terms of perceiving, understanding, interpreting .
- It is a mental model of manufacturing and its management
- It is a conceptual framework for production and its management.
- It is a fundamental model or frame of reference that we use to organize our observations and reasoning about manufacturing and its management.

Classification and description of production paradigms

In literature, the following classification of paradigms of manufacturing can be found [9] .

- Craft Production
- Mass production
- Mass customization
- Personalization

Their evolution based on the volume-variety criteria can be depicted as follows (Fig. 2.2).

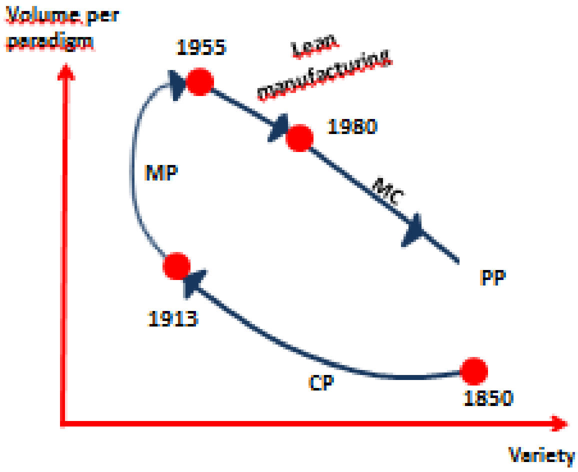

Fig. 2.2 Evolution of production paradigms [9]

1. ***The craft production*** (Fig. 2.3) was based on the hand-made tailored products for the concrete customer but at a high cost.

Fig. 2.3 Production of violins

Source: [10]

2. ***The mass production*** corresponds to the 2nd industrial revolution (see chapter 2.3). The key science, system and technology enablers of this paradigm are:
   - parts interchangeability
   - moving assembly lines
   - scientific management theory (division of labour).

Such a mass production system is very inflexible and it is not responsive to changing customer demands. The mass production relies on forecasting the future customer demand and scheduling the release of orders. Goods are produced to stock and sell. This system often results in high work-in-process levels and excess of inventories of fihisned goods. An example of the mass production is shown in Fig. 2.4.

Fig. 2.4 Mass production of airplanes
Source: [11]

The mass customization paradigm was an answer to the rising demand for product variety as a result of the market segmentation and global competition in the late 1980s, which could not be solved by the mass production.

Mass customization is enabled by several conceptual and technolgical enablers:

- product family architecture PFA
- reconfigurable manufacturing systems RMS
- delaying differentiation DD

PFA enables the producer to develop a product family strategy where certain functional modules are shared and others are produced in several variants each, so the final assembly can offer high variety of the output. A customer can select the combination of different module variants to obtain customized product. RMS enables rapid changes in its structure and control to adjust its production capacity and functionality within a part family in response to sudden market changes [12]. DD enables managing high variety in the manufacturing systems. The main idea of this concept lies in having common processes and assemblies up to the point of differentiation. This paradigm removes the main shortage of the mass production by providing high variety of products to the customer but at the cost of complexity of the assembly systems. In addition, the role of the customer is reduced to choosing the module combination.

3. ***Personalization paradigm***

The everpresent Internet, computers and responsive manufacturing systems represent an opportunity to change for anotherparadigm of product realization based on the personalization of products tailored to the individual needs and preferences of consumers. Customers create innovative products and realize value through collaboration with manufacturers and other customers. Enablers of these co-design activities are open product architecture, on-demand manufacturing systems, and responsive cyber-physical systems involving the user participation in design, product simulation/certification, manufacturing, supply and assembly that quickly meet consumer needs and preferences [13].

- *Open architecture products*

  Compared to the product family design methodologies for the mass customization based on products that consist of common modules and customized modules, a personalized product will have an open architecture with three types of modules: common modules shared across the product platform; customized modules allowing customers to choose, mix and match; personalized modules that allow customers to create and design. Product architecting is to determine what modules will be common, customizable, and personalizable in relation to manufacturability and cost.

- *On-demand manufacturing system*

  To be really responsible to the customer demand, the manufacturing system has to provide flexibility in producing personalized modules and assembling them with other manufacturer supplied modules. Additive manufacturing (Fig. 2.5) can play an important role in achieving such goals.

Fig. 2.5 3D Printing

Source: [14]

- *Cyber-physical systems* are based on synergy of computional and physical components (Fig. 2.6)

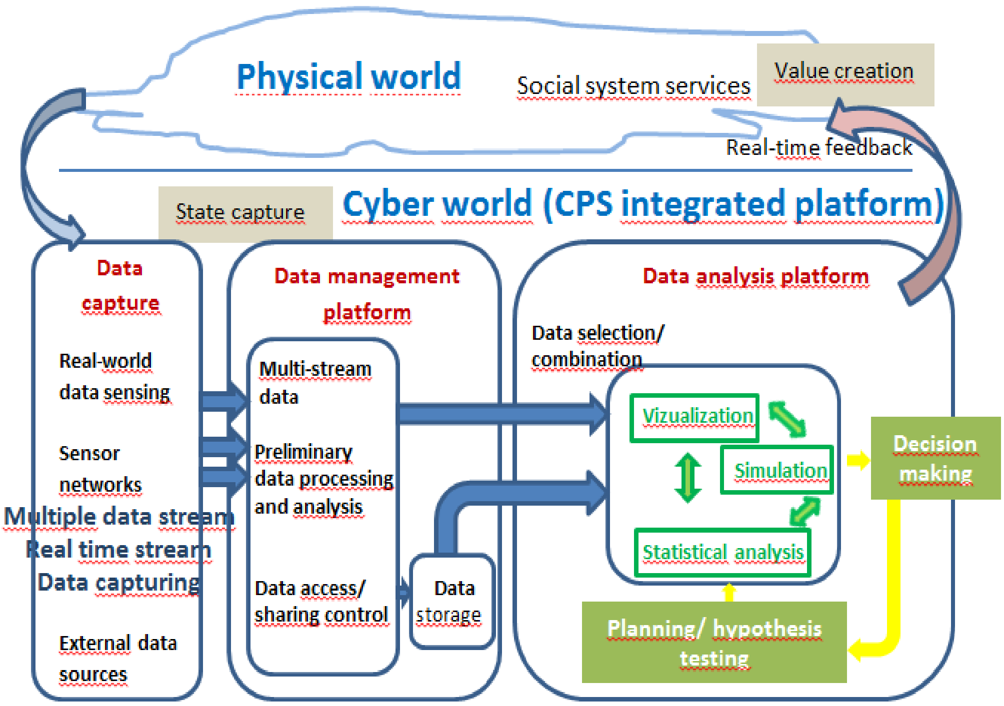

Fig. 2.6 Architecture of cyber-physical system [15]

The main differencies between the mass production, mass customization, and personalized production are summarized in Tab. 2.1 [9].

Table 2.1 Differences between the managerial paradigms

	Mass Production	Mass Customization	Personalized Production
Production goal	Scale	Scale Scope	Scale Scope Value
Desired Product Characteristics	Quality Cost	Quality Cost Variety	Qality Cost Variety Efficacy
Customer Role	Buy	Choose Buy	Design Choose Buy
Production System	Dedicated	Reconfigurable	On-demand

Every production paradigm has economical implications [16]. Fig. 2.7 shows relations between the cost per a produced unit and production volume in connection to the above compared production paradigms (also pay attention to the problem of economy of scope and the ocomony of scale). As it can be found, the mass customized products are produced in small amount with competitive price comparing with product produced in huge quantity.

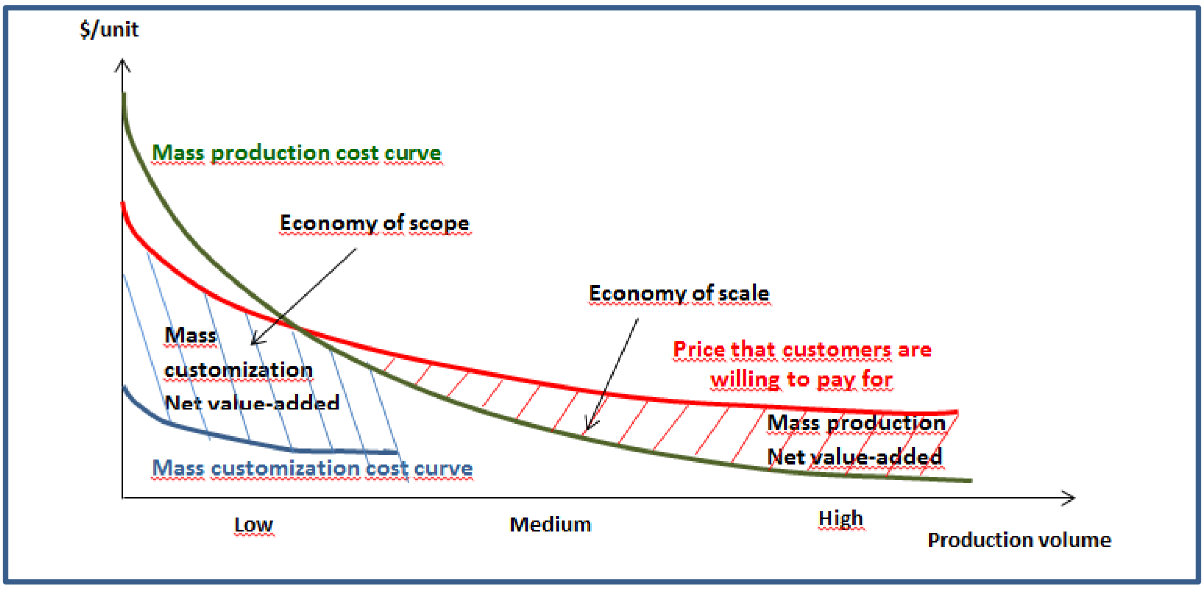

Fig. 2.7 Economic implication of mass production [16]

The economic and managerial literature of the 1990s and of the befinning of the 21st century presents the "sustainable development paradigm" ([17], [18]), which has wider and more complex opinion of the human development than the other paradigms. The sustainable development is a development that meets the needs of the present without compromising the ability of the future generations to achieve their own needs. Sustainable development implies economic growth together with the protection of the environmental quality, each reinforcing the other. The essence of this form of development is a stable relationship between human activities and the natural world, which does not diminish the prospects for the future generations to enjoy a quality of life at least as good as at present [19]. The paradigm with similar goals was defined by Tomiyama [20] and called the "post mass production paradigm". This paradigm aims at qualitative satisfaction rather than quantitative sufficiency and advocates sustainable production by separating economic growth from the material and energy consumption. This means reduction of the volume of manufactured products and manufacturing of adequate production, adequate consumption, and zero waste while maintaining and improving the quality of life. Reduction of the production volume while maintaining economic activities can be achieved by the life cycle strategies applying processes such as refurbishing, remanufacturing, recycling, or discarding [21].

2.3 Industrial revolutions

The principal changes in technology connected to the industry development are called industrial revolutions. The development of industrial revolutions over time is depicted in Fig. 2.8.

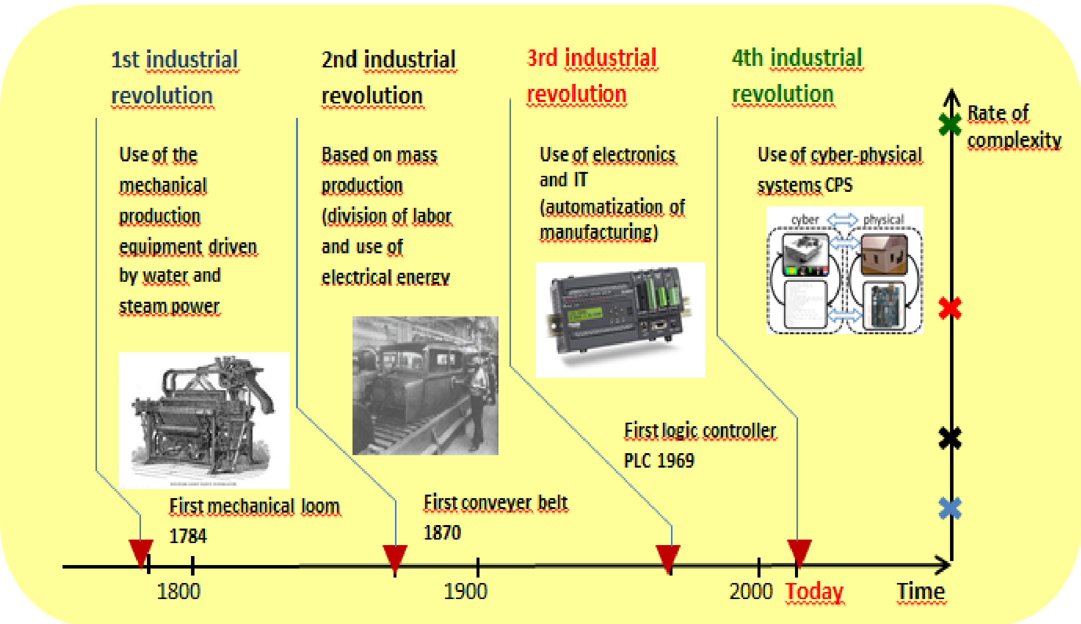

Fig. 2.8 Industrial revolution over time – summary [22]

- The first industrial revolution (1760 - 1840) was the transition from hand production to manufacturing methods based on the machines driven by water and steam power (Fig. 2.9).

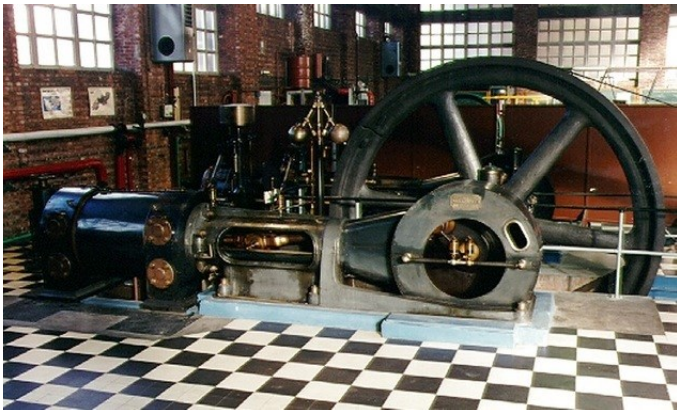

Fig. 2.9 Steam Engine

Source: [23]

- The second industrial revolution (the end of 19th century – 1914) was characterized by the transition from steam power to electric power as the main power source in industry (Fig. 2.10).

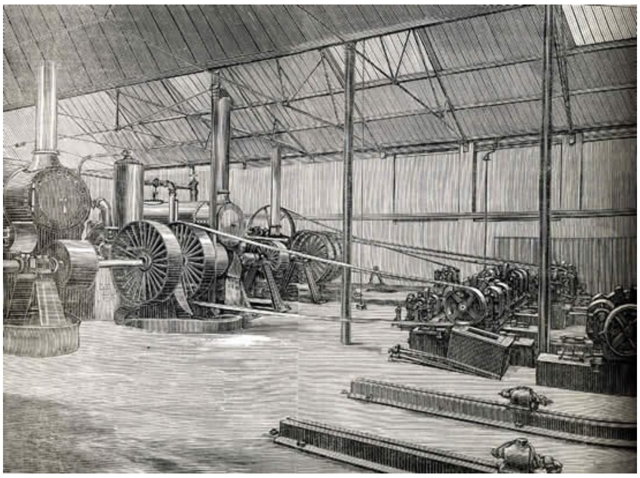

Fig. 2.10 Earliest power station

Source: [24]

- The third industrial revolution (Digital revolution, the latest 1950s – the late 1970s) is represented by the transition from analog, mechanical, and electronic technology to digital technology (Fig. 2.11).

Fig. 2.11 Digital technology

Source: [25]

- The fourth industrial revolution (also called Industry 4.0) is based on the *cyber-physical systems* (CPS), the *Internet of things* (IoT) and the *Internet of services* (IoS). CPS monitor physical processes make a virtual copy of the physical world and make decentralized decisions. Over the IoT the CPS communicate and cooperate with each other and humans in real time. Through the IoS, internal and cross-organizational services are offered and utilized by participants of the value chain (see Fig. 2.12).

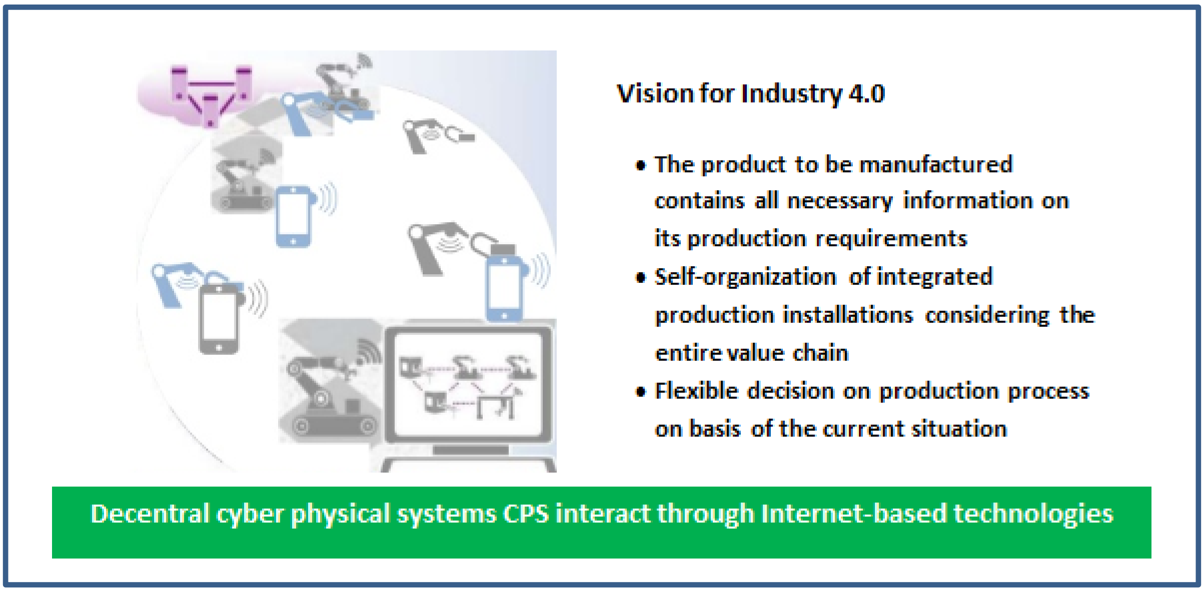

Fig. 2.12 Vision of the 4th industrial revolution [26]

The real manufacturing world is converging with the digital manufacturing world to enable organizations to digitally plan and project the entire lifecycle of products and production facilities. The factory of the future – the smart factory (Fig. 2.13) – is a paradise of efficiency where defect and downtime, waste and waiting are forgotten problems.

Fig. 2.13 Smart factory

Source: [27]

Six design principles for implementing Industry 4.0 are as follows:

- ***Decentralization***: the ability of CPS within Smart Factories to make decisions on their own.
- ***Interoperability***: the ability of CPS (transportation means, assembly stations, and products), humans and Smart Factories to connect and communicate with each other using the IoT and the IoS.
- ***Modularity***: flexible adaptation of Smart Factories to changes in requirements by replacing or expanding individual modules.
- ***Real-Time Capability***: the capability to collect and analyse data and provide the derived conclusions immediately.
- ***Service Orientation***: offering services (of CFS, humans or Smart Factories) using the IoS.
- ***Virtualization***: creation of a virtual copy of the Smart Factory by linking sensor data (from monitoring physical processes) with virtual plant models and simulation models.

Time to reflection

- What is the role of competition and technological changes in the economical development?
- What is the difference between economy of scope and economy of scale?

Tasks

- Study problems of the social manufacturing, the cloud-based manufacturing and crowdsourcing, wikinomics yourself. What are the differences?
- Study the principles of sustainability and resilience yourself.
- Find practical examples of the mass production, mass customization, smart factory.
- Discuss the role of innovations and sustainability in the post-mass paradigms.

Summary of terms

- Administrative management
- Agile manufacturing
- Bureaucratic management
- Competition
- Contingency theory
- Craft production
- Crisis management
- Cyber-physical system
- Dedicated production system
- Delaying differentiation
- Economy of scope
- Empirical approaches
- Eonomy of scale
- Flexible manufacturing system
- Globalization
- Human relations management

- Change management
- Chaos theory
- Innovations management
- Internet of Services
- Internet of things
- JIT
- Leagile manufacturing
- Lean manufacturing
- Mass customization
- Mass production
- Moving assembly line
- On-demand production system
- Open architecture products
- Parts interchangeability
- Product family architecture
- Production paradigm
- Quantitative approaches
- Quick response
- Reconfigurable manufacturing system
- Responsible manufacturing
- Scientific management
- Smart factory
- System approach
- Team-building approach
- Total quality management
- Toyota production system
- Wikinomics

Questions

- What is the political and economical frame of the Phase 1 of the modern managment evolution?

- What are the main benefits and limitations of the scientific management?
- Who represents scientific management?
- Who represents other classical approaches to management?
- What were the main political, economical, and social reasons for changes in the management approaches after the Second World War?
- Define these changes of management.
- What were the main changes leading to Phase 3 of management evolution?
- What trends led to the beginning of Phase 4 of management evolution?
- Where do you put P. Drucker? What was his contribution to management?
- What is the main contribution of the chaos theory?
- What is the main contribution of T. Saaty, A. Sloan, P.Senge, R. Waterman, J. A. Schumpeter?
- What is the basis of the 3rd and 4th industrial revolutions?
- What is the social manufacturing?
- What is the principle of cloud-based manufacturing, crowdsourcing, wikinomics?
- What were the main factors leading to the mass production?
- Define parts´ interchangeability.
- What was the role of the Taylors scientific management in the mass production development?
- What are the advantages and disadvantages of the mass production?
- What are the main ways to ovecome limitations of the mass production?
- What are the main differences between the mass production, mass customization, and personalized production?
- What are the relations between the production paradigms and lean and agile manufacturing?
- What industrial revolution do you know and what is the breif characterization for each of them?
- What do you think about the future of the large industrial companies?
- What changes of an industrial organizations must be expected?
- What is the future of the quality assessment?

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3. LEAN MANUFACTURING

Time to study

600 min

Goal

after studying this chapter

- you will understand the historical place of lean manufacturing (production) in the development of management and conditions for its correct practical implementation;
- you will reveal differences between the Japanese TPS approach and Western approach to the lean management;
- you will know all principles of the lean management and the ways how to apply them in practice;
  you will find links between the lean principles and lean tools.

Lecture

3.1 Overview

The lean approach is widely considered to be the next big step in the evolution of manufacturing beyond Ford's mass production. It has gone beyond the mass production of automobiles to numerous types of manufacturing products and providing services: chemical processing, pharmaceuticals, nuclear fuel, ship and aircraft construction, medical products, construction industry, shoe making, sewing, banking and insurance services, health care, postal services, and others.

The history of the lean manufacturing goes back many centuries, well before Ford's famous production lines for the model T Ford; however it really began as the philosophy that we know today with Toyota and the development of the Toyota Production System (TPS). Toyota Motor Corporation set out the goal to be far better than Ford and the rest of the US

Automobile Industry. This ambition was quickly achieved by Toyota despite of a lack of resources and infrastructure. Company achieved this aim through the application of lean principles and many lean manufacturing tools. TPS were initiated by T. Ohno and S. Shingo focusing on the systematic efficient use of resources via level scheduling. The lean production provides a way to do more and more with less and less stock, less human effort, less material movement, less equipment, time and space and providing customers exactly with what they want. The term lean production was first coined by John Krafcik in his article "Triumph of the Lean Production System" [1]. Krafcik had been a quality engineer in the Toyota-GM *NUMMI* joint venture in California before coming to MIT for MBA studies. Krafcik's research was continued by the International Motor Vehicle Program (IMVP) at MIT, which issued the international best-selling book by J. Womack, D. Jones, and D. Roos called "The Machine That Changed the World" [2]. The lean approach represents a better way of managing production systems compared to the mass production.

The lean approach can be described as a strategy based on cost reduction and flexibility, focused on the process improvements via systematic identification and reduction of all ”wastes“ (non-value adding operations (muda)), results of unevenness in workloads (mura), and results of overloading (muri)) in order to create value for the customer . It can be said that lean manufacturing is all about minimizing costs. ”Lean“ means relatively small amount of money, invested into raw materials, work-in-process, and finished-goods inventory at any given time. Inventory costs are minimized via efficient purchasing and distribution systems that apply inputs just as they are needed, and send finished goods just as they are ordered. It also focuses on the organization´s core competencies whereas outsourcing many other productive activities. The concept of continuous improvement and waste reduction is considered to be a source of cost control factors. Lean production is not just a technological system but also a concept implemented through the whole company, which especially requires consensus on corporate culture [3].

The lean approach performs better when there is high volume, low variety, and predicable demand with certain supplies. In high variety and volatile supply chains where requirements of customers are unpredictable, a higher level of agility is asked for.

The main goals of lean manufacturing are as follows:

- Reduce total cost
- Eliminate waste
- Improve quality

- Reduce time

3.2 Definitions of basic terms

In this paragraph, definitions of the main lean terms are mentioned.

➢ **Definition of lean manufacturing (lean production, lean)**

- Lean manufacturing is a strategy based on a culture of continuous improvement, everyone´s seeking to identify and eliminate waste, enabling the business to deliver customer expectations at minimal cost and lead time.
- Lean manufacturing is a well-known production philosophy that focuses on optimizing processes through a continuous improvement. It includes JIT and TQM.
- Lean manufacturing is an approach that drives out waste, increases value to customers, improves profitability and competitiveness using tools and techniques that focus on teamwork and problem-solving methodologies.
- Lean is a systematic approach of eliminating waste in order to add value for the customer in every step.
- Lean production is a multi-dimensional approach that encompasses a wide variety of management practices, including JIT, quality systems, work teams, cellular manufacturing, supplier management, etc. in an integrated system. The core thrust of lean production is that these practices can work synergistically to create a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste.
- Lean manufacturing provides total satisfaction to the customers by pulling value from the value stream when required by these customers using the minimum amount of resources. This is achieved through the involvement and respect of all employees, and it is a never ending journey towards perfection.
- It is a systematic approach to finding and eliminating the root causes that lead to the waste found in all organizations.

➢ **Definition of value**

- Value is a capability provided to a customer at the right time at an appropriate price, as defined by the customer.
- A capability provided to a customer

– of the highest quality,
– at the right time,
– at an appropriate price
as defined by the customer.

- Value is what the customer is buying

- **Definition of waste**
  - Waste is any activity that consumes time, resources, or space but does not add any value to the product or service.
  - Waste is anything that happens to a product that does not add value from the customer´s perspective.
  - Waste is anything other than the absolute minimum resources of materials, machines, and manpower required to add value to the product.
  - Every activity should be considered to be waste unless it
    - meets an explicit customer requirement;
    - cannot be shown to be performed more economically.

- **Definition of value stream**
  - Value stream represents all the steps and processes required to bring a specific product from raw materials to a finished item in the hands of the customer.

- **Definition of flow**
  - Moving products through a production system without separating them into lots.

- **Definition of pull**
  - The pull system is a production method in which the production of an item starts only when there is actual demand from a customer.

- **Definition of a value added activity (VA)**
  - An activity that meets all three of the following criteria: 1) the customer is willing to pay for this activity; 2) it must be done right the first time; 3) the action creates the form, feature, or function of the product or service in some manner.

➢ **Definition of a non-value added activity NVA**

- An activity that increases the time spent on a product or service but does not increase its worth to the customer. It does not create the form, feature, or function of the product or service in any manner.

➢ **Definition of a business non-value added activity NVA**

- An activity that is required by legislature or activity necessary for working of an organization that adds no value from the perspective of the customer.

3.3 Toyota Production System and its principles

Toyota Production System (TPS) was developed by T. Ohno [4] in the 1950s when Japanese producers were trying to catch up with the Western ones. The productivity in Japanese firms was significantly lower compared to the American ones. It evoked the development of TPS. The objective of a new approach was to produce a variety of models of cars in low volumes. It was quite different from the prevailing mass production paradigm goals. TPS was not created overnight. It was the result of 10 years of improvement and development activities. The central concept of TPS is to reduce costs by eliminating waste. Two main pillars of TPS are JIT and Jidoka (autonomation). Techniques like Kanban, TPM kaizen, SMED, 5S, and Poka-joke support these two pillars. The goals, principles and methods of TPS can be depicted as the TPS house (see Fig. 3.1).

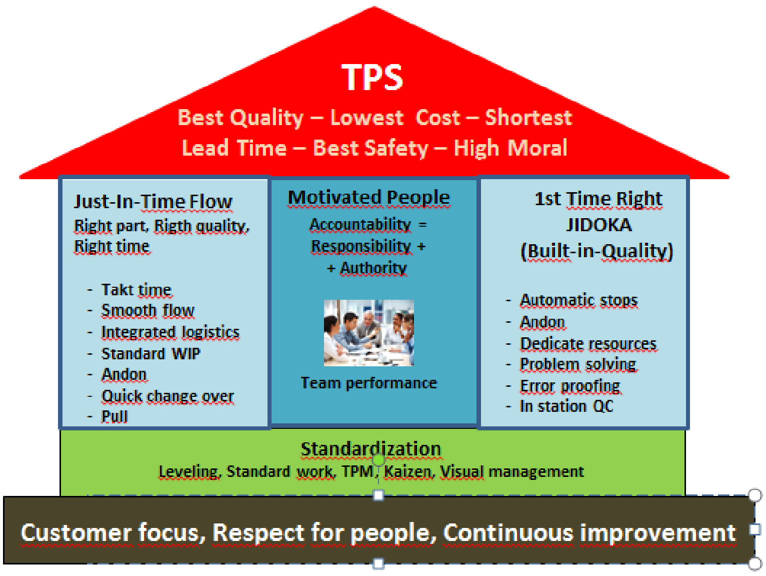

Fig. 3.1 TPS house [4]

TPS is based on 14 principles that can be divided into 4 fields forming so called 4P model.

4P model

The four Ps are Philosophy, Process, People/Partners, and Problem Solving – see Fig. 3.2.

Fig. 3.2 4P Model [5]

Philosophy

Toyota's leaders have seen the company as a vehicle for adding value to customers, society, the community, and its associates. It sets the foundation for all the other principles.

Process

Toyota leaders have learned that when they follow the right process, they get the right results.

People and Partners

TPS was at one time called the "respect for humanity" system. It does not mean only creating a stress-free and employee friendly environment, but also creating challenging environment that forces people to think and grow.

Problem solving

It means continuous solving the root problems to drive organizational learning. There are always opportunities to learn. A solver is expected to share the problem and its solution with others facing similar problems so that the company can learn.

In Tab. 3.1 the 4P model is unrolled into 14 principles.

Table 3.1 14 principles of TPS

Field	Principle
Philosophy	***Principle 1*** Base your management decisions on a long term philosophy, even at the expense of short-term financial goals
Process	***Principle 2*** Create continuous process flow to bring problems to the surface ***Principle 3*** Use the "Pull" system to avoid overproduction **Principle 4** Level out the workload (heijunka). (Work like a tortoise, not the hare) ***Principle 5*** Build a culture of stopping to fix problems, to get the quality right at the first time ***Principle 6*** Standardized tasks are the foundation for continuous improvements and employee empowerment ***Principle 7*** Use Visual Control so that no problems were hidden ***Principle 8*** Use only a reliable, thoroughly tested technology that servers your people and process
People/Partners	***Principle 9*** Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others. ***Principle 10*** Develop exceptional people and teams who follow your company's philosophy ***Principle 11*** Respect your extended network of partners and suppliers by challenging them and helping them improve
Problem solving	***Principle 12*** Go and see for yourself to thoroughly understand the situation (Genchi Genbutsu) ***Principle 13*** Make decision slowly by consensus, thoroughly considering all options; implement decisions rapidly ***Principle 14*** Become a learning organisation through relentless reflection (Hansei) and continuous improvements (Kaizen)

Detailed information about these principles can be found in [7].

3.4 Lean principles

Based on the Japanese TPM, James P. Womack et al. introduced the systematic concept of lean production in their book titled "The Machine that Changed the World" [2]. Five lean principles accentuated in this book, having common essential concept of doing more and more with less and less are expressed as follows (see also Fig. 3.3):

1. Precisely specify value by specific product as perceived by the customer.

2. Identify the value stream for each product.
3. Make the value flow without interruptions.
4. Let the customer pull value from the producer.
5. Pursue perfection.

These lean principles can be used to define the aim of any lean system, which is to clearly specify value in order to line up all the activities for a specific product (family) along a value stream, and make the value flow smoothly at the pull of the customer in pursuit of perfection.

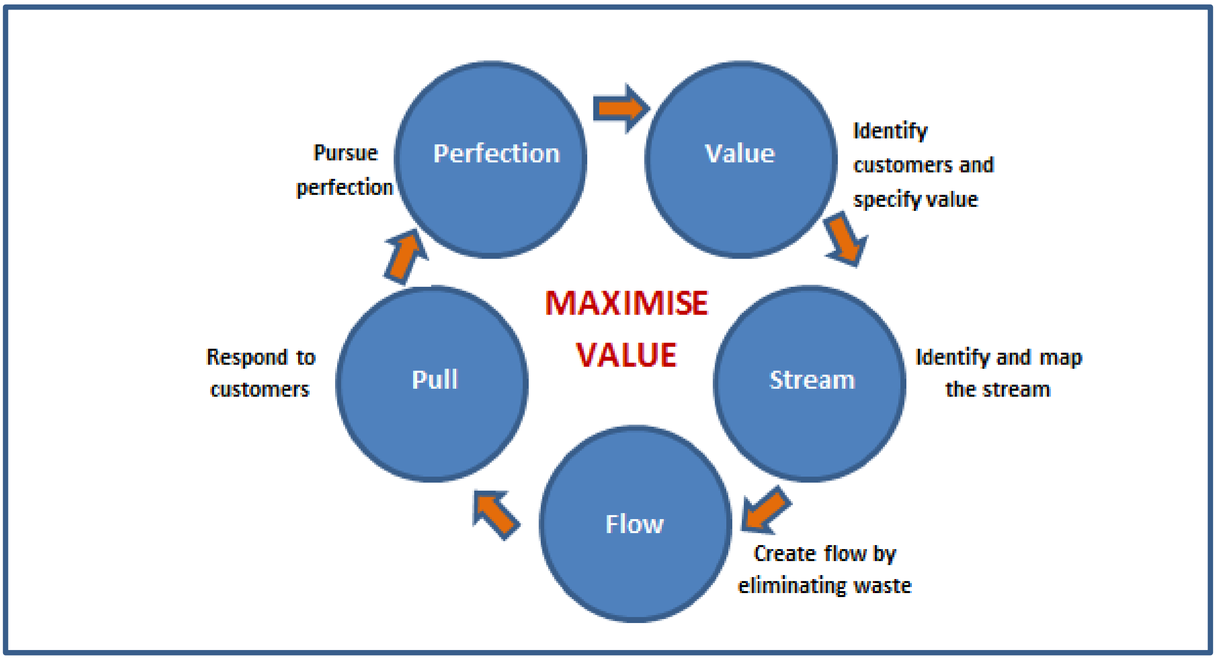

Fig. 3.3 Lean principles by Womack [8]

The principles offer a framework for developing strategies and plans that will result in lean processes and can be adapted for any type of organisation. Any organisation that does not realize these principles will probably not gain the full benefits from lean approach. Waste reduction programmes without customer input, for example, will not achieve the same level of improvement as efforts that include it. In fact, waste elimination practised in isolation can lead to customer dissatisfaction and the loss of profits or reduction in service levels. Continuous improvement must not be considered as isolated; such efforts achieve minimal gains that are often unsustainable.
Five lean principles put the customer at the heart of everything that producers do. Ensuring that the product or service produces added value for the customers helps to identify and

eliminate the non value adding and wasteful activities that come into delivering that product or service to that customer.

These lean principles can be used to define the aim of any lean system which is to "Clearly specify value in order to line up all the activities for a specific product (family) along a value stream and make the value flow smoothly at the pull of the customer in pursuit of perfection." A basic explanation of these principles can be found in Fig. 3.4**.**

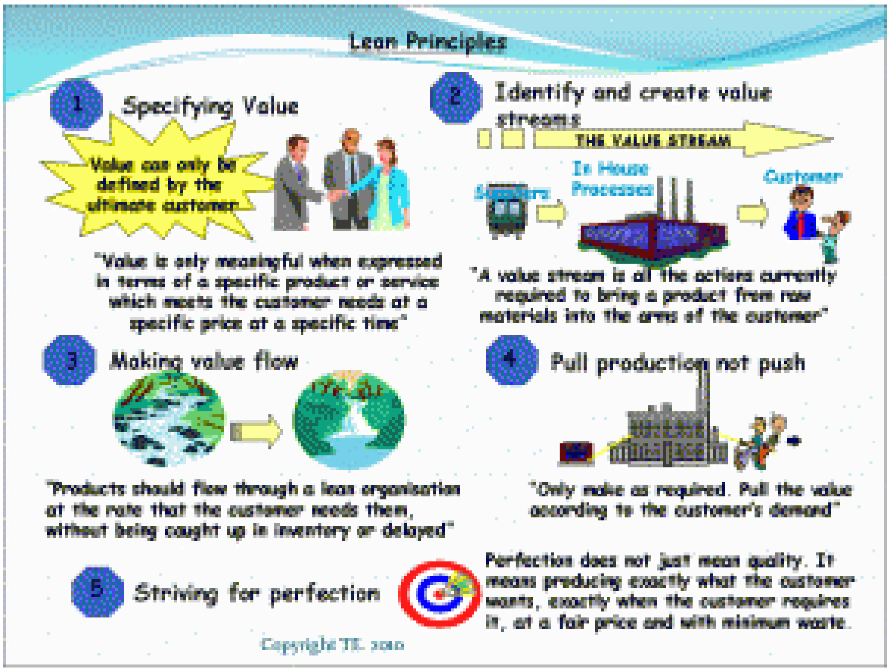

Fig. 3.4 Graphical depiction of 5 lean principles

Source: [9]

It must be underlined that although these principles form the backbone of lean manufacturing, they are achieved through respecting and involving workforce in every aspect of the business.

Many definitions express "lean" as being about eliminating waste, but lean is more about preventing waste. Implementing the lean principles defined above, identifying those actions that add value and making them flow at the pull of the customer prevents the waste from occurring. Lean should not be a hunt for waste it must be a journey to add value. Whilst lean manufacturing has a huge toolbox of tools and techniques, you cannot define lean manufacturing from those tools. Lean is more than the sum of all of those tools; applying tools in isolation will not necessarily bring the expected and required benefits.

Principle 1 - Precise specification of value by specific product as perceived by the customer

This principle is about building a relationship around clear communication and shared understanding in a way that will allow the organization to deliver what corresponds to its customer needs. The starting point is to recognize that only small fraction of the total time and effort in organizations actually adds value for the end customers (not only consumers but also other stakeholders, such as the society, employees and shareholders). All non-value activities can only be targeted and removed through clearly defined value for a specific product or service from the end customers´ perspective (how the customer perceives the value). It means that value is defined by the customer, and it is meaningful only if expressed in terms of a specific product (quality) meeting the customers' needs at a specific price (cost) and at a specific time (delivery).

In other words, an organization needs to define exactly what it is that the customers want, not what it thinks the product is. For instance the customer wants quickly and safely cooked food, not necessarily a microwave oven, or the customer wants access to the Internet, not necessarily a desktop computer and so on. It is not about producers forcing what is most convenient for them onto the consumers.

Value

Value is something that the customer specifically wants and is prepared to pay for. Yet, organizations spend the majority of their time doing something other than adding value. Studies show that organizations tend to add value to a product or service only for 5 % of their time. The rest of the time is spent on wasteful pursuits; they are waiting, reworking, transporting, moving, and doing many of other wasteful things that the customer does not consider to be something that they should pay for. These are the wastes of lean and lean manufacturing implementation is to a large extent focused on seeking out these wastes in order to eliminate them. However, this often leads to a wrong way of lean implementation. Organizations need to seek out the value adding steps and make those as efficient and free of waste as possible. But looking for waste, they often tend to start working on improving processes that are wasteful and unwanted by the customer as such. They end up making non-value adding processes more efficient.

Identification of value

There are different ways to identify value and non-value adding steps. We here mention two tools: quality function deployment (QFD) – see Fig. 3.5 and value stream mapping (read more below in this chapter).

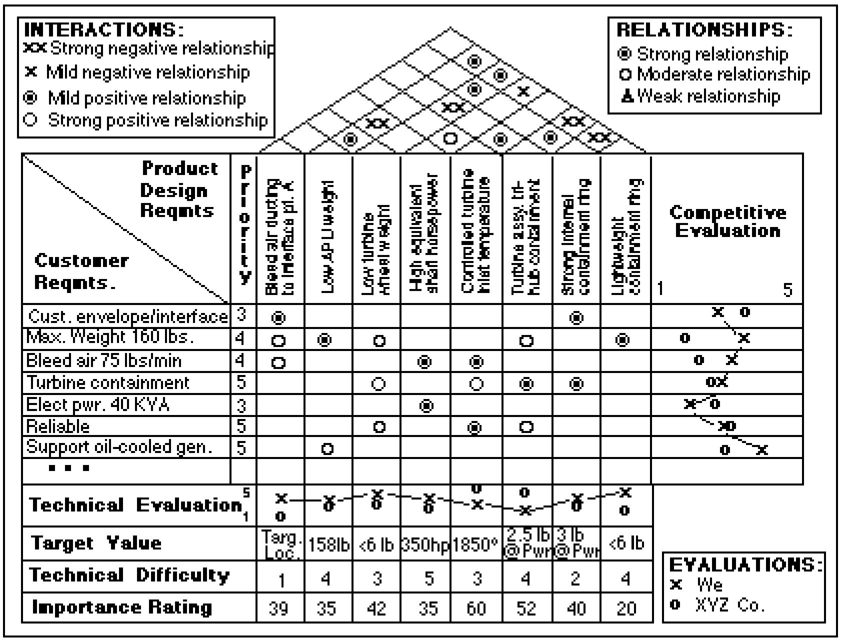

Fig. 3.5 QFD for defining value according to the customer

Source: [10]

Three dimensions of the customer satisfaction (QCD)

The customer satisfaction, however, comes down to three main areas: quality, cost and delivery (QCD). Which is the most important to your customer may depend on the product or service that is delivered. Somebody looking for a new sound system may prefer the quality first, while the customer that needs a new chair may want it tomorrow, not in 5 weeks. The person looking for a "consumable" R-DVD may only be motivated by the cost. Understanding customers´ needs is vital in being able to keep them fully satisfied. This means giving them the best quality, the right delivery time (which is not always immediate), and the right price.

In other words, lean approach is very much about providing quality; tools such as Poka Yoke and Kaizen are very much focused on ensuring that service and product quality are perfect.

Lean is also about delivery: Just in Time is about providing flow using Kanban systems to ensure that the customers get what they want when they want it. We use standardized working through 5S and keep our machines reliable through TPM to help achieve this.

Lean is also about cost: costs can be reduced by removing all non-value adding steps. In this context, it must be pointed out that this is the result of implementing lean. Lean is not "Just" a cost cutting machine to help improve profits without any thought of the customer!

Influence of value adding and non-value adding activities on the lead time

In manufacturing or service orientated processes, there are a series of steps that make up the total lead time to provide the customer with a product or service. This lead time is characterized by value added activities (VA) and non-value added (NVA) activities as shown on the picture below:

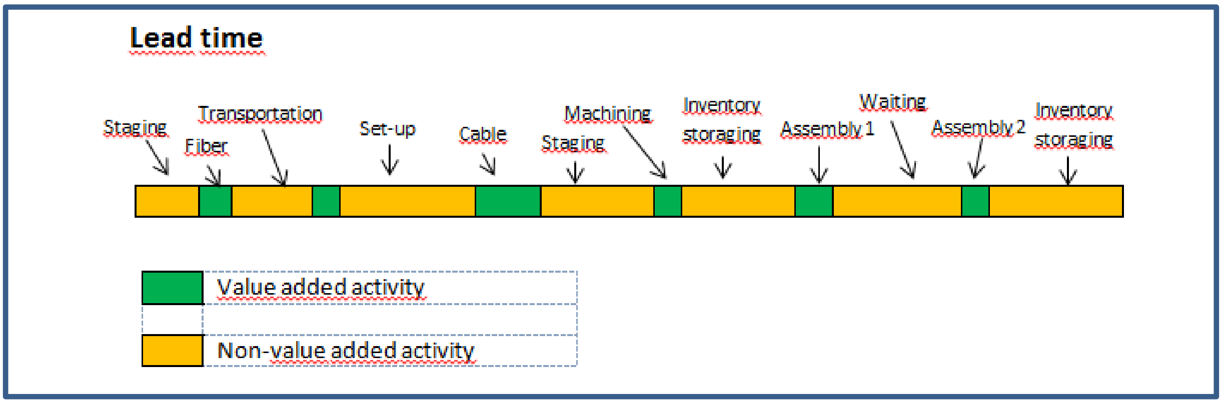

Fig. 3.6 VA and NVA [11]

Both types of activities take time and spent money but only VA earns money. The goal is to reduce non-values added activities (waste) so as to maximize the value to the customer. This value creating activity is the only activity the customer is willing to pay for. A non value adding activity essentially delays the time to complete the product or service. By focusing on reducing or eliminating non-value adding activities, the lead time to the customer can be shortened as shown in Fig. 3.7. This will result in lower costs, higher capacity for more demand, and increased customer satisfaction, which are all desirable aspects to help your business grow profitably. But it must be added, that NVA can be divided into two groups: 1. activities that create no value but are unavoidable due to current technologies or production methods or assets (sometimes called necessary business non-value adding or essential non-value-adding, or non-value adding required activities BNVA); they are likely to be difficult to remove in the short term, but it may be possible to eliminate them in the medium term by changing equipment or processes); 2. steps that create no value and are avoidable.

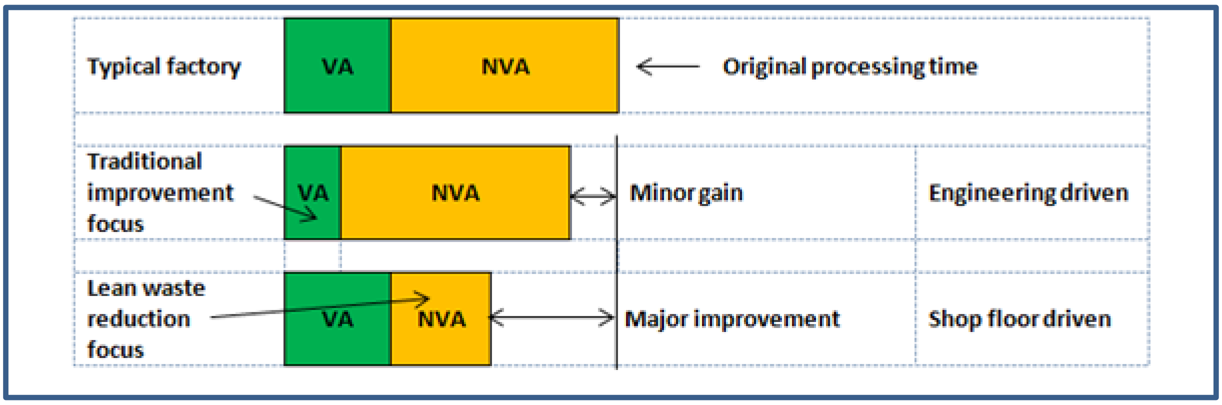

Fig. 3.7 Elimination of non-value adding activities [11]

In Tab. 3.2 some examples of VA, BNVA and NVA can be found.

Table 3.2 Examples of activities

VA **Goal: improving**	**BNVA (necessary waste)** **Goal: reducing**	**NVA (unnecessary waste)** **Goal: eliminating**
Designing / assembling products; Ordering raw materials; Preparing engineering drawing; Making informed decisions; Innovating	Activities evocated by regulatory requirements (legal regulators); Maintenance; Accounting	Rework; Shipping; Multiple signatures; Counting; Handling; Inspection; Setup; Downtime; Transport; Delay; Storage

Principle 2 – Identification of the value stream for each product

Once the organization understands what its customers want, the next step is to identify how it delivers (or not) to them. To be able to remove the waste from processes, it is essential that all the activities, across all the areas, involved in delivering that product or service are understood. Analysing the entire flow of a product will almost always reveal enormous amounts of waste and other non-value added activities. Value stream analysis will almost always show that all three types of activities occur along the value stream: steps that create value (VA); steps that create no value, but are unavoidable due to current technologies or production methods or assets (BNVA); and steps that create no value and are avoidable.

To become truly lean, not only the entire enterprise must analyse and improve the value stream as a whole. A lot of companies have a narrow vision of this approach. The obvious viewpoint is that lean can only work on the shop floor or operational aspects of the business.

That is the lowest form of lean. Other companies might know more and understand that they can improve effectiveness and efficiencies also in the support functions. However, both groups of organizations still have not been utilising the true potential of lean, and will therefore only achieve pockets of improvement. They forgot about the fact that they are only one of the supply chain partners that must work together to achieve shared goals. From this point of view the value stream starts with the first organization´s supplier and ends with its last customer. The integration of the value stream creates the virtual extended enterprise where everyone works together to ensure the continual improvement of their services to each other, reduce costs, reduce lead times, and improve quality as required. Very effective instrument for the analysis of the values stream is value stream mapping (an example of such map can be seen on Fig. 3.8 and the method is discussed in detail later in the chapter 4).

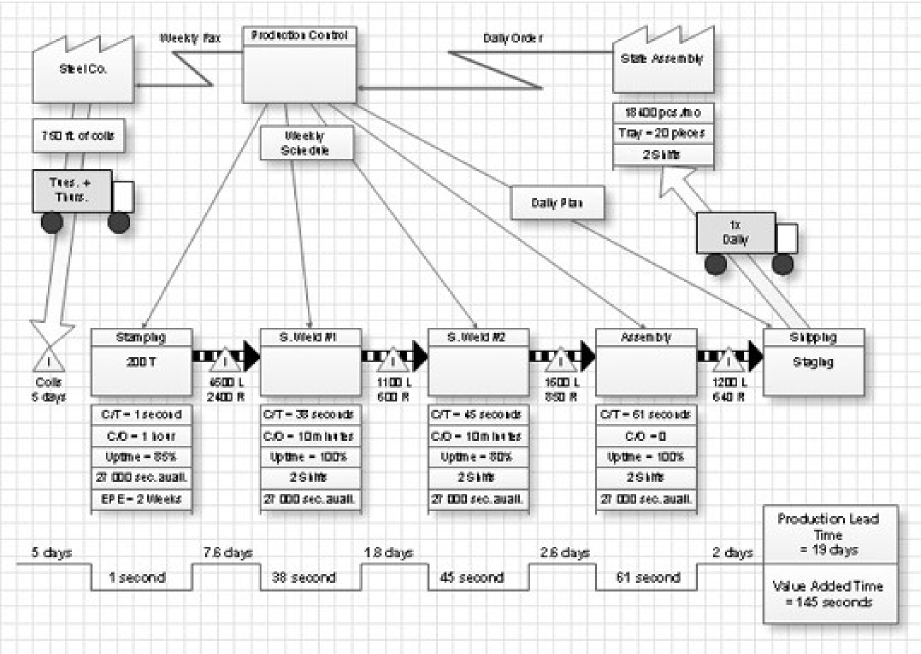

Fig. 3.8 Example of value stream map

Source: [12]

Identification of VA, BNVA, and NVA

When defining value stream and classifying each activity the next questions should be asked ([13]):

VA activities:

- Does the task add a form or feature to the product or service?

- Does the task enable a competitive advantage (reduced price, faster delivery, fewer defects)?
- Would the customer be willing to pay extra or prefer us over the competition if he or she knew we were doing this task?

BNVA activities:

- Is this task required by law or regulation?
- Does this task reduce the financial risk of the owner(s)?
- Does this task support financial reporting requirements?
- Would the process break down if this task were removed?

NVA activities:

- Does the task include any of the following activities: counting, handling, inspecting, transporting, moving, delaying, storing, all rework loops, expediting, multiple signatures?
- Taking a global view of the supply chain, having made these improvements, to how many factories do we really need to deliver projected volume? Will the faster lead time a lower costs fill up the existing facilities?
- With faster lead times, how many distribution centres can be eliminated?

Principle 3 - Making the value flow without interruptions

In order to eliminate the waste, processes must be changed and reorganised so that the product or service flows through all the value adding steps as effective and efficient as possible. Typically, when the first Map of the process was created, only 5 % of activities add value; this can rise to 45 % in a service environment.

What is the reason? Traditional mass methods call for large batching to be carried out before the batch can move onto the next stage. This creates wait times (bottlenecks) while the product waits for the next operation. Traditional firms believe that, it is efficient since this keeps everyone busy. But things work better if the focus is put on the product and its needs, rather than the organization or the equipment, so that all the activities needed to design, order, and produce a product occur in a continuous flow. Eliminating the waste ensures that the product or service "flows" to the customer without any interruption, detour, or waiting.

The 3rd lean principle entails probably the greatest departure from traditional "mass" thinking. Developing and implementing strategies to continually improve the flow will lead to great savings and improved service to the customer. But there is no "One Size Fits All" here –

different companies have different conditions and working methods, so understanding their specific bottlenecks and problems are the key to improving. A great problem with the practical implementation of the principle of flow has been related to the fact that managers or process engineers trying to apply this principle have been still dealing with disconnected processes rather than looking at the whole value stream for major breakthroughs and managing the entire flow of value-added activities for specific products. The right access to the application of the 3rd lean principle asks for redefining the work of functions, departments, and firms so they can make a positive contribution to value creation and address the real needs of employees at every point along the stream so that it is actually in their interest to make value flow.

Connected flow

The ideal flow would be "one piece flow" (single-piece flow or real continuous flow), however, this is often not feasible due to machine setups and the need to flow multiple product streams through individual machines or cells. But what the organization can try to achieve is the "connected flow" of products or value from one step to the next, each step being a value adding step. Achieving connected flow means implementing a means of connecting each process step within a value stream. When the connected flow has been achieved, there is a relationship between processing steps. That relationship is either a pull system such as a supermarket or FIFO lane or a direct link (one-piece flow). One-piece flow is the *ideal* method for creating connected flow. Achieving one-piece flow helps manufacturers to meet true just-in-time manufacturing. That is, the right parts can be made available when they are needed and in the necessary quantity. Simply speaking one-piece flow means that parts are moved through operations from step to step with no work-in-process (WIP) between either one piece at a time and a small batch at a time. This system works best in combination with a cellular layout in which all necessary equipment is located within a cell in the sequence in which it is used (see Fig. 3.9).

Fig. 3.9 Comparison of One-piece flow and batch processing

Source: [14]

However, one-piece flow can be achieved only under the following conditions:

- Processes must be able to consistently manufacture a good product. If there are many quality issues, one-piece flow is impossible.
- Process times must be repeatable as well. If there is much variation, one-piece flow is impossible.
- Equipment must have very high (almost 100 percent) uptime. Equipment must always be available to run. If equipment within a manufacturing cell is plagued with downtime, one-piece flow will be impossible.
- Processes must be able to be scaled to tact time, or the rate of customer demand. For example, if tact time is 10 minutes, processes should be able to be scaled to run at one unit every 10 minutes.

One-piece flow implementation

When conditions mentioned above are met, one-piece flow can be applied in the following steps:

1. Decision which products or product families will go into the cells and determining the type of cell: Product-focused or mixed model.
    - For product focused cells, demand needs to be high enough for an individual product.
    - For mixed model cells, changeover times must be kept short; a general rule of thumb is that changeover time need to be less than one tact time.
2. The calculation of tact time for the set of products that will go into the cell:
   Tact time = Available work-time per shift / Customer demand per shift
3. Determination of the work elements and time required for making one piece.
4. Determination if the equipment to be used within the cell can meet tact time.

Considerations here include changeover times, load and unload times, and downtime.

5. Creating a lean layout.

   For this step, 6S method (eliminating those items that are not needed and locating all items/equipment/materials that are needed at their points of use in the proper sequence) is very effective tool. Space between processes within a one-piece flow cell must be limited to eliminate motion waste and to prevent unwanted WIP accumulation. U-shaped cells are generally best; however if this is impossible due to factory floor limitations, other shapes will do (see Fig. 3.10).

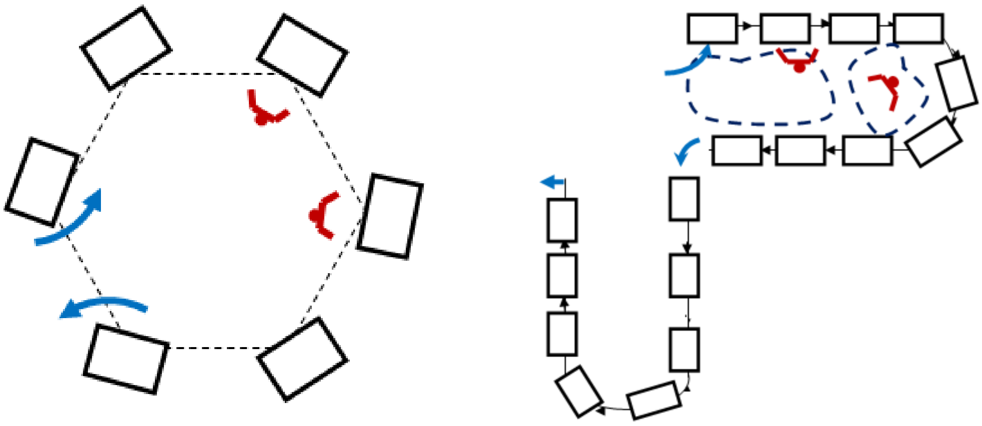

Fig. 3.10 Typical cell shapes

6. Balancing the cell and creating standardized work for each operator within the cell; determination of the number of operators to meet tact time, and then splitting the work between operators:

   Number of operators = Total work content / Tact time

Without meeting the above conditions, some other form of connecting flow must be used (pull system). This means that there will be a buffer of inventory, typically in the form of a supermarket or FIFO lane between processes; the goal would be to eventually achieve one-piece flow (no buffer) by improving the processes.

Principle 4 – Customers pulling the value from the producer

As compared to the push production, which is based on the demand forecast, the pull production is based on the actual or consumed demand (some comparisons can be found in Fig. 3.11 and 3.12).

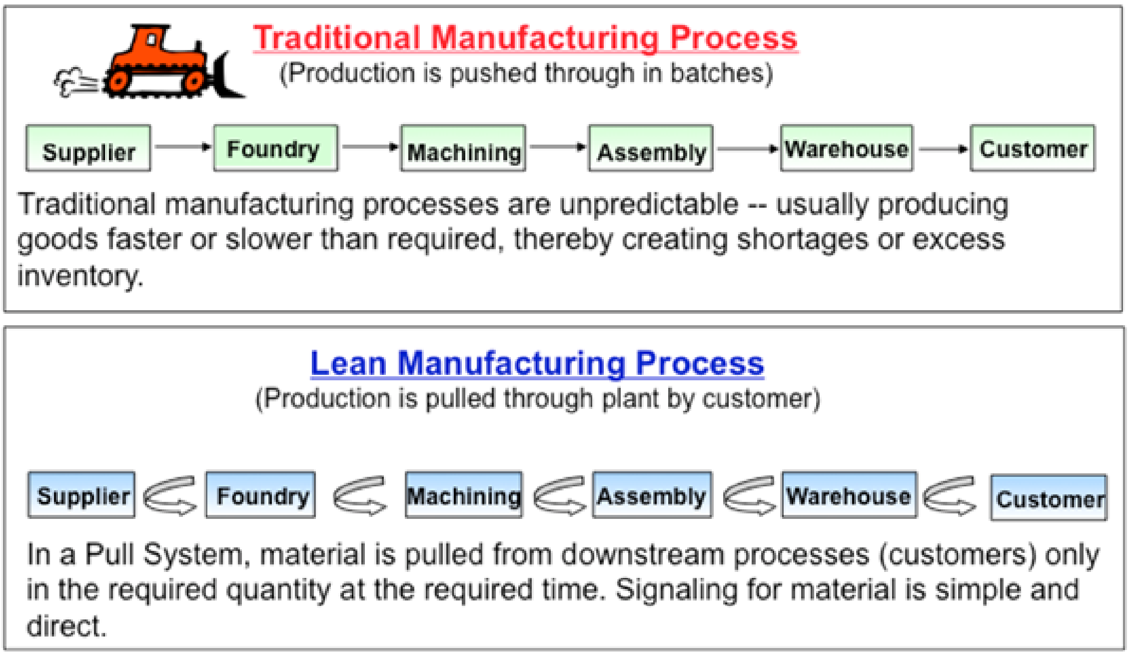

Fig. 3.11 A brief description of the Push and Pull system

Source: [15]

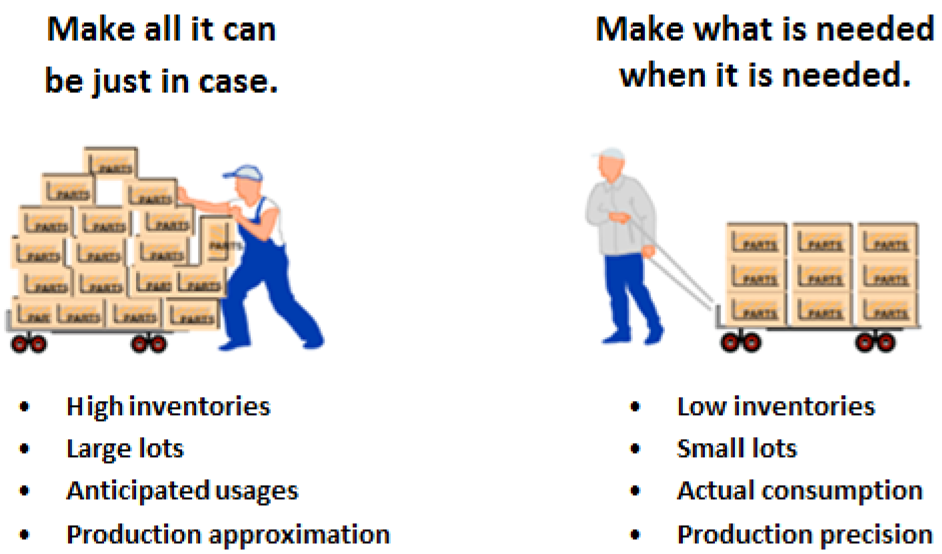

Fig. 3.12 Push vs. Pull [16]

By understanding the demand that customers put on the processes organization can build its processes to meet that demand. It means delivering what the customer needs, when he needs it to the place where he needs it. When flow is introduced, the customer can be let to pull the product from the organization as needed. It means that the organization will produce only at the pull of the customer. As a result, the customer demand becomes much more stable when customers know they can get what they want when they need it.

Pull production rather than pushing production through a factory using scheduling can be achieved very simply in many cases. Using Kanban systems and "supermarkets", it is possible to set up the production so that customers' orders can be quickly satisfied when they are made and the parts either manufactured to order from standard components or drawn from a small buffer stock, and then replenished in much the same way a supermarket will refill the shelves as customers buy product.

An example of a pull inventory control system is the just-in-time, or JIT system. The goal is to keep inventory levels to a minimum by only having enough inventories, not more or less, to meet the customers' demand. The JIT system eliminates waste by reducing the amount of storage space needed for inventory and the costs of storing goods.

Principle 5 - Pursuing perfection

If the first four steps have been achieved, the organization will have already prevented a huge amount of waste in its processes. However, with the help and support of all of its employees, the organization needs to be even better and strive towards perfection; delivering exactly what the customer wants, when he wants it at an acceptable (minimum) price with zero waste. This principle requires a business to continuously strive for excellence, and not to stop when progress is made.

The principles 1 - 4 interact with each other, enabling value to flow faster, always discover hidden waste in the value stream. In direct dialogue with customers, the product teams always find ways of specifying value more accurately, and often learn of ways to enhance flow and pull as well. In a truly lean system, everyone involved (subcontractors, first tier suppliers, systems integrators or assemblers, distributors, customers, employees) can see everything so it is easy to discover how to create value better.

The 5th lean principle is realized through the improvement process. The improvement activities can be implemented via continuous improvement (Kaizen) or radical changes (Kaikaku) (see Fig. 3.13).

Kaizen

Kaizen is continuous improvement by empowering all employees in creative problem-solving activities. It represents small and incremental improvements (it represents evolution). People are involved in solving problems in their work area. These improvements normally do not cost much money. The employees´ effort focuses on making their work easier and more interesting resulting in cost savings, safety and quality improvement, better throughput, or pleasing their customers. Kaizen is also a training tool for teaching individual problem-solving skills.

Kaikaku

Kaikaku is also improvement process but on a larger scale. Kaikaku also represents innovation bringing new processes, new products, new machines, and new concepts. Kaikaku can be seen as a radical change, transformation, a reform, or it is sometimes viewed as a revolution. It means radical overhaul of an activity to eliminate all waste and create greater value for the customer. It is a rapid and radical change process, similar to radical innovation, though innovation is not necessary for Kaikaku. Kaikaku is also known as Breakthrough Kaizen, Kaizen Blitz, Flow Kaizen, and System Kaizen.

While Kaizen is improving (optimizing) the way we do things, Kaikaku is rethinking the way we do them.

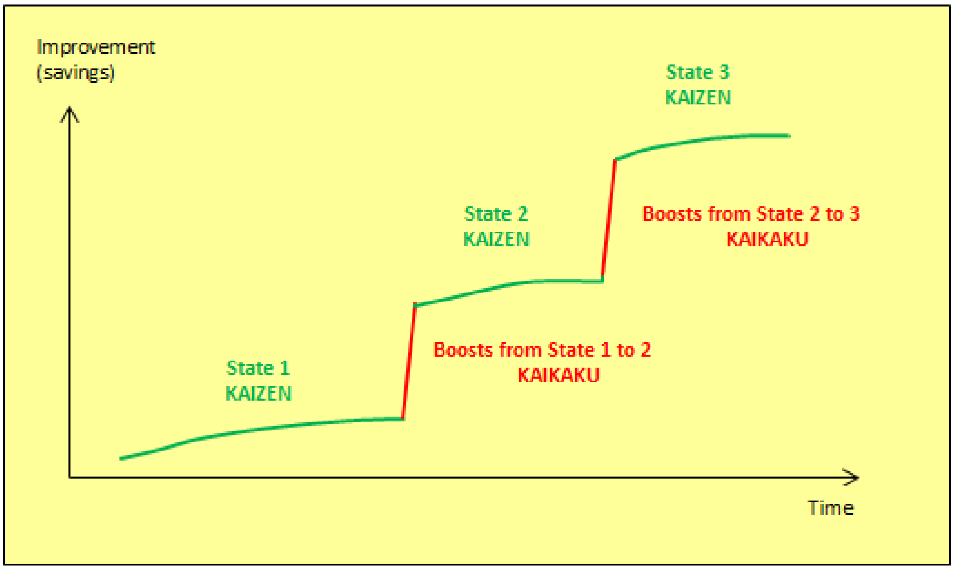

Fig. 3.13 The relations of Kaizen and Kaikaku [17]

Kaikaku is also meant as a precursor to Kaizen activities. Kaizen and Kaikaku are two complementary tools that help organization to progress towards the same objective. And the right tool must be chosen depending on the situation. The implementation of the associated changes will probably present the phases shown in the more realistic figure below. Although relatively short in time, they must be considered with adequate care, especially those immediately after the changes since those usually produce disturbances (see Fig. 3.14).

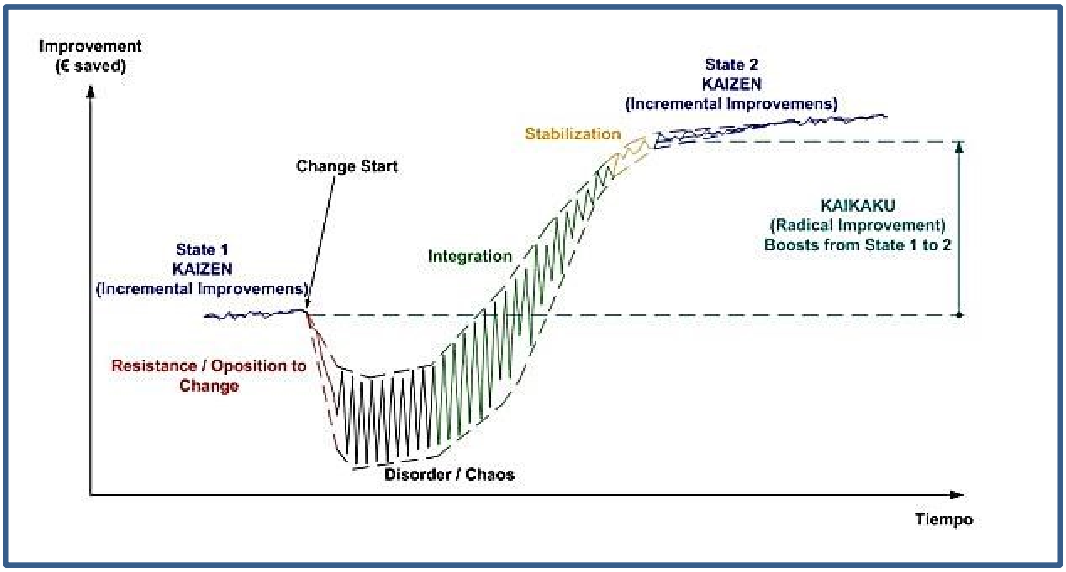

Fig. 3.14 Improvement implementation

Source: [18]

Additional lean principles

As it is discussed by P. Hines [19] – the principles of the lean business system) the traditional lean approach defined using 5 lean principles [7]) is too piecemeal, too short term in nature, and it puts too little stress on the areas required to make it sustainable in most organizations (it is focused only on muda, it implies that risk is at absolute minimum, attention to employee engagement is insufficient, importance of people was almost totally missed. For that reason the new set of 8 lean principles was designed (Purpose, Process, People, Pull, Prevention, Partnering, Planet, Perfection). The detailed explanation of these principles can be found in the above-mentioned publication (Peter Hines – the principles of the lean business system).

3.5 Waste

The main reason for reducing and eliminating waste is requirement for increasing profit via reduction of costs. In addition, waste has a major impact on the customer’s satisfaction with your products and services. The customers want on time delivery, perfect quality, and at the right price. It is something that cannot be achieved if waste will be allowed to persist within the processes.

Waste can be defined as follows: it is any activity that consumes time, resources, or space but does not add any value to the product or service.

As to the removal of waste; not only muda (non-value adding steps), but also mura and muri, must be removed (Fig. 3.15). In fact, by concentrating on solving mura and muri, the creation of muda is prevented.

Fig. 3.15 3M

Source: [20]

Working on Just in Time (JIT) principles with Heijunka, Kanban and other techniques enable production smoothing and flow; removing the causes of mura, unevenness. The other lean tools such as 5S and TPM help to remove muri, overburden.

It should be first concentrated on ensuring that mura is removed and creating a predictable flow; this in turn highlights the muri (unreasonableness) within the system which can then be eliminated. By following this route, the vast majority of muda that is present within the production system is often eliminated.

Mura

Mura is the waste of unevenness or inconsistency (variation). It can be found in fluctuation in customer demand, process times per product or variation of cycle times for different operators. When mura is not reduced, one increases the possibility for muri and therefore muda. mura can be reduced by creating openness in the supply chain, changing product design, and creating standard work for all operators.

Variation exists in many forms and it influences efficiency of a process in multiple ways. There is variance in customer demand, variance in product mix, variance in production methods within a plant or within processing times, and variance in the way of working. Influencing the variation of customer demand has everything to do with cooperation in a supply chain. When organizations in a supply chain do not share information about customer demand or inventory levels, the bull-whip effect emerges whenever customer demand fluctuates. This effect describes how a small change in customer demand from end customers can lead to a high change in order size upstream in the chain, which in turn leads to large inventories in the overall supply chain. There are three recommendations to reduce the variation of customer demand:

1. reduce the number of links in a supply chain. External warehousing or moving parts of a plant is not a good idea in this sense;
2. reduce delivery times between links;
3. create transparency between links in the supply chain when it comes to order portfolios.

This will reduce the tendency to increase the order size at every link.

Variance in the process can be reduced using various tools. The variation in the product mix has relatively low impact on a production process when the processing times are balanced for different products. There are following methods to reduce this form of variance: Modular product design at the design level, production levelling in production planning, building flow at the production level, and standard work and 6S at the workstation level.

At the level of production design, the variation between products can be minimized by using modular designs. It will reduce the number of possible material routings in the factory and a number of inventory items. One example of modular design is a series of wardrobes at IKEA where a choice between a number of drawers, doors, and handles leads to a relatively large amount of combinations for end customers to buy. A method to reduce the impact of customer variance in the production planning is the tool Heijunka (production-levelling). With Heijunka, one defines a fixed interval in which all product types can be produced. The shorter the intervals the more often a product is manufactured and the shorter the lead time of each product will be. Because the lead time is reduced, the uncertainty in customer demand reduces as well. When yearly customer demand is cut in smaller pieces, changes in customer demand can be smoothed out between the different production runs. To implement Heijunka, changeover times should be minimized to minimize the cost of changeovers. A tool that can be used for reducing changeover times is SMED (Single Minute Exchange of Die). Next to optimizing product design and production planning, the way products move through the plant should be optimized. Ideally, products flow through the plant, which means products never have to wait to be worked on as they move between the necessary workstations. When the processing time of workstation 2 is longer than that of workstation 1, either every product coming from workstation 1 has to wait before station 2 can work on it, or station 1 has to wait for free capacity at workstation 2. A graphical way of visualizing the line balance is the Yamazumi. At the workstation level, all operators´ handling should be optimized to minimize the production variation. Standardizing procedures and layout prevents different work cycles for different operators performing the same task and employees to search for materials or tools they need. Standard work describes the safest and most efficient method to perform a certain sequence of tasks while 6S describes the safest and most efficient layout for a workstation. Reducing variation is one of the reasons Standard Work and 6S form the basis of every lean implementation, which is why they are the foundation of the lean house for the shop-floor.

Reducing mura (variation) is important for every lean organization. Variation is always buffered by inventories, capacity, time, or a combination of those. More *mura* therefore leads to more *muda* (waste). Eliminating waste will lead to higher results if variation is also reduced. By applying (a number of) the tools described in this article, the impact of variation on any production process can be reduced. The lower the impact of variation on the process, the higher the flexibility to respond to changes in the customers' demand.

Muri

Muri – overburden can result from mura, and from removing too much muda (waste) from the process. When operators or machines are utilized for more than 100 % to finish their task, they are overburdened. This means *breakdowns* when it comes to machines and absenteeism as far as employees are concerned. To optimize the use of machines and make sure they function properly, preventative and autonomous maintenance can be implemented. To prevent overworked employees, safety should be the focus of all process designs and all standard work initiatives.

When people are overburdened, they feel stressed, or even burned-out. Overburdened machines result in breakdowns and faster wear-out. Since muri rises as a result of mura, the best way to minimize muri is to minimize mura. Therefore, it is important to know how to handle variations and the way people and machines respond to them. People related muri can be minimized by implementing 6S, standard work and using Jidoka principles.

Machine related muri can be minimized by maintaining all machines as effectively and efficiently as possible. Maintenance can be divided into three types: Corrective, Preventative, and Autonomous Maintenance. Preventative and autonomous maintenance are the methods to minimize muri.

Muda

Muda - waste, can be defined in eight types, seven defined by Toyota and 'non-utilized skills (non-used talent)'. These are: defects, overproduction, waiting (delay), transport, inventories, motion and excess processing, non-utilized talent - see Fig. 3.16.

Fig. 3.16 Eight wastes

Source: [21]

According to Taichi Ohno [22] there is only one way to find the hidden wastes in your system: by observation. In his famous exercise, he asks managers to 'stand in the circle' he draws on the shop floor and lets them look around from the circle until they see a problem. Gemba and other systematic tools to eliminate wastes are very effective, too.

1. ***The waste of defects***

Defects are the most obvious of the seven wastes, although not always the easiest to detect before they reach your customers (see Fig. 3.17). Quality errors that cause defects invariably cost you far more than you expect. Every defective item requires rework or replacement, it wastes resources and materials, it creates paperwork, it can lead to lost customers. The cost of rejects and rework are often compared to an iceberg; only a small fraction of the true cost is visible above the water level.

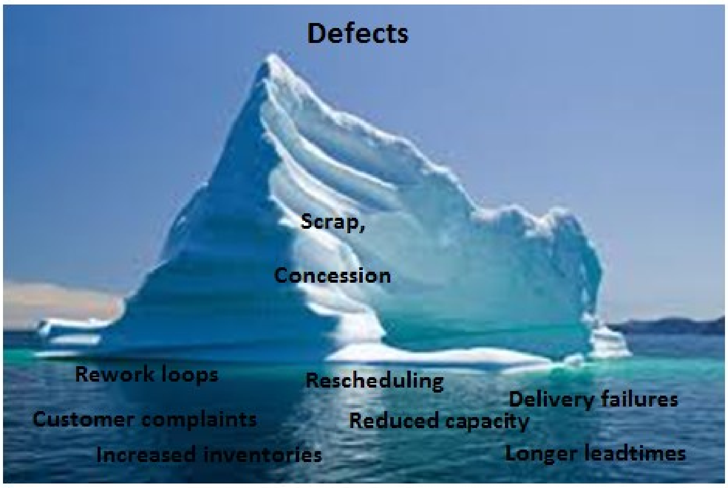

Fig. 3.17 The scrap iceberg [23]

In addition to the obvious cost of the initial scrap item, there is a number of other costs that are not always obvious or considered although frequently far in excess of this initial cost. The general rule of thumb is to multiply the cost of the scrap by a factor of ten to arrive at the true cost to the business. There are costs associated with problem solving, materials, rework, rescheduling materials, setups, transport, paperwork, increased lead times, delivery failures and potentially lost customers.

Defects can be caused by many other problems, many that should be avoidable with a little thought when designing products, processes and equipment. Many defects are caused by incorrect method due to non-standard operations, differences in the way that processes are undertaken by different operators in different shifts. The possibility of errors is often built into products by failing to think about how items can be assembled while they are designed (components that can be assembled incorrectly if the operators do not align them correctly for instance).

Defects can also be caused due to incorrect, inefficient, or insufficient maintenance. Nonexistence of a culture that empowers and makes operators confident enough to stop the process, highlight problems and allow them to be solved leads to the production of nonconforming units, too. Wrong incentive system that rewards the wrong behaviours, paying for quantity rather than quality, encouraging employees to work as fast as possible, and even penalizing them if they do not make the numbers with little thought to the consequences on the quality of our products or services can lead to the production of defects, too.

Examples of wastes of defects

- Scrap produced by poorly maintained fixtures.

- Parts assembled with the incorrect orientation.
- Missing screws and other fixing due to lack of controls.
- Incorrect components used due to incorrect or missing instructions.
- Poorly made components that continued to be produced as the employees wanted to reach their performance bonus.
- Parts damaged due to excessive handling.
- Faulty parts that have reached the customer.

These wastes can be eliminated or reduced using various techniques for identification and elimination of wastes; however within lean manufacturing, it is preferred to prevent defects occurring in the first place. This prevention of defects can be achieved by a number of different techniques from autonomation / Jidoka (Machines with "human" intelligence that are able to detect when a non-standard event has occurred) through to Poka Yoke devices that detect if a product is defective, either preventing the process from running or highlighting the defect for action.

Implementation of standard operations procedures (SOP) and training to ensure that the correct methods are undertaken and standards achieved are very valuable preventive techniques, too.

The most important factor, however, is the empowerment of teams to solve and prevent their own problems.

2. The waste of overproduction

Overproduction (Fig. 3.18) is producing too much or too early. It usually exists because of working with oversize batches, long lead times poor supplier relations. Overproduction leads to high levels of inventory which mask many of the problems within your organization.

This could be done to cover up for possible defects (as written above) or because it is economically interesting to produce large batches. One can recognize overproduction in large inventories and WIP. Overproduction is thus caused by large batch sizes, unreliable processes, unstable schedules, unbalanced cells, working to forecast (not actual demand). It can be avoided by balancing supply to demand.

This type of waste can be reduced using tools like SMED (quick changeover) and Kanban, JIT.

Fig. 3.18 Overproduction

Source: [24]

3. The waste of waiting

Waiting (Fig. 3.19) disrupts flow, one of the main principles of lean manufacturing; as such, it is one of the most serious of the seven wastes or seven mudas of lean manufacturing.

Waiting time can be the time that a product spends on the shop floor without value being added to it. People and machines can also have waiting time in their working cycle when they have to wait for information, instruction, or materials.

Fig. 3.19 The waste of waiting

Source: [25]

In general, waiting time is a result of failure to synchronize activities. It results from poor man / machine coordination, long changeovers, unreliable processes, batch production, time required to perform rework. Tools that help find waiting time in a process are time studies, tact time, and line balancing. Time studies describe the entire process in different types of time. One can define process times, waiting times, and lead times. Process time is the sum of cycle times where value is being added to the product. Waiting times are the times where value is not added to the product, for instance when it is waiting for a process step to start, of being moved to another station. The lead time of a product is the total time a product spends on the shop floor, process times plus waiting times, from input materials until the product is sent to the customer. By measuring and visualizing these various times, improvements (or kaizen) can be focused on a single point in the process at a time. Tact time is the beat in which the customer actually demands the product. For instance, if the customer's demand is 730 products a year, tact time is 2 products a day. This means the factory should ideally produce 2 products a day, to stay flexible for changes in customer demand. When production is faster than tact, products have to wait in the warehouse until they can be shipped to the customer. When production is slower than tact, even worse, the customer has to wait for his order. The third tool to reduce waiting times in a process is line balancing**.** This tool is used to balance a line so that all sequential workstations had equal cycle times. When the cycle time or station 2 is larger than station 1, every product that comes from station 1 has to wait, or station 1 has to wait until station 2 has finished its cycle. A visual way to balance a production line is the Y*amazumi.*

Examples of wastes of waiting

- Operators / Machines standing idle whilst they wait for a previous process production to be sorted due to quality problems.
- Waiting for a breakdown to be resolved.
- Waiting for a previous process to complete a batch of material prior to movement.
- Waiting for the forklift truck to deliver a batch of components.
- Waiting for information from the engineering department.
- Waiting to be told which product is required next.
- Operators waiting or working slowly whilst waiting for a previous operation to complete its cycle.

4. ***The waste of non-used talents***

As it was mentioned earlier, two pillars in lean thinking are “Continuous Improvement” and “Respect for People”. Non-used talent (see Fig. 3.20) is not one of the Ohno’s original wastes, but it is one of the most important wastes. It is a result of failing to make use of the people within the organization. Western companies still tend to operate within a command and control environment and take little real notice of what their employees really think and what they can contribute.

Fig. 3.20 Underutilized people

Source: [26]

The tools to reduce this type of waste are 6S, standard work, communication cells, Kaizen and Andon. Next to these tools, employees should be trained in practical problem solving using 5x why to get to the root cause of a problem instead of fixing symptoms. As to Andon, it does not work when the fundamental worldview of the company is that they do not want to know if there are problems, or that they do not value the employees’ opinions or input — that is a bigger problem than the cumulative effect of all defects in the company (more precisely, that is the root cause of waste as well as issues in organizational effectiveness). The solution can be found in acceptance of the following rules:

1. Every problem seen by an employee must be communicated.
2. Problems must not be passed up or down the value chain;
3. Continual improvement must be an inevitable part of the employee work.
4. There is an end-customer, but the person upstream and downstream from the employee is also his customer.

If an organization does not subscribe to these basic principles, then no matter how many Andon cards are available at your company - nobody will pull them.

5. The waste of transport

Transport (Fig. 3.21) is the fifth type of waste connected with moving products, materials and tools needed to perform the necessary tasks in production. Excess transport can be caused by poor layouts (large distances between operations), complex material handling systems, large batch sizes, overproduction, multiple storage locations. Processes should be as close together as possible and material should flow directly from process to process without any significant delays.

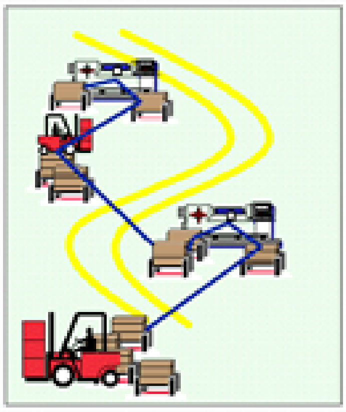

Fig. 3.21 Transportation

Source: [27]

A way to visualize the different transport movements is the Spaghetti diagram. Tools to reduce transport in production form a production line or work cells. To minimize transport of tools by people, 6S can be implemented. With spaghetti diagrams, one can draw all movements of products and tools with a pen on a plant map. This is a perfect moment to use the circle of Ohno. Observe every movement and draw it on the map. One way to reduce the amount of transport in production is to change the layout of the plant into production lines in which a product flows through the same workstations in the same order. A second option is using work cells, where small production lines are built in a U-shape. Input and output of each workstation should all be on the same side to reduce distance between cells. A product can flow through the cells needed for that particular product. Finally, the transport of tools by operators can be reduced using 6S. When every workstation has a standard location to keep all the tools needed at that workstation, in the form of shadow boards for example, the operator does not need to walk around and look for a tool needed.

6. The waste of inventory

Inventory includes all products and materials on the shop floor where no value is being added at the moment. Inventory is waste because the materials are paid for by the company, but the customer has not yet payed for the final product. In addition to the pure cost of the inventory itself, inventory feeds many other wastes. It has to be stored, it needs space, it needs packaging, and it has to be transported around. Moreover, it might be damaged during transport and become obsolete. It hides many of other wastes in your systems (see Fig. 3.22).

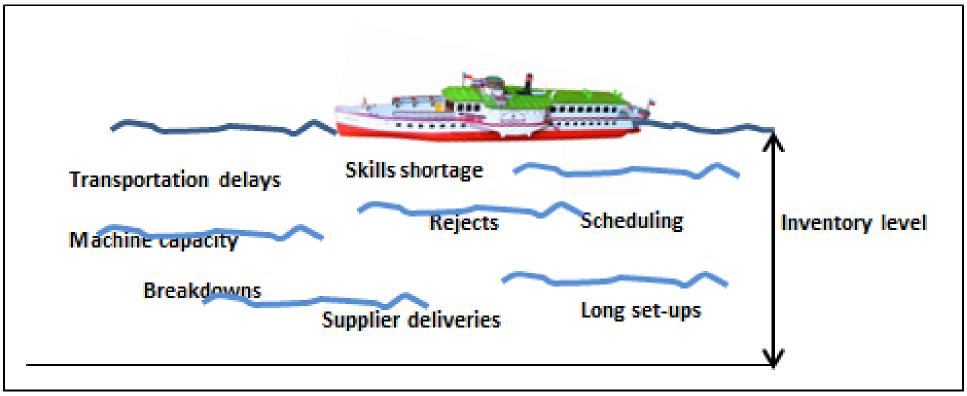

Fig. 3.22 The sea of inventory hides other wastes [27]

Tools that can help reduce the amount of inventory in production are the already described *work cells* and *Kanban.* A third tool to reduce inventory is creating *One-Piece-Flow*. Within a one-piece-flow, batches are reduced to 1 item. This way, you immediately reduce the amount of WIP with a factor of the size of the current batch size.

7. The waste of motion

Motion (Fig. 3.23) can again be found in both people and machines.

Fig. 3.23 Excessive moving (reaching too far)

Source: [28]

Unnecessary motions are those movements of a man or machine that are not small or it is not easy to achieve what is needed. Excessive travel between workstations, excessive machine movements from start point to work start point, an operator having to reach high to get a certain part or press a certain button are all examples of the waste of motion.

Examples of the waste of motion

- A machine that travels an excessive distance from start point to where it begins work.
- Heavy objects placed on low or high shelves.
- Searching for tools and equipment
- Walking across work space to retrieve components or use machines.
- Constantly turning and moving product during assembly.
- Having to reorient component when taken from its location.
- Reaching excessive distances when taking components and tools.

Tools that help reduce this type of waste are Standard Work**,** 6S, and Spaghetti Diagrams.

8. The waste of excess processing

Over-processing waste represents an extra effort or activities that add no value from the customer' perspective. It means use of inappropriate techniques, oversizing equipment, working to tolerance that is too tight, performing processes that are not required by the customer, and so forth. One of the biggest examples of over-processing is the deployment of a "mega machine" that can do an operation faster than any other, but every process flow has to be routed through it causing scheduling complications, delays, and so forth. In lean: small is beautiful – use small appropriate machines where they are needed in the flow, not to break the flow to route through a highly expensive monstrosity.
Over processing is caused by no standardization of best techniques and unclear specification. Such waste can be eliminated by work standardization (clear, standardized instructions).

Examples of over-processing waste:

- Over-installing from a quality standpoint;
- Changing filters and belts without authorization (not sold with job);
- Over-engineering;
- Using old specifications (over-specifying);

- Multiple reviews (checks & balances); too much control;
- Extra process steps; doing more than necessary to get the job done;
- Hand estimating vs. error-proofing on computer;
- Writing down phone info instead of keying directly into computer;
- Clarifying orders;
- Redundant information gathering;
- Unnecessary regulatory paperwork.

Tab. 3.3 summarizes eight types of waste and tools for their reduction or elimination.

Table 3.3 Eight types of waste and tools for their elimination or reduction

Number	Waste	Tool
1		JIDOKA Poka Yoke Standard operations procedures (SOP) Team work
2	Overproduction	SMED JIT Kanban
3	Waiting	Time studies Tact time Line balancing Visual control 6S SMED
4	Non-used talent	SOP 6S Kaizen Andon Enterprise resource planning (ERP)
5	Transport	Spaghetti diagram Value stream mapping (VSM) Work cells 6S One-piece flow
6	Inventory	Work cells Kanban One-piece flow VSM
7	Moving	Spaghetti diagram¨ VSM SOP 6S
8	Excess processing (over processing)	SOP

3.6 Lean tools and techniques

There are various tools and techniques that enable to realize goals and principles of lean approach and to eliminate or reduce wastes. Selection of 25 essential lean tools can be found on http://www.leanproduction.com/top-25-lean-tools.html (see Tab. 3.4).

Table 3.4 Essential lean tools and techniques

Lean Tool	Description	Purpose
5S	Organize the work area: Sort (eliminate that which is not needed) Set In Order (organize remaining items) Shine (clean and inspect work area) Standardize (write standards for above) Sustain (regularly apply the standards)	Eliminates waste that results from a poorly organized work area (e.g. wasting time looking for a tool).
Andon	Visual feedback system for the plant floor that indicates production status, alerts when assistance is needed, and empowers operators to stop the production process.	Acts as a real-time communication tool for the plant floor that brings immediate attention to problems as they occur – so they can be instantly addressed.
Bottleneck Analysis	Identify which part of the manufacturing process limits the overall throughput and improve the performance of that part of the process.	Improves throughput by strengthening the weakest link in the manufacturing process.
Continuous Flow	Manufacturing where work-in-process smoothly flows through production with minimal (or no) buffers between steps of the manufacturing process.	Eliminates many forms of waste (e.g. inventory, waiting time, and transport).
Gemba (The Real Place)	A philosophy that reminds us to get out of our offices and spend time on the plant floor – the place where real action occurs.	Promotes a deep and thorough understanding of real-world manufacturing issues – by first-hand observation and by talking with plant floor employees.
Heijunka (Level Scheduling)	A form of production scheduling that purposely manufactures in much smaller batches by sequencing (mixing) product variants within the same process.	Reduces lead times (since each product or variant is manufactured more frequently) and inventory (since batches are smaller).
Hoshin Kanri (Policy Deployment)	Align the goals of the company (Strategy), with the plans of middle management (Tactics) and the work performed on the plant floor (Action).	Ensures that progress towards strategic goals is consistent and thorough – eliminating the waste that comes from poor communication and inconsistent direction.

Table 3.4 Essential lean tools and techniques – cont.

Lean Tool	Description	Purpose
Jidoka (Autonomation)	Design equipment to partially automate the manufacturing process (partial automation is typically much less expensive than full automation) and to automatically stop when defects are detected.	After Jidoka, workers can frequently monitor multiple stations (reducing labour costs) and many quality issues can be detected immediately (improving quality).
Just-In-Time (JIT)	Pull parts through production based on customer demand instead of pushing parts through production based on projected demand. Relies on many lean tools, such as Continuous Flow, Heijunka, Kanban, Standardized Work and Tact Time.	Highly effective in reducing inventory levels. Improves cash flow and reduces space requirements.
Kaizen (Continuous Improvement)	A strategy where employees work together proactively to achieve regular, incremental improvements in the manufacturing process.	Combines the collective talents of a company to create an engine for continually eliminating waste from manufacturing processes.
Kanban (Pull System)	A method of regulating the flow of goods both within the factory and with outside suppliers and customers. Based on automatic replenishment through signal cards that indicate when more goods are needed.	Eliminates waste from inventory and overproduction. Can eliminate the need for physical inventories (instead relying on signal cards to indicate when more goods need to be ordered).
KPI (Key Performance Indicator)	Metrics designed to track and encourage progress towards critical goals of the organization. Strongly promoted KPIs can be extremely powerful drivers of behaviour – so it is important to carefully select KPIs that will drive desired behaviour.	The best manufacturing KPIs: Are aligned with top-level strategic goals (thus helping to achieve those goals) Are effective at exposing and quantifying waste (OEE is a good example) Are readily influenced by plant floor employees (so they can drive results)
Muda (Waste)	Anything in the manufacturing process that does not add value from the customer's perspective.	Eliminating muda (waste) is the primary focus of lean manufacturing.
Overall Equipment Effectiveness (OEE)	Framework for measuring productivity loss for a given manufacturing process. Three categories of loss are tracked: Availability (e.g. down time) Performance (e.g. slow cycles) Quality (e.g. rejects)	Provides a benchmark/baseline and a means to track progress in eliminating waste from a manufacturing process. 100% OEE means perfect production (manufacturing only good parts, as fast as possible, with no down time).

Table 3.4 Essential lean tools and techniques – cont.

Lean Tool	Description	Purpose
PDCA (Plan, Do, Check, Act)	An iterative methodology for implementing improvements: Plan (establish plan and expected results) Do (implement plan) Check (verify expected results achieved) Act (review and assess; do it again)	Applies a scientific approach to making improvements: Plan (develop a hypothesis) Do (run experiment) Check (evaluate results) Act (refine your experiment; try again)
Poka-Yoke (Error Proofing)	Design error detection and prevention into production processes with the goal of achieving zero defects.	It is difficult (and expensive) to find all defects through inspection, and correcting defects typically gets significantly more expensive at each stage of production.
Root Cause Analysis	A problem solving methodology that focuses on resolving the underlying problem instead of applying quick fixes that only treat immediate symptoms of the problem. A common approach is to ask why five times – each time moving a step closer to discovering the true underlying problem.	Helps to ensure that a problem is truly eliminated by applying corrective action to the “root cause” of the problem.
Single Minute Exchange of Die (SMED)	Reduce setup (changeover) time to less than 10 minutes. Techniques include: Convert setup steps to be external (performed while the process is running) Simplify internal setup (e.g. replace bolts with knobs and levers) Eliminate non-essential operations Create standardized work instructions	Enables manufacturing in smaller lots, reduces inventory, and improves customer responsiveness.
Six Big Losses	Six categories of productivity loss that are almost universally experienced in manufacturing: Breakdowns Setup/Adjustments Small Stops Reduced Speed Startup Rejects Production Rejects	Provides a framework for attacking the most common causes of waste in manufacturing.
SMART Goals	Goals that are: Specific, Measurable, Attainable, Relevant, and Time-Specific.	Helps to ensure that goals are effective.

Table 3.4 Essential lean tools and techniques – cont.

Lean Tool	Description	Purpose
Standardized Work	Documented procedures for manufacturing that capture best practices (including the time to complete each task). Must be "living" documentation that is easy to change.	Eliminates waste by consistently applying best practices. Forms a baseline for future improvement activities.
Tact Time	The pace of production (e.g. manufacturing one piece every 34 seconds) that aligns production with customer demand. Calculated as Planned Production Time / Customer Demand.	Provides a simple, consistent and intuitive method of pacing production. Is easily extended to provide an efficiency goal for the plant floor (Actual Pieces / Target Pieces).
Total Productive Maintenance (TPM)	A holistic approach to maintenance that focuses on proactive and preventative maintenance to maximize the operational time of equipment. TPM blurs the distinction between maintenance and production by placing a strong emphasis on empowering operators to help maintain their equipment.	Creates a shared responsibility for equipment that encourages greater involvement by plant floor workers. In the right environment this can be very effective in improving productivity (increasing up time, reducing cycle times, and eliminating defects).
Value Stream Mapping	A tool used to visually map the flow of production. Shows the current and future state of processes in a way that highlights opportunities for improvement.	Exposes waste in the current processes and provides a roadmap for improvement through the future state.
Visual Factory	Visual indicators, displays and controls used throughout manufacturing plants to improve communication of information.	Makes the state and condition of manufacturing processes easily accessible and very clear – to everyone.

In the next chapters some of these tools will be described in more detail.

Tasks

- Discuss what are the relations between muda, mura, and muri.
- Think of the application of the lean approach in non-manufacturing conditions.
- Try to discuss applying the basic lean principles to health care.
- Give several examples of all types of wastes in manufacturing and non-manufacturing conditions

Summary of terms

- 4P model
- 5S (6S)
- Andon
- Business non-value added activity
- Connected flow
- Continuous improvement
- Defects
- Excess processing
- Flow
- Heijunka
- Inventories
- Jidoka
- JIT
- Kaikaku
- Kaizen
- Kanban
- Lean principles
- Lead time
- Lean manufacturing
- Manufacturing cell
- Motion
- Muda
- Mura
- Muri
- Non-utilized talent
- Non-value added activity
- One-piece flow
- Overproduction
- Perfection
- Poka-Yoke

- Pull
- QCD
- QFD
- Radical changes
- SMED
- Standardized work
- TMP
- Toyota production system
- Transport
- Value
- Value added activity
- Value stream
- Value stream mapping
- Waiting
- Waste

Questions

- Why has the lean approach been evolved?
- What are the limitations of this approach?
- What are the main goals of the lean approach?
- What is the difference between Toyota production system and the lean approach defined by Womack?
- What are the main 5 lean principles?
- Explain every of 5 lean principles separately in detail.
- What are VA, NVA, and BNVA? How to identify them? Why to identify them?
- What are differences and relations of muda, mura, and muri?
- How to reduce or eliminate muda, mura, and muri?

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4. VALUE STREAM MAPPING

Time to study

480 min

Goal

after studying this chapter

- you will be able to read the value stream map;
- you will be able to create the current state and future state value stream map.

Lecture

4.1 Overview

Value stream mapping (VSM) is a lean management method for analyzing the current state and designing a future state for the series of events that take a product or service from its beginning through to the customer. It can be applied to nearly any value chain.

As a tool for identifying the inherent waste and losses within processes, it is the basic instrument for the implementation of all lean principles. It forms a support for the prioritization of continuous improvement activities at the value stream. Compared to other process mapping techniques (for instance flow charts), value stream mapping shows the flow of materials as well as information; it indicates lead time and cycle time for each process; it identifies each step as VA and NVA activities; it requires thorough first hand study of the process.

4.2 Definitions of the basic terms

- ***Value stream***

  It is a flow of all activities (VA and NVA) needed to fulfill a customer's request.

- ***Value stream map***

  It is a drawing that makes the flow of material and information visible. The current state map describes the process as it is today. The future state map describes the ideal state based on applying lean principles.

- ***Value stream mapping (VSM)***

  It is often a hands-on process to create a graphical representation of the process, material and information flows within value stream.

- ***Value stream analysis***

It is a planning tool to optimize results of eliminating waste realized in the following steps:

- selection of the product / product family;
- creation of the current value stream map;
- application of lean techniques to reduce waste;
- creation of the future state value stream map.

4.3 Phases of the value stream analysis implementation

VSM is a highly effective continuous improvement tool, but it must be used effectively.

The process of value stream analysis can be realized in 4 phases containing the following activities.

Phase 1 - Understanding the Current State

- Training the value stream mapping (VSM) team: Selection of a cross-functional team that includes all stakeholders of the process or the area to be mapped. These teams must include the operators and maintenance personnel with first-hand knowledge of the process or the area as well as those who must support them.
- Physical walking the path of the material flow, beginning from each source of primary and secondary materials required to support the operation as well as the actual manufacturing or production process that is being mapped.
- Documentation of each step observed or discovered as part of the walk-down. Identifying the communication points and how the communication occurs – creating the current state VSM.

Phase 2 – Analysis and reflection

- Analysis and gaining consensus for the value stream analysis. The current state VSM must be discussed with all stakeholders, and their consensus that the map truly reflects how the process is currently performed must be gained.
- Identification of limiting factors, deficiencies and losses associated with the current process. The impact on performance and cost for each of the limitations must be identified. Care must be taken to assure the true root causes, not the symptoms, of each limiting factor are identified.
- Proposal of cost-effective solutions for each of the factors, deficiencies, and losses that are limiting the effectiveness and efficiency of the current process must be created. Solutions must directly address the root cause of the identified issues and be affordable.
- Changing the VSM to reflect the proposed changes that will eliminate or mitigate the limiting factors associated with the initial process map. All the recommended changes must be clearly identified and included in the "Future State" VSM.

Phase 3 - Improvement

- Socialization of the future-state value stream map with all stakeholders. Their consensus is inevitable before proceeding to the implementation stage. It must be assured that all stakeholders are given the opportunity to review and comment on the new process.
- Modification of all affected procedures, bills of material and training materials to reflect the changes to be implemented. This step cannot be omitted or minimized without incurring serious restrictions to any real benefits derived from the proposed changes.
- Training all concerned personnel on the new procedures. Assure that all workers are trained and can apply them before attempting to implement.
- Implement the changes identified through the VSM process. These changes should be implemented based on descending priority—greatest benefit first and thoroughly documented. The preferred approach is to implement the changes in discrete increments with sufficient time between changes to determine the resultant benefit derived from each discrete change.

Phase 4 - Sustaining

- Establishment of effective key performance indicators (KPIs) that will accurately measure performance and cost change within and for the applicable process. These KPIs, in conjunction with a verified baseline of the current-state process, will be used to verify and validate changes.

- Monitoring and reinforcing compliance with the new standard procedures and practices established as a part of the improvement process. One cannot assume that all stakeholders will immediately and voluntarily adhere to the changes that are being implemented.
- Institutionalization of verified and validated improvements across the manufacturing site.
- Creation of the "current state" VSM and inclusion of all pertinent data and information.

4.4 Creation of the value stream map

Value stream and should involve representatives from all the areas within the process being mapped. This process should be facilitated and led by an expert with experience in creating value stream maps. A value stream map is best created by hand using a pencil (it will be needed to make frequent corrections and changes) on a sheet of A3 paper. It is better to create it by hand and involve the entire team in its creation rather than to leave it on some IT expert who is not familiar with the analyzed process. The current state value stream map and the future state map are created.

A. Current state map

- shows the current state of work processes;
- provides understanding of the need for change;
- allows understanding of where opportunities lie.

To create the value stream map, the following steps should be made next:

1. Selecting the product (family) to map
2. Selection of symbols
3. Defining and drawing the process boundaries, the process steps and material flow
4. Defining and drawing information flows
5. Collecting the process data
6. Calculating the time line
7. Interpreting the data
8. Desing of improvement actions
9. Next Steps (Ideal and future state maps)

1. *Selection of the product or product family*

Firstly, it must be decided what exactly should be mapped. If there is a huge range of products, it is necessary first to conduct a product family analysis. The product family is a group of products that pass through similar processing steps and use common equipment in the downstream processes. The product family analysis is a simple review of produced products and processes they go through. It may not be necessary to analyze all products; for instance, a Pareto analysis can be a good tool to decide which products must be incorporated into the analysis - either based on the volume or value or their combination. The product family analysis matrix (see Fig. 4.1) is a very simple but useful tool for this analysis.

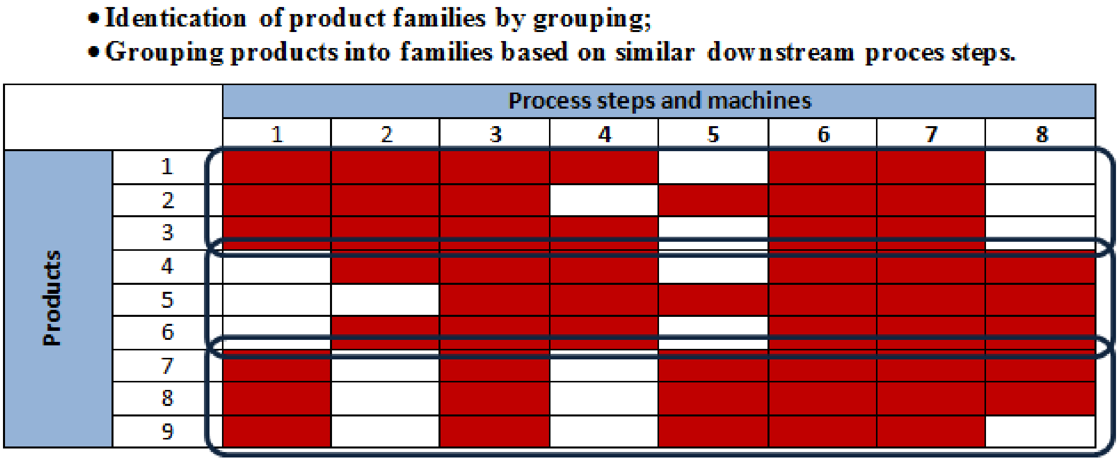


Fig. 4.1 Product family matrix [1]

The value stream map can then be concentrated on either a single product or a family of products sharing common processes.

2. *Selection of symbols*

Tab. 4.1 contains commonly used value stream mapping symbols and their meanings. For mapping, only symbols relavant to the depicted process are used.

Table 4.1 VSM symbols

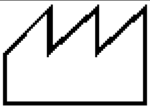
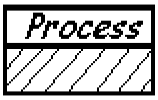
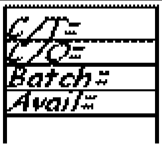
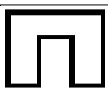
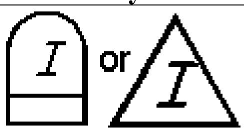
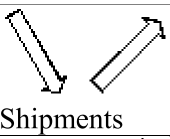
Process symbols	
 Customer/Supplier	This icon represents the **Supplier** when in the upper left-hand corner, the usual starting point for material flow. The **Customer** is represented when placed in the upper right-hand corner, the usual end point for material flow.
 Dedicated Process	The **Dedicated process icon** is a process, operation, machine or department, through which material flows. Typically, to avoid unwieldy mapping of every single processing step, it represents one department with a continuous, internal fixed flow path. In the case of assembly with several connected workstations, even if some WIP inventory accumulates between machines (or stations), the entire line would show as a single box. If there are separate operations, where one is disconnected from the next, inventory between them and batch transfers, use multiple boxes.
 Shared Process	The **Shared process icon** represents a process operation, department or workcenter that other value stream families share. Estimate the number of operators required for the Value Stream being mapped, not the number of operators required for processing all products.
 Data Box	The data box goes under other icons that have significant information/data required for analyzing and observing the system. Typical information placed in a Data Box underneath **Factory** icons is the frequency of shipping during any shift, material handling information, transfer batch size, demand quantity per period, etc. Typical information in a Data Box underneath **Manufacturing process** icons: **C/T** **C/O** **Uptime** **EPE** (a measure of production rate/s) - Acronym stands for "Every Part Every___". **Number of product variations**. **Available Capacity** **Scrap Rate** **Transfer Batch** size (based on process batch size and material transfer rate)
 Workcell	**Cellular manufacturing** is an important part of VSM and Lean operations. The workcell symbol indicates that multiple processes are integrated in a manufacturing workcell. Such cells usually process a limited family of similar products or a single product. The product moves from a process step to a process step in small batches or single pieces.
Material symbols	
 Customer/Supplier	These icons show inventory between two processes. While mapping the current state, the amount of inventory can be approximated by a quick count, and that amount is noted beneath the triangle. If there is more than one inventory accumulation, use an icon for each. This icon also represents storage for raw materials and finished goods.
 Shipments	This icon represents movement of raw materials from suppliers to the Receiving dock/s of the factory. Or, the movement of finished goods from the Shipping dock/s of the factory to the customers.
	This icon represents the "pushing" of material from one process to the next process. Push means that a process produces something regardless of the immediate needs of the downstream process.

Table 4.1 VSM symbols – cont.

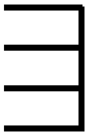
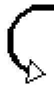
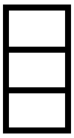
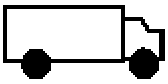
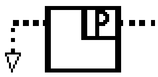
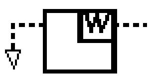
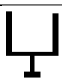
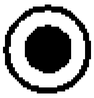
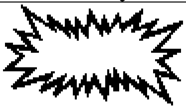
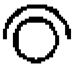
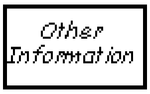
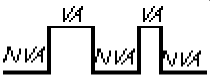
 Supermarket	This is an inventory "**Supermarket**" (kanban stockpoint). Like in a supermarket, a small inventory is available and one or more downstream customers come to the supermarket to pick out what they need. The upstream workcenter then replenishes stocks as required. When continuous flow is impractical, and the upstream process must operate in batch mode, the supermarket reduces overproduction and limits total inventory.
 Material Pull	Supermarkets connect to downstream processes with this "**Pull**" icon that indicates physical removal.
 FIFO Lane	
 Safety Stock	This icon represents an inventory "hedge" (or safety stock) against problems such as downtime, to protect the system against sudden fluctuations in customer orders or system failures. Notice that the icon is closed on all sides. It is intended as a temporary, not a permanent storage of stock; thus; there should be a clearly-stated management policy on when such inventory should be used.
 External Shipment	**Shipments** from suppliers or to customers using external transport.
Information symbols	
 Production Control	This box represents a central production scheduling or control department, person, or operation.
 Manual Information	Manual Information
 Electronic Info	
 Production Kanban	This icon triggers production of a pre-defined number of parts. It signals a supplying process to provide parts to a downstream process.
 Withdrawal Kanban	This icon represents a card or device that instructs a material handler to transfer parts from the supermarket to the receiving process. The material handler (or operator) goes to the supermarket and withdraws the necessary items.
 Signal Kanban	This icon is used whenever the on-hand inventory levels in the supermarket between two processes drops to a trigger or minimum point. When a Triangle Kanban arrives at a supplying process, it signals a changeover and production of a predetermined batch size of the part noted on the Kanban. It is also referred to as "one-per-batch" kanban.
 Kanban Post	A location where kanban signals reside for pickup. It is often used with two-card systems to exchange withdrawal and production kanban.

Table 4.1 VSM symbols – cont.

 Sequenced Pull	This icon represents a pull system that gives instruction to subassembly processes to produce a predetermined type and quantity of product, typically one unit, without using a supermarket.
 Load Leveling	This icon is a tool to batch kanbans in order to level the production volume and mix over a period of time
 MRP/ERP	Scheduling using **MRP/ERP** or other centralized systems.
 Go See	Gathering of information through visual means.
 Verbal Information	This icon represents verbal or personal information flow.
General symbols	
 Kaizen Burst	
 Operator	
 Other Stuff	
 Timeline	The timeline shows **Value added times** (Cycle Times) and **Non-value added** (wait) times. Use this to calculate Lead Time and Total Cycle Time.

Source: [2]

3. *Defining the process boundaries and process steps*

Then it must be decided where the boundaries of the map will be. Most maps are conducted from supplier through to customer within an organization and these should be the first boxes placed on the map to define the process (see Fig. 4.2). However, it is possible to map the entire supply chain. In this case, the start and end points for the process map would be the raw materials and the final consumer and instead of putting boxes for the process steps, companies must be used.

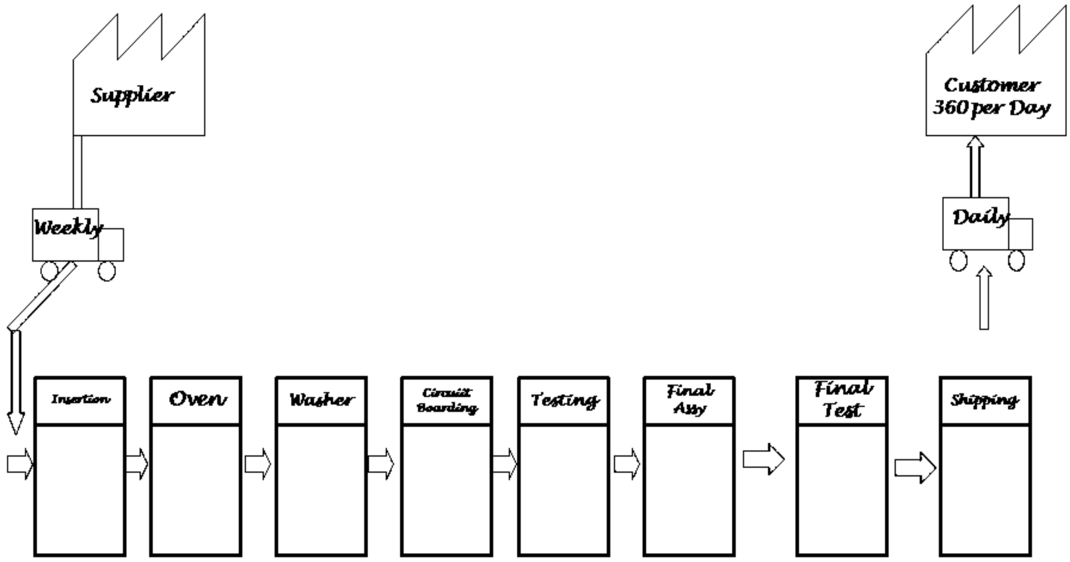


Fig. 4.2 Ploting boundaries, process steps and material flow

Source: [3]

Once the process boundaries are established, the process steps are depicted. Some people advocate walking the process from customer back to supplier or the other way round, but it is not necessary to do it in every situation. The process steps are the various operations performed on the product that are generally located in a single place with one point that inventory enters and then leaves. Each operation does not need to be broken down into specific tasks (there are other process mapping techniques, such as flow charting, that would be a better tool for analyzing the process in such detail).

4. ***Adding information flows to value stream map***

One of the things that distinguish value stream mapping from the majority of other mapping tools is depicting the information flows into the map. It describes how the customers order the product, with what frequency, and which method they use, how the organization translates it back to its supplier. It also includes information how the organization communicates requirements to its processes to ensure that they produce what the customer wants (see Fig. 4.3).

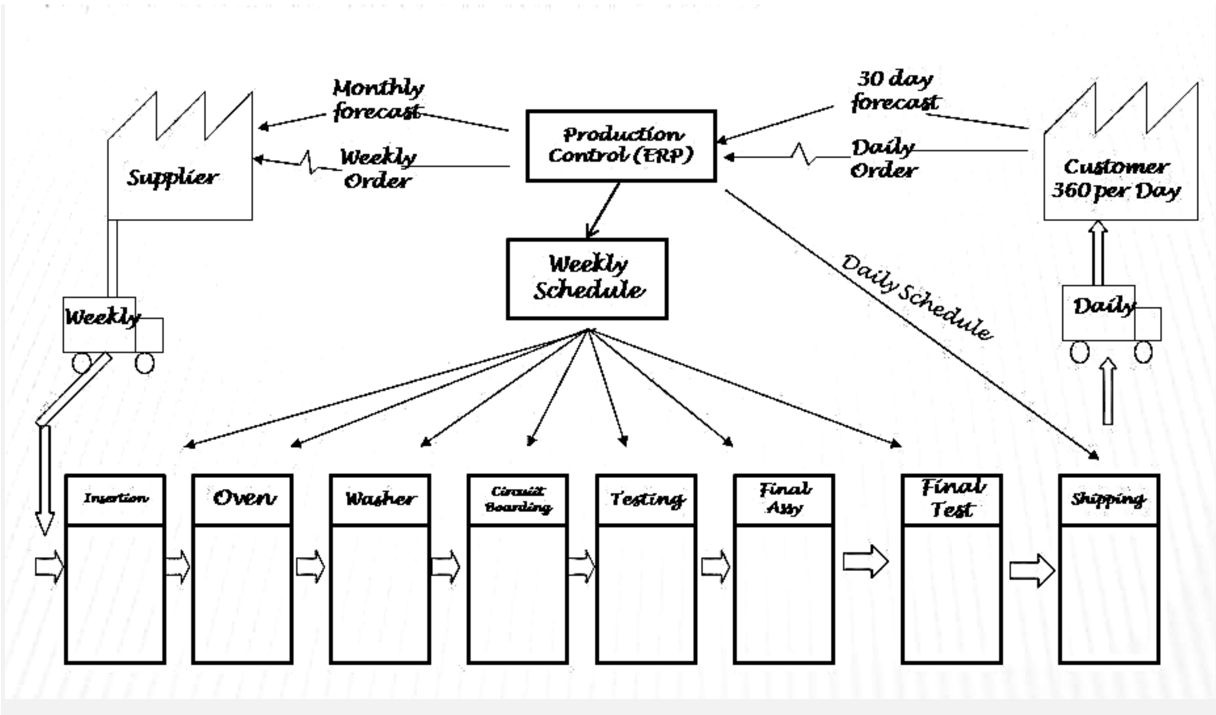


Fig. 4.3 Adding information flows

Source: [3]

5. *Collecting process data*

In this step, the team collects data regarding the performance of each step of the process; typical types of data are as follows:

- Inventory
- Cycle time (time taken to make one product)
- Change over time (from last good piece to next)
- Up-time (on-demand machine utilization)
- Number of operators
- Shifts worked
- Net available working time
- Scrap rate
- Pack size/pallet sizes
- Batch Size

It is necessary to avoid "historical" measures where possible and use the current information obtained during the own process analysis. Then this data are recorded in the "data boxes" on the Value Stream Map (Fig. 4.4).

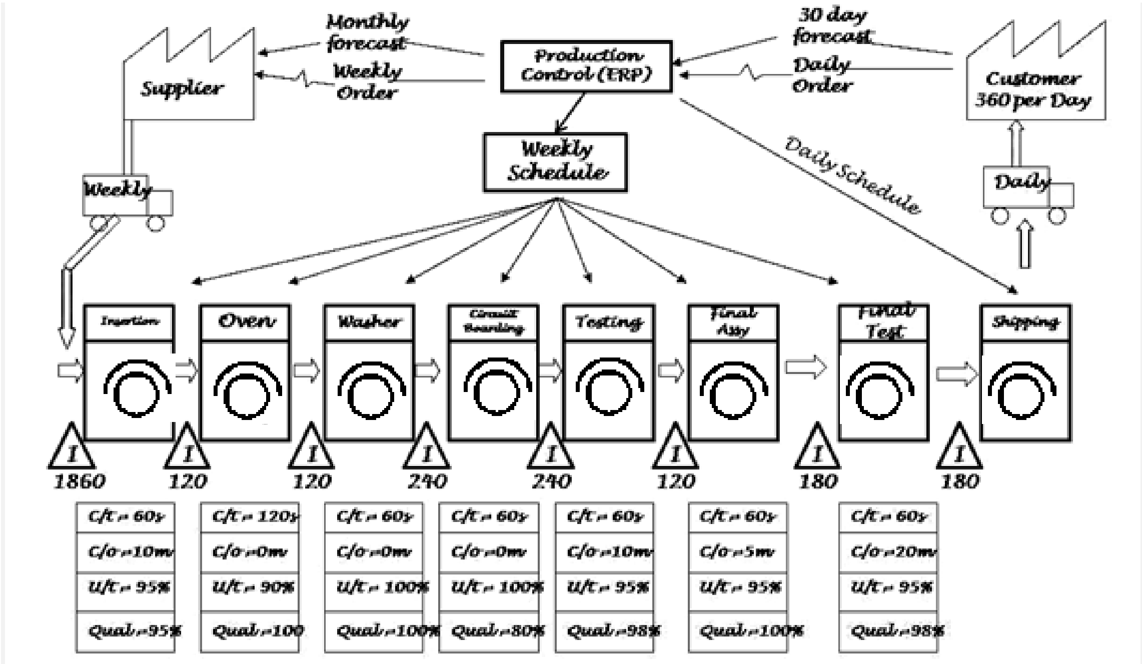


Fig. 4.4 Adding data to data boxes

Source: [3]

Methods of collecting the mentioned data are stated in the following table.

Table 4.2 Methods of collecting data for VSM

Acronym	**Description**	**Method**
CT	***Cycle Time*** Time before repeating operation. Time to complete a single unit of production (often corresponds to the value adding time);	Measuring
C/O	***Change over time*** Time spent for changing the setting from one type of product to another	Measuring
AT	***Available time*** The actual time available in the shift for carrying out the processes and changeovers	Measuring
SU	***Set up time*** Product change, time from the last good part to the next one	Measuring
UT	***Uptime*** The actual operating time divided by the available time	Calculation Formula: UT = (AT-C/O)/AT (%)
Y	***Yield*** % how many pass inspection	Observing

Table 4.2 Methods of collecting data for VSM – cont.

SC	Scheduled Changes Number of scheduled changes per week	Asking
TR	Travel How far does the Operators travel to do their job	Measuring
I	Inventory Count the amount of inventory before and after the process.	Counting
OPS	Operators per shift	Asking
PS	Production scheduling by supervisor	Asking
WT	Waiting time Find out how often operators wait for something to do; how often they wait for another operation to be done.	Asking, observing
IFU	Inventory flow up Where inventory comes from, all sources.	Asking
IFD	Inventory flow down Where inventory goes to, all places.	Asking

The most common VSM measures denoted in the data boxes are CT, C/O, UT, AT.
When counting inventory, it must be questioned carefully as it is not unusual to find pallets of inventory stored in odd locations due to previous problems or as a contingency.

6. ***Calculating the time line***

In the end, the time line is created to give information about total process times and lead times for inventory through the processes; the inventory at each stage and the daily demand is used to calculate the amount of stock in days, and this is added to the top of the time line; this will allow to calculate a total lead time. The cycle time for one product is then placed in the lower portion, and this will be added to give a total processing time.
At this point, it is usual to have lead times that take several days to several weeks and processing times that take only a few minutes, which highlights just how much waste there is in the system.
This map gives the completed current state value stream map (see Fig. 4.5).

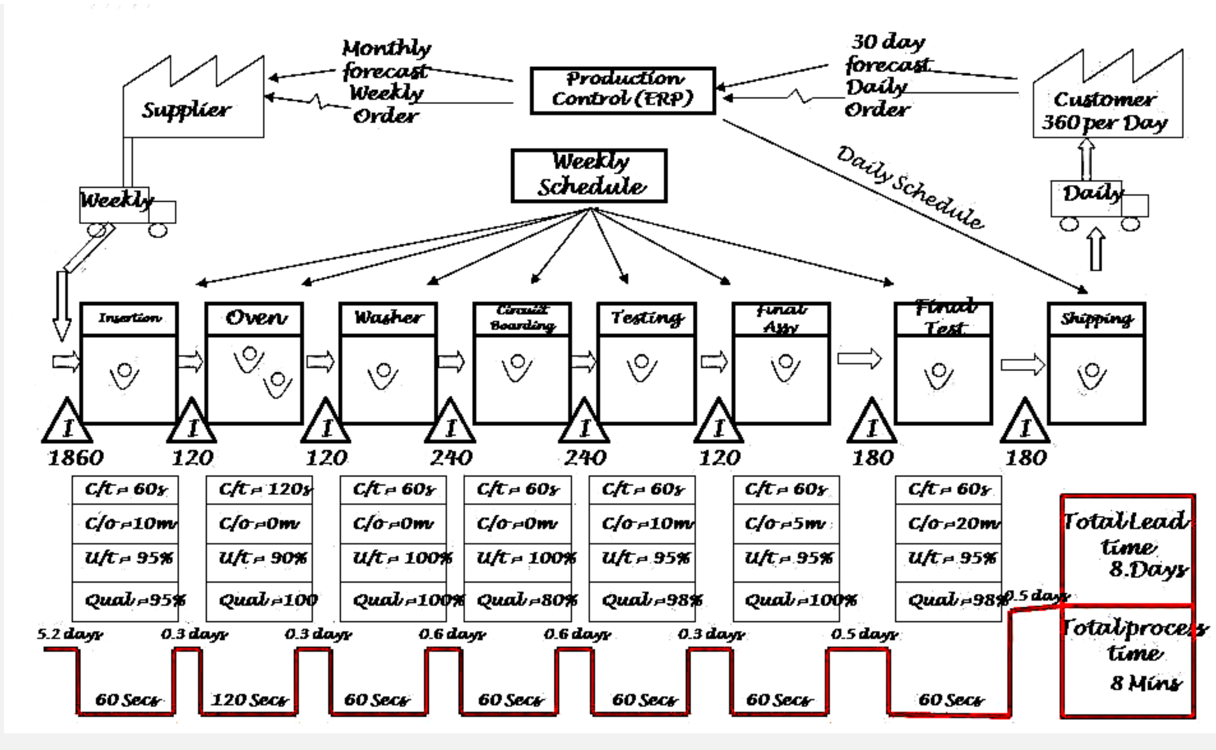


Fig. 4.5 Completed current state value stream map

Source: [3]

The completation of the current value stream map is summarized in the following table.

Table 4.3 Steps of the current value stream map completation

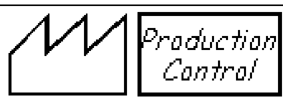
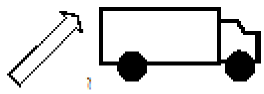
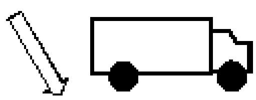
Step no.	Step description	Symbols
1	Draw Customer, Supplier and Production Control icons	
2	Enter customer requirements per month and per day	
3	Calculate daily production and container requirements	
4	Draw outbound shipping icon and truck with delivery frequency	
5	Draw inbound shipping icon, truck and frequency	

Table 4.3 Steps of the current value stream map completation - cont.

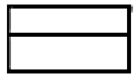
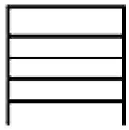
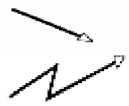
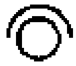
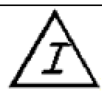
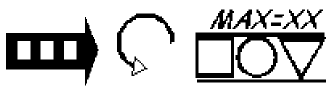
Step no.	**Step description**	**Symbols**
6	Add process boxes in sequence, left to right	
7	Add data boxes below process boxes	
8	Add communication arrows and note methods and frequencies	
9	Obtain process attributes and add to data boxes. Observe all times directly!	CT, C/O, Uptime, Avail, Lot…
10	Add operator symbols and numbers	
11	Add inventory locations and levels in days of demand and graph at bottom	
12	Add push, pull and FIFO icons	
13	Add other information that may prove useful	
14	Add working hours	
15	Cycle and Lead times	
16	Calculate Total Cycle Time and Lead Time	

Fig. 4.6 shows another current state map example.

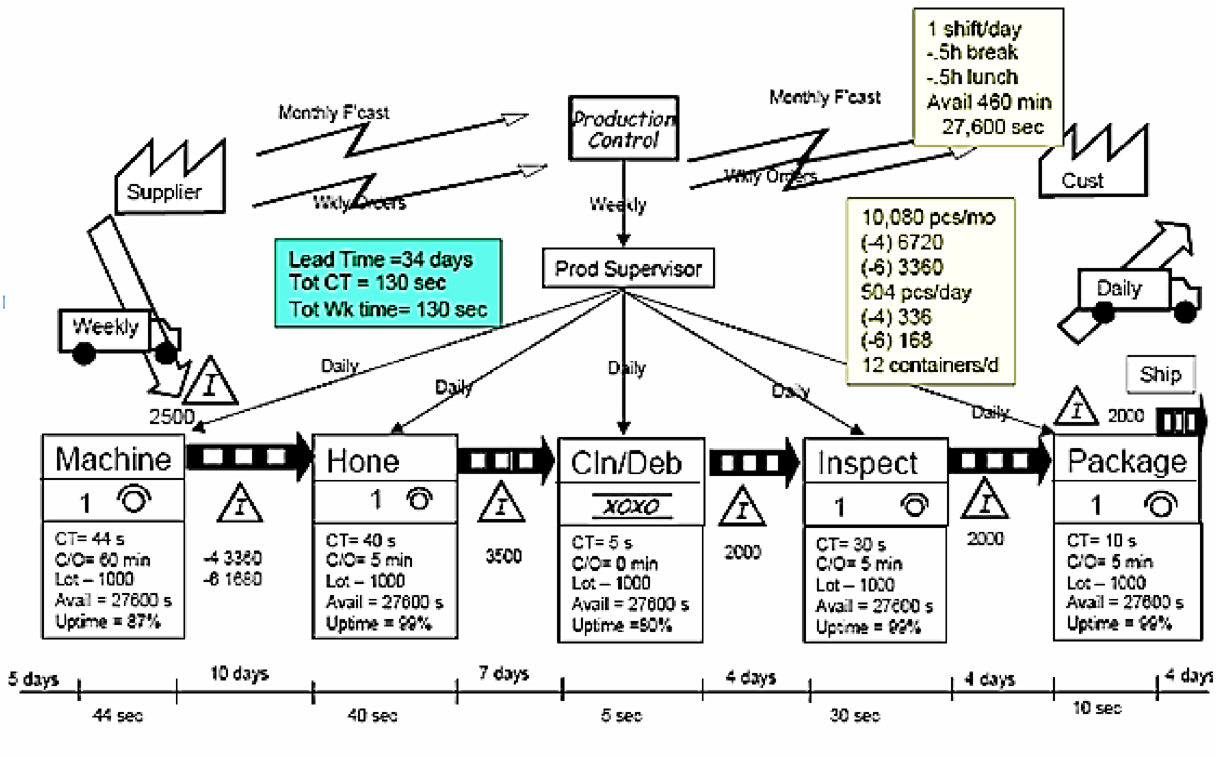


Fig. 4.6 Example of the current state value stream map

Source: [4]

7. ***Interpreting the current value stream map***

The data boxes and the timeline contain much information about the process, now it can be seen in one document where the problem areas within the process represent issues such as

- Excessive Inventory
- Long cycle times
- Low uptime
- Excessive Setup Times
- Poor Quality / Rework

Multiple suppliers and customers in value stream map

The map discussed above is a fairly simple map with just one customer and one supplier. But more often the organization has multiple suppliers and customers and it may be necessary to draw on more than one map. If the organization has many suppliers, it may be worth concentrating on the most important suppliers or grouping them into similar types. As to the multiple customers, they can be grouped according to similar requirements, such as weekly or monthly demands.

B The future and ideal state value stream map

The problems highlighted above could all be tackled one by one; however, some goal must be set. The team guided by the expert should create an ideal state value stream map, which should envision the best possible state of the process, this should then be agreed by senior management as the ultimate goal of the value stream mapping exercise.

Mapping the future state requires more art, engineering and strategy than the present state, and it needs background knowledge in cellular manufacturing,tact time, setup reduction, implementing change, Kanban, kaizen, grouping technology, lot sizing.

Once the ideal state is achieved, reaching the shared vision can be planned. The simplest way to do it is to plan a series of improvements, each taking two to three months, and use the value stream map to communicate what must be done. The kaizen burst symbols can be added on the current state map to highlight the improvements that are planned to achieve, for instance, reducing the setup time on the final test from 20 minutes to 5 minutes; the aspirations for the improvements become the future state value stream map. It may need several iterations of future state maps before the ideal state will be finally reached (see Fig. 4.7).

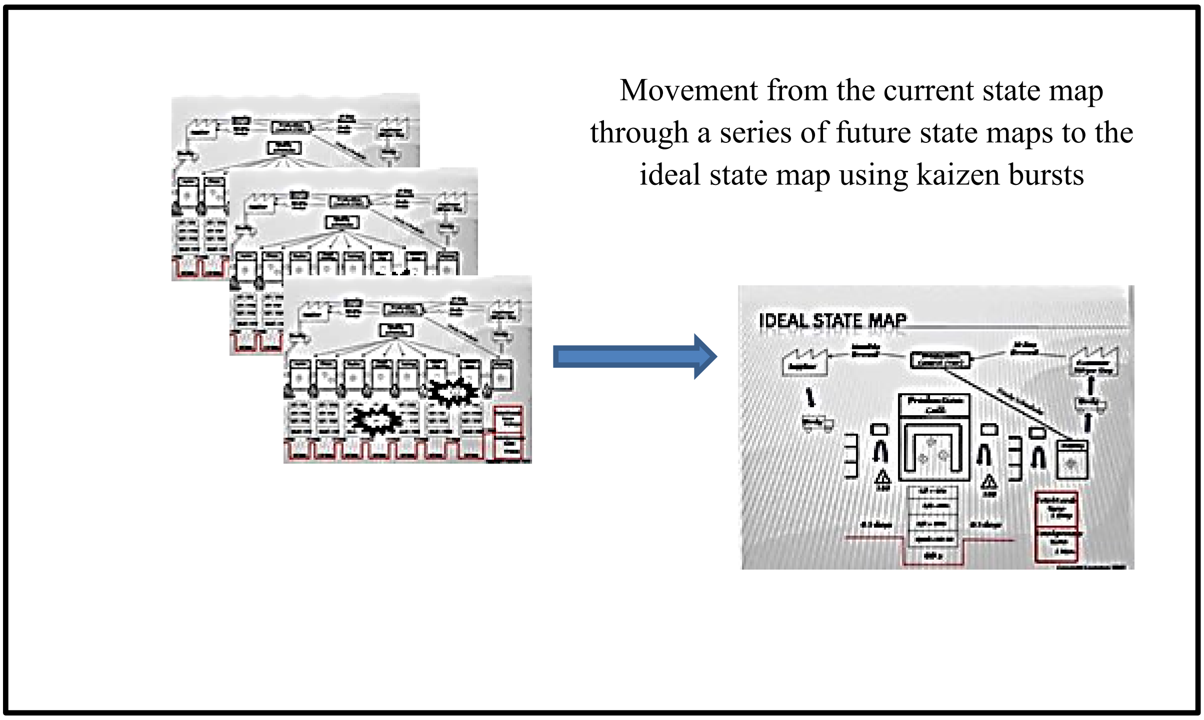


Fig. 4.7 Moving from the current state through an iteration of the future state maps towards the ideal state [3]

The future state map can be completed through the following steps:

1. Setting the tact time;

2. Identifying bottleneck processes the operation with the longest cycle time determines total system output;
3. Identifying lot sizing / Setup opportunities;
4. Identifying potential workcells;
5. Determining Kanban locations (between cell and supplier, between cell and customer);
6. Establishing scheduling methods;
7. Calculating performance data.

On Fig. 4.8 the example of the future state map can be found.

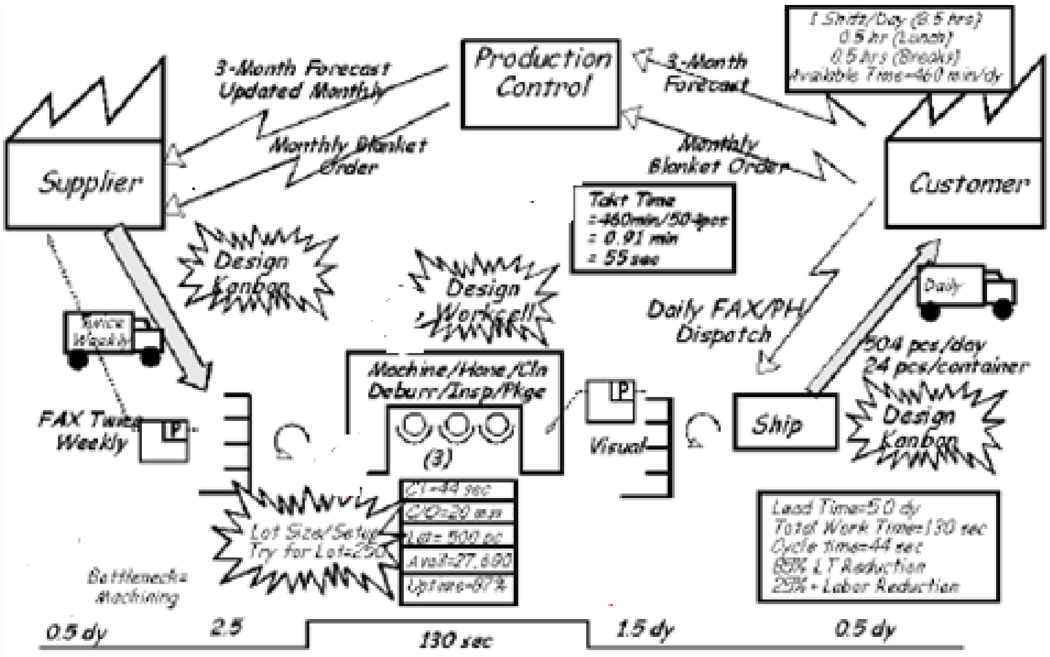


Fig. 4.8 Example of the future statre map

Source: [4]

Tasks

Task 1

Read from the map any 10 pieces of information depicted in the following map.

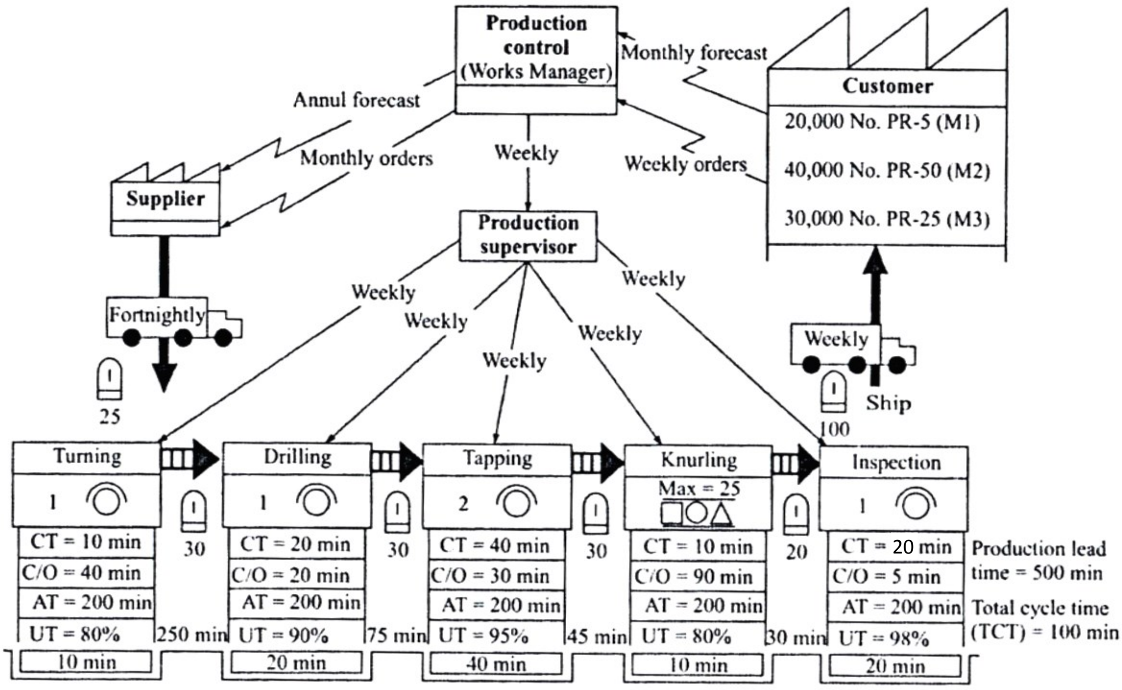


Fig. 4.9 Current value stream map

Source: [5]

Task 2

The maps presented in Fig. 4.10 and Fig. 4.11 are the current and future state maps developed during the beginnning of the lean implemention programme in an automobile component manufacturing company. List 120 changes that have been made in the future state map to achieve the objectives of lean manufacturing.

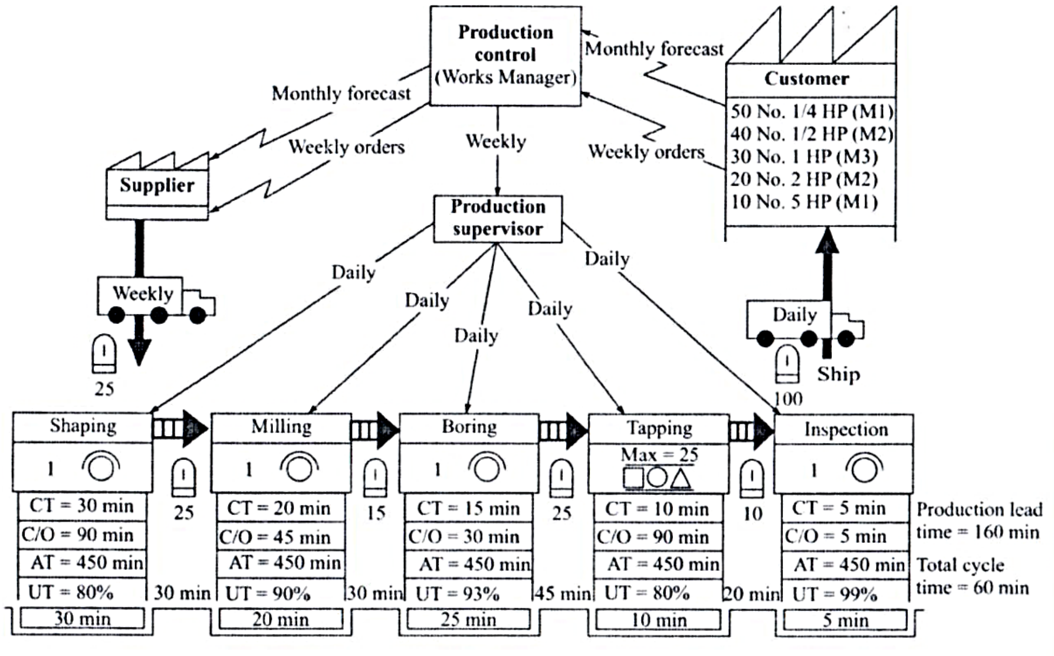


Fig. 4.10 Current state map

Source: [5]

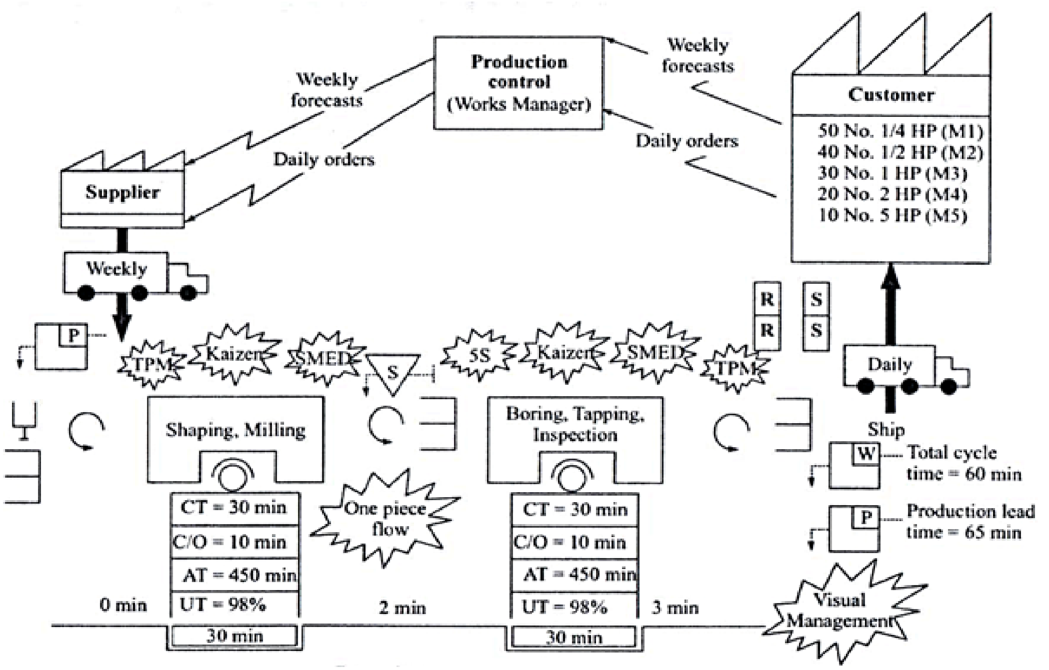


Fig. 4.11 Future state map

Source: [5]

Summary of terms

- Available time
- Change over time
- Current value stream map
- Cycle time
- Future stream map
- Lead time
- Tact time
- Uptime
- Value stream mapping

Questions

- What are conventional techniques used for depicting the processes? How is value stream mapping different from them?
- What is the value stream?
- What is the purpose of value stream mapping?
- In which manufacturing conditions is it suitable and effective to apply value stream mapping?
- What are the phases of implementation of value stream mapping?
- What steps must be taken to create the current state map?
- What steps must be taken to create the future state map?
- What are the differences between the current and future state maps?
- What data must be selected during value stream mapping?
- What outcome measures are obtained from the value stream map?

Key to solutions

Task 1

- Quantity to be supplied is communicated to the supplier electronically.
- Quantity to be supplied is communicated to the supplier annually.
- Threee models under the code names PR-75, PR-50, and PR-25 are manufactured in the company in annual quantity of 20,000, 40,000 and 30,000 respectively.
- The supplier supplies the goods fortightly.
- Five processes, namely turning, drilling, tapping, knurling, and inspection are caried out to produce the three models.
- Production lead time is 500 min.
- Total cycle time is 100 min. Hence, non-value adding time is 400 min.
- All processes require one operator, while tapping proces along requires two operators.
- All activities carried out under the processes of turning, drilling, tapping, and knurling are “pushed“. After the inspection is completed, the finished goods are „pulled“.
- The uptime of the knurling proces is the lowest, in which case it is 70%.

Other pieces of information can be found in the maps.

Task 2

- Shaping and milling machines are placed in one cell, and this cell is maintained by a single operator.
- Boring machine, tapping machine, and inspection are located in one cell, and this cell is maintained by one operator.
- The “push“ system is replaced by the “pull“ system.
- Supermarkets are introduced in front of both cells to meet the unexpected demand.
- Total productive maintenance (TPM) is to be introduced in both cells.
- Withdrawal Kanban is made operational in front of the supermarket of the first cell.
- Kanban is introduced in both cells to enable the operators to machine only quantity indicated in the kanban cards.
- Single minute exchange of die (SMED) is introduced in both cells.
- 5S technique is planned to be applied in the second cell.
- The production lead time is reduced from 160 min to 65 min.

Other pieces of information can be found in the maps.

References

[1] http://leanmanufacturingtools.org/551/creating-a-value-stream-map/

[2] http://www.strategosinc.com/vsm_symbols

[3] http://leanmanufacturingtools.org/551/creating-a-value-stream-map/

[4] http://www.asq-1302.org/wp-content/uploads/2010/09/VSM.pdf

[5] Devadasan, S. R.: Lean and Agile Manufacturing. Theoretical, practical and research futurities. Delhi: PHI Learning, 2012.

5. 5S

Time to study

360 min

Goal

after studying this chapter

- you will be familiar with the principle of 5S and the contents of every "S" phase;
- you will be able to implement 5S method.

Lecture

5.1 Overview

5S is one of the most powerful Lean Manufacturing Tools and a cornerstone of any successful Lean implementation. The real goal of 5S is introducing standard operational practices to ensure efficient, repeatable and safe ways of working.

In addition to standardized working which provides workers stable foundations for building improvements through implementing other lean tools, it also provides a highly visual workplace. One of the most important benefits of 5S is making problems immediately obvious.

5S is a team run process and should be implemented by people working within the area in which 5S is being applied. It cannot be applied by an outsider without knowledge of the workplace.

5.2 Definition of 5S

- 5S is a simple tool for organizing the workplace in a clean, efficient and safe manner to enhance employees´ productivity, visual management, and to ensure the introduction of standardized working.

- 5S relates to workplace organisation and forms a solid foundation upon which the organisations base their drive for continuous improvement.
- It is a systematic and methodical approach allowing teams to organise their workplace in the safest and most efficient manner.
- 5S is a methodical way to organize the workplace and working practices as well as being an overall philosophy and way of working.
- 5S is a method to improve the workplace management and standardize processes making them more efficient and less stressful for employees.
- 5S is a generic tool that can be used for realization of continuous improvement of quality and productivity and the cycle time reduction.
- 5S is a system to reduce waste and optimize productivity through maintaining an orderly workplace and using visual cues to achieve more consistent operational results

5.3 Origins of 5S

5S as a methodology has come out of the techniques within Total Productive Maintenance (TPM) and from the Toyota Production System (TPS). However, for instance creating ergonomic and efficient workplaces has its roots in Taylor´s "scientific management" and Gilbreth's "time and motion studies."

5.4 The Principle of 5S

It is implemented in 5 steps each called after a different Japanese term: Seiri, Seiton, Seiso, Seiketsu, Shitsuke, hence 5S. English meaning of these words is as follows (see Fig. 5.1):

Seiri: Sort, Clearing, Classify

Seiton: Straighten, Simplify, Set in order, Configure

Seiso: Sweep, Shine, Scrub, Clean and Check

Seiketsu: Standardize, Stabilize, Conformity

Shitsuke: Sustain, Self discipline, Custom and practice

Fig. 5.1 Steps of 5S

Source: [1]

5C and CANDO

Using English equivalents 5S is called 5C or CANDO (see Tab. 5.1)

Table 5.1 5 C and CANDO steps

5 C steps	CANDO steps
• Clearing • Configure • Clean and Check • Conformity • Custom and practice	• Cleanup • Arrange • Neatness • Discipline • Ongoing Improvement

5.5 Description of 5S steps

1. Seiri or Sort

Fig. 5.2 Seiri removing Clutter

Source: [2]

Seiri or Sort (Fig. 5.2) refers to the sorting of the clutter from the other items within the work area that are actually needed. This stage requires the team to remove all items that clearly do not belong to the working area and leave only those that are required for the processes in question on a daily basis.

Of course, not everything that "does not belong in the area" is trash or worthless. For this reason, what is called a "parking" or "red-tag" area must be created here in advance. Indeed, some items that evidently may have some value and be useful in a different place of the plant or can be sold to someone else will be taged using a simple "RED Label" of any size. Then all those items are carried to the "red tag area" and are made available to people from other areas of the plant where they can and will be utilized. The rest of items (worthless) will be properly disposed of. Ideally, the "red tag area" will be open for only a few days, then the valuable items not needed should be moved to a warehouse and someone must take care of them to return, sell, donate, or any other alternative. This should be accomplished in a reasonable timely manner.

Some materials, because of their nature, need to come to the area in higher volumes than strictly required, for these, an appropriate rack or storage space must be assigned close to the area where we can get the materials we will use in the next period of time (usually not more than 4 hours).

2. *Seiton or Straighten / Set in order*

Seiton or Straighten is the process arranging the required items, remaining after the first step on the work place in an efficient manner using ergonomic principles (see Fig. 5.3). It must be also ensured that items are clearly identified and have a clearly identified home – "A place for everything, and everything in its place." The goal is for anyone (when this step is finished) to find anything they may need in just a few seconds.

Fig. 5.3 Seiton organized workspace

Source: [3]

The "place" assignment must be logical and determined by the direct user of the workstation. Some arrangements may be necessary, such as: shelves, racks, drawers using the creativity of our team. Consider the ease of access and ergonomic work postures; another factor is safety. In order to assure that tools, jigs, and other repetitive-use items go back to their exact place, some visual systems will be helpful. In the case of tools, the whiteboards with shadows for each tool are excellent; in some cases, it will be convenient to utilize conventional colour codes. This helps avoid confusion when there are tools that look very much alike and differ in size or application (see Fig. 5.4). For major items like carts, trash cans, dollies, incoming and outgoing pallets, it may be found convenient to use delimitation lines, so they are always kept in the same spot. Shelves assigned to keep certain materials or tools should also show a clear identification that makes it easy for the user to find and return them when necessary.

Fig. 5.4 Arranged tools

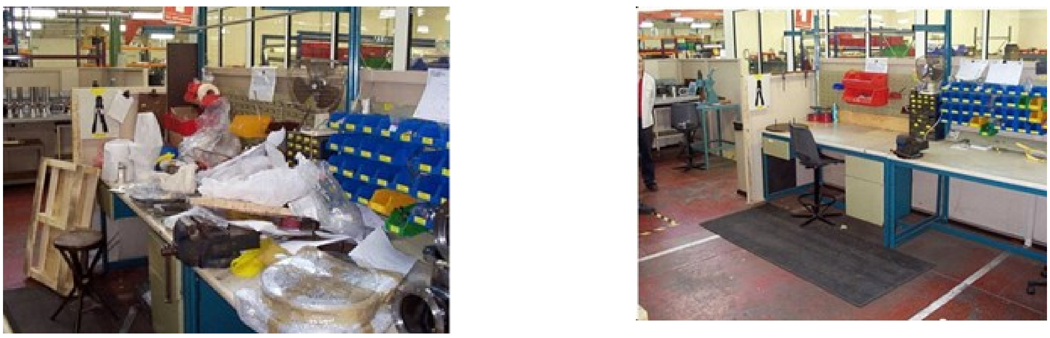
Source: [4]

3. Seiso or Sweep / Shine

Seiso or Sweep is the thorough cleaning of the area, tools, machines, and other equipment to ensure that everything is returned to a "nearly new" status. This step is very important and the team must focus not only on cleaning the area, but also find the root cause(s) or the origin(s) of contamination. This step is very useful to inspect the equipment and installations. Cleaning is inspection, after that initial effort, it will be much easier to keep the area clean. Cleanliness contributes to make the area safer and the people who work in it will be happier.

When the working area is somewhat complex, we may need to create a standard procedure to clean it well and keep it like that all the time. The team must establish a self-audit system and find out if any additional prevention is needed to avoid contamination and decay of the area. It represents "Autonomous Quality" here.

Some pictures of before and after states are a great tool to boost the satisfaction and self-esteem of the team (Fig. 5.5).



Before After

Fig. 5.5 Seiso Cleaning or Sweep

Source: [5]

4. Seiketsu or Standardize

Seiketsu or standardize (Fig. 5.6) is the process to ensure that what was done within the first three stages will become standardized; standard work is one of the most important principles of Lean manufacturing.

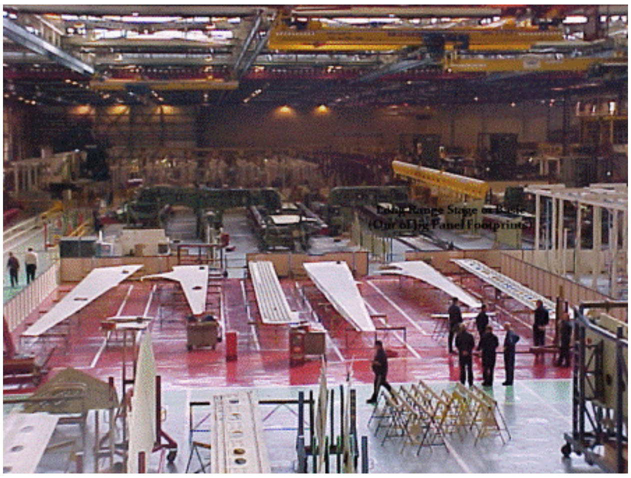


Fig. 5.6 Standardize – Seiketsu

Source: [6]

5. Shitsuke or Sustain

The main goal of Shitsuke or sustain isto ensure that the organization keeps on the continual improvement using the previous stages of 5S, maintaining workplace management, conducting audits, using information boards (Fig. 5.7), and so forth. 5S should become part of the culture of the company and the responsibility of everyone in it.

Fig. 5.7 5S Sustain – Shitsuke

Source: [7]

Lean 6S

Some companies implement 6S. 6S is 5S plus the added step of safety. Safety means that the stress is put on safety aspects of all activities reviewing every action and each area to ensure any potential hazard was not overlooked. But it should be an integral part of the steps of 5S and not a separate stage in itself.

5.6 Implementation of 5S (6S)

5S could be implemented using the following step by step approach as proposed in the presentation [8].

To start the 5S implementation, each phase must be thoroughly analysed and addressed using the P-D-C-A Cycle and approach as it is depicted on Fig. 5.8:

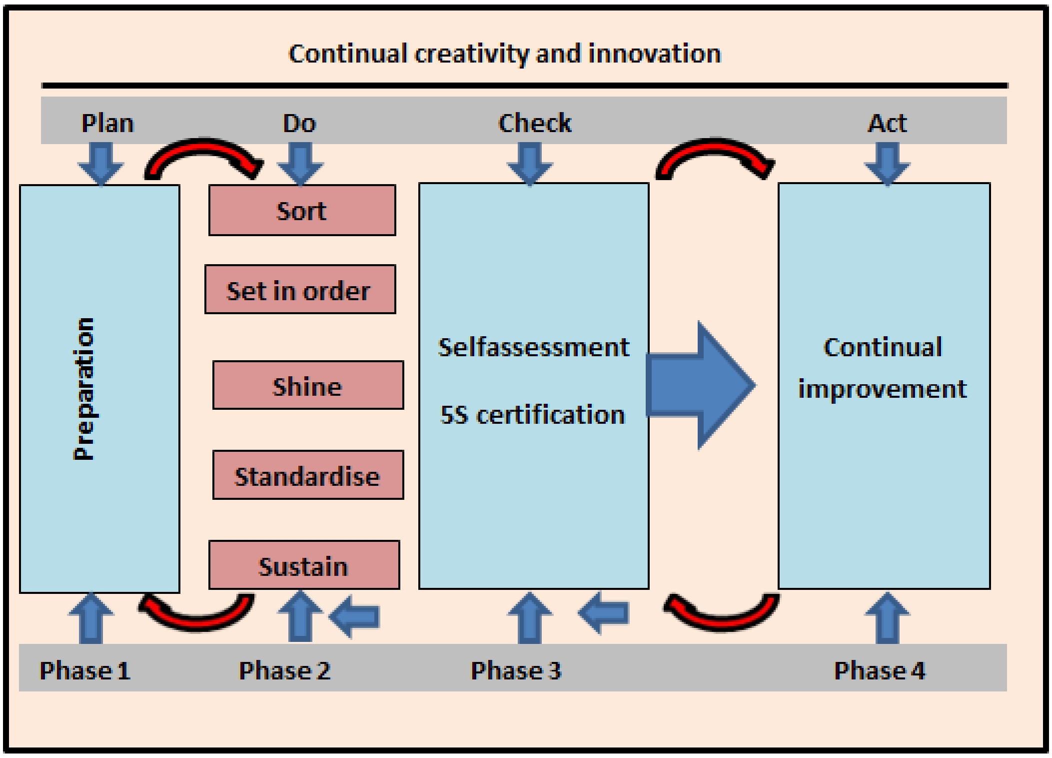


Fig. 5.8 Scheme of 5S implementation [8]

PLAN

Preparation:

- Provide training and education for everyone.

- Form 5S Council.
- Set-up 5S Zones.
- Determine 5S objectives, goals and implementation phases.
- Plan 5S action plan and 5S Launch.

DO

Sort:

- Identify what is necessary and what must be eliminated (Red-Tag strategy)

Set in Order:

- Define what and how to arrange.

Shine:

- Identify dirt sources.
- Identify root causes.
- Take action to eliminate dirt sources and root causes.

Standardise:

- Who is responsible?
- What actions to take to maintain the desired condition?
- When must those actions be taken?
- Where must they be applied?
- What procedures need to be followed

Sustain:

- Everyone understands, obeys, and practises the rules and procedures
- Continual efforts at sustaining the desired condition

CHECK

Assessment:

- Conduct Internal 5S Audit

- Benchmark within the department and with other organisations
- Ensure the established 5S procedures are followed

ACT

Continual Improvement:

- Develop QE 5S practices into a HABIT
- Compare actual goals with the set goals
- Reward and recognise efforts of staff
- Register 5S Certification
- Participate in National 5S Competitions
- Review Plan-Do-Check-Act Cycle

Task

Task 1

Imagine that a cement manufacturing company wishes to implement lean manufactruring through the adoption of the 5S tool. This company has 1000 employees. In spite of the fact that the employees have been exposed to lean manufacturing concepts, no formal activities in this regard have been initiated up to now. Describe and explain the steps that the company must take.

Summary of terms

- 5C
- 5S
- 6S
- Autonomous quality
- CANDO

- Cleaning
- Red-tag
- Safety
- Self-audit
- Shining
- Sorting
- Standardization
- Straightening
- Sustainability
- Sweeping
- Vizualization

Questions

- How does 5S aid the implementation of lean manufacturing?
- What are the purspose and goals of 5S?
- What is the difference between 5S and 6S?
- What activities must be realized when implementing the step “Set in order”?
- What is red tagging?
- How to apply the step “Shine”?
- Describe the activities carried out to implement the 5S step “Shine”?
- What activities must be realized when implementing the 5S step “Standardize”?
- Describe the activities carried out to implement the 5S step “Sustain”?
- What additional activities are to be realized to implement 5S comprehensively?

Key to solutions

Task 1

Study the subchapter 4.3.3 in more detail and try to find more information about the 5S complex implementation in literature or via Internet.

References

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6. KANBAN

Time to study

480 min

Goal

after studying this chapter

- you will understand the purpose of kanban and conditions for its effective application;
- you will know various kanbans and how different kanban systems operate;
- you will be able to suggest the kanban implementation.

Lecture

6.1 Overview

Kanban is often presented as a central element of "lean" manufacturing and is probably the most widely used type of the "pull" signalling system. The word kanban comes from the Japanese language and stands for Kan- card, Ban- signal. To put it simply, such "pull" production system controls the flow of work through a factory by only releasing materials into production when the customer demands them, i.e. only when they are needed - Fig. 6.1.

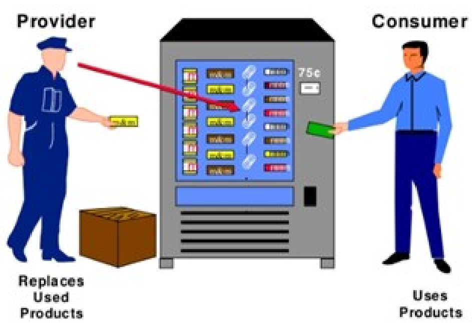

Fig. 6.1 The main principle of the kanban system (Source: [1])

Instead of estimating the number of a specific item the market will want and producing based on that amount (the principle of the push system), kanban produces items in direct relation to the number requested by the market. On the other hand, with kanban, properly implemented, materials are always available to meet the facilities production demands. Kanban is not a scheduling system, but rather a production control system.

Some common *benefits* of application of kanban system are as follows: it

- lowers overhead costs;
- standardizes production goals;
- increases efficiency;
- reduces obsolete inventory;
- improves flow;
- prevents over production;
- provides managers progress reports;
- improves responsiveness to changes in demand;
- improves teamwork.

Kanban preconditions are

- high demand rate;
- small variations in demand;
- limited number of product variants;
- good supplier relations.
- smooth production involving a stable product mix
- short setups
- proper machine layout
- standardization of work
- improvement activities
- autonomous defect control

6.2 Definitions

- Kanban is a specific type of inventory control system.
- Kanban is a "signal card," referring to the reorder slip used to procure more supplies. The kanban system is a means to achieve Just-in-time (JIT) production. It works on

the basis that each process on a production line pulls just the number and type of components the process requires, at just the right time.

- Kanban is the visual signal that authorizes the production or movement of items.
- Kanban is a signalling device that gives authorization and instructions for the production or withdrawal (conveyance) of items in a pull system.
- Kanban is a paperless production control system where authority to pull, or produce comes from a downstream process.

6.3 Kanban goals, principles, properties and rules

The main kanban ***goals*** are as follows:

- Controlling and balancing the resource flow;
- Eliminating waste of handling, storage, expediting, repair, rework, excess inventory;
- Manufacturing and shipping only what has been consumed;
- Providing visual control of all resources.

The kanban system is based on the following principles and core properties [2]:

Principles

- Start now with what you are doing;
- Target the incremental change;
- Current processes, people, roles & titles;
- Every team member is a leader.

Core Properties

- Limit the work in progress;
- Visualize the workflow;
- Improve continuously and collaboratively;
- Process to be explicit to every team member.

Rules

Kanban can be effectively realized only through these rules:

1. Customer processes order goods in the precise amounts specified on the kanban.

2. Supplier processes produce goods in the precise amounts and sequence specified by the kanban.
3. No items are made or moved without a kanban.
4. All parts and materials always have a kanban attached.
5. Defective parts and incorrect amounts are never sent to the next process.
6. The number of kanban is reduced carefully to lower inventories and reveal problems.

6.4 Description of kanban

Let us consider the case of an assembler who is drawing a particular component from a pallet containing 100 pieces when full. As the last piece is drawn, the assembler takes an identifying card from the empty pallet and sends it back down the line to the earlier work centre where that part (among others) is made. On receiving the kanban card, the work centre responsible for supplying the component makes a new batch of 100 and sends it to the assembly post (so that the assembler is not kept waiting, there will probably be an extra pallet in the system to maintain the supply while the new batch is being made). This means that there is a minimum of paperwork, and the order cycle is generated on a "pull" basis, the components only being made when there is an immediate need for them, thus keeping work-in-progress to a minimum. A kanban system gives production control instructions to each and every work area. It does this by connecting information flow with material flow by attaching kanban cards to the actual goods.

Fig. 6.2 depicts the kanban system with supermarkets and FIFO lane.

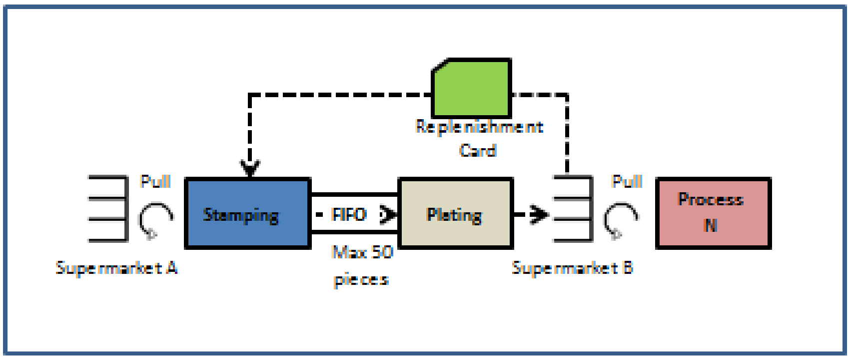

Fig. 6.2 Kanban example [3]

As we can see in the previous figure, process N starts the initial pull cycle by removing items from Supermarket B. When the supermarket inventory level reaches a user-specified order point, Stamping receives a kanban card that authorizes it to produce the kanban quantity. Using material pulled from Supermarket A, stamping processes items and places them in the FIFO lane which holds no more than 50 items as a source of supply for plating. Stamping cannot produce more until space opens up in the FIFO lane as a result of parts being removed on a first-in, first-out basis by plating. Plating moves completed items to Supermarket B for use by process N, completing the loop.

6.5 Types of kanban systems

Kanban "card or other device"[1] and systems are used to synchronize the flow of parts in systems (often manufacturing and assembly) where many different parts come together at various points in a long and often complex process. When the kanban system functions correctly, nothing is ever made or moved without a kanban signal of some kind. This enables companies to limit the extremely deadly waste of overproduction since things are not produced until they are needed. In addition to setting limits, kanban also physically links material and information flow through a card or, as we often see today, through a bar code scan. And finally, kanban makes abnormalities visible since no material should be without a kanban and kanbans on the shop floor can be found only attached to the material, in the heijunka board or in the kanban post box.
Two kinds of kanban cards are mainly used: Withdrawal and production-ordering cards.

A Withdrawal kanban WK (move cards, conveyance cards or C-cards)

This type of kanban signal signify that a part has moved, but has not been consumed. This may trigger movements upstream, but not the production of a new part. It specifies the kind and quantity of product which a manufacturing process should withdraw from a preceding process. The withdrawal kanban in Fig. 6.3 shows that the preceding process which makes this part is forging, and the person carrying this kanban from the subsequent process must go to position B-2 of the forging department to withdraw drive pinions. Each box of drive pinions contains 20 units and the shape of the box is "B". This kanban is the 4th of 8 issued. The item back number is an abbreviation of the item.

[1] To trigger replenishment activity different methods can be applied. Kanban cards are the most common, but kanban containers are often used and in automating kanban systems bar coding of cards or containers is used. But kanban can be also triangular metal plates, coloured balls, electronic signals, or any other device that can convey the needed information while preventing the introduction of erroneous instructions.

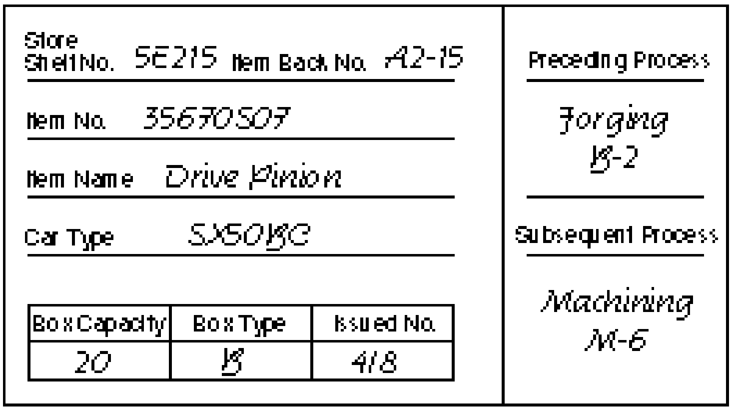

Fig. 6.3 Example of withdrawal kanban

Source: [4]

A production-ordering kanban (POK-card)

It specifies the kind and quantity of product which the preceding process must produce. The one in Fig. 6.4 shows that the machining process SB-8 must produce the crankshaft for the car type SX50BC-150. The crankshaft produced should be placed at store F26-18. The production-ordering kanban is often called an in-process kanban or simply a production kanban.

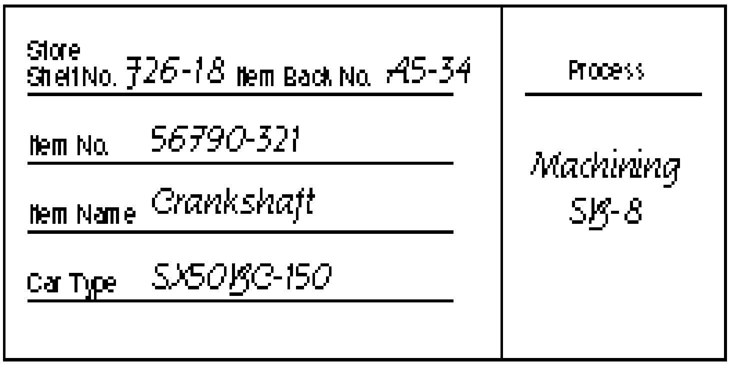

Fig. 6.4 Example of production-ordering kanban

Source: [4]

One-card kanban system

The “one-card” is the simplest implementation of kanban system. This approach is used when the upstream and downstream workstations (respectively, the preceding and succeeding processes) are physically close to each other, so they can share the same stock buffer. The card is called “production order kanban” (POK).The stock buffer acts either as the outbound buffer for the first (A) workstation or as the inbound buffer for the second (B) workstation. A schematic diagram of a one-card system is shown in Fig. 6.5.

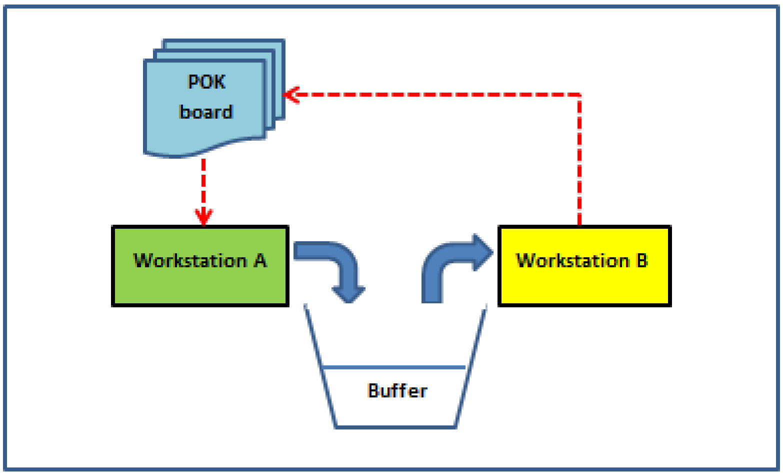

Fig. 6.5 One-card kanban system [5]

Here, each container (the JIT unit load) has a POK attached, indicating the quantity of a certain material contained, along with eventual complementary information. The POK also represents a production order for the workstation A, indicating to replenish the container with the same quantity. When a B operator withdraws a container from the buffer, he removes the POK from the container and posts it on a board. Hence, A operator knows that one container with a specific part-number must be replenished in the stock buffer.

Single-card systems work well in companies in which it is relatively easy to associate the required quantity and timing of component parts with the schedule of end products. These are usually companies with a relatively small range of end products, or products which are not subject to rapid, unexpected changes in demand levels.

Two-card kanban system

In this kanban system, each workstation has separate inbound and outbound buffers. Two above mentioned types of cards are used: production order kanbans (POK) and withdrawal kanbans (WK). A schematic diagram of a two-card system is shown in Fig. 6.6.

Each work-in-progress (WIP) container in the inbound buffer has a WK attached each WIP container in the outbound buffer has a POK. WK and POK are paired, it means that each given part number is always reported both in *n* POK and *n* WK. When a container is withdrawn from the inbound buffer, the B operator posts the WK on the WK board. Then, a warehouse-keeper operator uses the WK board as a picking list to replenish the inbound buffer: he takes the WK off the board and look for the paired POK in the outbound buffer. Then, he moves the corresponding quantity of the indicated material from the A outbound to the B inbound buffer, while exchanging the related POK with the WK on the container, restoring the initial situation. Finally, he posts the left POK on the POK board. Hence, like in the previous scenario, A workstation operator knows that one container of that kind must be replenished in the outbound stock buffer. The effectiveness of this simple technique is significantly influenced by the policy followed to determine the kanban processing order, in the boards.

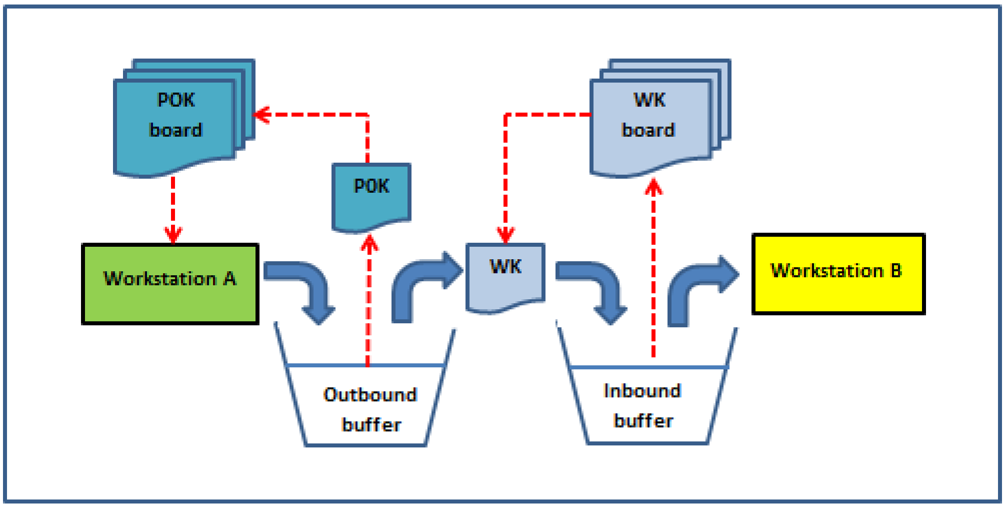

Figure 6.6 Two-cards kanban system [5]

Two-cards kanban system rules

1. No parts made unless P-kanban authorizes production;
2. Exactly one P-kanban and one C-kanban for each container (the number of containers per part number is a management decision);
3. Only standard containers used, always filled with the prescribed (ideally, small) quantity

Standard approaches to manage the kanban board

From the previously described procedure, it is clear that the production sequence of each workstation is given by the management of the kanban cards posted on the POK board. There are various ways for managing the board.

The most commonly used policy [6] requires having a board for each station, and this should be managed as a single First-In-First-Out (FIFO) queue. The board is usually structured as one vector (one column, multiple rows): POK are posted on the board in the last row. Rows are grouped in three zones (red/yellow/green) indicating three levels of urgency (respectively high/medium/low). Kanbans are progressively moved from the green to the red zone and the workstation operator will process the topmost kanban. If a kanban reaches the red rows, it means that the correspondent material is likely to be requested soon, by the succeeding process. Thus, it should be urgently replenished in the outbound buffer in order to avoid stock-outs. This policy is vulnerable to high setup times and differences among workstation cycle times: in this latter case, indeed, the ideal job sequence for a workstation may be far from optimal for the preceding one. It is noticeable that the coloured zones on the board only provide a visual support for the operators and do not influence the job processing order.

A *heijunka box* is a sort of enhanced kanban board: it still acts as a visual scheduling tool to obtain production levelling at the workstations. However, unlike the traditionalboard, it manages to keep evidence of materials distinctions. Usually, it is represented as agrid-shaped wall schedule. Analogously to the simpler board, each row represents a time interval (usually 30-60 minutes), but multiple columns are present, each one associated with a different material. POKs are placed in the so-called "pigeon-holes" within the box, based on number of items to be processed in the job, and on the material type. Workstation operators will process all the kanban placed in the current period row, removing them from the box. Hence, heijunka box not only provides a representation for each job queued for production, but for its scheduled time as well, and allows operators to pursue production levelling when inserting new POKs in the boxes.

6.6 Determining number of kanban cards

The number of cards influences the rate of WIP (work in process) inventories in the system. For that reason, it is very important to be able to set this number as properly as possible. The next formula is one of the most frequently recommended ways to set the number of kanban cards [7]:

$$N = \frac{\bar{d}L + S}{C} \tag{6.1}$$

where

N…number of kanbans or containers

$\bar{d}$… average demand over some time period

L…lead time to replenish an order

S…safety stock

C…container size

6.7 Kanban implementation

There are five main steps of implementing a kanban system:

1. Visualize the current workflow.
2. Apply Work-in-Process (WIP) limits.
3. Make policies explicit.
4. Manage and measure the flow.
5. Optimize iteratively with data.

Tasks

Task 1

Determine number of kanban cards when d = 150 bottles/hour

$\bar{d}$= 150 bottles/hour

L = 30 min = 0.5 hours

S = 0,1(150 · 0.5) = 7.5 bottles

C = 25 bottles

Task 2

Study principles and properties in detail using literature.

Task 3

Study some case study of kanban implementation and describe the particular steps of it.

Summary of terms

- FIFO lane
- Heijunka
- Inventory
- Kanban
- Kanban board
- One-card kanban
- Production kanban
- Supermarket
- Two-card kanban

- Visualization
- WIP

Questions

- What are the basic principle and main goals of the kanban system?
- What can serve as a kanban?
- Is the kanban system suitable for each production conditions?
- What are the properties and rules of the kanban?
- What is the principle of one-card kanban system?
- What is the principle of two-card kanban system?
- What is the function of the kanban supermarket?
- What is FIFO lane?
- How to implement the kanban system?

Key to solutions

Task 1

$N = \frac{(150 \cdot 0,5)+7,5}{25}$ = 3.3 cards or containers

Round up to 4 to have some slack or down to 3 to support improvements.

Task 2

See recommended literature and Internet.

Task 3

See recommended literature (for instance [8]) and Internet.

References

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7. SMED

Time to study

360 min

Goal

after studying this chapter

- you will be familiar with goals and principles of SMED;
- you will be able to propose the SMED implementation.

Lecture

7.1 Overview

SMED (Single-Minute Exchange of Dies) is a system for dramatically reducing the time of equipment changeovers. The essence of the SMED system is to convert as many changeover steps as possible to "external" (performed while the equipment is running), and to simplify and streamline the remaining steps. The name Single-Minute Exchange of Dies comes from the goal of reducing changeover times (Fig. 7.1) to the "single" digits (i. e. less than 10 minutes) [1].

Fig. 7.1 Rapid changeover

Source: [2]

7.2 Definition

- SMED (Single-Minute Exchange of Dies) is a system for dramatically reducing the time it takes to complete equipment changeovers.
- SMED is the term used to represent the Single Minute Exchange of Die or setup time that can be counted in a single digit of minutes.

7.3 Benefits of the SMED implementation

A successful SMED program will have the following ***benefits***:

- Lower manufacturing cost (faster changeovers mean less equipment down time);
- Smaller lot sizes (faster changeovers enable more frequent product changes);
- Improved responsiveness to the customer's demand (smaller lot sizes enable more flexible scheduling);
- Lower inventory levels (smaller lot sizes result in lower inventory levels);
- Smoother start-ups (standardized changeover processes improve consistency and quality).

7.4 Principle of SMED

The changeover steps are termed "elements". There are two types of elements:

- internal elements (elements that must be completed while the equipment is stopped);
- external elements (elements that can be completed while the equipment is running).

The SMED process focuses on making as many elements as possible external, and simplifying and streamlining all elements. The SMED system has three major phases as shown in Fig. 7.2.

These phases are performed in sequence and the entire sequence can be repeated.

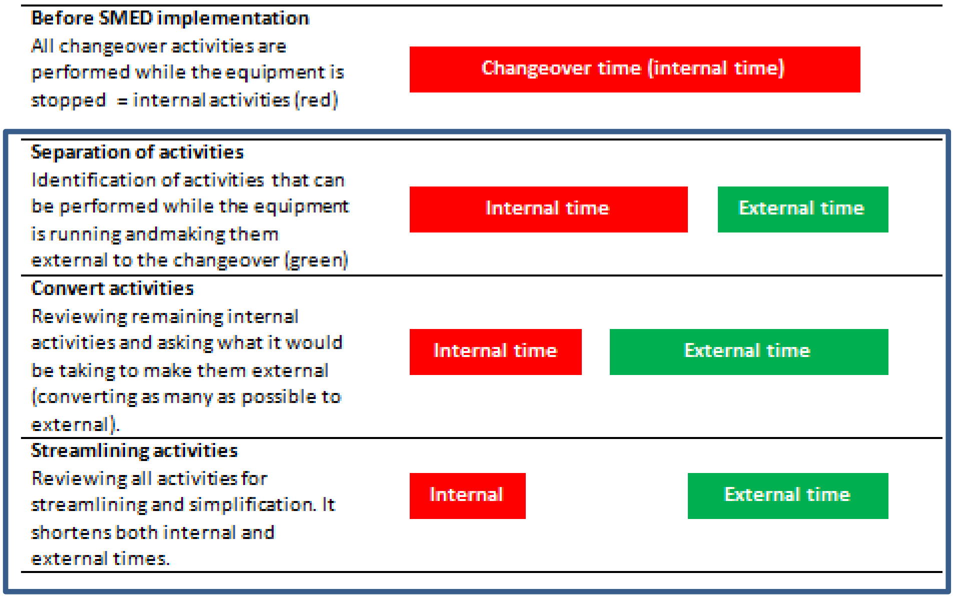

Fig. 7.2 Three major phases of SMED [3]

7.5 Implementation of SMED

SMED can be implemented through the following steps.

1. Identification of the pilot area

In this step, the target area for the pilot SMED program is selected. The ideal equipment will have the following characteristics:

- The changeover is long enough to have significant room for improvement.
- There is large variation in changeover times (for instance changeover times range from one to three hours).
- There are numerous opportunities to perform the changeover each week (the proposed improvements can be quickly tested).
- Employees familiar with the equipment (operators, maintenance personnel, quality assurance, supervisors) are engaged in the implementation of SMED and motivated.
- The equipment is a constraint/bottleneck. For that reason, it needs to minimize the potential risk by building temporary stock and otherwise ensuring that unanticipated down time can be tolerated.

It is a good idea to include the full spectrum of associated employees in the selection process, and create a consensus within the team as to the target equipment choice.

Once the target equipment has been selected, record a baseline time for the changeover. Changeover time should be measured as the time between the production of the last good part (at full speed) and the production of the first good part (at full speed).

2. Identification elements

In this step, the team identifies all of the elements of the changeover. The most effective way of making this is to videotape the entire changeover and then proceed from the videotape to create an ordered list of elements, each of which includes an element description (what work is performed) and element time (how long it takes to complete the element).

3. Separating external elements

In this step, elements of the changeover process that can be performed with little or no change while the equipment is running are identified

For each element, the team should ask the following question: *Can this element, as currently performed or with minimal change, be completed while the equipment is running?*

If the answer is yes, the element can be categorized as external and moved before or after the changeover, as appropriate.

Examples of external elements are as follows:

- retrieval of parts, tools, materials, and/or instructions;
- inspection of parts, tools, and/or materials;
- cleaning tasks that can be performed while the process is running;
- quality checks for the last production run.

The output from this step should be an updated list of changeover elements, split into three parts: before changeover external elements, internal elements done during changeover, and after changeover external elements.

4. Converting internal elements to external

The current changeover process is carefully examined with the goal of converting as many internal elements to external as possible.

For each internal element, the following questions should be asked: *If there was a way to make this element external, what would it be? How could we do it?*

This will result in a list of elements that are candidates for further action. This list should be prioritized so the most promising candidates are acted on first. Fundamentally, this comes down to performing a cost/benefit analysis for each candidate element:

- Cost as measured by the materials and labour needed to make the necessary changes.
- Benefit as measured by the time that will be eliminated from the changeover.

Once the list has been prioritized, work can begin on making the necessary changes.

Examples of techniques that can be used to convert internal elements to external are:

- Preparing parts in advance (e. g. preheating dies in advance of the changeover)
- Using duplicate jigs (e. g. performing alignment and other adjustments in advance of the changeover)
- Modularizing the equipment (e. g. replacing a printer instead of adjusting the print head so the printer can be configured for a new part number in advance of the changeover)
- Modifying the equipment (e. g. adding guarding to enable safe cleaning while the process is running)

The output from this step should be an updated list of changeover elements, with fewer internal elements, and additional external elements (performed before or after the changeover).

5. Streamline remaining elements

In this step, the remaining elements are reviewed with an eye towards streamlining and simplifying so they can be completed in less time. First priority should be given to internal elements to support the primary goal of shortening the changeover time.

For each element, the team should ask the following questions: *How can this element be completed in less time? How can we simplify this element?*

As in the previous step, a simple cost/benefit analysis should be used to prioritize action on elements.

Examples of techniques that can be used to streamline elements are:

- Eliminating bolts (e.g. using quick release mechanisms or other types of functional clamps);
- Eliminating adjustments (e. g. using standardized numerical settings; converting adjustments to multiple fixed settings; using visible centrelines; using shims to standardize the die size);
- Eliminated motion (e. g. reorganizing the work space);
- Eliminated waiting (e. g. making the first article inspection a high priority for QA);
- Standardized hardware (e. g. so that fewer tools are needed);
- Creating parallel operations (e. g. taking into consideration that with multiple operators working on the same equipment, close attention must be paid to potential safety issues);

- Mechanization (normally this is considered a last resort).

The output from this step should be a set of updated work instructions for the changeover (i. e. creating standardized work) and a significantly faster changeover time (see Fig. 7.3).

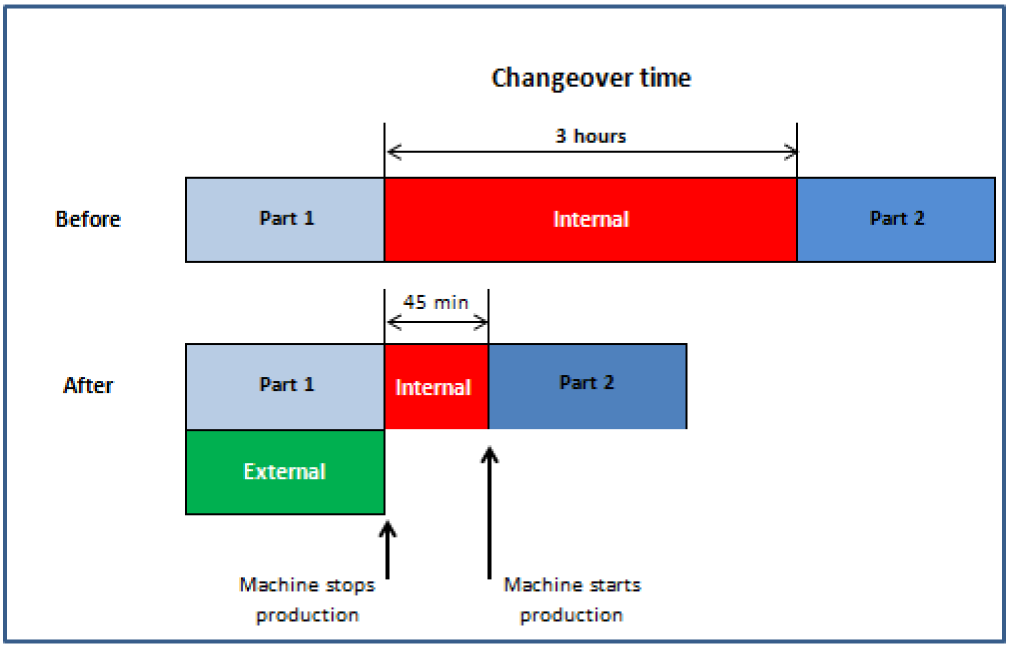

Fig.7.3 Result of the effective SMED application [4]

Task

Task 1

Find out some case study of the SMED implementation and study its steps.

Summary of terms

- Changeover
- Setup time
- Lot size
- Internal element
- External element
- Streamlining

Questions

- What is the main goal of SMED?
- What type of waste is eliminated via SMED application?
- What steps must be taken to implement SMED?
- What are the goals of every step of SMED deployment?
- What is the difference between external and internal elements?
- How to reach the time reduction of changeover using SMED?
- Give some examples of internal and external activities.
- Define several tools for streamlining changeover activities.

Key to solutions

Task 1

Try to find some case study in literature or via Internet.

References

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8 TPM

Time to study

480 min

Goal

after studying this chapter

- you will understand various types of maintenance;
- you will be familiar with the origins, goals and principles of TPM;
- you will know that wastes can be reduced or eliminated via TPM;
- you will reveal which other lean tools are preconditions for effective application of TPM;
- you will know all activities that must be realized when implementing TPM.

Lecture

8.1 Preview

Total productive maintenance (TPM) is a management process developed for improving productivity by making processes more reliable and less wasteful. TPM is an extension of TQM (Total Quality Management). TPM is based on operators´ involvement in maintaining their own equipment and emphasizing proactive and preventive maintenance and maintenance prevention that creates a foundation for improved production [1].

It means that TPM is a critical adjunct to lean manufacturing. If machine uptime is not predictable and the process capability is not sustained, extra stocks must be kept to buffer against this uncertainty, and the flow through the process will be interrupted. The reason of unreliable uptime lies in breakdowns or badly performed maintenance.

Traditionally, the operator is not viewed as a member of the maintenance team; in TPM, the machine operator is trained to perform many of the day-to-day activities of simple maintenance and fault-finding as a member of teams including a technical expert (an engineer or maintenance technician).

In such way, the operators are able to understand the machine and identify potential problems before they can impact production. It leads to decrease downtime and reduce costs of production.

The beginning of TPM can be traced back to 1952, when preventive maintenance was introduced into Japan companies from the USA (Deming). Nippondenso, part of Toyota, was the first company in Japan that introduced the plant wide preventive maintenance in 1960. However, in the system of preventive maintenance, operators produced goods using machines and the maintenance groups realized the maintenance of those machines. With the high level of automation in Nippondenso, maintenance became a problem because of lack of personnel. So the management decided that much of the routine maintenance of equipment would be carried out by the operators themselves. Autonomous maintenance, one of the features of TPM, is more cost-effective as the operator (compared to a highly skilled engineer) is on a lower pay rate. Instead of reducing cost, the operator had a better understanding of the equipment daily working, and he could point out when any problem had appeared or if quality was decreasing, and so on. Thus, the maintenance group could focus only on more complex problems and project work for long term tasks. The support and information from operators and production engineers made it possible to make changes that lead to maintenance prevention and increased quality through fewer defects and a reduction in scrap. Thus, preventive maintenance along with maintainability improvement were grouped as productive maintenance. The aim of productive maintenance was to maximize plant and equipment effectiveness to achieve the optimum life cycle cost of the production equipment. Therefore, Nippondenso of the Toyota group became the first company to obtain the TPM certifications.

8.2 Definitions

TPM

- TPM is a method for improved machine availability through better utilization of maintenance and production resources.
- TPM is a system of maintaining and improving the integrity of production and quality systems through the machines, equipment, processes, and employees that add business

value to an organization. TPM focuses on keeping all equipment in top working condition to avoid breakdowns and delays in manufacturing processes.

- TPM (Total Productive Maintenance) is a holistic approach to equipment maintenance that strives to achieve perfect production (no breakdowns, no small stops or slow running, no defects, no accidents).
- TPM establishes a world class reliability based maintenance system utilizing proactive, predictive, and preventative maintenance practices focusing on the entire equipment life cycle.
- TPM is a comprehensive initiative to increase the up time of any equipment in an organization.
- TPM is the machinery equivalent of Total Quality Management (TQM) and involves everyone in the organization in focusing on eliminating the Six big losses through the use of a performance measure known as OEE.
- TPM is the systematic execution of maintenance by all employees through small group activities.

Maintenance

- ***Breakdown Maintenance (reactive, corrective maintenance***) – it corrects equipment deterioration after the occurrence of a breakdown.
- ***Pro-active maintenance*** it covers preventive + predictive maintenance.
- ***Autonomous Maintenance*** – it is an "independent" maintenance carried out by the operators of the machines rather than by dedicated maintenance technicians. This is the core concept of TPM. It gives more responsibility and authority to the operators and releases the technical personnel to do more preventative and improvement works.
- ***Preventative Maintenance*** **(*preventive maintenance*) -** routine maintenance to maintain the basic equipment conditions, replace deteriorating parts, and maintain equipment in on-spec condition. This approach can sometimes result in unnecessary maintenance. Preventive maintenance may be *periodic maintenance*, *planned maintenance,* or *predictive maintenance*.
  - ***Periodic maintenance (time-based maintenance)*** – it is a form of preventive maintenance consisting of servicing, parts replacement, surveillance, or testing at predetermined intervals of calendar time, operating time, or number of cycles.

– ***Planned maintenance*** – it is a form of preventive maintenance consisting of refurbishment or replacement that is scheduled and performed prior to unacceptable degradation of a structure, system, or component.
– ***Predictive Maintenance (condition-based maintenance)*** **-** corrects equipment deterioration by condition monitoring and machine diagnosis and helps detect impending problems before they occur. This methodology tries to predict the failure before it actually happens by directly monitoring the machine during the normal operating condition. The repair can be then scheduled at a time that minimizes the impact on production. It seeks to make the maintenance more economically efficient by allowing to use components within the machines that would be replaced at regular intervals under preventative maintenance programs for far longer, sometimes several times their expected life spans.

Maintenance prevention

- It indicates the design of the new equipment. Weaknesses of current machines are sufficiently studied (on site of information leading to failure prevention, easier maintenance and prevention of defects, safety and ease of manufacturing) and are incorporated before commissioning the new equipment.

8.3 TPM Principles and goals

The main three *principles* of TPM are as follows:

1. Operators perform maintenance functions for which they have been trained that do not require skilled maintenance persons.
2. Skilled maintenance persons train equipment operators in equipment maintenance functions.
3. Maintenance personnel move from the “fire-fighting” mode to the prevention mode.

The main *goals* of TPM implementation can be formulated as follows:

– to maximize overall equipment effectiveness (zero breakdowns and failures, zero accident, and zero defects etc.) through total employee involvement;
– to improve equipment reliability and maintainability as contributors to quality;
– to raise productivity with the aim of maximum economy in equipment for its entire life;

– to cultivate equipment-related expertise and skills among operators.

8.4 The traditional TPM model

The traditional approach to TPM was developed in the 1960s and consists of 5S (see Chapter 5) as a foundation and eight supporting activities (sometimes referred to as pillars) – see Fig. 8.1.

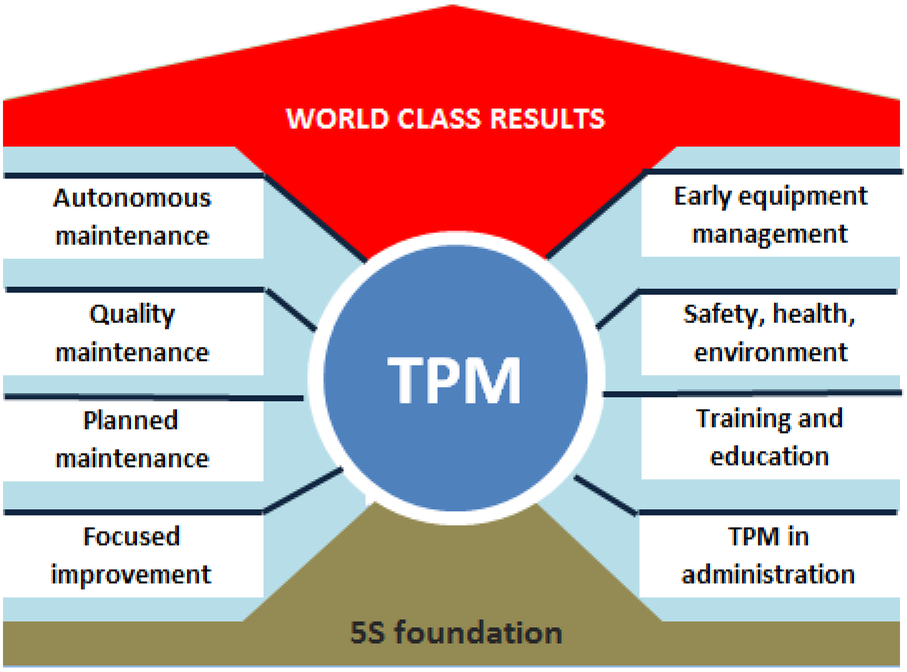

Fig. 8.1 The traditional TPM model [2]

The 5S Foundation

The goal of 5S is to create a work environment that is clean and well-organized (it is described in detail in Chapter 5). It logically creates a foundation for well-running equipment. For example, in a clean and well-organized work environment, tools and parts are much easier to find, and it is much easier to spot emerging issues such as fluid leaks, material spills, metal shavings from unexpected wear, hairline cracks in mechanisms, etc.

Eight Pillars

Eight pillars of TPM are predominantly focused on proactive and preventative techniques leading to the improvement of the equipment reliability. Every pillar is characterized in the following table.

Table 8.1 Description of 8 TPM pillars

Pillar	Description	Purpose
Autonomous Maintenance	Gives responsibility for routine maintenance, such as cleaning, lubricating, and inspection, to the operators.	– Gives the operator greater "ownership" of his equipment. – Increases the operator´s knowledge of his equipment. – Ensures that the equipment is well-cleaned and lubricated. – Identifies emergency issues before they become failures. – Disengage maintenance personnel for higher-level tasks.
Planned Maintenance	Schedules maintenance tasks based on predicted and/or measured failure rates.	– Significantly reduces probability of unplanned down time. – Enables most maintenance activities to be planned for time when equipment is not scheduled for production. – Reduces inventory through better control of wear-prone and failure-prone parts.
Quality Maintenance	Design error detection and prevention into production processes. Apply root cause analysis to eliminate recurring sources of quality defects.	– Specifically targets with improvement projects focused on removing root sources of defects. – Reduces number of defects. – Reduces cost by detecting defects early.
Focused Improvement	Have small groups of employees work together proactively to achieve regular, incremental improvements in equipment operation (Kaizen).	– Recurring problems are identified and resolved by cross-functional teams. – Combines the collective talents of a company to create a foundation for continuous improvement.
Early Equipment Management	Directs practical knowledge and understanding of manufacturing equipment gained through TPM towards improving the design of new equipment (maintenance prevention).	– Maintenance is simpler and more robust due to practical review and employee involvement prior to installation.

Table 8.1 Description of 8 TPM pillars – cont.

Pillar	Description	Purpose
Training and Education	Fills in knowledge gaps necessary to achieve TPM goals. Applies to operators, maintenance personnel and managers.	– Operators develop skills to routinely maintain equipment and identify emerging problems. – Maintenance personnel learn techniques for proactive and preventative maintenance. – Managers are trained on TPM principles as well as on employee coaching and development.
Safety, Health, Environment	Maintain a safe and healthy working environment.	– Eliminates potential health and safety risks, resulting in a safer workplace. – Specifically targets the goal of an accident-free workplace.
TPM in Administration	Apply TPM techniques to administrative functions.	– Extends TPM benefits beyond the plant floor by addressing waste in administrative functions.

Tab. 8.2 shows activities representing steps of the autonomous maintenance implementation.

Table 8.2 Steps of autonomous maintenance implementation

	Step	Activities
1	***Cleaning and inspection***	Elimination of all dirt and grime on the machine, lubricating, tightening bolts, and finding problems and their correcting.
2	***Eliminating problem sources and inaccessible areas***	Removal of sources of dirt and grime; prevention of spattering and improving accessibility for cleaning and lubrication; shortening the time it takes to clean and lubricate.
3	***Drawing up cleaning and lubrication standards***	Making standards that will ensure that cleaning, lubricating, and tightening can be done efficiently. (Working out a schedule for periodic tasks).
4	***Conducting general inspections***	Conducting skills training with inspection manuals and using general inspections to find and correct slight abnormalities in the equipment.

Table 8.2 Steps of autonomous maintenance implementation – cont.

	Step	Activities
5	***Conducting autonomous inspections***	Preparing standard check sheets for autonomous inspections; carrying out the inspections.
6	***Standardization through visual workplace management***	Standardization and visual management of all work processes. Examples of standards needed: •cleaning, lubrication, and inspection standards; •work area material flow standards; •data recording method standards; •tools and supplies management standards.
7	***Implementation of autonomous equipment management***	Development of company policies and objectives; making improvement activities part of everyday practice; keeping reliable mean time between failures data, analysing it and using it to improve the equipment.

8.5 The general measure of the TPM efficiency

Overall equipment effectiveness

Since its original development in Japan in the 1970s, Overall Equipment Effectiveness (OEE) has become a widely used metric for measuring manufacturing efficiency. OEE is the main tool of the TPM improvement program, and it is used to reduce or eliminate the "Six big losses" that limit production (see Fig. 8.2).

OEE identifies the percentage of planned production time that is really productive. It represents support for TPM by accurately tracking progress towards achieving "perfect production" (see Tab. 8.3).

Table 8.3 OEE and the rate of perfection

OEE score (%)	The rate of production perfection
100	perfect production
85	world class for discrete manufacturers
60	fairly typical for discrete manufacturers
40	uncommon for manufacturers without TPM and/or lean programs

OEE consists of three components each linked to one TPM goal and each taking into account a different type of productivity loss (see Tab. 8.4).

Table 8.4 Relations between the OEE components, TPM goals and the loss types

Component	TPM Goal	Type of Productivity Loss
Availability	No breakdowns	It takes into account ***Down time loss***, which includes all that stop planned production for an appreciable length of time (typically several minutes or longer).
Performance	No small stops or slow running	It takes into account ***Speed loss***, including all factors that cause production to operate at less than the maximum possible speed when running.
Quality	No defects	It takes into account ***Quality loss***, which is linked to the manufactured pieces that do not meet quality standards, including ones that require rework.
OEE	Perfect production	OEE takes into account all losses (Down time loss, Speed Loss, and Quality Loss), resulting in a measure of real productive manufacturing time.

Six big losses

OEE loss categories, i. e. down time loss, speed loss, and quality loss can be further disintegrated into so called Six big losses – the most common causes of lost productivity in the manufacturing (see Tab. 8.5). Six big losses are extremely important because they are nearly universal in the application in conditions of the discrete manufacturing and they give a great starting framework for reducing waste (i. e. productivity loss).

Table 8.5 Six big losses Source: [3]

Six big losses	OEE Category	Comments	Examples
Breakdowns	Down time loss	There is flexibility where to define the threshold between a Breakdown (Down time loss) and a Small stop (Speed loss).	▪ Motor failure ▪ Overheated bearing ▪ Tooling failure ▪ Unplanned maintenance
Setup and adjustments	Down time loss	This loss is often addressed through setup time reduction programs such as SMED (Single-minute exchange of die).	▪ Major adjustment ▪ Material shortage ▪ Operator shortage ▪ Setup/Changeover ▪ Warm-up time

Table 8.5 Six big losses – cont.

Six big losses	OEE Category	Comments	▪ Examples
Small stops	Speed loss	Typically only includes stops that are less than five minutes and that do not require maintenance personnel.	▪ Cleaning/Checking ▪ Component jam ▪ Delivery blocked ▪ Minor adjustment ▪ Sensor blocked
Slow running	Speed loss	Anything that keeps the equipment from running at its theoretical maximum speed.	▪ Alignment problem ▪ Equipment wear ▪ Incorrect setting
Start-up defects	Quality loss	Rejects during warm-up, start-up or other early production.	▪ Rework ▪ Scrap
Production defects	Quality loss	Rejects during steady-state production.	

Computation of OEE

As it can be found in Tab. 8.5 and seen in Fig. 8.2, the OEE is a result of Availability, Performance, and Quality, however, those 3 parts are the result of Six big losses. From Fig. 8.2 it can be understood how to compute OEE.

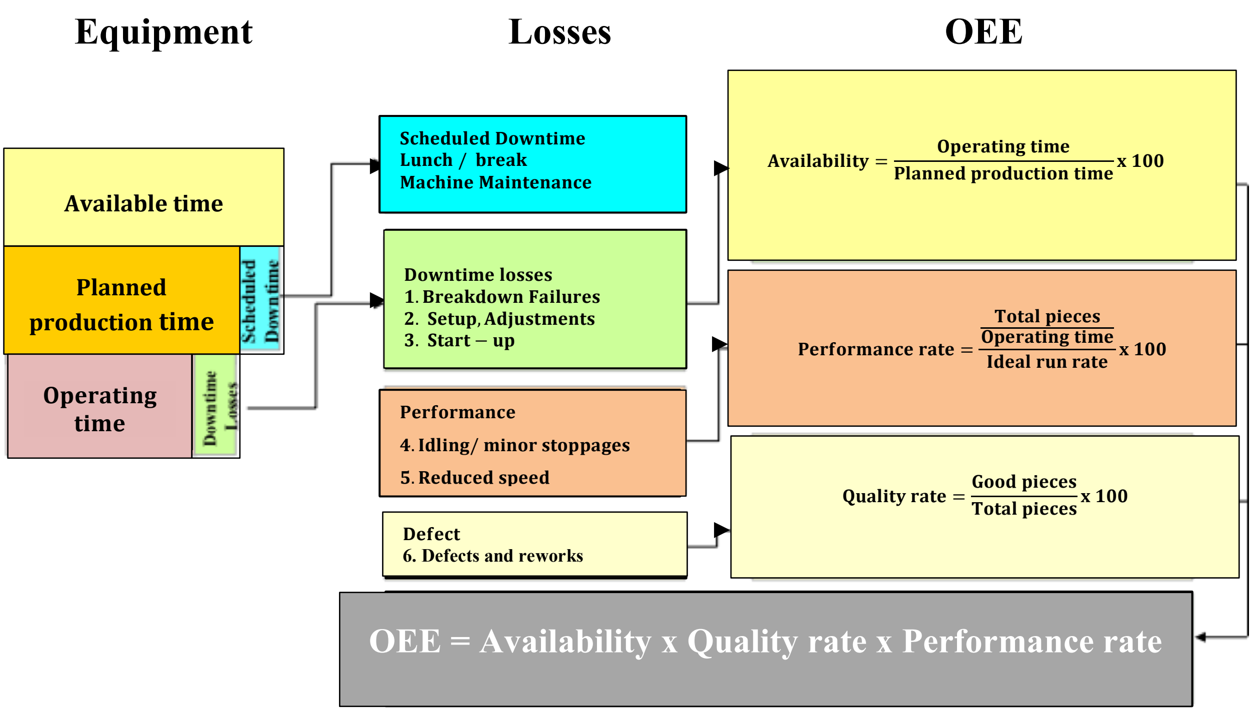

Fig. 8.2 Categories and formulae for computation of OEE

Ideal cycle time (*design cycle time, theoretical cycle time*) is the minimum cycle time that the production process can be expected to achieve in optimal circumstances.
Run rate is the reciprocal of *Cycle time.*
As it was mentioned earlier, OEE takes into account all three OEE factors, so it is calculated as (see Fig. 8.2):

$$\text{OEE} = \text{Availability x Quality rate x Performance rate} \tag{8.1}$$

8.6 Implementation of TPM

When implementing TPM, the following steps should be realized [4, 5, 6]:

Step 1 – Identification of pilot area

In this step, the target equipment for the pilot TPM program is selected. There are three logical ways to make this selection: equipment that will be easiest to improve, equipment that is bottleneck in the production system or the most problematic machine.
In order to create a wide base of support for the TPM project, the full spectrum of associated employees (operators, maintenance personnel, and managers) must be incorporated into the selection process and a consensus within the group as to the equipment selection choice must be reached. Then a project board where plans and progress updates can be posted should be created.

Step 2 – Restore Equipment to Prime Operating Condition

For now, the selected equipment must be cleaned up and prepared for the improved operation. It means that 5S and Autonomous Maintenance programs must be prepared and implemented.

Step 3 – Starting to measure OEE

In this step, a system for tracking OEE for the selected equipment must be created and implemented including down time cause code tracking.
Data should be gathered for a minimum of two weeks to identify recurring reasons for the equipment down time, and to identify the impact of small stops and slow cycles.

Step 4– Selection of major losses

In this step, the most significant sources of lost productive time are determined and Kaizen is introduced. During this step, OEE data should be again carefully reviewed each shift to monitor the status of solved losses, as well as to monitor overall improvements in productivity.

Step 5– Introducing Proactive Maintenance Tools

In this step, proactive maintenance techniques (concept of planned maintenance) must be integrated into the maintenance program.

Tasks

Task 1

Compute OEE using data from Tab. 8.6. Note that the same units of measurement (in this case minutes and pieces) are consistently used for the calculations.

Table 8.6 Data for OEE computing

Item	**Value**
Shift Length	8 h = 480 min
Short Breaks	2 x 15 min = 30 min
Meal Break	1 x 30 min = 30 min
Down Time	47 min
Ideal Run Rate	60 pieces per min
Total Pieces	19,271 pieces
Reject Pieces	423 pieces

Task 2

Study some recommended literature or sources on the Internet to learn the implementation steps of TPM in detail.

Task 3

Think out how to achieve the sustainable improvement of the production system using TPM.

Task 4

Study the principles and implementation steps of focused improvement in detail yourself.

Summary of terms

- Adjustment
- Autonomous maintenance
- Availability
- Breakdown
- Breakdown maintenance
- Down time
- Failure
- Focused improvement
- Maintenance
- Maintenance prevention
- OEE
- Performance rate
- Periodic maintenance
- Planned maintenance
- Predictive maintenance
- Preventive maintenance
- Pro-active maintenance
- Quality loss
- Quality maintenance
- Quality rate
- Setup
- Six big losses
- Slow running
- Speed loss

- Star-tup defect

Questions

- What are the principles and main goals of TPM?
- What waste can be reduced or eliminated through MTP activities?
- What are 8 pillars of TPM?
- What types of maintenance do you know?
- What are the differences between various types of maintenance?
- What are the weakness and benefits of various types of maintenance?
- What type of maintenance is preferred in TPM?
- What steps must be realized to implement the autonomous maintenance?
- What is OEE?
- Explain availability, performance rate, and quality rate.
- Explain Six big losses including some examples.
- What is the relation of OEE and Six big losses?
- What TPM pillar facilitates the empowerment of operators?
- What area the roles of operators in TPM?
- What are the roles of maintenance staff in TPM?
- In what new activities the operators must be trained in TPM?

Key to solutions

Task 1

Planned Production Time	= Shift Length - Breaks
	= 480 - 60
	= 420 min
Operating Time	= Planned Production Time - Down Time
	= 420 - 47
	= 373 min
Good Pieces	= Total Pieces - Reject Pieces

= 19 271 - 423

= 18 848 pieces

Availability = Operating Time / Planned Production Time

= 373 minutes / 420 minutes

= 0.8881 or 88.81%

Performance rate = (Total Pieces / Operating Time) / Ideal Run Rate

= (19,271 pieces / 373 minutes) / 60 pieces per minute

= 0.8611 or 86.11%

Quality rate = Good Pieces / Total Pieces

= 18,848 / 19,271 pieces

= 0.9780 or 97.80%

OEE = Availability x Performance rate x Quality rate

= 0.8881 x 0.8611 x 0.9780

= 0.7479 or 74.79%

Task 2

Study in literature (for instance [7]) or via Internet detailed road maps for the TPM implementation.

Task 3

Try to analyse some successful case study to determine success factors.

Task 4

Study the problem yourself in literature or via Internet.

References

[1] Nakajima, S.: Introduction to TPM. Cambridge: Productivity Press, 1989.

[2] http://www.leanproduction.com/tpm.html.

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9. AGILE MANUFACTURING

Time to study

600 min

Goal

After studying this chapter

- you will understand the purpose of agile manufacturing and conditions of its application;
- you will be familiar with principles and enablers of agile manufacturing;
- you will be to define differences and similarities between lean and agile concepts;
- you will understand the linkage between mass customization and agile approach.

Lecture

9.1 Preview

Agile manufacturing represents a new manufacturing concept that strives to respond to new economic and social conditions (see chapter 2**).** In Tab. 9.1 differences between traditional (mass) production and modern (agile) concept are formulated.

Table 9.1 Difference between traditional and modern approaches to manufacturing

Traditional approaches	Modern approaches
Uniform/standardized products	Highly variable/customized products
Self-contained platform	Open-ended platform for upgrades/information/services
Longer market life of product	Shorter market life of product
Produced to forecast	Produced to order
Low information content	High information content
Priced by manufacturing unit cost + margin	Priced by the customer perceived value
Characterized by a specific-market niche	Characterized by a multiple-market niche

All defined modern expectations can be met by the agile manufacturing concept.

Agile manufacturing is often viewed as the next step after lean in the evolution of the production methodologies. But it is a common misconception that agile manufacturing is the same as lean or flexible manufacturing. Agile management is a new concept where approaches such as lean or flexible manufacturing are implemented with a synergic effect resulting in enormous improvements in products, responsiveness to customers, innovation and flexibility. Katayama and Bennet [1] say that lean, flexible and agile production systems considerably overlap (increased product variety and lower fixed costs for the new product development and grouping parts into families in order to decrease setup times and WIP inventory). Flexible manufacturing, agility and leanness are considered as mutually supporting concepts.

9.2 History and basic ideas of agile manufacturing

The term agile manufacturing stems from the Agile Manufacturing Enterprise Forum at Lehigh University (Nagel and Dove [2]). One of the former definitions of agile manufacturing states that it is "the ability of an enterprise to survive in a competitive environment with continuous and unanticipated change and to respond quickly to rapidly changing markets that are driven by the customer valuing the products and services". (Lengyel [3]). An agile enterprise is an organization that displays the ability to thrive and reconfigure itself in a dynamic and competitive environment. In a dynamic environment, continuous and unanticipated changes occur outside the organization. It can be said that agile organization is one with the product variety, shorter product life cycles, and availability-driven customers (Mason-Jones [4]). In addition, an agile manufacturer tries to respond to customer desires for product customization (common feature with the mass customization concept) but in addition, it will be able to respond and adapt to other dynamic external changes. Agile companies seek to combine the advantages of time compression with techniques to reduce the costs of variety. The goal is to offer nearly instant delivery of small quantities of products meeting the expectations of customers for both customization and responsiveness. In more detail, the aims of agile manufacturing are to anticipate customers' requirements, create new markets and balance the people, process, and technology resources of the enterprise to delight customers and enrich not only customers but also members of the agile virtual enterprise.

Agile manufacturing is especially oriented to LVHM (low volume/high mix) production adding responsiveness (velocity) and flexibility to the manufacturing process. It is the most effective in the conditions where customized configurable or specialized orders offer a competitive advantage.

Agility development in organization requires dynamic and truly integrated management systems that are able to support a continuous change, and hence agile manufacturing cannot effectively operate without an optimal supply chain. Agility of the supply chain is the extent of the organization’s network capability.

Agile manufacturing will be really effective when there is a potential market for a personalized fast-delivery version of one of our current products; there is a new product that can be developed within the company’s sphere of competence (or alternately co-developed with a partner) that would strongly benefit from personalization and fast delivery.

9.3 Definitions

Agility

- it is a feature that relates to the interface between the organization and the customers;
- it is the organisation’s ability to thrive in a competitive environment characterized by continuous and sometimes unforeseen changes;
- it is the competence of an company to respond to constant changes, uncertainty and unpredictability.
- it is the change proficiency that can be measured using four metrics: time, cost, robustness, scope.

Versatility

- it means capability of or adaptability for turning easily from one to another of various tasks, …,…

Adaptability

- it is a feature that enables the production system to adapt itself to demand by adjusting or modifying its cost structure [1].

Flexibility

- ***Production flexibility*** - the universe of part types that the production system is able to make; it requires the attainment of the following seven flexibility types:

- ***Process flexibility*** - the ability to change between the production of different products with minimal delay;
- ***Product flexibility*** - the ability to change the mix of products in current production, also known as mix-change flexibility;
- ***Routing flexibility*** - the ability to vary the path a part may take through the manufacturing system;
- ***Volume flexibility*** - the ability to operate profitably at different production volumes;
- ***Expansion flexibility*** - the ability to expand the capacity of the system as needed, easily and modularly;
- ***Operation flexibility*** - the ability to interchange the sequence of manufacturing operations for a given part.

Robustness

- It is the ability to accommodate any uncertain future events or unexpected developments so that the initially desired future state can still be reached.

Resilience

- It is the ability of a system to return to its original state or move to a new desirable state after being disturbed

Agile manufacturing (AM)

- It is an enterprise level manufacturing strategy of introducing new products into rapidly changing markets;
- It is a concept that focuses on the fast response to changes of customer demand;
- It is a concept that secures competitive advantage from the production process that can be both efficient and responsive;
- It is an operational strategy focused on including velocity and flexibility in a make-to-order or configure-to order production process with minimal changeover time and interruptions;
- It means anticipating customer requirements, creating new markets and balancing the people, process, and technology resources of the enterprise to delight customers and enrich not only customers but also members of the agile virtual enterprise;

- It is a term applied to an organization that has created the processes, tools, and training to enable it to respond quickly to customer needs and market changes while still controlling costs and quality.

Flexible manufacturing system (FMS)

- It enables shifting manufacturing capabilities to form mass production and job shop environments to a mixed mode production setup (it is more suitable for lean production strategy than for the agile one).

Mass customization

- It is manufacturing in which customized products are created for a large number of customers with reasonable costs and high quality (*customized cost effectiveness* is the ability to produce customized products at mass production prices);
- It is providing tremendous variety and individual customization at prices comparable to standard goods and services;
- It is the ability to design and manufacture niche market or customized products at mass production efficiency and speed;
- It is a production of personalized or custom-tailored goods or services to meet consumers' diverse and changing needs at near mass production prices (enabled by technologies such as computerization, internet, product modularization, and lean production, it portends the ultimate stage in market segmentation where every customer can have exactly what he or she wants.

Virtual enterprise

- It is ad hoc alliance of independent experts (consultants, designers, developers, producers, suppliers, etc.) who join to pursue a particular business opportunity.

Concurrent engineering

- It is an integrated approach to product-design that takes into account all stages of a product's life cycle from design to disposal including costs, quality, testing, user's needs, customer support, and logistics.

9.4 Principles of agile manufacturing

In [5] four principles of agile manufacturing are defined:

- Enriching the customer
- Cooperating to enhance competitiveness
- Organizing to master change and uncertainty
- Leveraging the impact of people and information.

Van Assen [6] considers *decentralization* as another critical principle. It allows different segments of the organization to be able to respond to the changing environment in shorter response time.

Enriching the customer

It is of vital importance to satisfy the customers' demands and listen to the voice of the customer by adopting customer focused philosophies. The products of an agile company are perceived as solutions of customers' problems. Pricing the product can be based on the value of solutions to the customer (as compared to the pricing based on the manufacturing costs).

Cooperating to enhance competitiveness

Internal and external cooperation is the crucial factor of the agile company success. The objective is to bring products to customers as quickly as possible and required resources and competencies are found and used whenever they exist. The agile manufacturing concept supposes the real integration of a number of companies that each have some core skills or competencies that they insert into a joint venture operation based on using each partners' facilities and resources. That is why such joint venture members are called virtual corporations – they do not have any significant capital resources of their own. This organization enables to such corporation to be formed and changed very quickly. Central to the ability to form these joint ventures is the deployment of advanced information technologies and the development of organisational structures that support highly skilled, knowledgeable and empowered people.

Organizing to master change and uncertainty

The proper organization and flexibility is one of the prime objectives of an agile company in order to thrive on change and uncertainty and respond effectively to changing circumstances and problems while the human and physical resources can be reconfigured rapidly (for example planning without knowing the future which results in plant expansion or planning for potential customers). It needs new innovative, flexible organizational structures that make rapid decision, which is possible due to distributing managerial authority. People need to be empowered to convert change and uncertainty into new opportunities.

Leveraging the impact of people and information

One fundamental idea of agile manufacturing is the idea of using technologies to lever the skills and knowledge of people. It is necessary to bring people together, into dynamic teams formed around clearly identified market opportunities, so that it becomes possible to lever one another's knowledge. Through these processes, we should seek to achieve the transformation of knowledge and ideas into new products and services, as well as improvements to our existing products and services.

In an agile organization, knowledge is valued, innovation is rewarded. To provide resources that personnel need, to create entrepreneurial spirit and climate of mutual responsibility for joint success are the main tasks of the management.

In fact, agile principles should be seen as a natural extension and evolution of the lean principles (see Tab. 9.2).

Table 9.2 Agile principles as an extension of the main lean principles

Lean Production	Agile Production
Minimize Change	Enrich the Customer
Perfect first-time quality	Cooperate to enhance competitiveness
Flexible production lines	Organize to master change
Continuous improvement	Leverage the impact of people and information

Adapted from [7]

9.5 The key enablers of agile manufacturing

The main enablers defined in literature [8] are as follows:

- Virtual (distributed) enterprise
- Physically distributed teams and manufacturing
- Rapid partnership
- Concurrent engineering
- Integrated product/process/business information systems
- Rapid prototyping

- Electronic commerce

A conceptual model has been developed [8] as shown in Fig. 9.1 to illustrate the enablers of agile manufacturing. It can be seen from the model that different enablers of agile manufacturing are overlapping each other. Therefore, all the enablers/tools should be integrated to reach an effective integration and management of firms in a virtual enterprise.

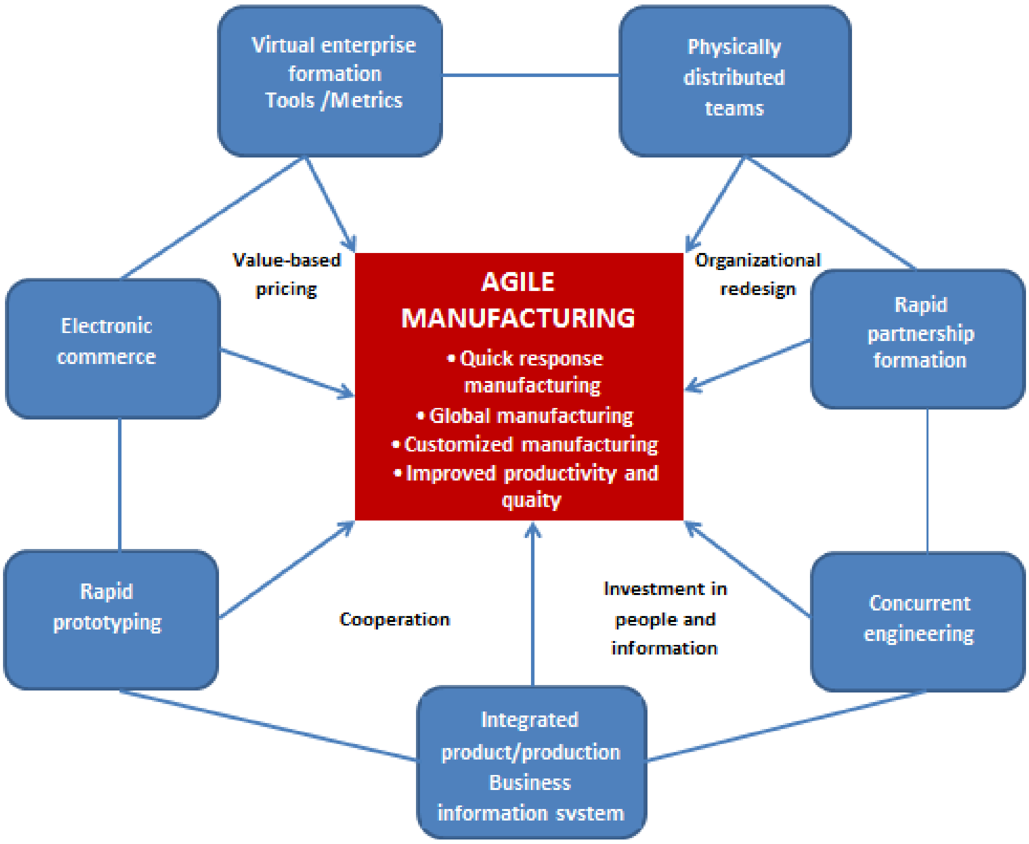

Fig. 9.1 A graphical depiction of agile manufacturing concept and its enablers [8]

Virtual (distributed) enterprise

Virtual (distributed) enterprise can be defined as ad hoc alliance of independent experts (consultants, designers, developers, producers, suppliers, etc.) who join to deal with a particular business opportunity. Such enterprise has little or no physical presence or infrastructure, it relies predominantly on telecommunications and networks, such as the Internet, and usually breaks down when its purpose is fulfilled or the opportunity passes. It is extremely focused and goal driven, having little investment requirements, low start-up and overhead costs, and fast response time. Geographically dispersed members of a virtual enterprise collaborate on the basis of their core strengths from wherever they are and whenever they are able to do so, and may become competitors in pursuit of another opportunity. Virtual enterprise properties enable the reconfiguration of the organization with the aim to respond quickly to changing market needs. That is, each functional aspect of the manufacturing design, production and marketing of a product may be performed by many different organizations. Co-ordination and integration are especially complicated under such organization. As it was mentioned earlier, virtual or distributed enterprises are temporary. For that reason, they must be easily assembled and disassembled. Another important issue is the data security. Computerized information systems with suitable protection may help to safeguard sensitive information.

Agile manufacturing requires the development of a system that covers virtual design, virtual manufacturing, and virtual assembly. It needs to extend the capabilities of existing parametric CAD/CAM systems, An Internet-assisted manufacturing system would be appropriate for agile manufacturing.

Physically distributed teams and manufacturing

New types of logical infrastructures, e. g. physically distributed teams and manufacturing facilities support agility and quick responses leading to reducing the time to reach the global market.

The physically distributed enterprise is a temporary alliance of partner enterprises located all over the world, where each contributes their core competencies to take advantage of a specific business opportunity. Such opportunities or market threats are typically short-term and arise suddenly in the competitive environment. Innovative research in distributed artificial intelligence and intelligent manufacturing systems is essential for physically distributed manufacturing organizations. Electronic mail systems and networks enhance the possibilities of distributed teams. Communication via electronic networks with some sophisticated features will improve the co-operative supported work in a distributed team and manufacturing environments. For example, a graphical user interface may allow front-end to the Internet. Also, using Multimedia, video conferencing can be organized to educate and train the people on a particular technology or method.

Rapid partnership

Partnership formation precedes the virtual enterprise formation. This could be done with the help of information technology, trade associations and partner-rating. The criteria for partnership formation should be based on delivery performance, product quality, infrastructure, productivity and the level of IT skills to ensure an effective strategic partner in a virtual enterprise. This could be achieved by rapid partnership formation tools, e.g. Multimedia, the Internet, database, Microsoft Project, Case Tools, and Electronic Data Interchange, benchmarking, review of past performance and their core competencies. A set of metrics based on both financial (e. g. rate of return on investment, sales revenue, profit, increase in market share), and non-financial (time to develop new products, time to reach new market, manufacturing cycle time, time to complete the partnership formation process) performance measures can also be used to evaluate the performance of partnerships.

Concurrent engineering

Concurrent engineering (CE), see Fig. 9.2, is the answer to the requirement of shorter product development cycles with the aim to respond as quickly as possible to changing customer demands. The application of CE in the product development indicates that new products are designed with inputs from all concerned.

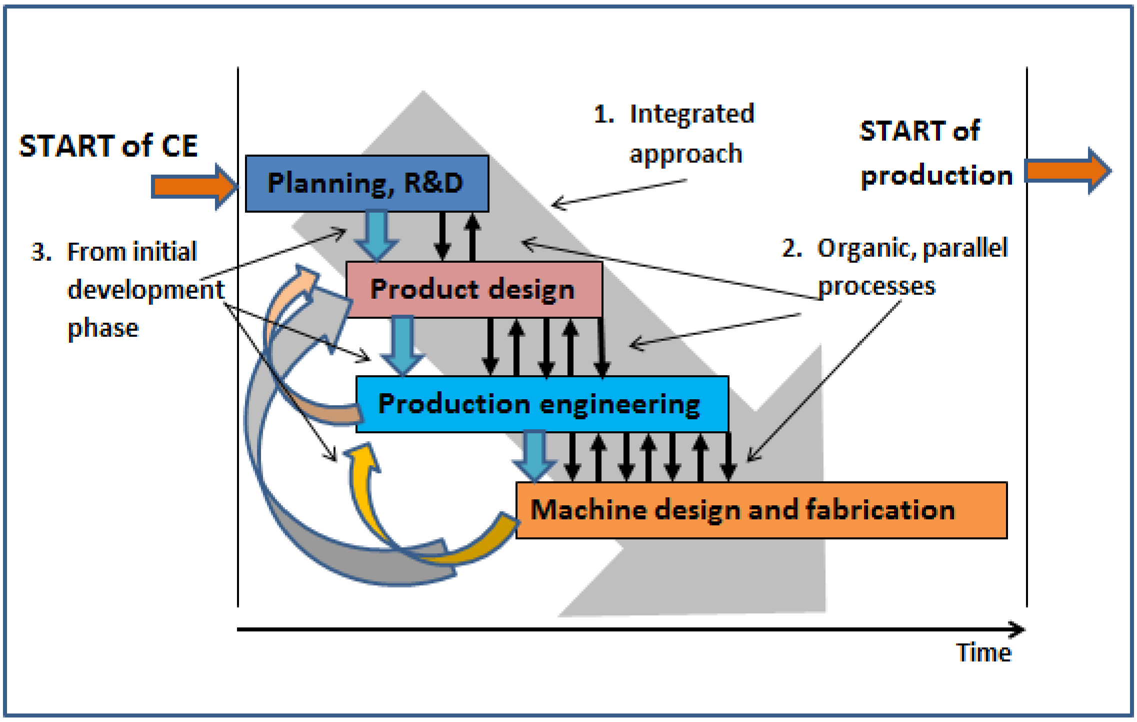

Fig. 9.2 Concurrent engineering principle [9]

Developing products for the agile concept is crucial. In many companies, concurrent engineering means no more than "keeping manufacturing in mind" by developing products. In agile condition, product development teams must concurrently develop flexible processes that are so agile that companies can quickly develop a broad portfolio of niche market products, build products to order, customize individual products at mass-production speed and efficiency, and rapidly introduce a steady succession of "new" products that are really planned "variations on a theme" based on common parts and modular product architecture.

There are several tools and techniques which support design and manufacturing engineers to improve the product development process in a CE environment: functional analysis; CAM tools; NC verification; solid modelling; finite element analysis; optimization; design for cost; value engineering; design for manufacture; design for assembly; design for ergonomics; design for reliability; failure mode and effect analysis (FMEA); robust engineering; and Taguchi methods [10]. In a virtual/distributed manufacturing environment, the information systems can be integrated using CE and system modelling using Object-Oriented Programming (OOP) with the objective to eliminate non-value adding activities.

Integrated product/process/business information systems

In the new and emerging agile manufacturing environment where multiple partners cooperate under flexible virtual enterprise structures, there is a great need for a mechanism to manage and control information flow among collaborating firms.

Frequent and dynamic interactions among partners in agile manufacturing enterprises entail the crucial role of an agile manufacturing information system (AMIS) that must provide partners with integrated and consistent information, as well as manage partner transactions accessing the information shared between distributed databases. Unlike a traditional enterprise where data are owned by the company itself, a virtual enterprise has multiple data ownership.

Rapid prototyping

Prototyping describes the design and generation of an early version of a product (see Fig. 9.3). The version does not necessarily have all the features of the final product, but has enough of the key features to allow testing of certain aspects (e. g. visual, physical, functional) of the product design against the product requirements. Rapid prototyping with help of advanced computer technologies, e. g. CAD/CAE and CE, helps to reduce the time to develop a product and reduce the non-value-added activities at the design stage itself. Therefore, rapid-prototyping is one of the major enablers for agile manufacturing.

Fig. 9.3 Rapid prototyping

Source: [11]

Electronic commerce

It is a type of business model, or segment of a larger business model, that enables a firm or an individual to conduct business over an electronic network, typically the Internet. Electronic commerce operates in all four of the major market segments: business to business, business to consumer, consumer to consumer and consumer to business. Since a close interaction between customers and supplier is essential for the agile manufacturing, the electronic commerce inevitably takes into account the geographically dispersed customers and their requirements.

The main motivation behind electronic commerce is to improve the response time to the customer's demand as quickly as possible by directly collecting the customer's requirements through an on-line communication system. A typical structure of electronic commerce can be seen in Fig. 9.4:

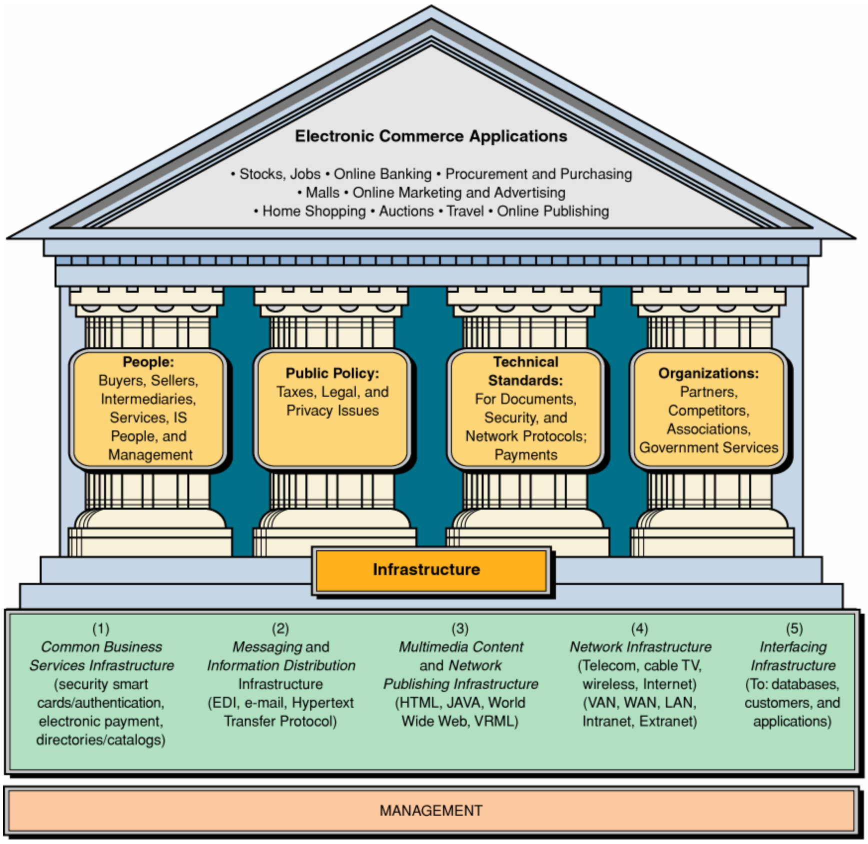

Fig. 9.4 A framework for electronic commerce

Source: [12], p.12, cited in [13]

9.6 Lean versus Agile production

It is important to remember that lean allows for waste free, efficient system that adds to the bottom line and in turn gives competitive pricing advantage. However, most customers today come to local manufacturing facilities for their ability to quickly adapt to changes, better technical support, shorter time to market, and most importantly, short production runs. Consequently, absolute focus on lean production may not be suitable for most local manufacturers, and the application of agile manufacturing principles on the enterprise level is important to maintain competitive against local and overseas competition.

Lean attributes (see Tab. 9.3) are best applied at the factory or floor level where efficiency takes precedence of all except safety. On the other hand, agile attributes (Tab. 9.3) are most suitable at the enterprise level where the ability to adjust to changing internal and external factors is more important. The emphasis in lean is put more on the technical and operational issues, while agile addresses the people and organizational issues.

Table 9.3 Comparison of Lean Production and Agile Manufacturing Attributes

Lean Production	Agile Production
Enhancement of Mass Production	Break with mass production; emphasis on mass customization.
Flexible production for product variety	Greater flexibility for customized products
Focus on factory operations	Scope is enterprise wide
Emphasis on supplier management	Formation Virtual enterprises
Emphasis on efficient use of resources	Emphasis on thriving in environment marked by continuous unpredictable change
Relies on smooth production schedule	Acknowledgement and attempts to be responsive to change

Adapted from [7]

The key difference between these two approaches is like between a thin and an athletic person, agile being the latter. One can be neither, one or both. Lean and agile production principles can be combined to help companies reduce operating costs while being responsive to customer demands [14, 15, 16]. In manufacturing theory, being both lean and agile is often referred to as leagile.

9.7 Agile manufacturing and mass customization

Agile manufacturing serves as a framework that integrates lean principles with mass customization [14]. Only few products today can be manufactured like mass-produced Ford Model T's, without any need for product variation or customization. Most today manufacturers are forced to customize products, to some degree, for increasingly selective customers or to compete in niche markets. This is accomplished by applying the agile product development techniques described later and implementing agile manufacturing. Mass customization is a proactive approach that anticipates the range of customization and designs it into product families and production system.

9.8 Agile product development

The term "Agile product development" can be interpreted in two ways:

1. as an agile product development process that can rapidly introduce a steady succession of incremental product improvements which can be called "new" products — that are really planned "variations on a theme," based on common parts and modular product architecture. This capability results in ultra-fast time-to-market, much faster than possible

with independent products that do not benefit from product-family synergies in design and manufacture.

2. as the development of agile products that can be manufactured in the following agile environments: Agile Manufacturing, Just-in-Time, Build-to-Order, and Mass Customization.

Tasks

Task 1

Study some recommended literature or sources on the Internet to understand the principles and tools of additive manufacturing and its purpose for agile manufacturing.

Task 2

Study the literature yourself and think of differences and similarities of quick response manufacturing and agile concept and between flexible manufacturing and agile approach.

Task 3

Study agile methods such as SCRUM and others yourself.

Task 4

Study some recommended literature or sources on the Internet to understand how to ensure reconfigurability and flexibility of agile manufacturing technologies including types of machines and the work cell layout.

Summary of terms

- Agility
- Versatility
- Adaptability
- Flexibility
- Robustness
- Resilience

- Agile manufacturing
- Flexible manufacturing system
- Mass customization
- Virtual enterprise
- Concurrent engineering
- Rapid partnership
- Integrated information system
- Rapid prototyping
- Electronic commerce
- Agile product development
- Additive manufacturing
- Quick response manufacturing
- SCRUM

Questions

- What are the circumstances of emerging agile concept?
- What are the main goals and benefits of agile manufacturing?
- What are the principles of agile manufacturing?
- What are the enablers of agile manufacturing?
- What are the differences and similarities of lean and agile concept?
- What is the relation between flexible, quick response, and agile manufacturing?
- Explain how the agile manufacturer can cooperate with its competitors.
- What is typical for agile product development?
- What is the place of innovations in agile concept?
- How are innovations supported in the frame of agile approach?
- What advanced technologies, machines and the work cells layout are typical for agile manufacturing?
- What are the main properties of such technologies?
- What are agile tools?
- What is the principle of additive manufacturing and what is its future?

Key to solutions

Task 1

Study in literature or via the Internet the principles and tools of additive manufacturing and its purpose for agile manufacturing yourself.

Task 2

Study in literature or via the Internet the differences and similarities of quick response manufacturing and agile concept and between flexible manufacturing and agile approach yourself.

Task 3

Study in literature or via the Internet agile methods yourself.

Task 4

Study the problem in literature (for instance [17]) or via the Internet in detail yourself.

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