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World Class Layouts

A study of packaging plants for liquid food

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Lund, May 2009.
Rikard Svärdby

Abstract

Title:	World Class Layouts A study of packaging lines for liquid food
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Supervisors:	Lennart Perborg, Lund University, Faculty of Engineering Gustav Nilsson, Tetra Pak Packaging Solutions
Background:	High automated factories are common in the packaging industry today, does the high production rate and low need of operator attention affect the production layout.
Objective:	The objective of the thesis is to define what world class layouts are for companies in the packaging industry, determine which design parameters governs the layout, and propose a way of measuring the layout and performance of the plant.
Methodology:	In order to determine what world class layouts are a literature review is performed, to clarify what the academy have found superior. Studies of three different companies in the packaging industry are done through interviews, along with observations and a final presentation of world class layouts are done.
Results:	The most important parameter in order to design and deliver world class layouts is the design method. Systematic Layout Planning is the method to develop a production layout and it should be designed considering: customer focus, fact-based decisions, continuous improvements, and involvement of the employee.
Key words:	World-class, layouts, packaging, Tetra Pak, Systematic Layout Planning, Lean, fact-based decisions, continuous improvements, employee involvement, customer focus, design parameters, metrics, performance measure.

Sammanfattning

Titel: World Class Layouts
A study of packaging lines for liquid food

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Handledare: Lennart Perborg, Lund University, Faculty of Engineering
Gustav Nilsson, Tetra Pak Packaging Solutions

Bakgrund: I förpackningsindustrin är automationsgraden idag väldigt hög, detta ger en hög produktionshastighet men ett lågt behov av operatörer. Den här rapporten kommer att behandla hur layouten påverkas av detta.

Mål: Målet med den här rapporten är att definiera vad en produktionslayout i världsklass är för företag i förpackningsindustrin, avgöra vilka parametrar som påverkar layouten och föreslå mätetal för att mäta layouten och produktiviteten i anläggningen.

Metodik: För att utröna vad en layout I världsklass är har litteraturstudier gjorts, för att förtydliga vad akademien har funnit överlägset. Fältstudier har gjorts på tre företag i förpackningsindustrin genom intervjuer och observationer på verkliga anläggningar.

Resultat: Den viktigaste paramtern för att designa och leverera produktionslayouter i världsklass är designmetoden. Systematisk lokalplanläggning är den metod som identifierats för att ta fram produktionslayouter och ska tas fram med hänsyn till: kundorientering, faktabaserade beslut, kontinuerliga förbättringar och medarbetarnas engagemang.

Sökord: World-class, layouts, förpackningsindustri, Tetra Pak, Systematisk lokalplanläggning, Lean, faktabaserade beslut, kontinuerliga förbättringar, medarbetarnas engagemang, kundorientering, design parametrar, mätvärden, effektivitetsmått.

Table of Contents

1 Introduction

In this introductory chapter the overall background of the problem is given as well as the purpose and objectives of the thesis.

1.1 Background

Tetra Pak was founded in the early 1950s as one of the first packaging companies for liquid milk. Since then, Tetra Pak has become one of the world's largest suppliers of packaging systems for milk, fruit juices, drinks, and many other products. Today it is the only international company in the world that is able to provide integrated processing, packaging, and distribution line as well as plant solutions for food manufacturing.[1]

Tetra Pak Packaging Solutions AB (from now on referred to as Tetra Pak) Capital Equipment is the division that provide the market with packaging solutions, from raw food to packages on a pallet. This is done, by first of all, a filling machine followed by different distribution equipment such as; straw applicators, card board packers, and palletizers. The steps are connected with conveyers, forming a packaging production line, a so called line layout.

Line layouts are characterized by the continuous material flow, the short time between operations, the high level of automation, and the small or nonexistent amount of stock between the operations. Together this is a system that gives the highest productivity which also is emphasized in lean manufacturing. Research in how a line layout is supposed to be designed is however lacking. Most research in the facility planning area concentrates in changing from a process layout to a more product focused cell layout. A fair amount of research is done about line balancing problems, allowing operators to work at more than one spot. This only concerns production systems with a high amount of manual work, which is not the case here.

Despite that fact, most research in facility planning still is concentrated on making the process layout cell or group layout. Less research is done when it comes to line layouts and what they are supposed to look like. This report is a attempt to identify the key issues to take in consideration while developing a line layout.

[1] Tetra Pak text presentation accessible through: http://neworbis.tetrapak.com 2008-11-13

The phrase *world class manufacturing* was first published by Professor Richard Schonberger as the book title of *World Class Manufacturing – the lessons of simplicity applied* 1986 where Schonberger describes how American companies have succeeded in Japanese production and management techniques.[2]

Production lines ought to be *lean and simple* as it is a centerpiece in world-class manufacturing and Schonberger have identified many examples in almost every industry; but not in the filling and packaging industry which is the subject of this study. Other industries have been shortening conveyers, reducing buffers, and closing gaps between processes but the canners, brewers, bottlers, and packagers have not. As protection from unreliable equipment, packaging industries did what they always had done inserted long conveyers between workstations and stuffed them with buffer stocks. The reason is that increasing line speeds and complex equipment makes failures likely, so to avoid full line stoppages for minor failures accumulation is used. Still, major problems do stop the line why lines in this business are down 30-50% of the time. The industries response to the poor line performance is to make the lines run even faster, which causes even more jam-ups.[3]

Tetra Pak have an overall goal to be a world class manufacturer and this thesis is one part of this larger movement, to ensure that Tetra Paks production layouts are world class. Development projects are driven all over the company.

1.2 Problem Specification

What defines a World Class production line layout? What design parameters are governing the layout? How can the layout be measured?

1.3 Objective

The objective of the thesis is to define what world class layouts are for companies in the packaging industry, determine which design parameters governs the layout, and propose a way of measuring the layout and performance of the plant.

1.4 Focus and Delimitation

Focus of the report will be how the facility layout affects productivity and how the layout can be as efficient and effective as possible. For example with regard to reduced losses, space utilization, material handling, waste, production stop. It will be limited to only regard the packaging industry yet the ideas will work as well in any continuously producing factory. The thesis will

[2] Maskell, H. Brian. *Performance measurement for World Class Manufacturing* (1991) pg. 3.
[3] Schoonberger, Richard J. World Class Manufacturing,: The next decade (1996) pg. 156.

address Tetra Pak's layouts and design methodology on an overall level and will not deal with the design of the machines only how these are located in the plant. Neither will it regard any kind of line balancing problem, as it is not an issue in this case.

1.5 Target Group

The primary target groups of this thesis are Project Managers and Project Engineers at Tetra Pak market companies and at the Project Support department. Other target groups are companies planning to put up a production line and academic researchers interested in the subject. In addition, the thesis might also be of interest to master students of engineering logistics and industrial management.

2 Methodology

To be able to fulfill the aim of the report a procedure has to be defined. How information is gathered, and the way the study is done, and why it is done that way, is presented in this chapter. The validity and reliability of the report is discussed as well.

2.1 Approach[4]

There are three different approaches towards science studies, inductive, deductive, and abductive. These three approaches are different paths between the general theories and the concrete empirics. This thesis uses a deductive approach which means that existing theories, in the subject, is studied and documented. A definition of world class layouts in Tetra Paks segment is composed based on literature studies in the subjects, world class, lean production, systematic layout planning, and production layouts. Reality is verified against these theories and logical conclusions of separate phenomenon are drawn of existing theory. A comparison with other industries is done, to address new perceptions of what a world class layout is.

This approach is chosen because an inductive approach would have needed a study of a large number of companies, preferably world wide. A deductive approach is much more time, money and travel effective. Further it exploits earlier studies better.

2.2 Qualitative and Quantitative Studies[5]

Quantitative studies are based on information that can be measured or evaluated in figures common in for instance mathematical models or surveys. Qualitative studies do not generate a number but gives a deeper knowledge about a certain subject, event, or situation such as information from interviews or observations. Qualitative studies are carried out through interviews and observations at Tetra Pak as well as at the compared industries. This is then verified with quantitative studies made with help of simulation.

2.3 Data Gathering[6]

There are two different types of data, primary and secondary. Primary data is the kind of data gathered trough observations or interviews. Secondary data is data that is already documented by someone else from literature, articles or internet.

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[4] Björklund, Pålsson (2003) *Seminarieboken* pg. 62
[5] Björklund, Pålsson (2003) *Seminarieboken* pg. 63
[6] Björklund, Pålsson (2003) *Seminarieboken* pg. 67 - 68

2.3.1 Secondary Data[7]

It is important to always be critical to secondary data, as it always is developed in another purpose than what lies in the objective of the reader. Secondary data can be based on literature or presentations.

The literature used in this report consists of written documents in the subjects world class manufacturing, lean production, and production layout planning. It is used to map existing knowledge within these certain subjects and to develop a theoretical framework of references. In order to find relevant, and enough, secondary data books are searched in the union catalogue for Lund University Libraries (Lovisa) and Google books in various keywords. Articles are searched by the database Compendex and Google scholar. Relevant books are also searched trough unstructured interviews with tutors but these interviews have not been documented and the outcome can only be found as references in the reference list. Other secondary data is documentation from Tetra Pak as well as the other industries. The main advantage of secondary data from literature is that much information can be retained with little resources.

Presentations at lectures or conferences may, like literature studies, offer much data with a small effort. However it is important to always evaluate the primary target of the presentation and how it can influence the presentation. Here data is gathered from lectures at Lund institute of technology.

Data regarding the different machines are gathered from Tetra Pak internal network foremost from installation manuals as well as other machine documents. To complement data regarding machine specifications and performance data is gathered from Tetra Paks line simulation tool.

2.3.2 Primary Data[8]

Primary data is collected in purpose to be used in the current study, the information is in direct relevance to the purpose if the study. Gathering methods to gather primary data can be interviews, surveys, observations, or experiments.

Interviews, different forms of questioning, can be done face to face, via telephone, or like a dialog trough e-mail. Note that e-mail is a type of written information, however it is primary data. Interviews give the possibility to ask attendant questions to receive deep knowledge about the subject. It is also possible, in some cases, to get additional information trough for example body

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[7] Björklund, Pålsson (2003) *Seminarieboken* pg. 67, 69- 70
[8] Björklund, Pålsson (2003) *Seminarieboken* pg. 68 - 71

language. Disadvantage of interviews is that they are time and travel consuming.

A semi structured interview approach is chosen with pre-distributed questionnaire. A semi structured interview means that a template of questions is formed, and in this case pre-distributed, but the purpose of the questions is only to use them as a discussion base. All questions do not have to be asked, the order is not set and there is a possibility to follow up the discussion with additional questions. This gives the possibility to follow up interesting, or unclear, subjects. To avoid misconceptions the part of the empiric chapter were the interviewee is involved has been sent for validation of the answers. In addition to the interviews observations has been done at the actual plant.

An interview with all questions, and there order, is called structured. It does not support the opportunity to follow up question but if there is more than one interviewee the answers are easy to compare. Interviews without predetermined questions are called unstructured.

During the interviews the aim has been not to ask leading questions and this has always been in mind to minimize the risk that the observer affects the result. Interviews have been memorized and written down directly after its finish. Some, but few, notes have been taken during the interviews. This approach is chosen because there is a possibility that the interviewee feels too observed to answer sensitive questions if the interview is recorded or written down. Of course there is a risk with memorizing as details or complete parts can be forgotten and this is why everything is documented as soon as possible after the interview.

The companies participating in this study have been chosen first of all by the criteria that they produce in line layouts and a continuous process, preferably with great experience in designing a production line. These companies are found through unstructured interviews with tutors. Some contacted companies have not been interviewed since they did not fit the profile or did not think they had something to contribute with.

2.4 Credibility[9]

Validity, reliability, and objectivity are measurements of the authority of the study.

[9] Björklund, Pålsson (2003) *Seminarieboken* pg. 59 - 60

2.4.1 Validity

Validity is the ability to measure what is meant to be measured. To ensure a high validity in this study questions have been clearly formulated and not leading. Data has also been triangulated trough observations.

2.4.2 Reliability

Reliability is the ability to redo the investigation. High reliability means that the result would be the same if the test is done again. To get a high reliability questions were made to address the same field from different perspectives.

2.4.3 Objectivity

To get a high objectivity all choices have been described and motivated as far as possible. This gives the reader a chance to evaluate the result which increases the objectivity of the study.

2.5 Definitions

2.5.1 Line Layout

In this thesis the word *layout* is defined as the physical location of the different machinery in a facility. A *line layout*, sometimes called *product layout* or *mass production layout*, is the type of layout where products are produced through a continuous process. The raw material enters the production line and is worked on in sequence until it leaves as finished goods.

2.5.2 World Class

In this report *world class* and *world class manufacturing* is defined as the aim to use what is identified to be best practice, in a particular subject.

2.6 Source Criticism

2.6.1 Literature

Literature is found through internet searches and unstructured interviews with tutors. The aim is always to find first hand literature and then derive it upwards so the most recent observations are taken in consideration as well.

The aim has always been to find the root source of the literature and then follow the progress to todays date.

The larger part of the methodology chapter uses Seminarieboken as source. The more sources used the higher the trustworthiness gets but seminarieboken is recommended by the department of industrial management and logistics at LTH why the author find it acceptable anyway.

Most of the theoretical framework originates from the book: *The Toyota Way* and it is important to be critical to this source. However this book is a portrait of Toyotas production and management philosophy out of an American viewpoint.

2.6.2 Interviews

When interviewing one person at a corporation the interviewer has to be aware of that the interviewee's personal perspective may not always be exactly the same as the official company perspective. When working with people, personal opinions are always an issue. In order to get a fair picture of the companies' layout work interviews have only been conducted with persons with an overview of the complete process.

There is always a risk that the interviewees tend to beautify their own company and to avoid the author have tried to visit actual sites or documentation from actual work, as far as possible. Another way of doing it could be to meet more than one person at each company to triangulate yet to get an appointment with one person has been considered sacrifice enough for the company; more persons would have been asking for too much.

2.6.3 Influence from Tetra Pak

A distinct job requester always puts objectivity into question. To do good research the researcher can not be influenced by the company requesting the research. The thesis is, however, written for the faculty of engineering at Lund University.

2.7 Reference Method[10]

This text uses the Oxford reference system and the placement of the footnote indicates how much of the text the note refers to. If the is located at a word in a sentence the note refers to the word. If the note is located in the end of a sentence but before the dot the note refers to that sentence. If the note is after the dot it in addition refers to prior sentences in the same part. If the note is in the headline it refers to all text to the next headline at the same level. A note at a low level outmaneuvers a note at a higher level.

[10] Björklund, Pålsson (2003) *Seminarieboken* pg. 83 – 84

3 Theoretical Framework

In this chapter relevant earlier studies and conclusions are presented. World Class Manufacturing theories are presented as well as conventional production layout theory.

3.1 Line Layout

A *line layout*, sometimes called *product layout* or *mass production layout*, is the type of layout where products are produced through a continuous process. The raw material enters the production line and is worked on in sequence until it leaves as finished goods. Advantages of a line layout are its high throughput, and therefore low productions cost per unit, and floor utilization. Disadvantages of the line layout are the high investment cost and lack of flexibility, as a production line often uses, more or less, single purpose equipment. Further expansion of the production line and sometimes the facility is difficult and if one machine breaks down, the whole line often has to stop.[11]

Other layout types are: *process layout, group layout, cellular layout and fixed position layout.* Mutual for all of these is that they are not as product specific as the line layout, and therefore generally have a lower throughput. None of these layout types are relevant in this study as the machines here are connected by belts.[12]

3.2 Systematic Layout Planning[13]

Systematic Layout Planning, SLP, is a method to plan the layout at a plant. It was first developed by R. Muther in the 1960: s. Here is a slightly different procedure presented, to better fit resource management and production techniques of today. It is also simplified to only fit line layouts. It works well with the scope to dispose and find the right dimension for a complete building as well as planning when the least unit is complete machines, as in this thesis. The method consists of eight different steps:

1. Product-, quantity-, process- and production analysis.
2. Function deployment and function requirements.
3. Relationship analysis.
4. Relationship chart.
5. Block layout.
6. Principal layout.

[11] Shim, Siegel. *Operations Management: A streamlined course for students and business people* (1999) pg. 207-208.
[12] Walters, D. *Operations Management: Producing goods and services* (2001) pg. 293-294.
[13] Bergensthål, Perborg. *Industriell Anläggningsteknik* (2001) pg. 98-111.

7. Evaluation.
8. Specific layout.

As an example a process with three inventory units and four operations (A to D) is used in some of the steps below.

3.2.1 Product and Production Analysis:

The first step is to list all basic data such as environmental requirements, volume, flows (material, personal), machine requirements, and product size. A pareto chart visualizes different product production volumes or forecasted customer demand, making it easy to see the product types with the highest demand and what material is required, see
Figure 1. Based on this production volumes and needed equipment can be chosen.

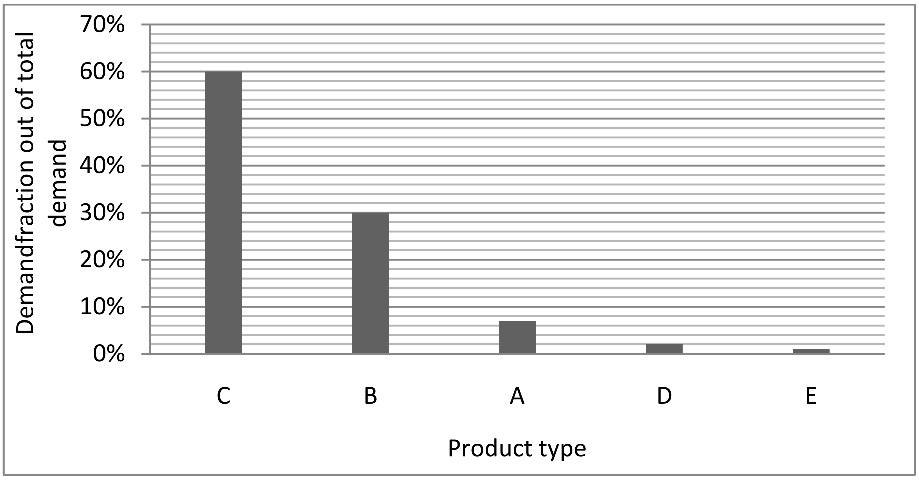

Figure 1. Pareto-chart.

In a production analysis a flowchart shows the different relations between the operations in the production process and contributes with a clear overview of it. To illustrate the SLP, a capricious example is used with 6 stations (1-6) where station 1 is storage, station 2 to 5 operations and station 6 finished goods inventory, see example of flow-chart in Figure 2 where inventory or buffers are symbolized with a triangle and operations with circles. In this example operation 3 and 4 are done parallel and then assembled in operation 5.

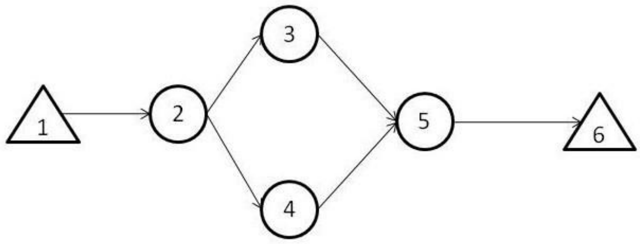

Figure 2. Flowchart

3.2.2 Function Requirements:

A function is defined by the requirements of the activity. Activities with the same requirements are grouped into one function, but here the intention is not to make a function deployment of the line. Requirements can be legal or physical and dependent of the activities, the plant, or the environment. The formulation of the function requirements list is important; it is the ground of the SLP. If it is not done properly, the rest of the work will suffer. In Figure 3 requirements are visualized to provide a clear overview over the requirements of each process. + means required. Black means high requirements, grey: general requirements, and light-grey: light requirements.

	Tech. require ments			Supply tech. req.			Transport technical requirements					
Func. / Req.	Floor	Height	Fire	Electricity	Gas	Air	Water, drain	Travers	Forklift	Crane	Conveyor	Lifting tackle
1									+			
6						+		+	+	+		
2						+					+	+
3											+	
4					+						+	
5											+	

Figure 3. Requirements systematically visualized.[14]

The space requirements of each machine are also listed here. Space for transportation is also needed depending on preferred transport method.

3.2.3 Relationship Analysis:

Analysis of the relationships found in the previous step. A matrix of preferred closeness between the different functions are graded with; a – for closeness absolutely necessary, e – closeness especially important, i – closeness important, o – ordinary closeness ok, u – unimportant, and x - undesirable, see

[14] Bergensthål, Perborg. *Industriell Anläggningsteknik* (2001) pg. 101.

example matrix in Figure 4**.** The grade can be based on different reasons, here symbolized with numbers, for instance production flow (1), material flow (2), personal flow (3), or similar requirements (4)[15].

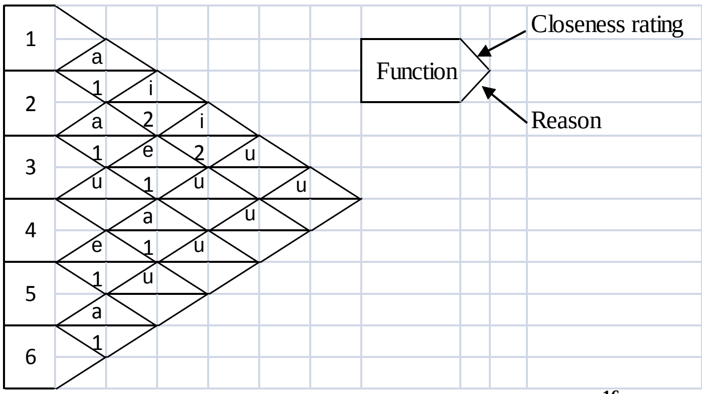

Figure 4. Closeness Matrix, example.[16]

3.2.4 Relationship Chart:

Visualizes the relationship analysis and the greatest flow of material. Every function is illustrated with a numbered circle and linked with lines indicating the rate of closeness preferred. A thick line indicates that closeness is preferred, or in other words that the flow is big between the functions. The aim is to make visualization with as few crossing flows as possible. An example is showed in Figure 5 where operations are illustrated with circles and stock as triangles.

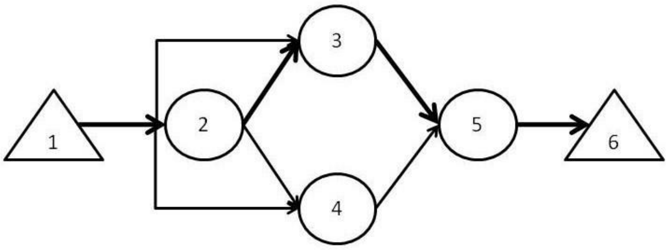

Figure 5. Relationship chart.[17]

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[15] Shim, Siegel. *Operations Management: A streamlined course for students and business people* (1999) pg. 211

[16] Loosely after: Bergensthål, Perborg. *Industriell Anläggningsteknik* (2001) pg. 105.

[17] Bergensthål, Perborg. *Industriell Anläggningsteknik* (2001) pg. 106.

3.2.5 Space Relationship Diagram:

The space requirements, for each function, are listed in a diagram, see example in Table **1**.

Table 1. Space diagram.

Station	Area req. (m^2)
1	100
2	15
3	115
4	23
5	17
6	132

The function- and relationship requirements are weighted together with the area requirements in a block chart. It looks much like a relationship chart but the boxes are proportional to the actual size of the machine or function. The relationship is visualized by the size of the lines, see example in Figure 6. Finally other requirements can be visualized with special marking of the layouts.

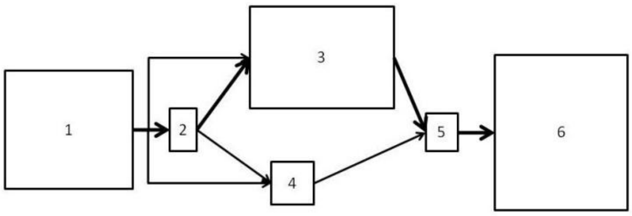

Figure 6. Blockchart.

3.2.6 Principal Layout:

The theoretic block layout is transferred to an actual line layout, done with respect to the different requirements. Generally it is better to make more than one primary layout, as the next step is evaluation of the different principal layouts. In the principal layout the different function spaces, with at least one side to a transport area, transportation areas, walls and doors are visualized. The plant is often fitted to site in this step as well.

3.2.7 Evaluation:

The main goals of a facility layout are to: minimize material handling cost, reduce bottlenecks in material and people movement, provide flexibility, provide ease of supervision, utilize available space effectively and efficiently, reduce hazards to people, and facilitate ergonomics.[18]

The different principal layouts are systematically evaluated to fit the need of the customer the best. All customer needs should be taken in consideration, it is therefore important to gather information from all different people who have an interest in the layout. The importance of a function is graded, by the stakeholder, from one to three. How good the layout fulfills this requirement is also evaluated from for instance one to three. There is also a possibility to grade from for instance minus one to three. This evaluation can be done by a concrete measurement or a more subjective personal estimate. Multiplication of these gives a score. An important criteria (3) well fulfilled (3) gives nine points. All points are summed, to find out what layout fits the needs the best.

Example of factor		(Customer) Weight of factor	Evaluation		Score	
			alt A	alt B	alt A	alt B
Activity	Material flow	3	3	2	9	6
	Load and unload	2	2	1	4	2
	Internal flexibility	3	3	2	9	6
	Expandability	2	3	3	6	9
	Administrative connections	1	2	1	2	2
Work environment	Contact	3	2	3	6	6
	Space	2	2	2	4	4
	Ergonomic	2	3	2	6	6
	Noise, light and air	3	1	3	3	3
	Safety	3	2	3	6	6
				Total	55	50

Figure 7. Consideration assessment.[19]

3.2.8 Specific Layout:

In the last step a detailed layout is developed, based on the best layout alternative from the previous step. Here is where all equipment is put in the model; specific machines, pallet shelves, electric centrals and transport passages.

[18] Shim, Siegel. *Operations Management: A streamlined course for students and business people* (1999) Pg. 206

[19] Bergensthål, Perborg. *Industriell Anläggningsteknik* (2001) pg. 110.

3.3 World Class Manufacturing

World Class Manufacturing is a widely used concept in many different industries, the exact meaning differs but the base idea of doing something *world class* is, of course, to use current best known procedure.

In manufacturing best procedure has been, since the fast recovery after World War II, Japanese production, and management, philosophy and is still considered to be the best in the world. Which is the reason why a world class manufacturer also have to consider the thoughts and principles that characterizes Japanese production philosophy. Japanese production philosophy is based on three fundamental pillars; customer orientation, commit to the whole enterprise, and decisions based on facts.[20]

A World Class company is comparing itself against other companies to ensure that the methods and systems applied are at vanguard of efficiency and productivity.

3.3.1 Basics of Lean Production

In this report lean production is set equally to Toyota production system (TPS), some argue they differ, some argue they do not. Lean production tend to be more focused on the tools used, while TPS focus more on achieving flow, but uses the same tools to achieve it. The goal, to eliminate waste, is the same in both approaches. Yet, in this report, Lean production and TPS are set equally but the intention is by no means to therefore disrespect either of them.

Toyota is well known for the short time between customer order and delivery, by eliminating all non-value-added waste. The result is a lean process that delivers high quality to the customer at a low cost, on time, and makes it possible for Toyota to get paid without holding enormous amounts of inventory. Similar lean processes are found during product development at Toyota, letting customers get updated features faster, with higher quality, and at lower cost. Lean processes are found throughout Toyota, though they are not as well documented as in manufacturing and product development. However it is important to remember that sometimes waste have to be created in short term to be able to eliminate waste in long term.[21]

All we are doing is looking at the timeline from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that timeline by reducing the non-value-added waste.[*]

[20] Schoonberger, Richard J. World Class Manufacturing,: The next decade (1996) pg. x.
[21] Liker, J. Meier, D. *The Toyota Way – Fieldbook* (2006) pg. 19-20
[*] Taiichi Ohno, 1988 “Father” of Toyota Production System

Cars are discrete objects, and hence lean production suits discrete product manufacturers the best. But with some adaptation a continuous process can also benefit from the thought of lean production, as almost all continuous process facilities sooner or later tend to produce some kind of discrete products. This gives the opportunity to use many of the principles of lean production.[22]

3.3.2 World Class Assessment Criteria

The question whether a company is a world-class manufacturer or not is often answered through an array of principles of which the company gets a score in if the total score is high enough the manufacturer is considered world-class. Below are three different assessment criteria presented.

Malcolm Baldrige National Quality Award

The Malcolm Baldrige National Quality Award is a award that is given to the American company that is considered to be outstanding in the following seven areas; *Leadership, strategic planning, customer focus, measurement, analysis, and knowledge management, workforce focus, process management,* and *results* are used. [23]

Underlined are the areas that the author found to regard the layout which will be further explained later in this chapter. Leadership, strategic planning, and process management are found to be concerning the management of the company or people therefore it does not aim at the production layout directly.

Schonberger

Schonberger suggests principles of customer-focused, employee-driven, and data-based performance. Sixteen principles are identified, and can be graded from one to five; *Team-up with customers, Capture customer information, Continual improvement, Frontliners involvement in change, Cut to the few best components, operations, and suppliers, Cut flow time and distance, start-up/changeover times, Operate close to customers' rate of use or demand, Continually train everybody, Expand variety of rewards, Continually reduce variation, Frontline teams record and own process data at workplace, Control root causes, Align performance measures with customer wants, Improve present capacity before new equipment, Seek simple, flexible, low cost equipment in multiples, and Promote/sell every improvement.*[24]

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[22] Billesbach, T. *Applying lean production principles to a process facility* (1994) pg. 40
[23] Baldrige national quality program, *criteria for performance excellence* (2008) pg. 7-23
[24] Schoonberger, Richard J. *World Class Manufacturing,: The next decade* (1996) pg 24-27

Also here are the areas concerning the layouts underlined.

ISO 9000

Another possibility is to use the eight quality management principles from ISO 9000; *customer focus*, *leadership*, *employees involvement*, *process approach*, *system approach*, *fact-based decisions*, and *supplier relations.* [25]

The different assessment criteria do obviously share a lot of the fundamental ideas from the Japanese production philosophy. Some of the criteria are focused of the strategic management and leadership of the company, which are out of scope of this thesis. The theoretical criteria concerning the layout are presented below.

3.3.3 Customer Orientation and Waste[26]

Mutual for all of the three evaluation methods is to focus on the customer and what the customer wants. (Customer focus, team-up with customers, capture customer information, Cut flow time and distance, start-up/changeover times, Operate close to customers' rate of use or demand, align performance measures with customer wants, customer focus)

All organizations are dependent of its customers and have to understand present and future customer demands. Toyota has identified everything that the customer is not willing to pay for as waste. However some waste is impossible to reduce due to for instance legal restrictions. Below is a listing of the seven wastes Toyota has identified and a short explanation.

Over production:

Producing earlier or more than is needed generates wastes such as overstaffing, storage, and transportation costs due to excess inventory. Inventories can be, other than ordinary physical inventory, a queue of information.

Waiting:

Workers watching an automated machine, waiting for the next processing step, tool, supply, part are all waste. Also lack of work because of no stock, lot processing delays, equipment downtime, and capacity downtimes is waste.

Transportation:

[25] http://www.sis.se/DesktopDefault.aspx?tabname=@iso9000&menuItemID=5870 2009-05-22

[26] Liker, J. Meier, D. *The Toyota Way – Fieldbook* (2006) pg 35 – 36.

Moving materials, work in process, or parts from place to place in a process or into or out of storage does not add value to the customer. It should therefore be reduced, as much as possible.

Over processing or incorrect processing:

Already in the product development process products should be designed to manufacture, without the cause of extra motion and defects. Waste is; taking unneeded steps to process the parts, inefficient processing due to poor tool or product design, higher quality than needed, working when not needed.

Excess inventory:

Excess inventory hides problems such as; production imbalance, late deliveries from suppliers, defects, equipment downtime, and long set up times. The aim should be to deal with these problems, to become a world class manufacturer, not to hide them. Unnecessary raw material, work in process and finished goods also cause longer lead times.

Unnecessary movement:

Motions employees has to perform, that is not adding value to the product is waste. Included are stacking parts, looking for tools, reaching for products, and walking.

Defects:

Of course any processed material that can not be sold is waste. For instance correction, rework, scrap, replacement production and inspections are wasteful time and effort. The right processes do the right product, the first time.

3.3.4 Fact-based Decisions[27]

(Measurement, analysis, and knowledge management, results, fact-based decisions)

Effective judgment is based on data-analysis which enables well-established decisions avoiding guessing and pre-assumptions. In the evaluation-part of the systematic layout planning it is important to grade the layouts based on facts.

In order to base decisions on facts data gathering and analysis must be made. Pareto charts are histograms used to visualize and prioritize problems, often a small number of issues cause most of the problems, which is visualized in the Pareto chart. A rule of thumb is that 20% of the issues cause 80% of the problems.

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[27] http://www.sis.se/DesktopDefault.aspx?tabname=@iso9000&menuItemID=5870 2009-05-22

3.3.5 Continuous Improvements[28]

(Continual improvement)

The only way to stay world class is to continuously improve otherwise other companies will soon beat you as companies constantly are developing in the race for market shares. The continuous improvement process is divided into the following four steps which also are illustrated in Figure 8.

Plan – do – check – act

- Plan: Develop an action plan
  Identification of a problem, suggestion of one of more solutions, and identification of a goal. The idea is that the problem should be relatively small and substantial; you should be able to see the complete problem. Data from before improvement is gathered in order to have a baseline to compare with when the improvement is done.

- Do: Implement solutions
  The solutions are implemented, if additional problems are found upon completion, of the initial problem, those are also solved until the goal from the plan is fulfilled.

- Check: Verify results
  Gathering of data to verify that the process is improved.

- Act: Make necessary adjustments to solutions, and to the action plan, and identify future steps
  First of all it is important that the solutions do not cause more problems than they solve. There always tend to be problems, at first, when something is changed and of course this kind of problems should be distinguished from real problems.

  After solving one problem the natural step must not to lay back and wait but to immediately identify the next problem, and its possible solutions.

[28] Liker, J. Meier, D. *The Toyota Way – Fieldbook* (2006) pg. 364-368

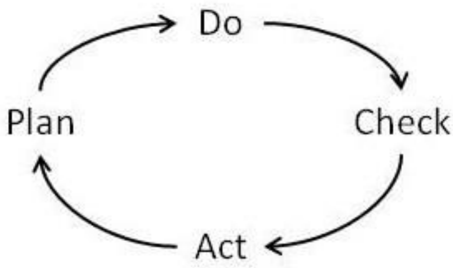

Figure 8. PDCA-cycle.

3.3.6 Employees Involvement[29]

(Workforce focus, frontliners involvement in change, employees involvement)

The employee is the company's key asset and the employee's engagement enables the full use of the employee's capacity. The operator is the one working in the layout and is consequently the one knowing the shortages and advantages of a certain layout. As the operators are the key assets in the organization they also need a satisfying work environment and the possibility to overview the operations. Following is a listing of what characterizes a good work environment and visual overview.

- **Work environment [30] :** Operators should have attractive and meaningful assignments. Physical and repetitive tasks should therefore be automated as far as possible. It is also important that the environment do not danger the health of the operator. Possible risks are in traffic, chemicals, noise, air pollution, and slippery floor. If any form of vehicle share space with operators it is important that the flows do not cross or are clearly marked.

  The environment should be easy to work in, proper lighted and avoiding an isolated localization of the operators. Noise and vibrations are experienced as annoying, even at healthy levels, and should be kept as low as possible. Everything should be in its, marked, place and the work environment should be clean and bright.

- **Visual overview**[31]**:** One of the key concepts in Lean production is visualization. It is important to have a visual material flow that always shows the effect of actions. All flows should be easy to overview

[29] http://www.sis.se/DesktopDefault.aspx?tabname=@iso9000&menuItemID=5870 2009-05-22

[30] Edegren, J. Kriterier på bra produktionssystem, (1982).

[31] Edegren, J. Kriterier på bra produktionssystem, (1982).

showing the operator how important he is and making him feel committed to line performance. Operators dependent of each other should as well be able to communicate with each other.

3.3.7 SMED

SMED, *Single Minute Exchange of Die*, is a method designed to minimize setup time. Set-up time is not value adding time as it does not add any value to the product the customer is willing to pay for. As the set-up time could be utilized as production time reduced set-up time makes the productivity go up. Another effect is the possibility to produce in smaller batches and consequently reduce stock, as the costs related to the set-up go down.[32] The method consists of three steps:

- **Separate internal and external set-up:** Internal set-up is the time when the machine must necessarily be inactive. External set-up is the percentage that can be done when the machine is running. The principle is that everything that is external set-up also should be handled as external set-up, and done while the machine is running. All external set-up is done before the machine is stopped and the internal set-up is done. This way the machine is stopped as short amount of time as possible.

- **Convert internal to external set-up:** Observed internal set-up is controlled so you can out rule the possibility that it is external set-up. The part that still is internal set-up should as far as possible be reworked so it can be done with the machines running.

- **Rationalization of set-up:** Each individual operation is analyzed in detail, to the maximum extent possible, to streamline the conversion operation.[33]

3.3.8 Six Sigma[34]

Six Sigma was firstly implemented at Motorola and have the goal to minimize variation in production and business processes. It uses a set of statistical and quality management methods in order to improve quality, and minimize variation. In statistics the symbol σ as standard deviation and is based on the idea that if one have six standard deviations between the output mean and the specification limit (products outside are defect) 3.4 defects will occur per million opportunities.

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[32] Shingo, S. *A Revolution in Manufacturing: The SMED System* (1985) pg 113
[33] Shingo, S. *A Revolution in Manufacturing: The SMED System* (1985) pg 28 - 31
[34] Pyzdek, T. *The Six Sigma Handbook* (2003) pg 3 - 7

The improvement work in Six Sigma is vital and one key method is DMAIC, *Define, Measure, Analyze, Improve, and Control.* The method is somewhat like the improvement circle. The definition step consists of mapping of improving projects and areas of improvement. Measuring, quantification of how the process is done today with relevant data. The data is analyzed in order to verify the cause-and-effect relationships. The process is improved and finally the process is controlled to ensure deviations from target are corrected before they result in defects.

3.4 Key Performance Indicators

There is not any universal metric to measure production yet there are many different measures which combined can give a fair picture. There is not enough with a number of, any, metrics either as it is important to know what is measured and what is left out.

3.4.1 Overall Equipment Efficiency (OEE) [35]

A time based metric based on three parts: availability, performance, and quality, in percentage, where OEE is the result from multiplying the three, see Equation I.

Equation I

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

Where:

- Availability, see A in Figure 9, is planned runtime divided by available working time. Set-up, planned maintenance, and major break-downs affect this quota. Available working time is all the time that the machine could be running according to schedule. Staff breaks are for instance excluded.
- Performance, see P in Figure 9, is actual runtime divided by planned runtime. Machine idle time, minor break-downs, short material refill stops, and reduced speed affect this quota.
- Quality, see Q in Figure 9, is actual value adding time (time producing something that the customer want to pay for) divided by actual runtime. Defect products are affecting this quota.

[35] Bellgran. Säfsten. *Produktionsutveckling*. (2005) Pg. 369-372

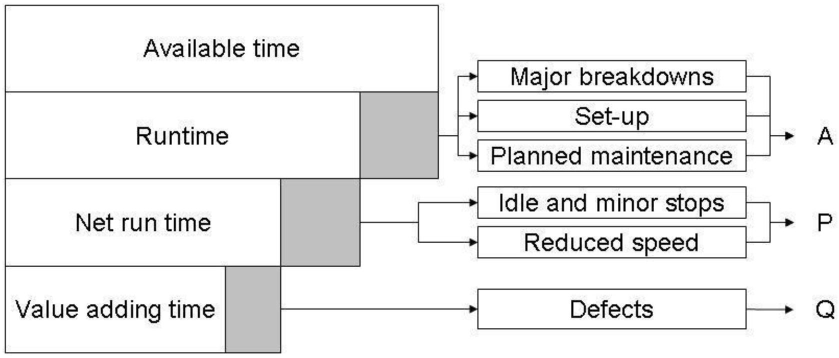


Figure 9. Time loss in availability (A), Performance (P) and Quality (Q).

The requirement in order to be able to win the Japanese award in total productivity is an OEE of at least 85% (for example 90% availability, 95% in performance, and 99% in quality). This means maximum one hour of set-up, maintenance, and major break-downs in one regular eight hour shift and still 99% of the products have to be approved, the first time. Even though the aim should be high a descent OEE, as first, can be to use the individual best availability, performance, and quality from a number of samples.

In order to reach maximum OEE all waste has to be minimized. OEE has the advantages of showing waste and waste reduction potential, as the parts are separated in three. Further the metric is easy to compare between factories and nations as it is not dependent of currencies. A weakness of the metric is that it is not an incitement to increase production speed nor does it deal with the number of operators required. Hence it is important to use more than one measure.

4 Empirics

Studies are done at three different companies; The Absolut Company, Carlsberg Breweries, and Tetra Pak Packaging Solutions. The Absolut Company has recently built a new filling line in Åhus. The brewing industry is well known for its large material flows and Carlsberg is one of the world largest brewing groups.

4.1 The Absolut Company, Åhus[36]

Absolut vodka is the fourth largest international premium spirits in the world, avaible in 126 markets, and origins from 1897 when Lars Olsson Smith introduced it under the name "Absolut Rent Brännvin". Absoult Vodka was owned by the Swedish government, through V&S group, for many years but was sold to Pernod Ricard holding company July 2008. "Brand owner" The Absolut Company has been formed within Pernod Ricard holding company in order to take responsibility for the brand Absolut.[37]

About 100 million liters of Absolut Vodka was sold 2007 and every bottle is produced in Åhus, southern Sweden. Sales have increased rapidly since the export began 1979.[38]

4.1.1 Håkan Nilsson

Director, manages all bigger projects in the Absolut Company. Has worked within the company for twenty-three years and had the overall responsibility while establishing the Absolut Satellit facility in Åhus. Before he has developed and established five production lines, at the old factory in Åhus.

4.1.2 Absolut Satellit, Åhus

The Absolut Satellit factory opened in december 2007. This factory along with the factory in central Åhus are the only bottling facilities within the company. The purpose of the factory is primary strategic risk diversification as well as increased production. Previously Absolut where dependent of one facility but now the have two which is good in case of emergency, for instance fire. Satellit is primarily constructed to be able to produce the few most crucial products in the Absolut product line.

Currently there is only one bottling line installed but space is left out for one additional line, hence half of the facility is empty. Blending and shipping is, as well, prepared for two further lines, which can be installed with an, already

[36] Based on observations at the the Satelit and an interview with Håkan Nilsson 20081105.
[37] http://www.absolut.com/about/qna 2008-11-26
[38] Absolut facts: Reachable through: www.abslut.com 2008-11-26

prepared for, extension at the current site. This involves a mirror of the current bottling facility, with shared goods reception, blending, and shipment facilities. Exterior infrastructure is already prepared for this extension. When additional lines are implemented this will be pretty much independent of the others, in terms of operators and equipment.

The factory is made to achieve a great flow through and around the complete facility. Crossing flows are minimized; to achieve this sometimes the flows are separated vertically.

The following numbers refers to the numbers in Figure 10. The product, spirit, has a separate arrival location and storage (3), due to legal restrictions, since it is extremely flammable. It is then diluted. The other raw material, bottles, caps, labels, sealing, and cardboard arrive to the arrival section inside the facility (1). A small amount of raw materials is stored (2). The bottles are automatically taken of the pallet (4) and sent into the production line, some bottle types have a cover, if that is the case it is removed in (5). The rest of the material is gathered by the operators, when needed. The order of the bottles is kept throughout the whole line. First off the bottles enter an accumulator (6), which by default keeps bottles for around 3.5 minutes of downstream production. Then come the combined dishwasher, filler and cap applicator (7) and then another accumulator (8), with the same specifications as the previously one. Then the bottles enter the bottleneck of the line; the combined labeler, sealer and medallion applicator (9) this machine sets the pace for the others. Downstream is first one accumulator (10), empty by default, so that the bottleneck can work it up in case of downstream failure. Then a cardboard packer (11) puts six or nine bottles in a case which is then elevated to cross the other flow, accumulated on the conveyer if necessary (12) and palletized (13). Then the pallets are stored (14) until one complete truck can be filled (15), which moves them to the storage at Åhus port. The bottles should never be touched by an operator, everything I supposed to be automatic. Operators just load additional material and repair the system if something breaks down.

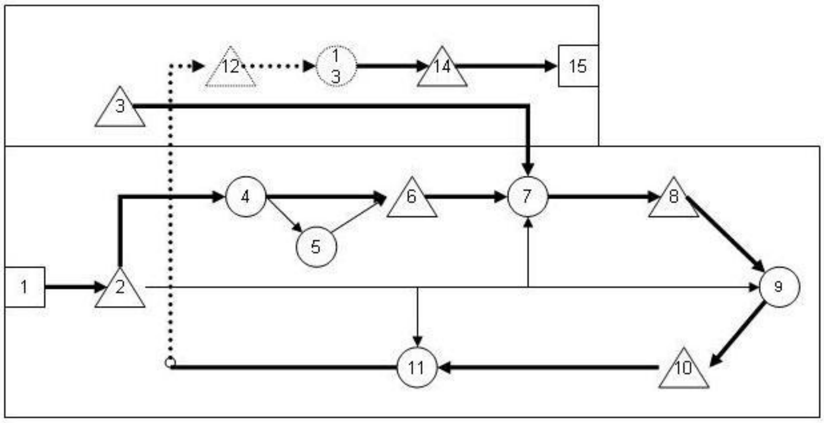


Figure 10. Sketch of the flows and processes at the bottling factory Satellit in Åhus.

As notable in Figure 10 the layout looks a lot like a U, with all operators located in the middle, for easy flow and good access to the machines. The palletizer (13) is on the other hand separated from the U. A straight line would be optimal, since there is one operator at each operation, but that would give a troublesome architecture as the building would be extremely long and thin, the distance that the secondary materials have to be moved is also very long. This layout gives an ease of secondary material, the distance is not that long from the raw material storage to the operations. It is also possible for the operators to help each other, in case of stoppage.

The layout is centralized around the operator and the machines have one operator side facing into the U, so all machines can be managed and refilled from inside the U. Hardly ever is something managed from outside the U. There is an automatic quality control after each step, controlling the task just preformed for instance checking that the cap is set properly. Defect products are taken away immediately so no extra work has to be done on a defect product.

Wasted product is analyzed and, if possible, sent back to the distillery where it is distilled once more and sold as non premium vodka.

4.2 Carlsberg Breweries A/S[39]

Carlsberg was founded 1847 by J.C. Jacobsen and is today one of the top five brewing groups in the world due to acquisitions and merges, for instance the merge with rival and Danish brewery Tuborg in 1970. Carlsberg primary operates in mature markets in Western Europe but is also operating on growing markets in Eastern Europe and Asia. Carlsberg Breweries A/S was

[39] http://www.carlsberggroup.com 2009-01-26

formed 2001 and is since 2005 owned completely by Carlsberg A/S, the parent company of the group, which is listed on OMX Nordic. The largest shareholder is Carlsberg Foundation, established by Carlsberg original founder.

4.2.1 Karl Hattesen

Senior Investment Manager. Evaluates which projects Carlsberg should invest in and determines if the plant plan is good enough, regarding for instance the plant layout.

4.2.2 Production Process

The production is divided into five steps, raw material handling, brewhouse, fermenting and beer processing, and filling. The filling line consists of a depalletiser (7), decrater (8), bottle washer (9), bottle inspection (10), filling and capping machine (11), filling inspection (12), bottle tunnel pasteurizer (13), labeler and coder (14), crater (15) and palletizer (16). Empty goods is stored (2), product and additional material storage (1), crates and pallets are stored in (3) and (4), crates are washed in (17), all inspections rejects bottles to (5). See Figure 11.

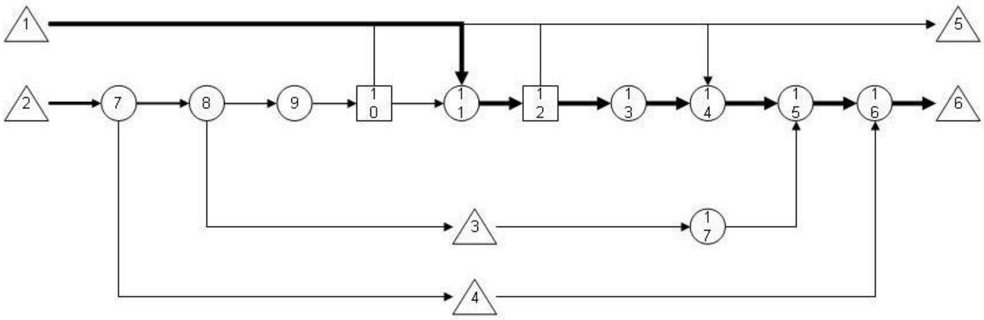


Figure 11. Flowchart of Carlsberg filling line

As the filling machine is the bottleneck of the line bottles are accumulated prior to it and, in case of downstream stops, after the accumulator.

Different types of bottles are used, both glass and plastic and both new and re-used, depending on product and market.

4.2.3 Organization

Every brewery presents their investment needs to the central Carlsberg organization, where they present a list of project initiatives and a justification of the needs. The projects that are approved will then develop a technical clarification consisting of, among other things, the complete plant layout. The layout work is done by the market companies but have to be approved by the central organization.

Carlsberg buy all their production equipment from external suppliers.

4.2.4 Design Process

Each market company, for instance Carlsberg Sweden, that wants to invest, presents a business case to Carlsberg Group. They present the reason for the investment along with capital expenditures and operational expenditures. Then Carlsberg judges if they are getting any money for the investment. If they do they will then come up with a proposal for a layout. This layout is then approved by Carlsberg.

Based on the needed capacity in the plant the area requirements are calculated for each of the steps in the production process. An additional space is also calculated for future extensions. A blockchart is constructed and each block is fitted to a yard and every block is proportional to the actual required space. These blocks are fitted into the yard, in a modular layout, if possible according to a marketing perspective. The brew house is identified to be good in a marketing perspective.

Material flows are also important, and the aim is not to have any crossing flows at the site. A sequel phase is always planned for, where the facility is extended due to a long term development plan. These extensions are however never invested in, other than in the land required.

Following are the top five priorities for Carlsberg when building a new facility.

1. Esthetics, Brew house is the showcase.
2. Prepare for extension.
3. Traffic.
4. Logistics.
5. Energy distribution.

Three different filling line layout archetypes, including returning equipment, are used I, Z, or U. The aim is to keep reused bottles and crates separated from the filled bottles. In the I-layout the dirty bottles enter on one side, go through the straight line, and then leaves filled at the other side of the building. The Z layout has a turn inside, but the bottles enter and leave on separate sides. Finally the U-layout, where the bottles enter and leave on the same side.

4.2.5 Considerations

- **Capacity**: every project is started with a forecast of the capacity needed in the facility. From this, required areas are calculated.

- **Capital Expenditures:** All cost related to the investment in the facility.

- **Operational Expenditures:** All cost related to operating the facility.

- **Hygiene and work environment:** As Carlsberg are in the food industry hygiene is important. Important issues are to keep dirty bottle flows separated from the product and clean bottles. This is done by separating the flows physically in the building.

  Carlsberg also have a concept they call *island design* with the aim of dividing all machines in clean and tidy zones, where dirt from one machine won't disturb other machines. If a bottle breaks that area is automatically rinsed and drains surrounding the area. The "island" is also made so that the operator can serve the machine from outside, aiding the goal to keep the work environment clean and light. Keeping the operator outside of the wet area prevents the operators from slipping on wet floor.

4.2.6 Product Waste

Carlsberg reuse wasted products if it is possible. These products are sent back to the fermenting, where they are reprocessed and put back in to the production.

4.2.7 Key Performance Indicators

Carlsberg uses ISO-standard key performance indicators of the production. One measure is line dependent performance, where the filler is the bottleneck and there for the machine the line performance is depending on. The independent part, which is left out, is for instance stops caused by the operators. Line performance is the measure Carlsberg uses to validate that the layout is satisfying.

Carlsberg also measures utilization factor, where actual runtime is compared to available runtime. This measure is typically around 40-50%, this low number is for most caused by set-up time.

4.3 Tetra Pak

Tetra Pak packaging solutions mainly provide the market with packaging solutions for liquid foods. Providing filling machines and necessary distributions equipment as conveyers, straw applicators, cap applicators, film wrappers, and cardboard packers as well as packaging material and cardboard, straws and caps Tetra Pak is a single source of multi-product solutions with matching equipment at every stage. To be able to fulfill promised line performance Tetra Pak is involved in the layout design process.

4.3.1 Implementation Process

Tetra Pak has a documented process to implement the layout at a customer site with 5 steps, see Figure 12.

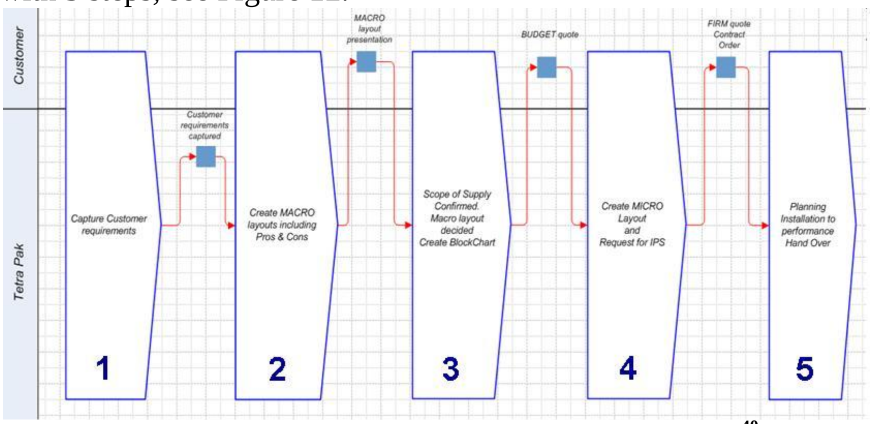


Figure 12. Layout implementation process.[40]

1. Capture customer requirements
2. Macro layout
3. Decide macro layout, create block chart
4. Micro layout
5. Implementation

4.3.2 Layout Archetypes

Tetra Pak has four different pre defined concept archetype layouts; straight, square, groups, and compact, suitable for different customer requirements, see Figure 13 - Figure 16. Five different considerations: the number of operators needed, investment cost, space utilization, line flexibility, and expandability are evaluated for each layout archetype with a score of: one - poor, three - good, and six - excellent. As you would expect a low number of operators and a low investment cost give a high score while a high value on the other three gives a high score.

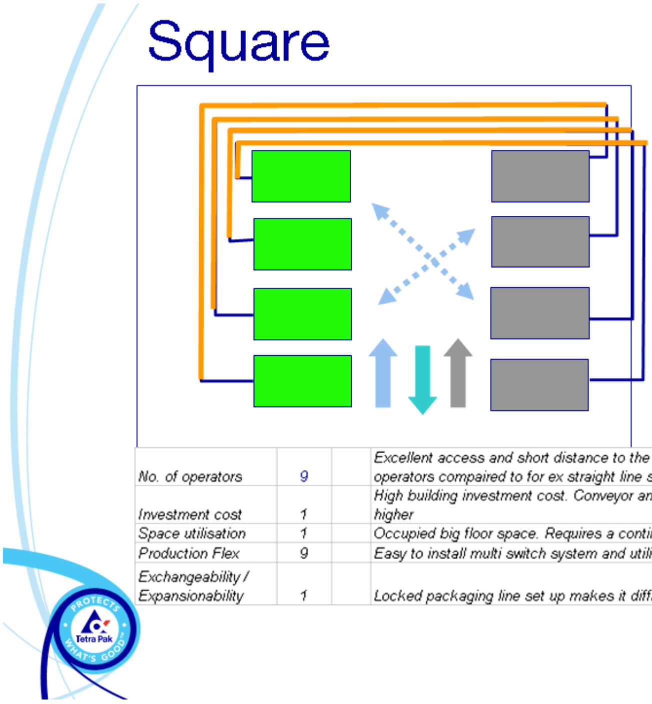
- **Operator square archetype**: The filling line layout has the operators in the center. Minimizing the operators walking distances.

[40] Tetra Pak internal.

- **Group archetype**: Same type of filling machines and distribution machines are grouped together.

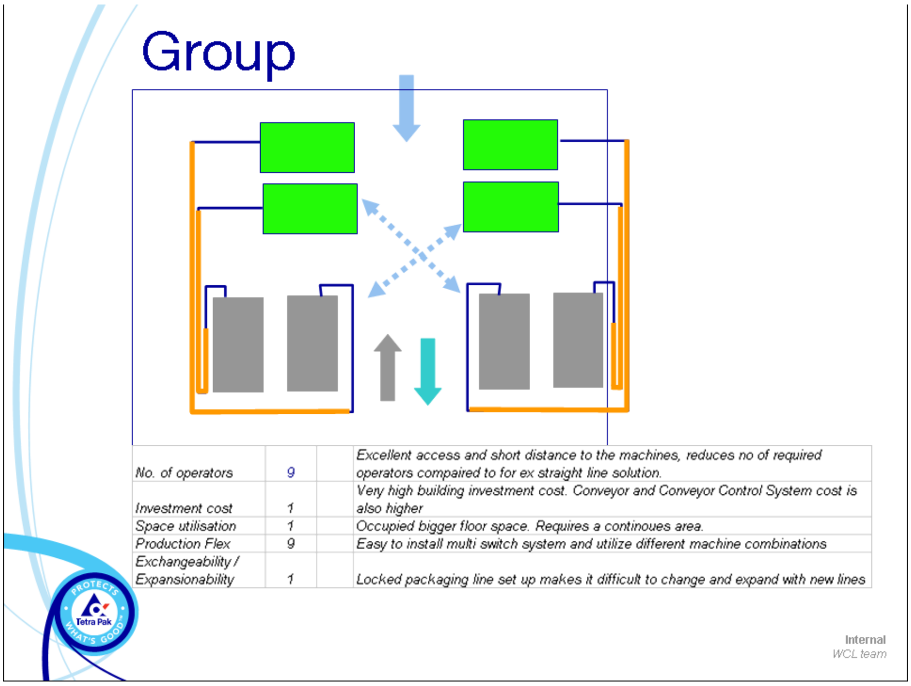
- **Straight line archetype**: Equipment in the filling line is positioned in a straight line. Filling lines are placed parallel to each other.

- **Compact archetype**: Minimum of footprint.



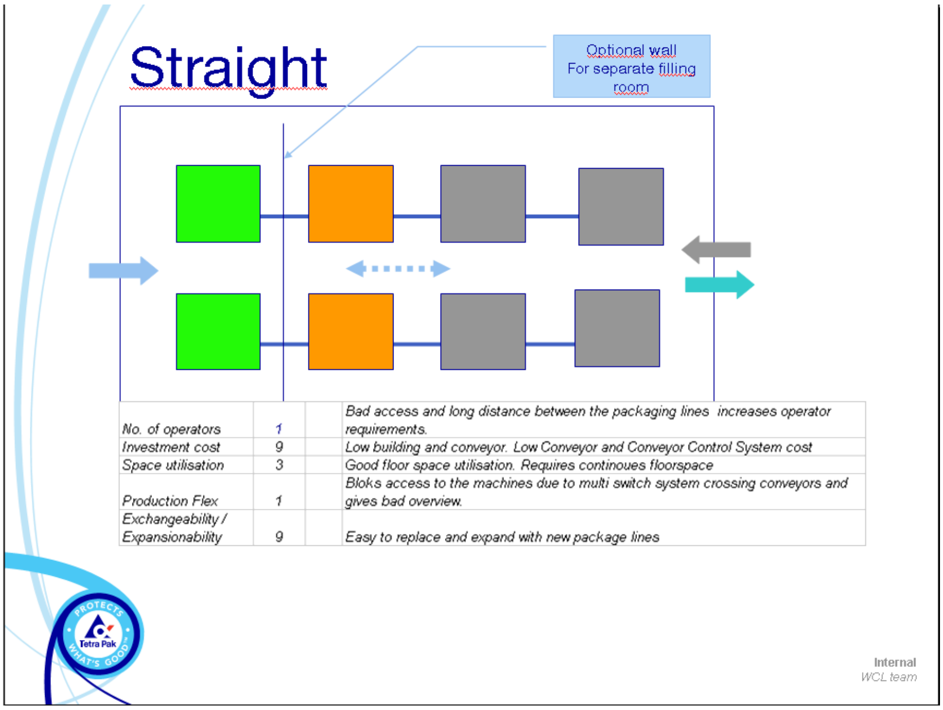
No. of operators	9	Excellent access and short distance to the machines, reduces no of required operators compaired to for ex straight line solution.
Investment cost	1	High building investment cost. Conveyor and Conveyor Control System cost is also higher
Space utilisation	1	Occupied big floor space. Requires a continoues area.
Production Flex	9	Easy to install multi switch system and utilize different machine combinations
Exchangeability / Expansionability	1	Locked packaging line set up makes it difficult to change and expand with new lines

Figure 13. Square



No. of operators	9	Excellent access and short distance to the machines, reduces no of required operators compaired to for ex straight line solution.
Investment cost	1	Very high building investment cost. Conveyor and Conveyor Control System cost is also higher
Space utilisation	1	Occupied bigger floor space. Requires a continoues area.
Production Flex	9	Easy to install multi switch system and utilize different machine combinations
Exchangeability / Expansionability	1	Locked packaging line set up makes it difficult to change and expand with new lines

Figure 14. Group



No. of operators	1	Bad access and long distance between the packaging lines increases operator requirements.
Investment cost	9	Low building and conveyor. Low Conveyor and Conveyor Control System cost
Space utilisation	3	Good floor space utilisation. Requires continoues floorspace
Production Flex	1	Bloks access to the machines due to multi switch system crossing conveyors and gives bad overview.
Exchangeability / Expansionability	9	Easy to replace and expand with new package lines

Figure 15. Straight

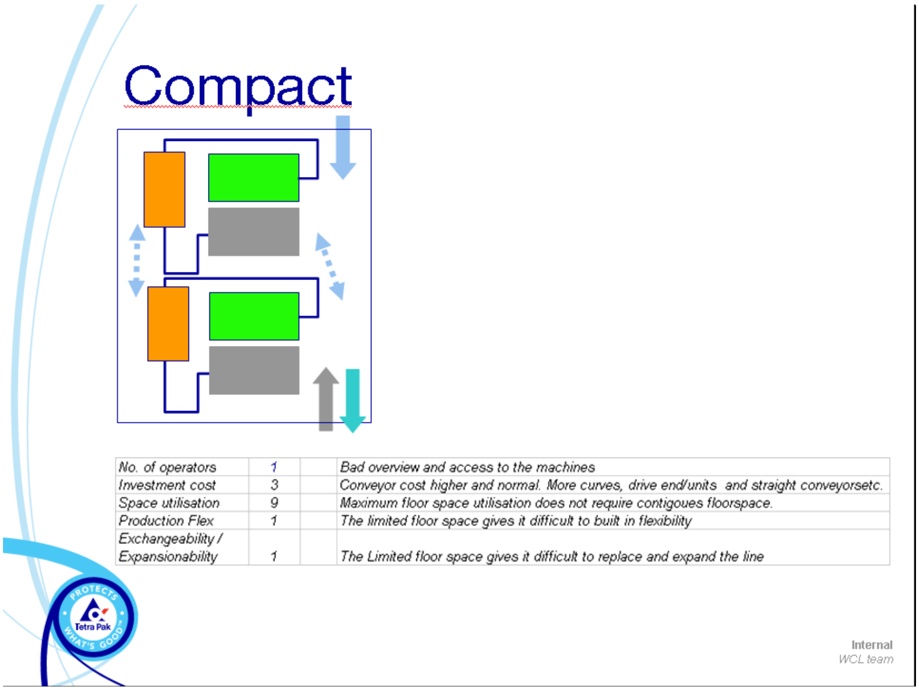


Figure 16. Compact.

4.3.3 Assessment

Customer requirements are captured through an assessment list. Tetra Pak determines customer top priorities in cooperation with the customer and then fill in the weight, see Table 2, with a one representing low priority, two medium priority, and three high priority. The weight is then multiplied with the score of the different layout archetypes summed up. Showing what layout archetype fits the customer desire the best.

Table 2. Assessment list and determination.

		Layout				Final score			
Assessment	**Weight**	Sq	G	St	C	Sq	G	St	C
Number of operators		6	6	1	1				
Investment cost		1	1	6	3				
Space utilization		1	1	3	6				
Line flexibility		6	6	1	1				
Expandability		1	1	6	1				
					Total:				

4.3.4 Macro Design

A block chart of selected archetype is designed and a budget is proposed. The archetype is only a concept and the macro layout will depend on which equipment that is involved in the line, furthermore many layouts are not greenfield sites. When expanding or upgrading a site the existing lines have to be taken in consideration. The block chart is a more detailed sketch of the layout archetype with the actual set of machines included. A description of why the macro layout meets the customer requirements is given and the layout is chosen in co-operation with the customer.

To reach the performance target, the Tetra Pak packaging line requires a minimum of two minutes package accumulation placed directly after the filling machine. Line Mean Mechanical Efficiency, LMME, is direct dependent of filling machine stop time and by using a package accumulator, it is possible to avoid stops of the filling machine caused by downstream distribution equipment stoppage. Measurements made on different Tetra Pak lines, shows that 90% of all downstream stops can be fixed within two minutes. To be able to empty the accumulator during production, downstream equipment requires an over capacity of at least 20%.

4.3.5 Micro Design

Is the detail engineering required to fully define the filling line requirements, including conveyor components, like drive/End units, package traps, line control etc. and also to secure the implementation of proper design requirements for each equipment in the filling line.

In order to save engineering time and promote Tetra Pak preferred solutions, Tetra Pak has developed a number of standard micro layouts, with different equipment combinations in the line.

Based on the package specification, a number of standard layouts are identified. A standard layout with equipment fitting the package specification is chosen as different package specification requires different distribution equipment. These pre defined lines with Tetra Pak equipment are made with the aim to find the best location of all packaging line components using preferred distribution solutions that preserves the package appearance and using minimum of conveyors within the existing design criteria. Standard layouts are pre-made CAD-drawings ready for the Tetra Pak Market Company project engineer to download and fit in at the local plant drawing. The point is that the customer can move the components around to fit it at the plant, but should not change the relative position of the equipment and at the same time maintain the standard layout design criteria. It is possible to increase the distance between the machines, e.g. longer conveyers than for the standard layout, but a decrease of conveyer length will affect line performance and moreover every machine needs in case of downstream stoppage, a required length of conveyers downstream to be able to place packages in process on.

The standard layout also aims to fulfill the line efficiency and to preserve the appearance of the packages. Package appearance is dependent of hose-brakes, pressure from other packages in long queues. The package appearance that should be maintained is the straight and sharp edges, flat top and panels, sealed flaps, and grip firmness. About 20% of the package appearance defects can be derived to line design, by excessive queuing with the packages pushing each other, hose brakes squeezing the package, and idle running chains friction on the package bottom.

4.3.6 Implementation

A layout book is created containing all necessary installation drawings for instance: cables, conveyer motors, compressed air, steam, and electricity.

4.3.7 Line Performance

Line performance is defined as Line efficiency (LE) in Equation II below. However due to difficulties in measuring the LE accurately Tetra Pak uses Line Mechanical Machine Efficiency (LMME), see Equation III below, as a measure for line performance.

Equation II

$$\text{LE} = \frac{\text{Number of Approved Packages}}{\text{Production Time} * \text{Nominal Capacity}}$$

Equation III

$$\text{LMME} = \frac{\text{Production Time}}{\text{Production Time} + \text{Filling Machine Stop Time}}$$

A good line performance is reached by minimizing:

- **Stop Time**
  - Waiting time
  - Restoration time

- **Waste of package and product**
  - Package jam waste
  - Start/Stop waste

- **Transportation time**
  - Operators
  - Service
  - Packaging material
  - Secondary packaging material

4.3.8 Follow Up

Tetra Pak make a follow up the implemented line by making sure it reaches the performance target before hand over, this is done by measuring the LMME once the commercial production is started. A survey is also made with the customer, answering the questions how well the layout design meets the customer requirements and how well requirements where captured. Customers can also leave comments regarding how the layout could have been better.

5 Analysis

In this chapter a short analysis of how the companies look at the layout, what they share and how they differ. Followed is the author definition of a World Class Layout and how it can be developed including the parameters governing the layouts and how the layout can be measured.

5.1 The Absolute Company

The Absolute Companies first consideration is to achieve a optimal flow at the complete plant. To have an overall perspective of the plant is good as sub-optimization can be devastating. If trucks can't load and unload it does not matter how many products the factory can produce per hour.

The absolute company has built the operations around the operators, so that they can help each other and seldom have to cross the production flow and access the machines easily. This layout contributes with a good visual overview and the opportunity for the operators to solve problems together. All crossing flows are aimed to be minimized both production and operator flows. The production is vertically separated, which includes moving the products vertically and that is, by Toyota, identified as waste. However it can sometimes be worth to utilize conveyer transportation to improve operator accessibility.

Conveyers are somewhat long and buffers or accumulation capacity is kept between every operation. As mentioned in the background of the thesis this is common for the packaging industry yet the aim must be to reduce accumulation and conveyer length as much as possible, to drive operation improvement.

To automatically inspect every product after each production step and take away all defect products is good. This way no time, and money, will be spent on products that cannot be sold anyway. The operations with the worst quality problems will also be visualized if the defect products are taken away after each operation. Thus it will be obvious which operations are in need of improvement. To re-distill defect product and sell it is a way to shrink costs of poor quality, however defects is a cost and the aim is to eliminate them.

The Absolute Company have prepared well for future expansion. As Absolute can double their capacity in the existing building, as half of the building is empty, the initial investment is also unnecessary large. The Absolute Company has also bought land to be able to build an, to the existing, identical house. The empty space is waste at the same time as a world class manufacturer has to have a long time-horizon in all investments and look to its long term return. To build a factory that is to small and have to be moved out of after just a couple of years is not a good investment either.

5.2 Carlsberg Breweries A/S

Carlsberg Breweries base is the planned capacity need in the factory. This is according to the first step of SLP and one have to think it is safe to assume that the production analysis is done as well, but perhaps not as explicit as in SLP.

Carlsberg share the overall goal, to minimize the number of crossing flows at the complete site, with Absolute. Carlsberg also have a plan for future expansion but always tries to keep the investments in future expansion as low as possible. Buying land is however seen as a minimum.

Capital expenditures and operational expenditures are good metrics to compare different layouts with each other. How much it cost to build and how much it cost to run. These metrics are among the most interesting design criteria for the layout and will also be used in my further analysis.

For Carlsberg it is important to have effective cleaning equipment. As the production rates are very high bottles breaks. This is once again related to the issues that are common for packaging lines, a production speed so high that quality suffers. The aim must of course be not to have any breaking bottles in the production process, as it makes the surrounding wet and dirty. To avoid these problems Carlsberg have drains around all machines and automatically splashes them with water if necessary. The idea of surrounding the machines with drains is however a good idea yet broken bottles should be avoided.

To plan the complete plant in order to place the brew house so it looks good for people passing outside the factory does not make sense for a engineer. The other design parameters are more or less aligned with the other companies and the overall goal to avoid crossing flows at the complete plant.

Utilization factor of about 50% is again a sign that the packaging industry focuses more on top speed of the machines than the actual approved bottles or packages. This is perhaps because filling equipment is sold pretty much only based on production-rate.

5.3 Tetra Pak

Tetra Pak have a clear process to develop the layout and, pretty much, uses SLP. The documented, and established, process is very good to be able to make sure the work is done properly, and in the same way, every time.

Tetra Pak differs some from the other companies as a new layout is developed for every sale. Carlsberg Breweries is the parent company of the Carlsberg market companies around the globe and also develops new layouts somewhat often. The Absolute Company is a rather small company and does not develop new layouts that often. As Tetra Pak repeats this process with every sale they have four principle, macro, layouts which are used to fit different customer archetypes. This has the benefit of not doing the same thing over and over again but to do it right one time. Parts of SLP should not be skipped but knowledge from earlier work must be utilized.

The layout is evaluated in the same way as in SLP which Tetra Pak is alone of the companies to do. The criteria to evaluate the layout can be discussed as well as the number of criteria used. Many criteria give a fuller picture but have the downside that it means more work. Later in this chapter a suggestion of parameters will be presented.

After installation and hand-over of a production line a survey for customer feed-back is handed out. To collect information from the customer is essential to be able to improve the next layout. Feed-back from many customers also shows issues that many customers experience and is more urgent to do something about. The other companies do not have the same possibility to gather feed-back from customers. The Absolute Company has no possibility but Carlsberg can do it from the market companies. It is important that the one filling in the survey understands the production completely and have hands on experience from it to be able to see all pros and cons with the layout and how well it fits the customer.

5.4 World Class Layout

Based on the principles of waste reduction gained earlier and gathered theory on production layouts a definition of what a world class layout contains will be presented.

First of all a world-class layout have to be customer orientated. The customer however can be many but the ones operating in the layout is one customer, the one paying for the machines another. The overall goal is, of course, to produce as many approved products as possible at the least effort.

5.4.1 Design Method

Systematic layout planning is the established method to design a production layout. One shortening of SLP is that it is primary developed to go through the process occasionally. For companies producing equipment the steps will have to be repeated for every single customer.

5.5 *World Class Systematic Layout Planning*

Systematic Layout Planning is a proven method and is done as presented in chapter 3.2 yet an addition is put to the evaluation part.

5.5.1 Evaluation

It is important that the customers' requirements regarding the layout are captured in the layout evaluation part. The different layout alternatives should be presented to the customer with an explanation, and measure, of why one layout is better than another. This explanation is based on facts. The criteria that are identified to influence the layout is presented below with a short explanation of how it influences the layout and how it can be measured.

The following parameters have been identified based on the theory from chapter 3 and the company studies in chapter 4. The parameters have been more or less common for all the companies and the theory study but not always explicit. Below is a proposal of the parameters that is found to be affecting the layout.

Capital expenditures

- **Investment:** The machines are chosen based on the product and production analysis in SLP and is a prerequisite for the layout planning. One design parameter is the size of the investment. His can be measured by the actual price for the equipment or complete plant, which is the exact figure. But to simplify the comparison between layouts and given that the machines are identical the investment can be compared by comparing the conveyer length. Because given a set of machines the only thing influencing the equipment cost is the conveyer length. Short conveyers' means less investment cost and faster lead time. All conveyers need to be justified either by machine technical requirements or gains in other areas, for instance less manual handling. Ideally conveyers would not be used at all but this means that every package type would need a special type of machine. Given that the machines are identical the only thing differing between two layouts regarding the equipment investment cost is the length of the conveyers. By measuring the length of the conveyers a fact-based comparison can be done between layouts.

- **Space utilization:** If only the primary flow would be taken in consider this part would be proportional to the number of conveyers. However the need of secondary material handling and passage affects these criteria.

The utilization of floor space can be measured by dividing the total floor space in a facility divided by the number of production lines installed in the facility or given a set of machines the required floor space can be compared between the layouts.

Operational expenditures

- **Material handling**: In a continuous production flow the primary material flow is generally very big, and the material handling equipment is constructed to make the handling speed high, for instance with conveyers. The secondary material flows are not always that optimized and is an area for possible improvements, especially as the handling is not that specialized for the purpose.

  To be able to compare the primary and secondary flow the speed of the transportation utility is used to normalize the values. The measure used is pallet meters per hour at a certain speed. The target of this value is of course low and is reached by have as short production line as possible and all operations close to the storage. This is also illustrated in the relationship analysis (see chapter 3.2.4).

- **Operator accessibility:** The number of operators is set by the accessibility of the machines. If machines break down seldom and are easy accessed by operators one operator can maintain more than one machine otherwise the operators would have much waiting time. Still the number of operators has to be balanced so that the machines do not have to wait, for an operator, which also would be waste. The accessibility is also important for the secondary material handling.

  Proposed measure is operator transportation meters or minutes per hour as it gives the possibility to evaluate how good the operator access is in different layouts. It can be an advantage to use some sort of simulation software to gather this kind of data. Otherwise an estimation of how often the equipment need operator attention can be used.

Functionality

- **Expandability:** When investing in a facility you do want it to meet the customer needs today, as well as tomorrow. Preparations for further investments in the future can be done to ease an expansion if the demand is expected to increase. This can be done by buying land so the facility can be extended, roads and fences can be built so it is easy to expand capacity. Lean production always aims at long term decision basis, so there can be a good idea to invest in a larger facility than needed, despite the fact that the extra space will be considered as waste for some years. One important note is that there is no point of changing the initial layout when the facility expands. The initial production layout should have as much space as it requires already from the beginning and space for expansion should be left free. Hence the metric is number of prepared for lines or number of prepared for lines divided by installed lines.

- **Line Flexibility**: A flexible line could be used for different products, based on the customer requirements. It is also supposed to change product type quick. In line layouts products tend to be of low value and produced in big batches. Metric to measure line flexibility is number of product types that can be produced per line. A by-pass machine is one way to multipurpose a line.

- **Crossing Material Flows:** A good layout facilities good and easy material supply. If paths where the operator is supposed to transport material congestions can stop the material flow. The goal should therefore be to minimize the number of crossing material flows.

Work environment

- **Work environment:** Operators should have attractive and meaningful assignments. Physical and repetitive tasks should therefore be automated as far as possible. It is also important that the environment do not danger the health of the operator, possible risks in traffic, chemicals, noise, air pollution, and slippery floor. If any form of vehicle share space with operators it is important that the flows do not cross or are clearly marked.

  The environment should be easy to work in, proper lighted and avoiding an isolated localization of the operators. Noise and vibrations are experienced as annoying, even at healthy levels, and should be kept as low as possible. Everything should be in its, marked, place and the work environment should be clean and bright.

- **Visual overview:** One of the key concepts in Lean production is visualization. It is important to have a visual material flow that always shows the effect of actions. All flows should be easy to overview showing the operator how important he is and making him feel committed to line performance. Operators depending on each other should be able to communicate. Visual contact between the operations following each other in the layout.

Hygiene:

- Easy to clean
- Surrounded by drains
- Possibility to separate the different operation

The hygiene in food industry should never be compromised. All areas in contact with the food must be proper cleaned. All floor and other areas that can be dirty with spill must be easy to clean. For instance will milk get sour and smell if it is not cleaned and it will also be slippery, a health risk for the operators.

While packing food it is necessary to have a production area that is right temperature and a controlled atmosphere. To be able to separate, for instance, the filling machine from the other machines will in this case be a way of making it easier to keep the right temperature and atmosphere conditions right.

5.5.2 Layout Follow Up

The follow-up of the layout, to be able to make the next one even better, and continuously improve the layouts are the author main addition to Muthers SLP.

As the operators are the ones working in the production layout the operators also have to give their feed-back on the layout. This is extra important, to gather the customers thoughts about the layout, for companies that, like Tetra Pak, design and deliver layouts continuously. Feed-back ought to be gathered and presented, preferably in a pareto-chart, continuously. The biggest issues can be identified and of course fixed.

5.5.3 Key Performance Indicators

The packaging industries have historically been focusing on how fast a machine can produce rather than how many packages that actually gets to be approved in the end.
Carlsberg measures utilization factor, which can be compared to the availability part in Overall Equipment Efficiency (see OEE on page 24) and line dependent performance. The downside with only measuring line dependent performance is that you hide a great improvement potential. The quality part is also left out. The Absolute Company measures delivered bottles per day, shift or hour. This does actually measure the exact same thing as OEE but you are not able to see which of the areas are in the biggest need of improvement as availability, performance, and quality are bunched into the same. Tetra Pak only measures LMME, which only takes the downtime of the filling machine in consideration. It does not either consider how much of the available time that actually can be used for production.

Overall Equipment Efficiency is identified to be the best practice in performance measure. The only downside is that it requires some effort to gather the required data. The advantage is that it shows improvement potential in the three areas, Availability, Performance, and Quality and only the actual approved products are measured against the total available time.

6 Results

In this chapter the definition of a World Class production line layout is presented, the deign parameters governing the layout, and how the layout can be measured.

6.1 World Class Production Layout

There is no possibility to determine what a world-class layout looks like in the general case, it does depend on the customer preferences and need. It is however possible to say that if the layout is developed through SLP, with focus on customer requirements and needs, all decisions and evaluations are based on facts, and the layout is continuously followed-up and feed-back is gathered from the operators working at the floor a world class layout will be obtained.

By listening to the customer, and operator, and continuously improve the layout according to their feed-back will ultimately generate a world class layout and ensure that World-Class layouts will be delivered in the future.

The packaging industry traditionally has a high focus on the production speed. By using the SMED methodology production time can be freed up and time can be utilized more efficiently. This is a great area of improvement for the complete industry.

6.2 Design Parameters Governing the Layout

The design parameters identified to govern or affect the layout are:

Capital expenditures

- **Investment**
- **Space utilization**

Operational expenditures

- **Material handling**
- **Operator accessibility**
- **Crossing material flows**

Functionality

- **Expandability**
- **Line Flexibility**

Work environment

- **Work environment**
- **Visual overview**

Hygiene:

- **Easy to clean**
- **Surrounded by drains**
- **Possibility to separate the different operations**

6.3 Measuring the Layout

The different design parameters can be measured as presented in Table 3.

Table 3. Metrics for the design parameters.

Parameter		Metric
CAPEX	Equipment investment	Total cost or differing equipment cost per line
	Space utilization	Floor space per line
OPEX	Material handling	Pallet meters per hour
	Operator accessibility	Operator travelling time (or distance) per hour
Function.	Expandability	Prepared lines
	Line flexibility	Product types per line
	Crossing material flows	Number of crossing flows per line
Work Environment	Visual overview	Operator supervisions points per line
Hygiene	Separation of operations	Availability to separate the operations

No exact metrics could be found for the more subjective parameters work-environment and easy to clean. The parameter surrounded by drains is parameter affecting the hygiene in the plant but it is not directly dependent of the macro perspective of the layout.

To measure the performance of the complete plant or lines Overall Equipment Efficiency is suggested to be used as it shows both improvement potential in the areas of availability, performance and quality as well as it focuses on the number of approved products rather than produced products.

6.4 Recommendations to Tetra Pak

Tetra Pak has put down much effort to be able to develop good production layouts. My recommendation is that Tetra Pak keep in the same direction. The design method is SLP and different layouts should be evaluated based on facts. Tetra Pak should follow all steps of SLP but when the method has been run through some times most of the steps will be very quick to go through. There is even a possibility to program computer software or pre-written Excel-documents to fasten up the process. In time I suggest that more layout archetypes is developed and tested against the existing archetypes. Fact-based decisions together with continuous improvements based on operators feed-back will make it possible for Tetra Pak to design and deliver World Class Layouts today and in the future.

6.5 Discussion of Findings

The method to develop a layout has not changed since R. Muther presented SLP in the 1960:ies and what the future will bring only time can tell. But up to this date SLP is still considered the best way to develop a layout. The advantages of the method are of course the systematic and thorough approach. Downsides are that it tends to be a little bit to thorough especially if the method is supposed to be used repeatedly. It is relatively easy to combine the thoughts of Japanese production philosophy with SLP.

It is important to be aware of the fact that these three companies are a small part of a large industry and may not be representative for the complete industry. These three companies are also differing as The Absolut Company is a smaller producer, Carlsberg Breweries consists of a group of producers, spread worldwide, and Tetra Pak provides equipment for packaging companies. Hence there is no possibility to compare the companies with each other but, on the other hand, as they balance each other it gives an overview of the packaging industry. Of course a larger study with a larger number of companies visited would have given a more reliable result perhaps with the possibility to generalize the conclusions even more.

6.6 Future Research Suggestions

This study has been concentrated on the packaging industry and the study has intimated that these issues are handled differently in other industries. It would be interesting to compare the packaging industry with other, comparable industries and see what differs. Possible industries could be pharmaceuticals, automotive industry, and general producing industry.

Another suggestion of future research is to make a complete world class layout assessment list, similar to the ones developed by R. Schoonberger or the criteria list for Malcoml Baldrige National Quality Award but only regarding the layout. Companies should then be able to score according to how well they perform in the different subjects. A 70-80% score out of total should then represent World Class Layout status. The criteria list could be based on how successful companies around the globe handle their production layouts.

Another subject of future research is to make a similar study to this one but make it lager, with more companies. This to make the results more reliable, and see if some company has developed new ideas in these matters. There are always a possibility that someone have developed some new kind of ideas that the academy does not yet know of. It would also be interesting to compare the packaging industry with other industries.

6.7 Conclusion

In order to become and stay a World Class Manufacturer the key is to continuously keep improving. Once the improvements stop competition will sooner or later beat you. The one identified method to develop a layout is R. Muthers *Systematic Layout Planning* including a layout evaluation based on facts in the areas: capital expenditures, operational expenditures, functionality, work environment, and hygiene. Feed-back is then gathered from the customer and the operator working in the layout in order to be able to make the next layout even better. In this layouts will continuously be improved.

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Appendix A

In this appendix a example of an Tetra Pak Layout will be designed according to World Class SLP.

Tetra Pak

In order to continue the analysis of Tetra Paks layouts an example site is used. This is chosen to have four packaging lines with different package sizes, but the same machine set-up. Four lines are in use, two flex-lines producing a Tetra Prisma Aseptic 1000 (ml) square with StreamCap, one speedline producing Tetra Brik Aseptic 1000 (ml) Slimline with SlimCap, and one compact flexline producing Tetra Brik Aseptic 250 (ml) Square with StreamCap. Square and slimline is referring to the shape of the package.

Figure 17. TPA 1000 Sq, TBA 1000 S, and TBA 250 Sq.

Product and Production Analysis:

A production line has one clearly defined primary flow and this is handled by conveyers. The secondary flows are the packaging material, additional material, and operator flow serving the machines. The material flow can be aided by hand stackers, forklifts, or AGV:s. Product size varies from the single package out of the machine, packed into cardboard, and then put on a pallet. Packaging material reels are collected on pallets of four reels per pallet. The three reels, not immediately used, are stored in direct relation to the machine, the same goes for cardboard, which is stapled two meters high per pallet, and caps, stapled four boxes per pallet. Glue and hydrogen peroxide is collected one container at the time.

Figure 18 shows what a packaging line can look like, with the filling machine (1), accumulator (2), cap applicator (3) and cardboard packer (4).

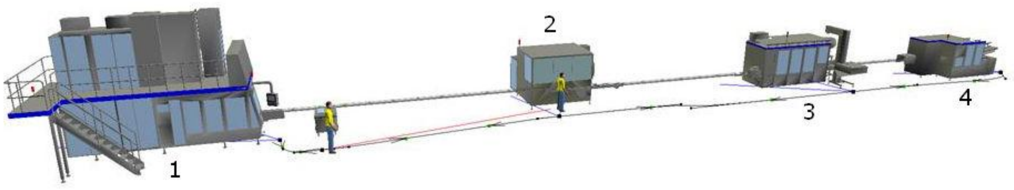


Figure 18. Machinery in example lines.

In the further analysis of the layout an example set up of four lines is used producing packages in different sizes but all with a cap and packed into cardboard. All lines utilize the possibility to accumulate after the filling machine, as it is the bottleneck. The accumulator uses first-in first-out principle and starts to accumulate when downstream equipment stop, because of failure.

The lines, numbered according to Figure 18 where (1) is the product supply and (3) is the finished goods inventory, used in the following analysis are:

- Line 1: Using an A3/Flex filling machine (11) with a capacity of 7 000 TPA 1000 Sq per hour, accumulator helix 30 with 47 m of possible accumulation (12), a StreamCap closure by cap applicator 30 (13), and packed into four mm thick cardboard, two by four by cardboard packer 32 (14).

- Line 2: Identical to the previous line but numbered from (21) to (24).

- Line 3: Utilizing a A3/Compact Flex filling machine (31) with a capacity of 9 000 TBA 250 Sq per hour. Accumulator helix 10 (32) with 30 m of accumulation is used and the packages are closed by cap applicator 30 (33) with StreamCap, and packed three by four in cardboard packer 32 (34).

- Line 4: A speedline with A3/Speed filling machine (41), packing 12 000 TBA 1 000 S per hour. Accumulator helix 30 (42) is used with 120 m of accumulation. Cap used is the SlimCap, with a cap applicator 30, speed (43). And a cardboard packer 30 (4) with packaging patterns two by three.

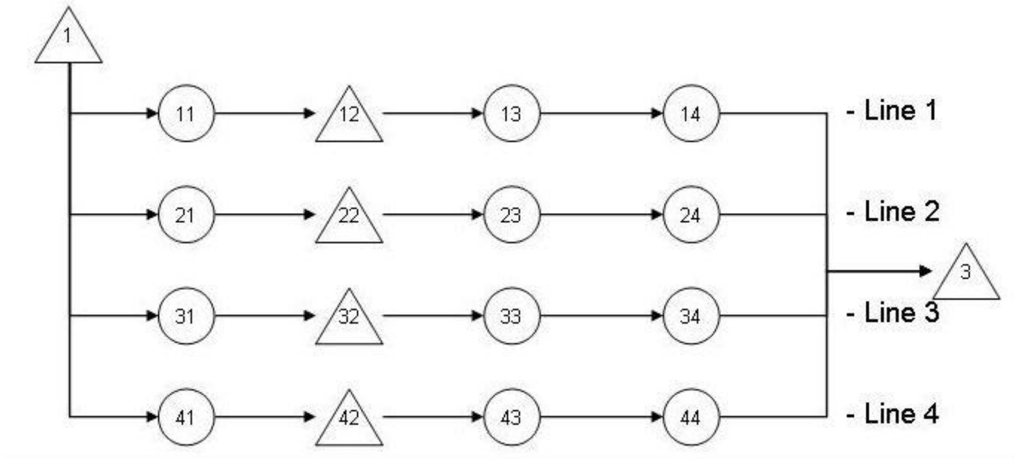


Figure 19. Example packaging lines.

The total gathered data for the different lines is showed in **Fel! Ogiltig självreferens i bokmärke.**.

Machine Type Material Flows

In Table 4 the material need from the storage per machine type (i.e. filling machines or applicators) is showed, as the number of times material has to be collected from the storage per hour. The percentage number shows how often the machine type need replenish from storage in comparison to all machines in the facility. Filling machines need replenishment 2.4 times per hour and the complete facility needs replenishment from the storage 12.5 times per hour. 2.4 divided by 12.5 is 20%. This notation will be used in the following tables (Table 5 -

Line 1	11	A3Flex_A	4.9	14%
	12	ACHx_Flex_A	0.1	0%
	13	CAP30_Flex_A	1.1	3%
	14	CBP32_Flex_A	3.5	10%
Line 2	21	A3Flex_B	4.9	14%
	22	ACHx_Flex_B	0.1	0%
	23	CAP30_Flex_B	1.1	3%
	24	CBP32_Flex_B	3.5	10%
Line 3	31	A3CF	3.4	10%
	32	ACHx_CF	0.1	0%
	33	CAP30_CF	1.0	3%
	34	CBP32_CF	3.1	9%
Line 4	41	A3/Speed	3.5	10%
	42	ACHx_Speed	0.1	0%
	43	CAP30_Speed	1.2	3%
	44	CBP30_Speed	4.1	11%

	Sum	35.5	100%

) as well. The number of times is not dependent of the carrier.

Table 4. Material supply from storage per machine type, loads/h.

FM	2.4	20%
Cap Applicator	1.4	11%
CBP	8.7	69%
Sum	12.5	100%

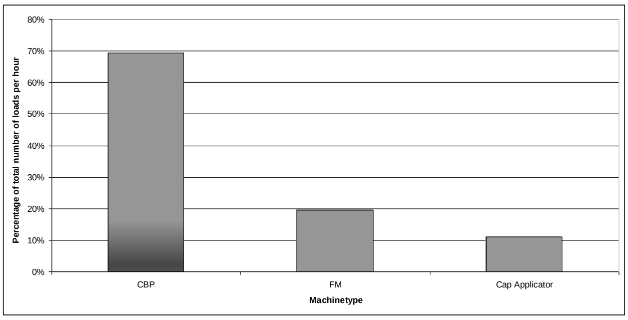


Figure 20. Material supply from storage per machinetype.

Figure 20 visualizes that the larger part of the material supply loads are connected to the cardboard packers. The picture shows that it is more important to facilitate an easy secondary material flow to the cardboard packer than the filling machines and cap applicators.

The filling machine needs, in addition to the packaging material, also the supply of product. The product flow is very large, why the filling machine should be placed in a way enabling connection with the product processing equipment.

Machine Material Flows

In Table 5 the material need from the storage per machine is shown, as the number of times material has to be collected from the storage per hour. The machines that needs the most loads per hour is the CBP 30 speed, yet the need is not more than one time per sixteen minutes. In Figure 21 the percentage of total routes per hour is showed per equipment. 30% of the total pallet need is related to the CBP 30 speed whilst the second most material requiring machine is the CBP 32 in the compact flex-line, with a need of 14% out of the total pallet need.

Table 5. Material supply from storage, loads/h.

Line 1	11	A3Flex_A	0.7	5%
	13	CAP30_Flex_A	0.3	3%
	14	CBP32_Flex_A	1.7	14%

Line 2	21	A3Flex_B	0.7	5%
	23	CAP30_Flex_B	0.3	3%
	24	CBP32_Flex_B	1.7	14%
Line 3	31	A3CF	0.2	2%
	33	CAP30_CF	0.4	3%
	34	CBP32_CF	1.5	12%
Line 4	41	A3/Speed	0.9	7%
	43	CAP30 Spd	0.3	3%
	44	CBP30 Spd	3.7	30%
		Sum	12.5	100%

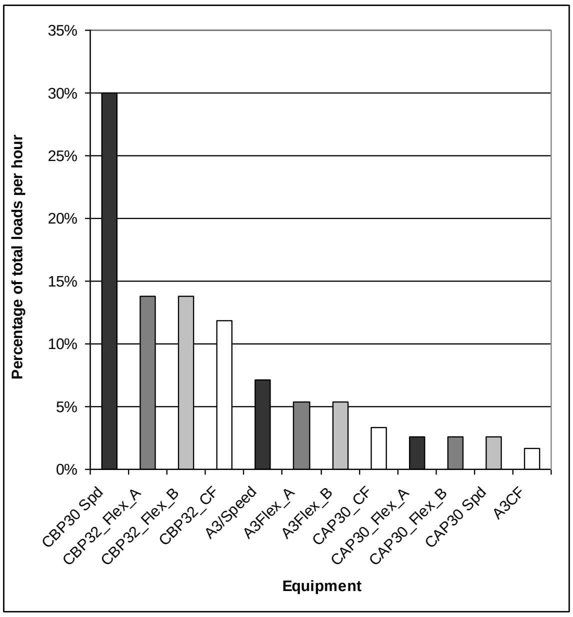


Figure 21. Loads from the storage per machine in percentage of total.

Operator Flows per Machine Type

In Table 6 the needed attention of the different machine types is presented. The figures shows number of times per hour an operator have to serve the machine, including: material refill, machine failure, and product sampling. The product sampling must be carried out two times per hour, per filling machine and one additional time, a given set of production minutes after packaging reel refill, which is making the filling machine the one needing the most attention.

Table 6. Operator attention per machinetype and hour.

FM	16.7	47%
Accumulator	0.3	1%
Cap Applicator	4.4	12%
CBP	14.1	40%
Sum	35.5	100%

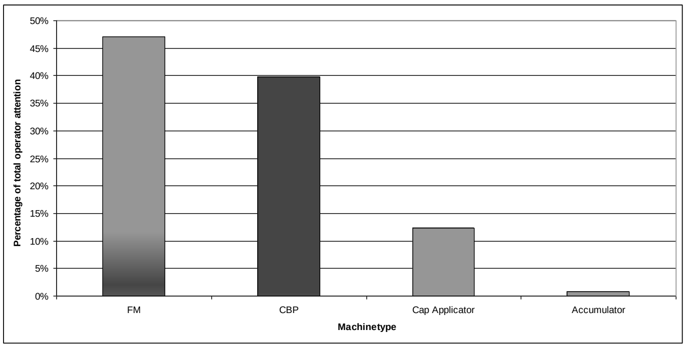


Figure 22. Operator attention per machine type, in percentage.

In Figure 22 the operator attention is visualized in percentage of total operator attention. The figure shows that the filling machines and the cardboard packers need the most attention. The cap applicators need attention in average every fifteenth minute and the accumulators very seldom have to be restored.

Operator Flows per Machine

In addition to the material supply the machines also break down, from time to time. Each time an operator has to serve it. For quality reasons the operator also has to take a sample two times per hour, for analysis in a lab. In Table 7 the equipment operator attention need is shown, including failures, refill of secondary material, and product sample. This is also visualized in Figure 23.

Table 7. Operator attention per equipment.

Line 1	11	A3Flex_A	4.9	14%
	12	ACHx_Flex_A	0.1	0%
	13	CAP30_Flex_A	1.1	3%
	14	CBP32_Flex_A	3.5	10%
Line 2	21	A3Flex_B	4.9	14%
	22	ACHx_Flex_B	0.1	0%
	23	CAP30_Flex_B	1.1	3%
	24	CBP32_Flex_B	3.5	10%
Line 3	31	A3CF	3.4	10%
	32	ACHx_CF	0.1	0%
	33	CAP30_CF	1.0	3%
	34	CBP32_CF	3.1	9%
Line 4	41	A3/Speed	3.5	10%
	42	ACHx_Speed	0.1	0%
	43	CAP30_Speed	1.2	3%
	44	CBP30_Speed	4.1	11%
	Sum		35.5	100%

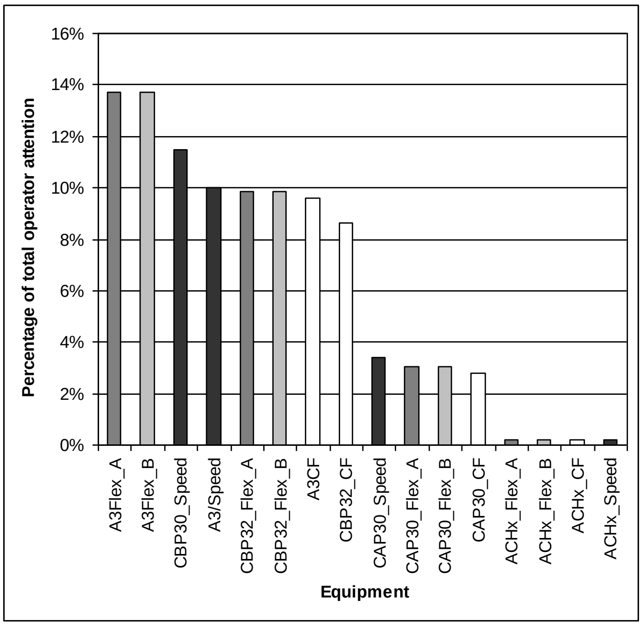


Figure 23. Operator attention per equipment.

Machine Requirements[41]:

In Table 8 each machines technical and supply technical requirements are shown along with the operator area requirement.

[41] Machine requirements found in Installation Manual: *81791-0111, 81588-0108, 2939731-0102, 2771031-0103, 2873601-0103, 2873657-0105, 2967801-0101, 2812254-0105.*

Machine	Requirement	Floorload (Tech.)	Height clearance (Tech.)	Hydrogene peroxide (Tech.)	Electricity, Fuse* (Supply tech.)	Air pressure [Bar] (Supply tech.)	Air consumption (peak) [Nl/min] (Supply tech.)	Water pressure [Bar] (Supply tech.)	Water temperature [C] (Supply tech.)	Water consumption [l/min] (Supply tech.)	Steam (Supply tech.)	Product (Supply tech.)	Operator area requirements [m]
FM	**A3/Flex**	◍	●	x	●	◍	◍	◍	●	●	x	x	9,6*4
	A3/CF	◍	◍	x	◍	◍	○	◍	○	○	x	x	8,5*4,5
	A3/Speed w PT	●	●	x	●	◍	●	◍	○	●	x	x	11,3*4,5
Ac	**AcHx 10**	○	◍	-	○	-	-	◍		○	-	-	4,7*4,0
	AcHx 30 47 m	○	◍	-	○	-	-	◍	○	○	-	-	5,8*4,0
	AcHx 30 120m	○	◍	-	○	-	-	◍	○	○	-	-	8,2*4,1
Ap	**CAP 30/Flex**	◍	◍	-	○	◍	○	◍	○	○	-	-	6,5*4,0
	CAP 30/Speed	◍	◍	-	○	◍	◍	◍	○	○	-	-	5,6*4,0
CBP	**CBP 32**	○	◍	-	○	●	○	-	-	○	-	-	5,9*3,2
	CBP 30 Speed	○	◍	-	○	●	◍	◍	○	○	-	-	10,9*3,5

Table 8. Machine requirement analysis.

		Floor load	Height	El.	Air		Water		
		[Tonnes]	[m]	Fuse [A]	Pressure [Bar]	Cons. [Nl/min]	Pressure [Bar]	Temp. [C]	Max cons. [l/min]
●	High	>10	>5	>150	>7	>1501	>5	<5	>25
◍	General	3-9	3-4,5	50 - 150	3-7	1000-1500	2-5	5-14	10-25
○	Low	<3	<3	<50	<3	<1000	<2	>14	<10

(x) means it is required and (–) means that is not used/required. All machines need 400 and 230 volt alternating current. Hydrogen peroxide is supplied in buckets from the storage, and is specified as it is toxic.

The space requirements of each machine are also listed here. Spaces for transportation, at least one and a half meter wide, is used under the assumption that hand stackers are used.

The filling machines are the only ones requiring product and steam. It is therefore natural to place these close to each other and close to the product processing area. Cardboard packers have higher requirements regarding air-pressure why these should be placed close to each other. Accumulators do not need any air, and hence is much easier to place in the facility.

Relationship Analysis:

Based on the speed of the three different transportation methods; human, human with pallet, and conveyer the closeness between different machines and departments can be evaluated. Assumed is that a person walks one meter per second, when the person is using a hand stacker the transportation speed is half a meter per second. The conveyer speed is twenty-one meters per second. To be able to compare the conveyer transportation method with the manual one a normalization method is presented beneath.

Conveyer transportation

Packages from the flex machine have a frequency of 8000 packages per hour. This machine produces Tetra Prisma Aseptic 1000 ml square packages, with a width of 80.8 mm, a depth of 73.9 mm and a height with cap of 244.4 mm.[42] These are packed two by four into 4 mm thick cardboard. An EU-pallet has the dimensions 1200*800*144 mm.

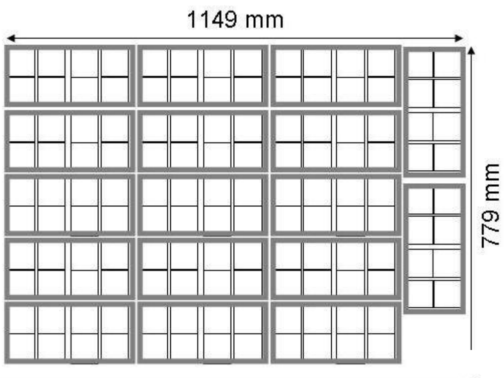


Figure 24. Pattern from above.

In Figure 24 the packing pattern is visualized, from above. Each cardboardbox is packed with four packages with the width of 80.8 mm and two packages with the depth of 73.9 mm. Every pallet is

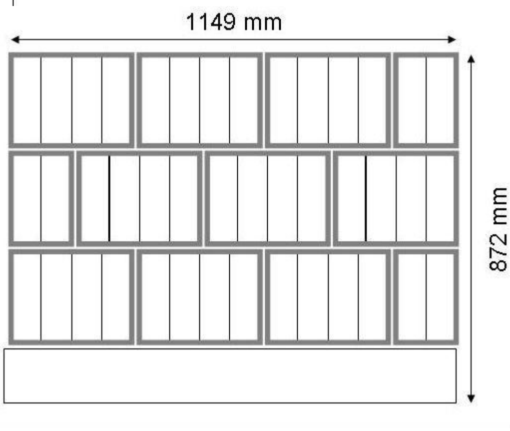


Figure 25. Pattern from side.

[42] http://packagedata.tetrapak.com/ 2009-02-16

then loaded with boxes three by five plus two crossing in every layer. As an EU-pallet is 144 mm high it can be packed in three, 243 mm high, layers to have the total height under 1 m, this is shown in Figure 25, where the total height is 872 mm. Every pallet is loaded with 408 TPA 1000 Sq.

The same calculations are done for the two other package sizes. Tetra Brik Aseptic 250 ml Square has a width of 57.2 mm, a dept of 52.1 mm and a height including the cap of 111.6 mm.

Packed four by three, in every cardboardbox, every pallet can take 175 cardboard boxes, five by five in seven layers, or 2100 TBA 250 Sq. Tetra Brik Aseptic 1000 ml Slim is 94.5 mm wide, 62.3 mm deep and 215.3 mm high including the cap. Packed two by three in the boxes every pallet can be loaded six boxes wide, four boxes deep and four boxes high, in total 96 boxes or 576 TBA 1000 S.

The machines have a capacity of 7000, 9000, and 12 000 packages per hour. This means 17 (7000/408) pallet loads of packages have to be transported every hour by the conveyers in the flex lines, A and B. In the compact flex line 4 pallet loads have to be transported every hour, and in the speedline 21 palletloads have to be transported every hour.

From-To Chart

Earlier we have determined how many times per hour every machine needs refill from the storage and how often every machine needs operator attention. This is combined with the number of pallets the conveyers have to transport in Table 9. For instance: from the storage (1) to the CAP30 in the Compact Flexline (12) 0.46 pallets have to be transported per hour at a speed of 0.5 m/s. 0.46 divided by 0.5 gives the weighted value 0.9*. From the filling machine in flexline A (2) to the accumulator (3) 17 pallets per hour are transported at a speed of 21 m/s and the calculated value is consequently 0.8 (=17/21). Analogically are the rest of the digits in the from-to chart, in Table 9.

* Unit: $s*m^{-1}*h^{-1}$. Divided by 3600 it would be m^{-1}.

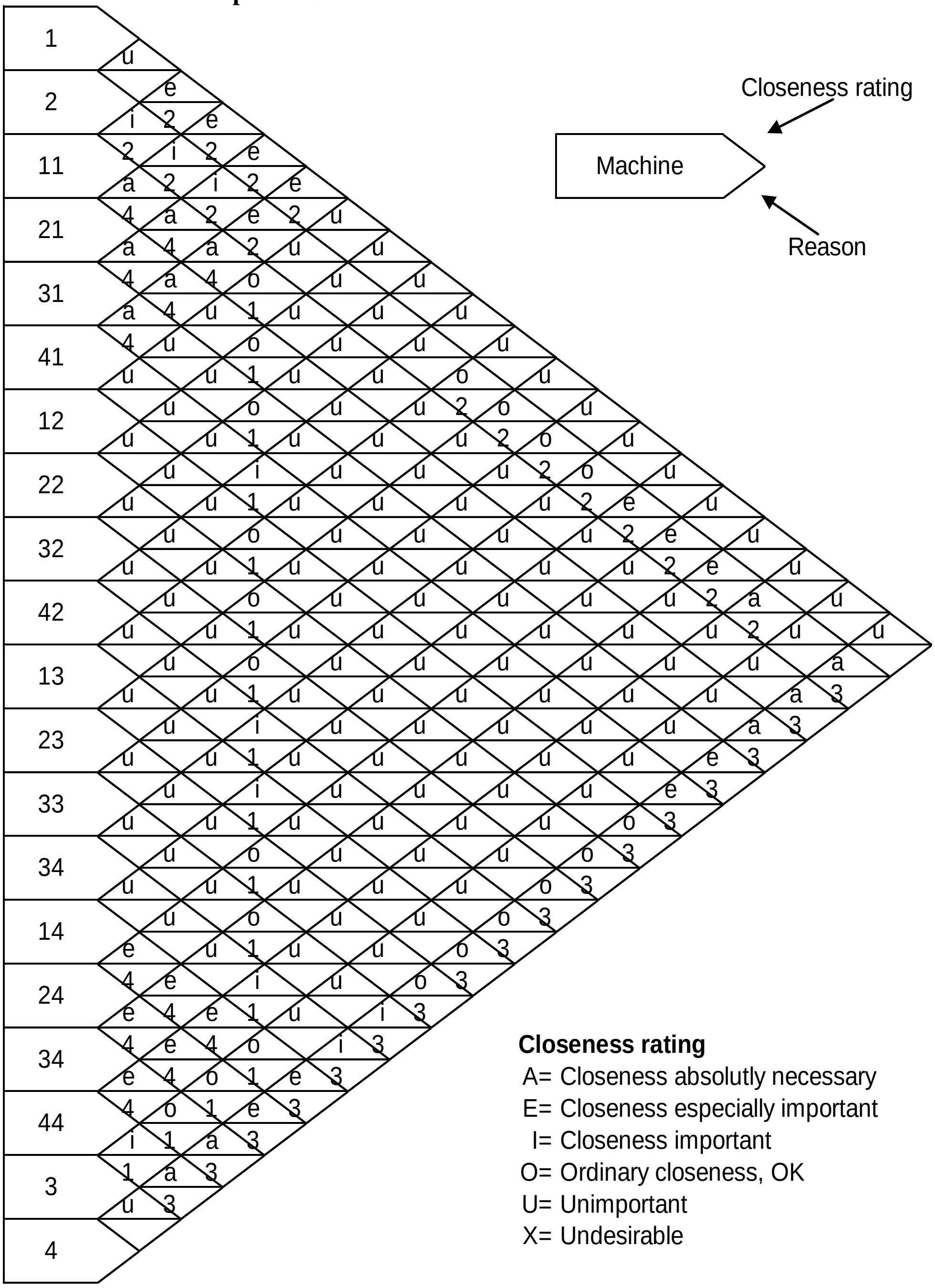
Table 9. From-to chart.

		2	11	12	13	14	21	22	23	24	31	32	33	34	41	42	43	44	3	4
2	Strg.		1,3		0,6	3,4	1,3		0,6	3,4	0,4		0,8	2,9	1,8		0,6	7		
11	Flex A			0,8																4,9
12	Ac a				0,8															0,1
13	Cap A					0,8														1,1
14	CBP A																		0,8	3,5
21	Flex B							0,8												4,9
22	Ac B								0,8											0,1
23	Cap B									0,8										1,1
24	CBP B																		0,8	3,5
31	CF											0,2								3,4
32	Ac CF												0,2							0,1
33	Cap CF													0,2						1,0
34	CBP CF																		0,2	3,1
41	Speed															1,0				3,5
42	Ac Spd																1,0			0,1
43	Cap Spd																	1,0		1,2
44	CBP Spd																		1,0	4,1
3	Warehs.																			
4	Op Area	13	4,2	0,1	0,8	1,8	4,2	0,1	0,8	1,8	3,2	0,1	0,6	1,6	2,7	0,1	0,9	0,3		

In the relationship chart, Table 10, a closeness rating is used where the flows are divided into five groups, A = closeness absolutely necessary, E = closeness especially important, I = closeness important, O = ordinary closeness OK, and U = closeness unimportant. The groups are assessed based on the from- to chart, Table 9. From-to chart.Table 9, and are divided as follows:

A= 4 -
E= 2.5 - 4
I= 1 – 2.5
O= 0.1 – 0,9
U= 0

Table 10. Relationship chart.



Closeness rating

A= Closeness absolutly necessary
E= Closeness especially important
I= Closeness important
O= Ordinary closeness, OK
U= Unimportant
X= Undesirable

Reason

1= Flow of production
2= Flow of materials
3= Flow of operators
4= Similar requirements

Relationship Chart:

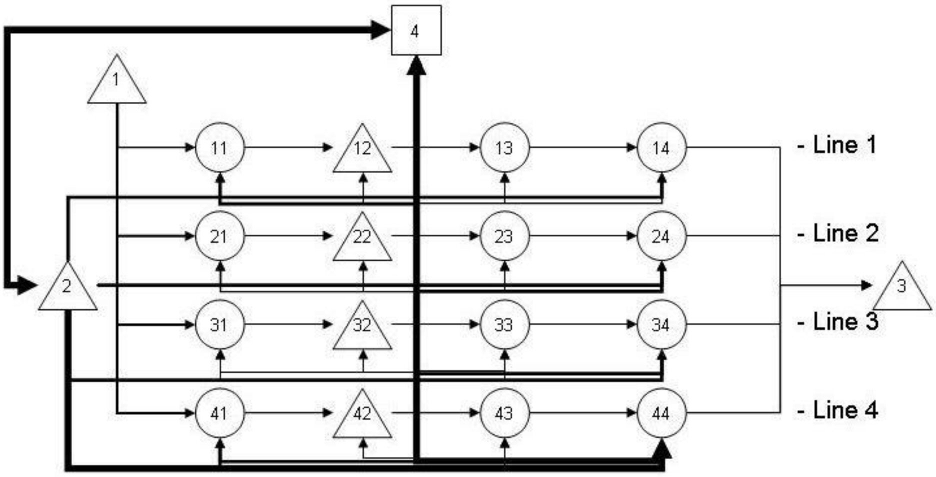


Figure 26. Flowchart of example site.

In Figure 26 the thickness of the arrows is proportional to the closeness requirements but only closeness requirements due to material flows are displayed.

As earlier defined number 1 is the product tanks, coming from the processing equipment. Number 2 is the secondary material storage, and 3 is finished goods warehouse. Number 4 is the operator areas; this will later be split up based on the number of operators serving the lines.

The equipment has a notation of two digits, where the first one refers to the line. Number 11 and 21 are A3/Flex filling machines, 12 and 22 accumulator helixes, 13 and 23 cap applicator 30s, and 14 and 24 card board packer 32s. Number 31 is the A3/Compact Flex, 32 yet another accumulator helix, 33 cap applicator 30, and 34 a cardboard packer 34. Number 41 is the A3/Speed filling machine, 42 accumulator helix 75m, 43 cap applicator 30, and number 44 cardboard packer 30 speed.

It is here assumed that every line only produces one package type and that no machine is by-passed. If the lines are set to produce packages without, for instance, caps half of the time the cap applicators will be de-connected from the flow. The arrows between the accumulator and cap applicator would in that case be half the size, while the other half would point direct on the cardboard packer. The result would slightly differ but the methodology would be exactly the same.

Block Chart:

Blockcharts of five different lines are developed. Two of them (Figure 27 and Figure 28) are Tetra Paks straight and square archetypes and Figure 29 is the layout The Absolute Company is using. He two last ones (Figure 30 and Figure 31) are developed by the author.

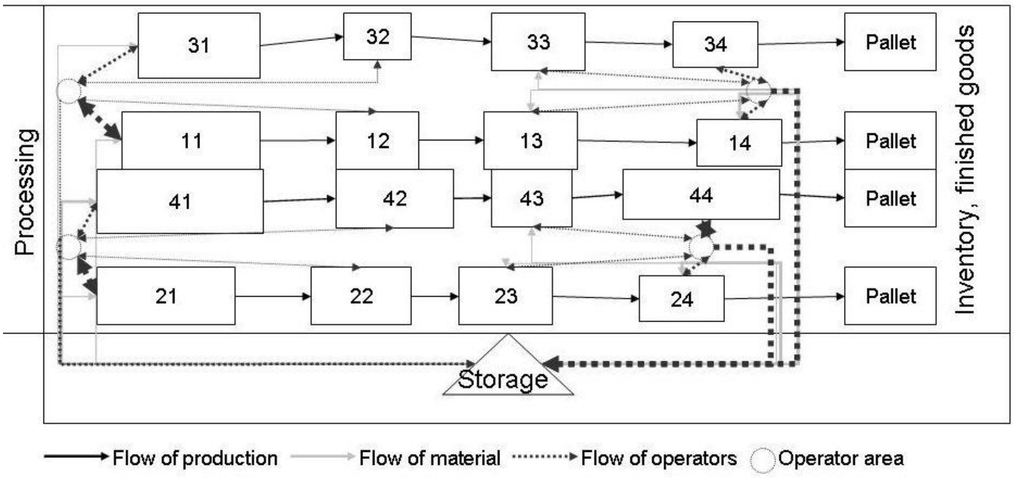


Figure 27. Blockchart of straight lines.

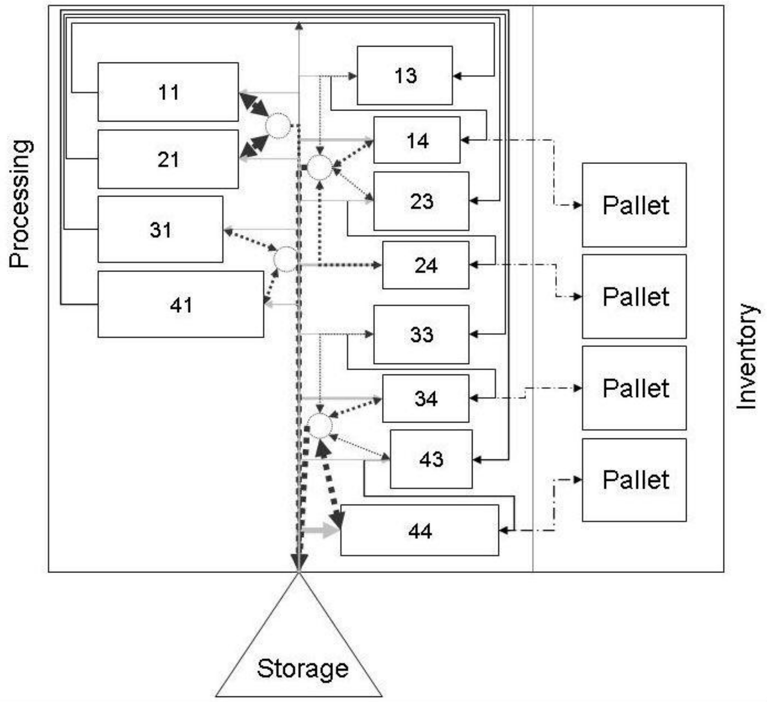


Figure 28. Operator Square.

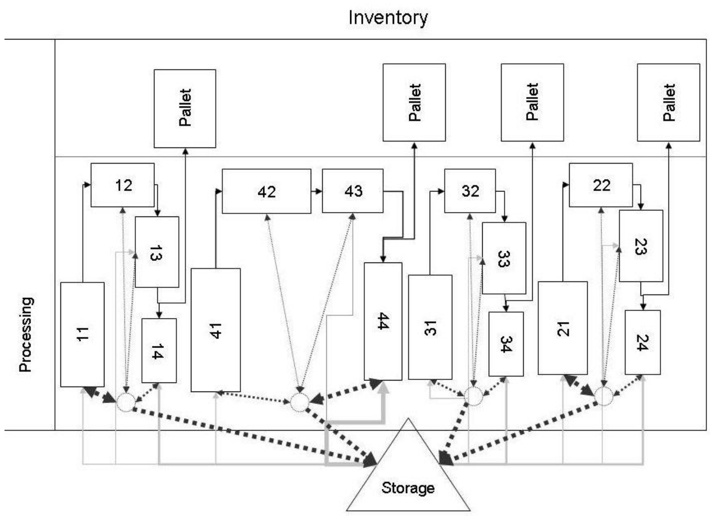


Figure 29. U-shaped lines.

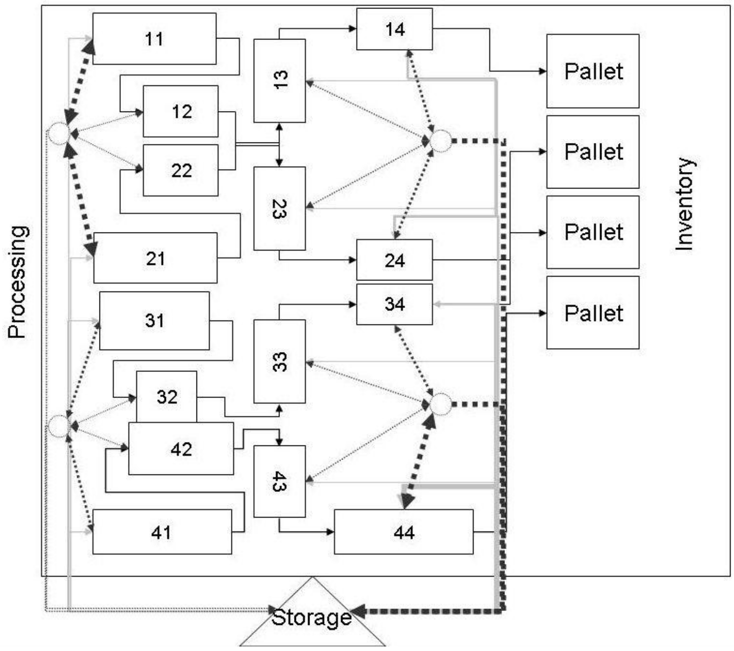


Figure 30. W-shaped lines.

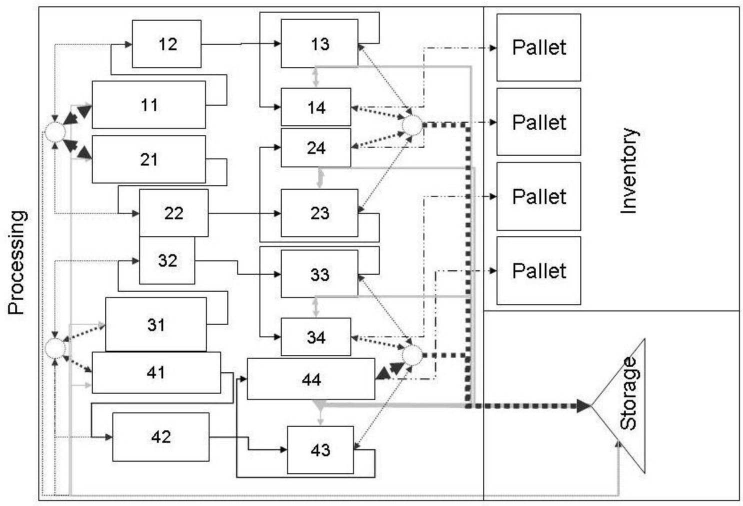


Figure 31. H-shaped lines.

Principal Layout:

When updating the block charts to principal layouts the rules set by the standard layouts[43] is used (see pg. 37) to find the required length of the conveyers. The high speed line, line 4, is the line that requires the longest

[43] Orbis, Tetra Pak internal network, A3 CompactFlex iLine Standard Layout, TP A3Flex200V Std Layouts, A3 Speed iLine Standard Layouts

conveyers, which also affects the layout. The compact flex line (line 3) has the smallest conveyer length requirements.
The layouts are designed in a way that service areas never are in conflict with each other. It is how ever possible to let machines share service areas (areas needed to open windows etc. on the machines) but it means that only one machine at the time can use the service area.

Operator areas are marked with circles, from a to d. Note that the operator area only is a place to quantify the distances in the layout. Exactly where the operator is located, in reality, depends on the situation but the operator area is a possible location. All distances are measured in the CAD-model and distances are presented in

Appendix .

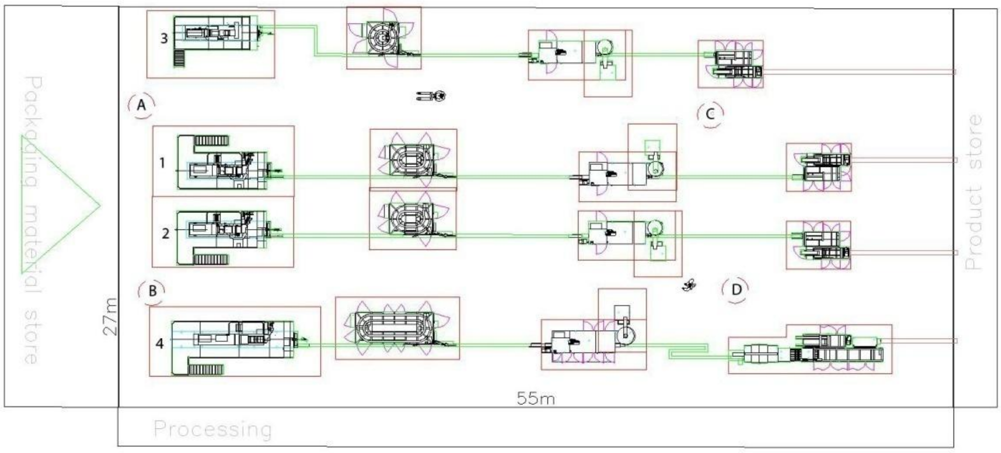


Figure 32. CAD-drawing of straight layout.

As the standard layouts is presented as straight lines the three different standard layouts can be seen in Figure 32 with the exception of the turn in line three, and the turns in line four. The turns in line four is placed there as this line is the longest and would otherwise result in a bigger building.

The rest of the layouts are shown in Figure 33 - Figure 37, where Figure 37 is the group layout first presented in Figure 14.

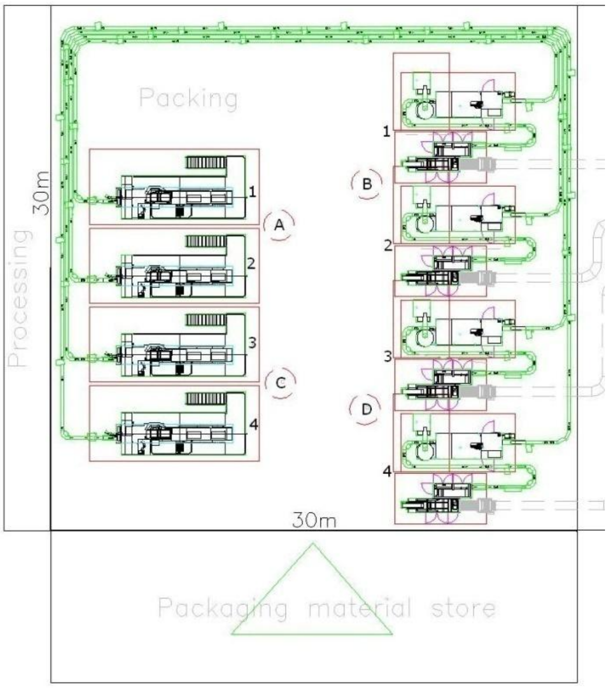


Figure 33. CAD-drawing of operator square.[44]

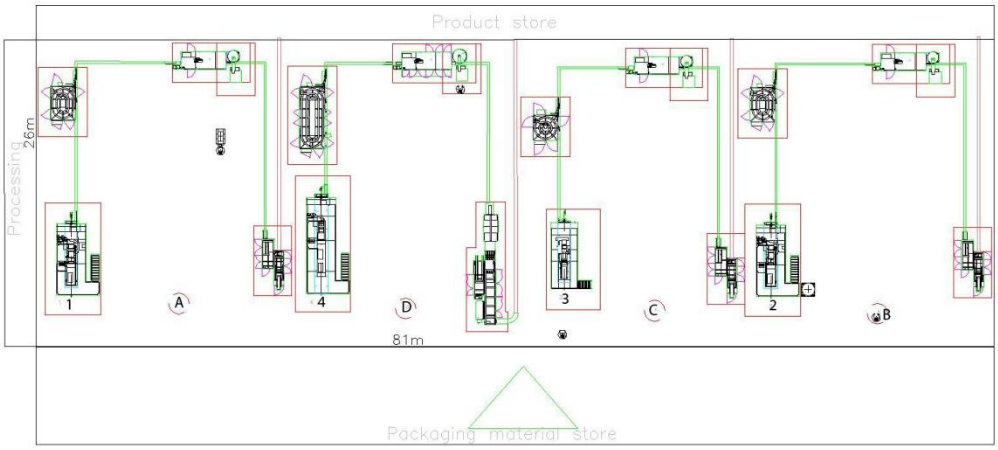


Figure 34. CAD-drawing of U-shaped layout.

[44] Tetra Pak

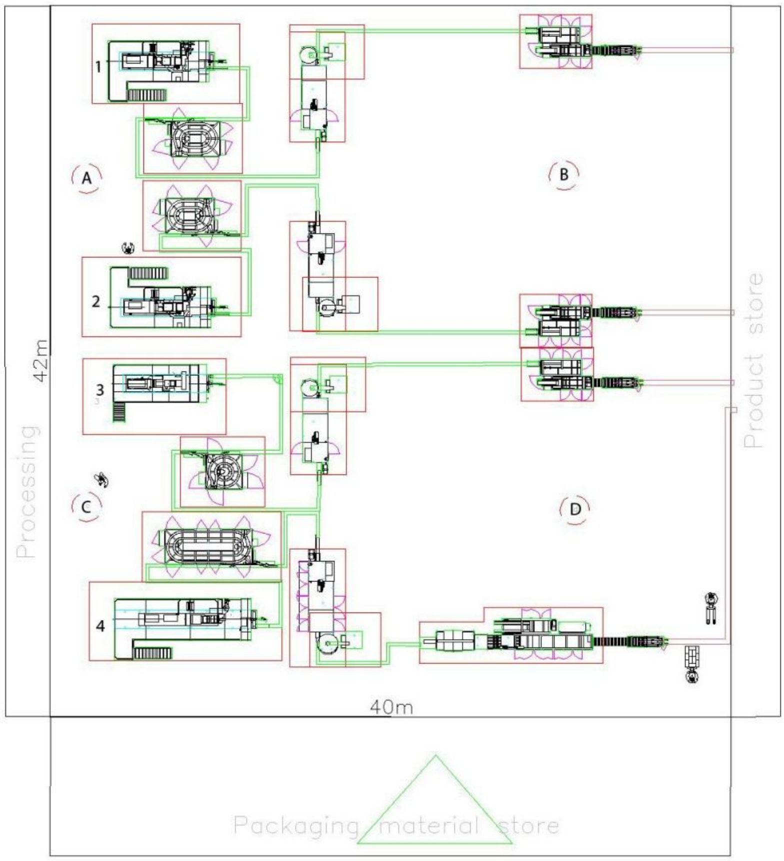


Figure 35. CAD-drawing of W-shaped layout.

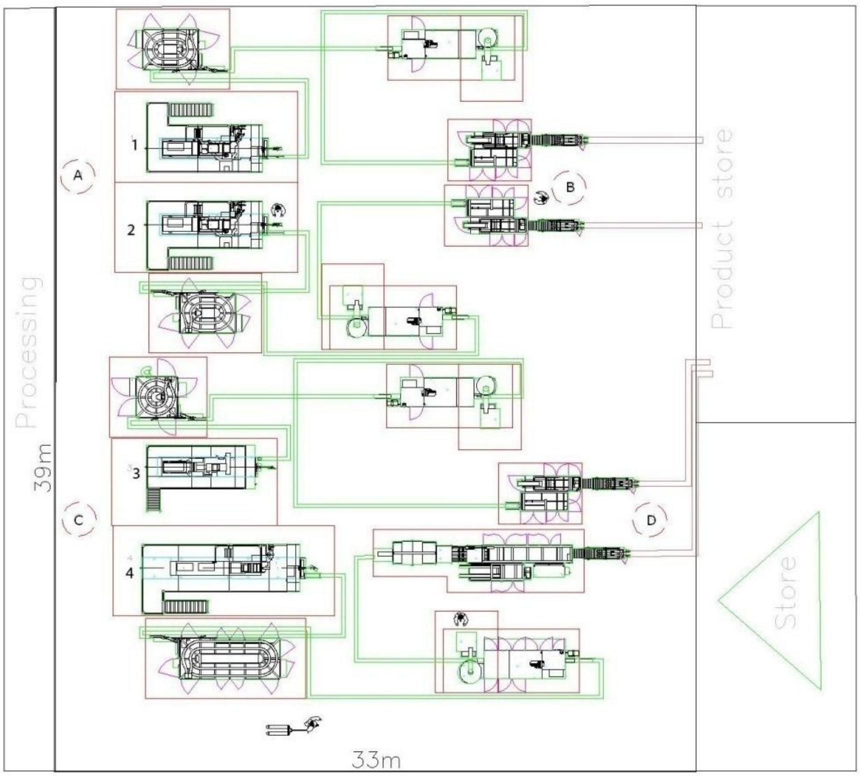


Figure 36. CAD-drawing of H-shaped layout.

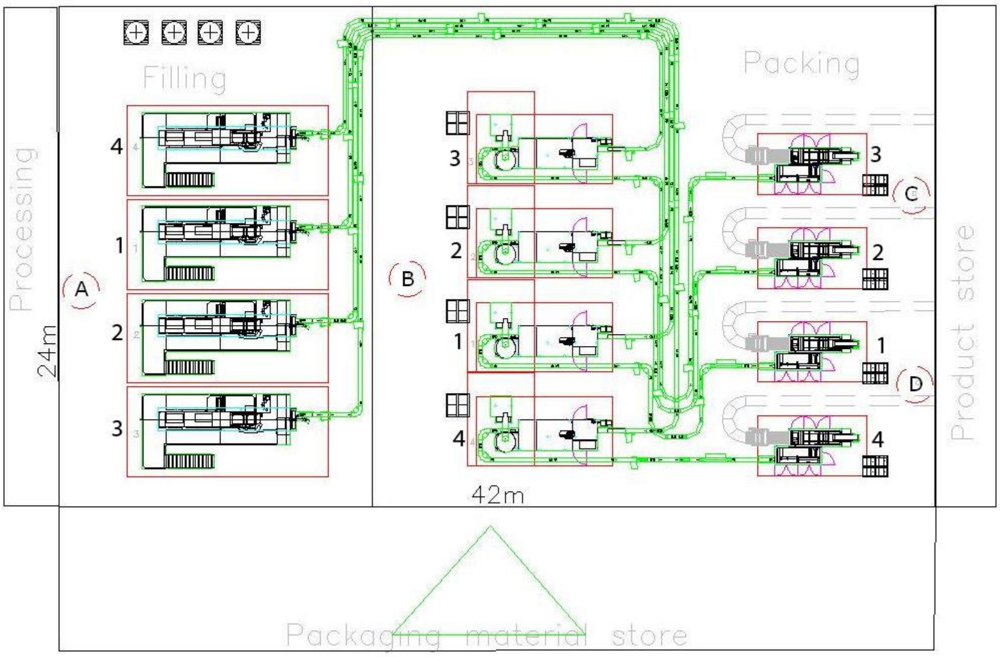


Figure 37. CAD-drawing of group layout.[45]

Evaluation:

The identified line criteria evaluation points are capital expenditures, operational expenditures, work environment, and hygiene. CapEx is divided into the three categories equipment investment, given a set of machines is the conveyer length the only factor affecting these criteria. Building investment, or space utilization, is based on the size of the filling- and packaging room.

OpEx is based on material handling/transportation and operator travel time.

Functionality is based on expandability, how many lines the layout is prepared for. line flexibility, number of package combinations that can be made, and the number of crossing material flows. Then we have the categories with work environment and hygiene. Work environment have the sub-category Visual overview; which is measured as the number of places the operator have to overview the line from. Hygiene is measured as if the filling room can be separated from the packaging room, which can be desirable in some countries as the filling room have temperature and air filtration requirements. In Figure 38 the evaluation is done for the different layouts. Note that the customer weight of factor depends on customer desire and is as a result not filled in.

[45] Tetra Pak

		Customer weigth of factor	Evaluation						Score					
			Straigt h	Square	U	W	H	Group	Straigth	Squa re	U	W	H	Group
CapEx	Equipment Investment		9	1	9	3	1	1						
	Space utilization		3	9	1	1	3	9						
OpEx	Material handling		1	9	3	1	1	3						
	Operator accessibility		1	9	3	1	3	3						
Functionality	Expandability		-	-	-	-	-	-						
	Line flexibility		-	-	-	-	-	-						
	Crossing material flows		1	9	9	3	1	1						
Work environment	Visual overview		3	3	9	3	3	1						
Hygiene	Separation of operations		9	9	1	1	1	9						
								Total:						

Figure 38**. Consideration assessment.**[46]

[46] Bergensthål, Perborg. *Industriell Anläggningsteknik* (2001) pg. 110.

Following is a short explanation of the different evaluation scores in Figure 38, there is not any best layout for all, the point is that the layout should meet the customers needs:

- **Equipment Investment**
  The total conveyer lengths are presented in Appendix C and the straight and U-layouts are the ones with the least required conveyer lengths and consequently the least capital investment cost given a set of machines.
- **Space utilization**
  Total space requirements are presented in Appendix C. Square and Group are the ones requiring the least space.
- **Material handling**
  The different distances that the material have to be transported in the different layouts is presented in Appendix C and combined with the pallet loads per hour that need to be transported, seen in Appendix A Table 9.
- **Operator Accessibility**
  Operator accessibility is based on the distances that have to be travelled by the operators shown in Appendix C and the number of times the number of times the Product and Production Analysis:.
- **Expandability**
  Expandability is not filled in here as we have not prepared for any additional lines.
- **Line flexibility**
  Lines flexibility is not filled in as we have assumed that every machine only produce one product.
- **Crossing material flows**
  Crossing flows is based on the number of times two operators' roads are crossed in the layout.
- **Visual overview**
  The number of operator areas is filled in as A-D in Figure 32-Figure 37. If the complete line can be monitored from one operator area the visual overview is considered great.
- **Separated operations**
  The layouts where it is possible to separate the filling machines from the other machines have a high score in this subject. This is in direct conflict with the previous parameter. But the important thing is that the customer desires are fulfilled.

Appendix B

This appendix shows machine data for the machines used in appendix A.

Line description	A3Flex PLH TPA 1000Sq	A3CF PLH TBA 250Sq	A3Speed PT TBA 1000S
Cap	StreamCap	StreamCap	SlimCap
CBP	CBP_32 (2x4) WAMF 4mm	CBP_32 (3x4) WAMF 4mm	CBP_30 (2x3) WAIF 4mm
Line description			
Filling machine	**A3/Flex**	**A3/CF**	**A3/Speed**
Capacity (pkgs/h)	6230	8010	10440
Nominal capacity (pkgs/h)	7000	9000	12000
Packages per reel	5500	17500	7700
H2O2 per container	59500	87429	51000
MTBF (hrs)	2	2,5	1,58
Continuous sampling (times per hour)	0,5	0,5	0,5
Package reels per pallet	2	4	2
H202 containers per load	1	1	1
MME	93,0%	94,0%	92,0%
MTTR [min]	9	9,6	8,5
LMME	89%	89%	87%
Accumulator	**AcHx_Flex**	**AcHx_CF**	**AcHx_Speed**
MME	99,6%	99,6%	99,6%
MTTR (min)	3,5	3,5	3,5
MTBF (hrs)	15	15	15
Cap Applicator	**CAP30_Flex**	**CAP30_CF**	**30_Speed**
Glue per container, for number of packages	26667	26667	55555
Caps per box, #packages	18000	18000	19800
MTBF (hrs)	2	4	2
MME	98,5%	99,2%	98,5%
MTTR (min)incl.45s responsetime	2,0	2	2
Glue containers per load	1	1	1
CAP boxes per pallet	4	4	4
Cardboard packer	**CBP32_Flex**	**CBP32_CF**	**CBP30_Speed**
Glue per bucket, for number of packages	38621	57931	40000
Cardboard, trays	275	275	525
Cardboard, packages	2200	3300	3150
MTBF (hrs)	2	2	2
Glue containers per load	1	1	1
Cardboard staples per pallet	1,8	1,8	1,0
MME	98,495%	98,495%	98,5%
MTTR (min)	1,83	1,83	1,83

Appendix B

Appendix C

This appendix shows distances between the different functions in Appendix A.

Distances in m:

U					
Packing room	80,3	25,6	=	2055,7	m2
Conveyer length	44,33	42,4	41,4	36,82	
	Line/OA				
	1/A	2/B	3/C	4/D	
FM-OA	7,73	7,73	5,9	6,1	
Helix-OA	17,55	17,55	15,8	15,4	
CAP-OA	18,75	18,75	18,2	18,7	
CBP-OA	7,52	7,52	5,3	4,8	
Store-FM	44,8	27,3	10,6	19,7	
Store-CAP	48,9	54,1	32,2	27	
Store-CBP	26,5	42,8	22,3	13,4	
OA-Store	31,6	31,6	15,2	11,5	

W					
Packing room	40,3	42,2	=	1700,66	m2
Conveyer length	49,9	49,7	51,9	52,4	
	Line/OA				
	1/A	2/B	3/C	4/D	
FM-OA	5,7	6,6	6,3	6	
Helix-OA	7,2	4,4	8,2	6,6	
CAP-OA	13,4	13,1	14,2	14	
CBP-OA	6,6	7,4	6,7	6	
Store-FM	66,6	48,2	42	26,9	
Store-CAP	65,6	59	45,53	42,1	
Store-CBP	57,4	46,7	37,8	32,6	
OA-Store	54,2	49,7	33,3	30,1	

Straight					
Packing room	55,5	26,6	=	1476,3	m2
Conveyer length	39,4	39,4	35,7	44,5	
	Line/OA				
	1/A	2/B	3/C	4/D	
FM-OA	4	3,4	4,2	3	
Helix-OA	16,8	16,2	15,3	15,4	
CAP-OA	6,1	6,8	9,1	9,5	
CBP-OA	6,5	4,6	2	4,9	
Store-FM	6,9	7,3	14,3	13,5	
Store-CAP	40,8	42,1	39,1	39,4	
Store-CBP	52,6	51,5	48	52,7	
OA-Store	10,1	9,6	45,2	46,2	

H					
Packing room	32,8	39,5	=	1295,6	m^2
Conveyer length	66	62,9	69,7	74,1	
	Line/OA				
	1/A	2/B	3/C	4/D	
FM-OA	3,1	3,3	3,3	3,3	
Helix-OA	6,3	8,8	5,8	8,6	
CAP-OA	7,7	10,8	11,1	7,2	
CBP-OA	6,4	4,8	7,7	7,8	
Store-FM	67,2	61,5	48,3	42,4	
Store-CAP	32,3	29,1	18,2	14,3	
Store-CBP	33,3	25	17,3	14,9	
OA-Store	62,3	24,5	45,4	6,9	

Square					
Packing room	29,9	30	=	897	m^2
Conveyer length	68,4	82,2	93	105,4	
	Line/OA				
	1/A	2/B	3/C	4/D	
FM-OA	1,4	2,2	1,4	2,2	
Helix-OA	9,9	9,9	9,9	9,9	
CAP-OA	10,3	5,3	10,3	5,3	
CBP-OA	3,3	4,9	3,3	4,9	
Store-FM	20,4	16,8	12,5	8,4	
Store-CAP	30,8	22,4	16	10,5	
Store-CBP	23,4	17,1	11,2	7,6	
OA-Store	18,6	20,9	10	8,7	

Appendix C

Group					
Packing room	42	24	=	1008	m^2
Conveyer length	77,3	83,4	90,6	72,4	
	Line/OA				
	1/A	2/B	3/C	4/D	
FM-OA	3,1	2,6	6,3	6,1	
Helix-OA	17,3	17,3	17,3	17,3	
CAP-OA	10,7	7,3	5,4	7,9	
CBP-OA	2,5	2,6	2,5	2,6	
Store-FM	32,4	28,5	22,7	36,2	
Store-CAP	12,1	18	21,4	7,4	
Store-CBP	30,4	33,7	38	20,7	
OA-Store	28,8	20,7	26,7	36,1	