E-Supplement to Chapter 9 Factory Planning and Process Design

Task Little's law
Let us assume that in a car garage, two standard repairs are offered in a special express service zone at extremely competitive prices. Batteries can be exchanged in workstation 1 and oil is changed in workstation 2. Prior to this, customers need to register and they also receive a general car inspection. Then they are assigned to either station 1 or 2 depending on the repair that is required (either battery or oil service).As shown in Fig. E-9.1, 200 customers per day arrive at that garage:

- As stated, all customers pass through the general inspection where on average 20 cars are in the system for inspection.
- Sixty per cent of clients request an oil service, so average inventory is seven cars.
- The other 40% want their batteries exchanged, so average inventory is three cars.

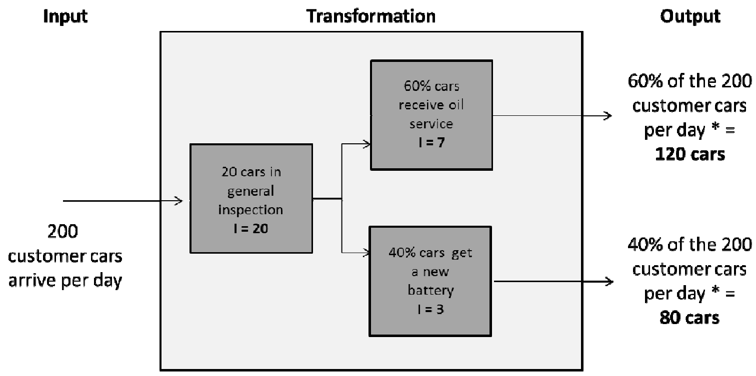


Figure E-9.1. Little's law – example of usage in a car garage

What is the average waiting time for the cars in that car garage?
For the entire car service system, we can calculate that the average inventory of cars is 20 in general inspection + 7 cars on average in oil service + 3 cars on average receiving a battery exchange = **30 cars are on average in inventory**.
In total the **average throughput rate per day equals 200 cars**. Taking the fundamental formula based on these average values, we can calculate the average **waiting time for the entire car garage system as follows**:

W = L / λ = (30 cars inventory in the garage) / (200 cars in total per day) = 0.15 cars per day = **72 minutes of waiting time on average** for a day with 480 minutes working time.

Tasks break-even point

a) As the production manager, you are asked by management to determine the profit, if 15,000 units are sold.

Profit P →TR – TC or also (p – vc)*x - fc

[5$/unit – (1$/unit + 2$/unit)]*15,000 units/year – 20,000$/year

2$/unit*15,000 units/year – 20,000$/year

30,000$/year- 20,000$/year

10,000$/year

If 15,000 units are sold per period (in our example per year), the corresponding profit equals 10,000$ per year.

b) A new machine will need to be bought in order to produce new goods with higher quality and be more ecologically efficient. This new machine will cost a tital of$28,000. In future, the plan will be to produce 12,000 units per year. As a production manager, you are asked to determine the payback period for that machine.

Profit P → TR – TC or also

(p – vc)*x - fc

[5$/unit – (1$/unit + 2$/unit)]*12,000 units/year – 20,000$/year

2$/unit*12,000 units/year – 20,000$/year

24,000$/year- 20,000$/year

4,000$/year

Now you need to identify the payback period:

Payback Period in Years = Total Cost of the Machine / Profit per Year

For our example, this means:

Payback Period in Years = 28,000$ / 4,000$ per Year= 7 years.

c) \management is not satisfied, because they expected a much shorter payback period. That is why they ask you right now to determine what profit and production volume in units is needed, if the payback period is to be exactly four years.

To calculate this, you will need to identify the required minimal annual profit. Therefore, take the total cost of the new machine and divide it through the expected payback period in years.

For our example, the result is:

Required Min. Annual Profit = **Total Cost of the Machine / Expected Payback Period in Years**

Required Min. Annual Profit = **28,000$ / 4 years**

7,000$/year

Now you will need to calculate the corresponding production volume in units x, that will generate the required profit:

Profit P ➔ TR – TC or also (p – vc)*x – fc

7,000$/year= TR – TC or also
[5$/unit – (1$/unit + 2$/unit)]*x units/year – 20,000$/year
2$/unit*x units/year – 20,000$/year ||+ 20,000$/year
27,000$/year = 2$/unit * x units / year ||: 2$/year

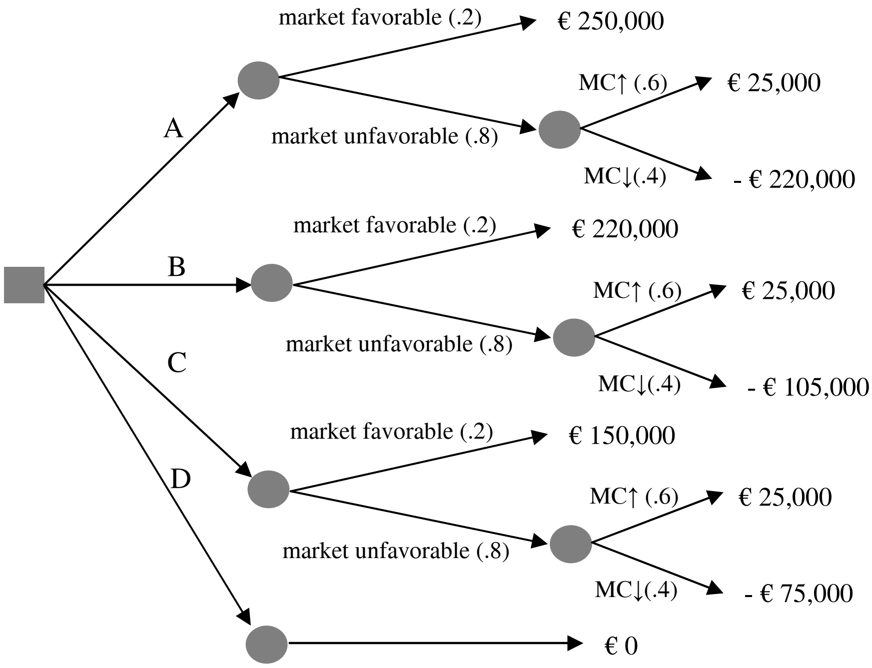
➔ **x = 13.500 units / year**

In order to meet the objective stated by management to reach a payback period of 4 years, the corresponding production volume should equal 13,500 units per year.

Decisiontree analysis

A large chocolate bar producerwants to invest in a refurbishment of their production line because they assume a favourable market development and want to speed up their machines to increase efficiency. The probability that the market will be favourable during next year is 0.2, and 0.8 that market development is unfavourable. In case of an unfavourable market the company decides it will start a large marketing campaign (MC) to promote their brand –especially two months before Christmas and Easter. The probability that the MC works is 0.6, and 0.4 that the campaign is unsuccessful.

Calculate the expected monetary value (EMV) of four investment strategies: large investment (A), medium investment (B), small investment (C) or no investment (D). The expected gain and cost of each strategy are given as shown in Fig. E-9.2.



FigureE-9.2. Decision tree: Whether toinvest in refurbishment

First we have to calculate the EMV of the MC to work out the second step ofthe EMV of investments.

$$EMV\ (MC1) = 0.6 \times €25,000 + 0.4 \times (-€220,000) = -€73,000$$
$$EMV\ (MC2) = 0.6 \times €25,000 + 0.4 \times (-€105,000) = -€27,000$$
$$EMV\ (MC3) = 0.6 \times €25,000 + 0.4 \times (-€75,000) = -€15,000$$

$$EMV\ (A) = 0.2 \times €250,000 + 0.8 \times EMV\ (MC1) = -€8,400$$
$$EMV\ (B) = 0.2 \times €220,000 + 0.8 \times EMV\ (MC2) = €22,400$$
$$EMV\ (C) = 0.2 \times €150,000 + 0.8 \times EMV\ (MC3) = €18,000$$
$$EMV\ (D) = €0$$

As we can see it is recommended from a financial point of view to opt for a medium investment.

Queuing theory model

In a post office one post clerk works with one line waiting. He is able to serve 45 customers/hour and there are on average 38 customers/hour in the post office. Calculate estimated inter-arrival time, service time and utilization factor and analyse waiting time and the length of the system and the queue. Furthermore find out the probability that no more than two customers are in the post office (waiting or being served) at any one time.

The post office manager wants to find out if it is a good idea to employ one more post clerk because it is getting busier in the office. For that reason he wants to use the queuing model with one waiting queue and two counters to analyse whether it would increase customer satisfaction if there were shorter waiting times. Analyse the model and comment on whether one additional post clerk would be a good idea (disregarding the salary). Assume that every employee works at the same speed.

Part I

$$\textit{Inter-arrival time} = \frac{1}{38} = 0.026h = 1.56\min$$

$$\textit{service time} = \frac{1}{45} = 0.022h = 1.32\min$$

$$\rho = \frac{38}{45} = 84.4\%$$

The time between arrivals of any two customers is 1.56mins; being served takes 1.32mins, and the post clerk is occupied 84.4% of the time.

$$L_Q = \frac{0.844^2}{1-0.844} = 4.57$$

$$L_s = 4.57 + 0.844 = 5.41$$

There are on average 4.5 people waiting in the queue and approximately 5.5 people in the system.

$$T_Q = \frac{0.844^2}{38 \times (1-0.844)} = 0.12h = 7.2\min$$

$$T_s = 0.12 + \frac{1}{45} = 0.142h = 8.52\min$$

Customers are on average waiting 7.2 mins in the queue and spend 8.5 mins in the post office in total.

Now we want to know the probability that two or fewer people are in the system. We need to calculate the probability that no one is in the system, one person, ortwo persons are in there and summarize results.

$$P_0 = 0.844^0 \times (1 - 0.844) = 0.156$$
$$P_1 = 0.844^1 \times (1 - 0.844) = 0.132$$
$$P_2 = 0.844^2 \times (1 - 0.844) = 0.111$$
$$P(x \leq 2) = P_0 + P_1 + P_2 = 0.156 + 0.132 + 0.111 = 0.399$$

The probability that no ,more than twopeople are in the system is 39.9%.

<u>Part II</u>

$$\rho = \frac{38}{2 \times 45} = 42.2\%$$

Two post clerks would be occupied 42.2% of the time.

$$P_0 = \frac{1}{\sum_{i=0}^{c-1} \frac{(c \times \rho)^i}{i!} + \frac{(c \times \rho)^c}{c!} \times \frac{1}{(1 - \rho)}}$$

$$P_0 = \frac{1}{\frac{(2 \times 0.422)^0}{0!} + \frac{(2 \times 0.422)^1}{1!} + \frac{(2 \times 0.422)^2}{2!} \times \frac{1}{(1 - 0.422)}} = 40.65\%$$

The probability that the system is empty is 40.65%. Now it is possible to calculate the number of customers waiting in the queue.

$$L_Q = \frac{c^c \times \rho^{c+1}}{c! \times (1 - \rho)^2} \times P_0 = \frac{2^2 \times 0.422^{2+1}}{2! \times (1 - 0.422)^2} \times 0.4065 = 0.18$$

If there aretwo post office counters and 38 estimated customers per hour, 0.18 customers are waiting in the queue.

The estimated number of customers in the whole system is:

$$L_s = L_Q + c \times \rho = 0.18 + 2 \times 0.422 = 1.024$$

On average there is one customer in the system.

Waiting time in the queue is:

$$T_Q = \frac{L_Q}{\lambda} = \frac{0.18}{38} = 0.00474h = 0.2844\min = 17\sec onds$$

Waiting time in the whole system is:

$$T_s = T_Q + \frac{1}{\mu} = 0.00474 + \frac{1}{45} = 0.027h = 1.62\min$$

As you can see the waiting time in the system is 1.62 minutes.

As you can see the waiting time with two employees is virtually zero. Customer satisfaction would probably increase.

Case study: Planning and control of construction projects based on takt time to increase supply chain efficiency

Construction is the business of erecting buildingsandit is characterized by long-term investment with many uncertainties that are influenced by internal and external factors, such as weather, budget, government, technical restrictions and resources. Berstelsen (2004) compared construction with traditional manufacturing andprovided statistical evidence that productivity inthe construction industry is behind the productivity in traditional manufacturing.

The Committee on Advancing the Competitiveness and Productivity of the US Construction Industry (2009) pointed out that inadequate scheduling is one of the reasons why productivity in civil engineering did not increase during recent decades.Forbes and Ahmed's (2011) study stated that in traditional construction projects, approximately 50% of the activities planned for a given week are likely to be completed in that week. The main causes of activities not being completed include unsynchronized processes, waste and problems in construction SCs.

This case study describes a luxurious construction project in the south of Brazil which had good results with regard to the metrics of time, cost and inventory reduction in the SC. The goal of this casestudy is to demonstratethe possibilities of streamliningSC management in the constructionindustry using the concept of *takt time*-based planning and control to ensure just-in-time (JIT) information transfer and material deliveries to construction sites at lowest cost and maximum value for the customer.

Unlike manufacturing, construction is a project-based production process. Almost all construction projects are unique, but depending on the way of looking at it, many repetitive processes can be found. Lean construction tries to manage and improve construction processes with minimum cost and maximum value by considering customer needs (Koskela et al. 2002).

The construction industry recognizes the benefits of good planning at SC level, especially when faced with problems of high inventory levels, restricted physical space, lack of material, obsolescence and the high frequency of transference of materials from one point to another at constructions sites. Whereaslean manufacturingset out ways to streamline manufacturing processes,the idea behind lean consumptionis that *by minimizing customers' time and effort and delivering exactly what they want when and where they want it, companies can reaphuge benefits* (Womack and Jones 2005).

The concept of consumption can be aligned with the concept of takt. *Takt time* is defined as the *pace* of production; it is theaverage unit of production time needed to meet customer demand. The purpose of takt time is to serve as a management tool to indicate whether production is ahead of or behind schedule. It serves as an alignment tool, aligning proceeding with following processes, aligning resource requirements with demand, and aligning corporate functions with real-time production needs.

One of the main points of streamlining the SCin the construction industry is to introduce takt time tofacilitate a positive overview of the consumption of materials and subcontracted services. Prerequisites for introducing takt time at a construction site are to identify and create repetitive and standardized processes. In a 27-floors building, the macro activities will be repeated 27 times because many of the activities are the same,and a detailed analysis will show that many activities are also repeated on a daily basis. In balancing the production lead time (i.e., cycle time) based on takt time, supply can be aligned with demand.

With a defined takt time, the sequence and content of activities to be accomplished can be defined. Once takt time is set, alignmentofthe consumption of materials withsubcontractors'services can be achieved, ensuringaccomplishment of the work in the predefined time.

Knowing exactly what is the material consumption, and linkingthat with fixed periods to ensure a shorter lead time,can allowinventory to be fixed through more frequent deliveries of smaller lot sizes. Lot sizes will be delivered to accomplish the takt work content following lean logistics concepts and the pull system.

In the early 1990s, Japanese construction companies had already adopted the takt schedule management method. In 2001, a major Korean construction company, Samsung Engineering & Construction, combined the takt with other lean construction principles (Samsung 2001).

In order to understand takt schedule management systems, there are concepts that need to be learned and which are explained by the KICEM – Korean Institute of Construction Engineering and Management (2003), as shown in Fig. E-9.3:

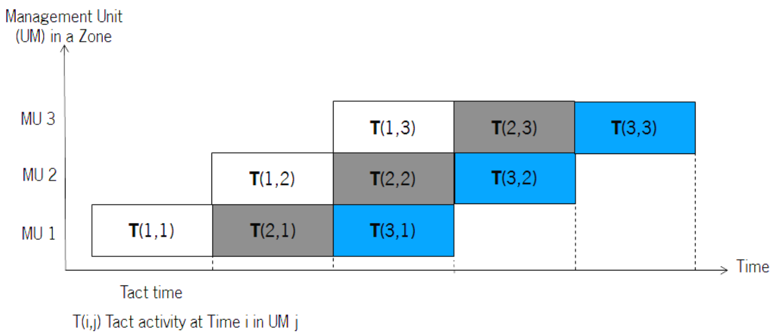


Figure E-9.3. Takt schedule management concepts

MU - Management Unit: In building construction, a floor or a divided workspace in a floor will be one unit. Each MU has a similar work pattern. Inaddition to the MU, there are also zones and sub-zones. For example, in the construction of an apartment, a floor can be divided into two zones: Zone 1 –a public zone including elevator hall; and Zone 2 –private zone including residential units.

Takt Activity: This is one unit of activity or an element of a network of works in anMU. Each takt activity is executed sequentially in an MU. A building construction can be described as a network (or flow) of management units and each management unit can be described as a network of takt activities.

Takt Time: This is the duration of a takt activity. In takt schedule management, takt time should be constant so that the entire takt can flow continuously. In other words, tact activities are executed in a synchronized manner at one single time. For takt time to be constant, the resources for takt activities should be well organized and stabilized.

The methodology used in the this case study was takt planning and control, which was adopted in five main steps and implemented in the construction of a 27-floors building to ensure that detailed planning and control of the work content was based on takt time (see Fig. E-9.4).

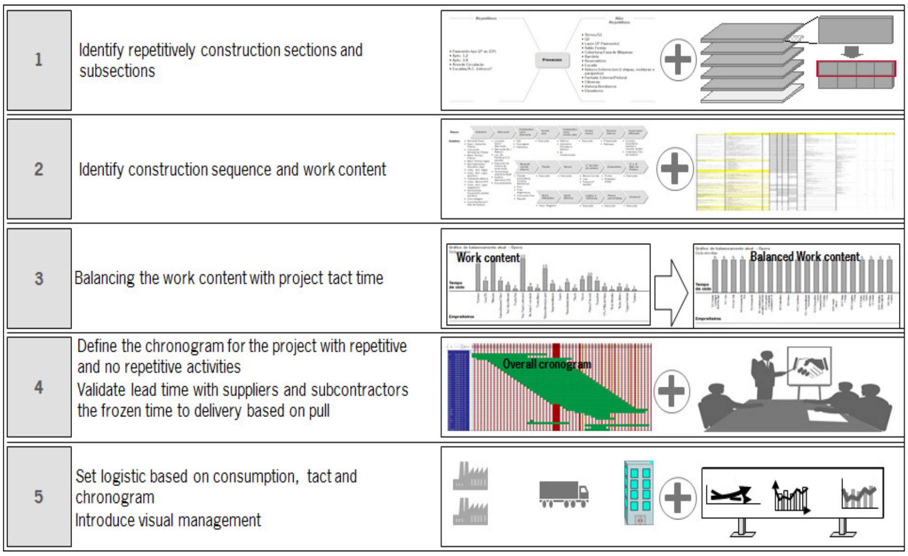


Figure E-9.4. Five steps to takt planning and control

- The first step is to identify the macro deliverables of the project and separate the ones that are repeatedfrom those that occur just once. At the 27-stock building, it was identified that the main activities were repeated at least 27 times.
- The second step is to detail the work content of each subsection of the repeat activities.The sections and subsections of the repeat deliverables were detailed in hourly activities that needed to be executed. The sequence of execution of the project is discussed at this phase and the technology to be used is also defined.
- The third step is to define the takt time for the project and balance all of the work content for each subsection based on it. At this phase, any waste actions, such aswaiting time and unbalanced work, need to be identified and eliminated.
- The fourth step is to generate achronogram of the project with the repetitive and non-repetitive activities and align that with all selected suppliers and subcontractors. Agreement of the chronogram and deliverables should also be firmed up in a contract base.
- The fifth step is to design JIT logistics – based on agreed lead time, batch size, chronogram, area and takt time – that dictates consumption. To ensure control of the project, visual management control with specific key performance indicators needs to be set.Introduction of the pull concept is important at this phase so that delays occurring during the process can be corrected without affecting the overall project.

Using the methodology indicated, construction time was reduced by almost 45% and labour cost reduced by 43% when compared with similar projects made by the same construction company. The methodology is now being used for other construction projects in Brazil.

Summary

Any construction project should start byfollowing a careful analysis of material need, work content and construction sequence otherwise it may result in extra cost, labour and/or time, or client dissatisfaction.

It is very difficult to set logistics and anSC if consumption is unknown. Takt time is key to defining targets for suppliers and subcontractors. Materials and services provided by companies in aconstruction project SC typically account for almost all of the cost of the project. The way in whichthose products and services are procured and managed has a profound effect on the outcome of the project – not only in terms of profitability for all parties, but also the way in which the completed facility meets the client's justifiable expectations of cost, quality and delivery date.

The evolution of construction projects is closely connected with SC planning. With a constant or leverage consumption which can be set by implementation of the takt time concept, the SC can help to increase construction site productivity.

We thank Mr Alex Bolinelli for preparing this casestudy.

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Case Study: The journey from craft over mass to lean production

The following material describes the journey that took place in the automotive industry between 1895 and 2000, based on the work documented by Womack, Jones and Roos in 1990 in their world-renowned book, *The Machine that Changed the World*, which is enriched by contemporary publications on this subject. We start with the history of the automotive industry from craft production through mass production to lean production. There, the characteristics of the respective production paradigms are summarized, indicating the path towards the lean thinking philosophy and emphasizing itsrelationship with the required establishment of alean culture.

Craft production

The story of different production paradigms can be started with the company PanhardetLevassor (P&L) in Paris, which was visited in 1894 by Evelin Henry Ellis, a wealthy member of the English Parliament. Evelyn Ellis wanted to order an automobile from the machine-tool company P&L, which was at this time building several hundred automobiles per year, following the so-called craft production system. P&L products were all hand-made (manufactured), thus they all differed in shapes and tolerances, as even all primary parts were cut, filed or further treated by hand by the skilled staff. Ellis required a special carbody and also complete rearrangement of the pedals, transmission and engine controls; as all products were completely hand-made to customer orders, this did not create huge problems for P&L, as Womack et al. (1990) described.

To summarize, the craft production principle focused on highly skilled workers who managed their individual scope of work on their own, including for example work preparation activities. These craftsmen used simple but flexible tools to produce the goods the customer asked for –but one item at a time. As described earlier under the aspect of the process flow structures, the historical approach of craft production can be closely linked to the job shop principle.As a consequence, products produced in job shops or batch shops to support the craft production approach are extremely customized but also costly.

Womack, Jones and Roos (1990: 22) summarized craft productionas:

- workforces that werehighly skilled in design, machine operations and fitting. Most workers progressed through an apprenticeship to a full set of craft skills. Many could hope to run their own machine shops, becoming self-employed contractors to assembler firms;
- organizations that were extremely decentralized, although concentrated within a single city. Most parts and many of the vehicle's designs came from small machine shops. The system was coordinated by an owner/entrepreneur in direct contact with everyone involved – customers, employers and supplier;
- having use of general-purpose machine tools to perform drilling, grinding and other operations on metal and wood;
- having very low production volume – 1,000 or fewer automobiles a year, only a few of which (50 or fewer) were built to the same design. And even among those 50, no two were exactly alike since craft techniques inherently produced variations.

Today, in the investment industry (e. g. for example the production of turbines, windmills, railway vehicles…) products are still highly customized and numerous special arrangements are engineered, later hand-made, for customers. Thus, the products are in principle **engineered-to-order** or at least **made-to-order**. However, today, automation levels in the investment goods industry areextremely low, production volumes per customer are also low. These range from a few products to some hundreds in rarecases. One could summarize that annual production volumes in that industry are in very similar regions as in the initial craft production of automobiles. On the other hand the adjustment (engineering) and manufacturing efforts are extremely high, thus it is very much comparable to (automobile) craft production, with the same effect of high production cost per unit.

Mass production at Ford

The number of car manufacturers has grown constantly since 1900, as Womack et al. (1990) pointed out. Production cost was high, but consistency and reliability of products was rather poor. The pioneer, who invented mass production as an alternative to craftsmanship, was Henry Ford. He strived for areduction in production cost, at the same time increasing quality by applying mass production. On the purpose of 'Manufacturing', Henry Ford stated in his book, *My Life and Work*, "Manufacturing is not buying low and selling high. It is the process of buying materials fairly and, with the smallest possible addition of cost, transforming those materials into a consumable product and giving it to the consumer".

The concept of mass production suggests the creation of higher volumes of standard products to generate scale effects and thus lower costs per item following standardized process steps. But what is mass production and how was it invented? Henry Ford started the design of his "A" model in 1903. Five years later he presented the twentieth variant of his initial product, the "T" model [comment fromauthor: the twentiethletter in the alphabet is T]. This T model was simplified from a manufacturing perspective. It was designed for the purpose for easy manufacturing (one could say designed"for manufacturing and assembly") and was also easy to use, to repair and to drive by customers (pre-1900 automobiles required chauffeurs).

Womack et al (1990) report that, when Ford started car production in 1903, cycle times totalled 514 minutes, because each worker needed to collect all the required parts from the material buffers, bring them to the production location, perhapsneeded to do some adjusting (filing down of parts) and then finally run the assembly.

The first optimization Ford conducted was to bring the material to the workerswhile still conducting "stationary assembly", meaning that workers had to walk from one station to the next and then perform their tasks. The workers increased their knowledge of their particular assembly operations due to their specialization, and continuously improved their performance; today we would refer to the learning curve effect. As parts became more precise and reworking was no longer needed, the cycle time reduced from 514 minutes to 2.3 minutes, as Womack et al. (1990) described. They further emphasized (ibid. 1990: 24): "The key to mass production wasn't – as many people then and now believe – the moving or continuous assembly line. Rather, it was the complete and consistent interchangeability of parts and the simplicity of attaching them to each other. These were the manufacturing innovations that made the assembly line possible."

Then in 1913 Ford implemented the assembly line, whichmade workers walking from one station to the next unnecessary. On that Ford pointed out in his autobiography: "Along about April 1, 1913, we first tried the experiment of an assembly line. We tried it on assembling the flywheel magneto. We try everything in a little way first—we will rip out anything once we discover a better way, but we have to know absolutely that the new way is going to be better than the old before we do anything drastic."

With the assembly line in the Highland Park Factory, the product came to the workers and thus the cycle time was reduced from 2.3 to just 1.19 minutes (Womack et al., 1990: 26). This was a remarkable leap in productivity within just ten years and at the same time cost per product was also significantly reduced, so that it was possible to produce 2 million Ford T models per year in the early 1920s.

To summarize, the key principles presented in this section of the casestudy which were applied to generate competitive advantage were: working-to-gauge, meaning the respect of same measures and strictlykeeping to tolerance limitations, at the same time focusing on interchangeability, simplicity and ease of attaching single loose parts. This allowed Ford to employforeigners ("workers spoke 50 languages and many of them could barely speak English")and mainly unskilled staff just to do their jobs.

The staffwho did the reordering, planning, scheduling, conducting the call-offs, etc. were the industrial engineers. They needed to plan and supervise the processes. On the other handworkers did not share information on issues or on optimization potential. Therefore, quality inspectors, repairmen, planners, housekeepers, industrial engineers, etc. were required as highly qualified indirect workers, who almost did not exist in craft production. In the engineering domains further specialization took place: besides the industrial engineers there were also manufacturing engineers evolving, who designed the required machinery, tools and jigs. Product engineers joined, who designed cars with further specialization in engine, carbody, interiors and so on. Other engineers dealt with optimizing assembly operations or designing special supporting devices. In essence knowledge workers evolved and manual workers lived in coexistence. Womack et al. (1990: 30) summarized: "These original 'knowledge workers' – individuals who manipulated ideas and information but rarely touched an actual car or even entered a factory – replaced the skilled machine-shop owners and the old-fashioned factory foremen of the earlier craft era. These worker-managers had done it all – contracted with the assembler, designed the part, developed a machine to make it, and, in many cases, supervised the operation of the machine workshop."

Ford designed, engineered and produced parts centrally in Detroit, but the cars were then (by 1926) assembled at 36 locations in the US and in 19 other countries all over the globe, leading to another problem: the same kind of product was not sufficient for the global market! This led in the early 1930s to different products being created in separate but fully integrated manufacturing systems in England, Germany and France. Ford followed the experience hehadbuilt up in production optimization, adopting the approach of vertical integration, meaning doing most of the parts on his own (e. g. the "Rouge Complex" in Detroit).As suppliers were not able to beat his productivity level, he needed higher tolerances and closer proximity to meet the master production schedules;but adopting this "visible hand" approach led to enormous management complexity, as Womack et al. described. He even created his own steel mill and glass production at the Highland Park Factory and operated a rubber plantation in Brazil, iron mines in Minnesota and had Ford ships to carry iron and coal (Womack et al. 1990: 37).

Ford was focusing on an intensive **level of vertical integration**, he was respectively **managing and even owning fundamental elements of the complete SC**covering e. g. internal raw material suppliers and operating the internal distribution services.

"Ford's idea was that by making everything, from food to tractors to airplanes, in a standardized form at high volume, he could dramatically reduce cost of products and make the masses rich. He financed all his projects internally […] and was determined to maintain total control of his company. Eventually, these steps beyond Highland Park all came to naught, partly because the synergy among industries […] was never there, but also because Ford himself had absolutely no idea how to organize a global business except centralizing all decision-making in the one person at the top – himself. This concept was unworkable even when Ford was in his prime, and it nearly drove the company under when his mental powers declined in the 1930s." (ibid. 1990:37).

Mass production at General Motors

At the same time, Alfred Sloan was working for General Motors (GM) and identified that the company was suffering from two major problems: GM needed to (i) manage all the enormous enterprises William Durant – the GM founder –had acquired; and (ii) rethink their overlapping product portfolio, aiming for a basic product that would suit every purse and purpose (Sloan, 1963). Ford only created one product, so this was an unknown problem for them, but they struggled with the management of all their factories and engineering units. Sloan on the other handcompleted the mass production system, which Ford had pioneered: Sloan (1963: 154-155) decentralized the five different car divisions (from cheap to expensive, i. e. from Chevrolet to Cadillac) plus the component-making divisions (e. g. gears or generators) and their self-reliant global companies (e. g. Opel in Germany or Vauxhall in Britain), which were managed by regular key performance indicator (KPI) reviews.

In addition to the engineering evolution described in the section on "Mass Production at Ford", Sloan even forced the creation of new professions such as financial or marketing specialists – as examples of experts in other non-production oriented functions (Sloan, 1963).

Sloan also perfected standardization: the reuse of the same components (such as pumps or generators) across all products and divisions that were made over many years on standardized machines; introduction of additional features such as car stereos or air conditioning systems to keep customer interests high. The principles GM applied on the shop floor remained the same as they were when invented by Ford. American car makers considered their workers as an element of variable cost, so that in line with the cyclical swings in the markets, lay-offs took place, respecting levels of seniority – not competence. This required the creation of work rules and the establishment of workers' unions.

In summary, the mass products are designed by engineering specialists, but in contrast to craft production, in a mass production environment rather low-skilled workers are employed who use special machines and devices to assemble standardized products at high volume (Womack et al.1990).

Mass production can be considered as the mix of the principles defined by Ford's focus on factory practices with GM's focus on marketing and management inventions and the role of the workers and their unions, as described by Womack et al.

In a mass production environment such as was applied in the automotive industry, any disruption due to a defective machine or missing parts would have led to a stoppage of the entire production processes. This is the reason why mass production has led to the creation of high inventory levels of buffering material to compensate for machine breakdown. Also, human buffers (workers) have been considered as well as additional space for materials or semi-finalized products. Berning (2001) pointed out that Henry Ford applied the principles of scientific management (Taylor 1911) in production of the so-called Model T, in which he produced automobiles in a continuous production flow in large quantities (mass) so that it was possible to reduce the vehicle assembly time from 728 hours down to 1.5 hours.

Changing production for a new model or product requires high changeover efforts (design of new special machines, jigs, tools, etc.) and thus continued production and usage of standard designs is preferred in a mass-production environment (Womack et al. 1990).

Other companies in other industries copied the mass-production principles and only a few niches remained occupied by craft producers. Mass production demonstrated for decades that it was the dominating production paradigm increasing from 1.7 million in 1919 (Sloan 1963: 151) to an output of 7 million cars produced in 1955 in the US as indicated by Womack et al. (1990).

In the 1950s, three companies accounted for 95% of the sales, making them known as the big three – GM, Ford and Chrysler. But 1955 was also the year the downturn began for the US automakers, because of increasing imports, especially from Japan. At this point in time, mass production as pioneered by Ford and GM was state of the art all over the globe, thus the competitive advantage of the US'sbig three was eroded. This was attributable to Ford's openness for visitors of other car producers.

After World War II, across Europe huge manufacturing facilities (e. g. by Volkswagen (VW), Renault, Fiat or Mercedes-Benz) were created. The European producers offered either economic and compact cars (like the VW Beetle), or cars that offered more fun to drive (like the MG) or luxury cars that were technologically much more advanced (like Mercedes). The result was enormous success, expansion and ever increasing export rates from the European automotive industry from 1950 into the mid-1970s due to numerous innovations (e. g. front-wheel drive, fuel injection or new body structures).

The American car industry's problem was that it offered simple add-on features like air-conditioning or car stereos, easily and quickly offered by other car producers. A further American problem was that offering more space-efficient cars with lower fuelconsumption (demanded due to the fuel crisis in 1973) required enormous engineering efforts and long factory redesigns and technology changeovers.

What Ford and GM experienced in the 1930s with their interchangeable workers, repeated itself in European factories in the 1950s, because German producers employed for example Turkish or Yugoslavian immigrants; the French industry employed for exampleMoroccan or Algerian workers who to a large extentjoined workers' unions and remained in the countries of their employment. In parallel, wages increased and monthly working hours decreased.

At the same time, the Japanese reinvented the process of producing automobiles in a way Womack et al. (1990) called "lean production", a process summarized in the hard-copy part of this book.