# COMMERCIAL PLUG-IN COOLER PRODUCTION DEVELOPMENT FOR ASTE FINLAND OY:
# INCREASING THE EFFICIENCY OF CURRENT PRODUCTION
# AND
# DEVELOPMENT OF THE PRODUCTION SHOP FOR FACTORY EXTENSION

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ABSTRACT

The thesis project is a part of the production development project of Aste Finland Oy (Name changed on the demand of the contracting party), it proposes an optimisation of assembly production and introduces a solution for a production shop for the factory extension. Aste Finland Oy is a young company which produces display cabinet coolers. The company has experienced a high demand for its goods, however has been unable to meet the demand and take advantage of the current market situation, thus, the company was interested in increased production capacity.

Moreover, the demand is not even throughout the year and if the company is not able to deliver products in four to eight weeks after the quotation was released, the customer is lost. Thus, it was very critical for Aste Finland Oy to have backup capacity in order to immediately respond to the demand. It should be mentioned, that the production techniques of Aste Finland Oy did not allow to organise material and product flow in a reasonably efficient way, thereby the company was in need for a solution which would allow it to fully benefit from the implementation of optimised production solution.

This project was aimed to provide Aste Finland Oy with a thorough production analysis and recommendations which should be used in order to solve production problems experienced by the company. The adoption of recommendations developed during the current research project allows the company to reduce the number of workers by 35% and save approx. EUR 200 000 per year. The study consisted of two cases: the first case solved the problem with current production and offers solution for its optimisation, the second case solved the problem of production extension and provided company with the proposal for entire production line, with a list of equipment and tools needed, information on suppliers, cost calculation and an investment analysis for different scenarios.

**Keywords** production development, production shop layout, investment calculations, production optimisation

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# 1 THEORY

## 1.1 Assembly

The research project was focused on an assembly-type production it was essential to understand the meaning of assembly, assembly line and their history.

In the current research project, the term “assembly” was used to describe a technological process during which some components are joined together to form a product which represents some value to its final user. The term of an assembly line is described as: “A series of workers and machines in a factory by which a succession of identical items is progressively assembled” (Oxford Dictionaries, 2018).

### 1.1.1 History of assembly

The first prototypes of the assembly line appeared in the Ancient Era. The Production was developing step by step due to the evolution of human culture and technology, whic, in its turn, allowed new practices to be introduced to the production techniques.

One of the oldest and renowned examples of the assembly line is Terracotta Army in China (Thomopoulos N. T., 2014). In 1974 a group of farmers was digging a water well and discovered a burial with statues of soldiers made from terracotta. This burial also called mausoleum is a part of necropolis with the tomb of the first Emperor of China, Qin Shi Huang. The mausoleum held more than 8100 soldiers and 670 horses which were buried with the emperor in 210-209 BC. Although the construction took place more than 2000 years ago each statue is a masterpiece with highly detailed costumes and customised faces, thus each figure is unique. Researchers have found that statues were produced in workshops during an assembly type production. Firstly, components of figures, such as arms, legs, bodies, and heads were produced severally and then joined together. Statues then processed detailing operations to get the unique look. Moreover, the name of the workshop was imprinted on the figure. Thereby the production of the Terracotta Army is one of the earliest known assembly lines with quality control (Thomopoulos N. T., 2014).

In the sixteenth century, the Arsenal in Venetia developed a production line of ship components such as guns, sails, handwheels, rigging, winches, lights. (Davis, 2007)

All parts were produced separately and then added to the ship body. By virtue of assembly production, it was possible to release almost one ship in a day.

At the end of the eighteenth century, the U.S. military production has implemented a new way to produce guns, particularly muskets this implementation was influenced by American inventor and manufacturer Eli Whitney. (Woodbury, 1964). He is known for his invention of the cotton gin and the milling machine; however, he also made a significant contribution to the development of production and mass production forthcoming. In 1798 Whitney signed a contract with the U.S. government, he was obliged to deliver 10000 muskets by 1800. He started developing new production based on the combination of machine power, a division of labour, process focus and interchangeability principle. Prior to Whitney, muskets were made individually, by one master, thus it was usually impossible to use one gun's parts with another gun. According to the interchangeability principle, all components should be mass produced with tolerances allowing to assemble the final product using spare parts from different batches. Whitney used new metal processing techniques in order to decrease skills required to perform operations, thus hiring less-skilled workers and saving money on salaries. Unfortunately, he was unable to produce muskets in time, which some historians connect with the fact that he took the money and moved to South Carolina, where he tried to gain from the cotton gin. (Baida, 1987). Moreover, during price negotiations with the government he was able to include fixed costs such as equipment and machinery to the actual price of the product, thus he contributed to the development of cost accounting and economic efficiency of production.

Even though some people claim that Whitney was the inventor of the interchangeability principle, the earliest known advocate for such principle is French artillery officer, Jean-Baptiste Vaquette de Gribeauval, also known for revolutionising of French cannon and its production. (Hounshell D. A., 1984). One of the most well-known ancestors of the assembly line is meatpacking industry of Chicago in the nineteenth century (Halpern, 1997). Each worker was assigned to his/her working place and the meat was conveyed through the production line by the means of overhead trolleys, thus the product was moving through the production line and workers stood at personal working stations performing standard tasks at each step of the production (Pacyga, 2015).

Due to the specifics of meat processing, this is an example of true disassembly line.
Small gradual changes finally led to the system known as Mass Production or Fordism, after Henry Ford.

Even though the first automotive assembly line was developed by Ransom Olds, (Thomopoulos N. T., 2014) (Domm, 2009). Henry Ford and his production engineers, particularly Charles Sorensen developed previous techniques and brought it to the completely new level. In 1909, Ford and his engineers started working on the new principle of production line's functional organisation. The workshop was divided into workstations, where standard operations were performed. Cars were moved by means of conveyor and workers were standing at one location next to it, little by little adding value to the product, so the end of the line was releasing final product – Model T (Pine, 1999). Thus, the principle of flow of work to the worker was implemented.

Business historian David Hounshell writes,

In "moving the work to the men" the fundamental tenet of the assembly line, the Ford engineers found a method to speed up the slow men and slow down the fast men. The assembly line would bring regularity to the Ford factory, a regularity almost as dependable as the rising of the sun. With the installation of the assembly line and the extension of its dynamism to all phases of factory operations, the Ford production engineers wrought true mass production. (Hounshell D., 1985)

Finally, when the line was introduced to the production, the time spent by workers to release one car decreased dramatically: from more than 12 hours to 2.5 hours. In six months, the time to produce one car dropped to 1,5 hours (Pine, 1999).

It is important to understand, that the development of the production led to more than only lower production costs, but also higher output with better quality products and thus less waste due to fewer defects. All these changes led to the economies of scale (Pine, 1999).

Ford company was introducing new equipment which increased fixed cost, however, it was also increasing the efficiency of workers and therefore total throughput, which led to significantly decreased unit costs. Thus, the company was able to lower the price of the unit which led to greater number of people who could afford to buy Ford's production. Increased consumption led to the greater production and lowered costs and prices, which led to even larger consumption as illustrated in Table 1 and Figure 1).

Table 1 - Total Model T Sales (1908-1916) (Pine, 1999)

| Calendar Year | Retail Price (Touring Car) | Total Model T Sales |
|---|---|---|
| 1908 | $850 | 5,986 |
| 1909 | 950 | 12,292 |
| 1910 | 780 | 19,293 |
| 1911 | 690 | 40,402 |
| 1912 | 600 | 78,611 |
| 1913 | 550 | 182,809 |
| 1914 | 490 | 260,720 |
| 1915 | 440 | 355,276 |
| 1916 | 360 | 577,036 |

Total production was 2 million in 1923 (Pine, 1999, s. 24) and by 1927 Ford sold more than 15 million Model T cars (Thomopoulos N. T., 2014).


Figure 1 Model T production and price over 17 years (Visual Software Systems Ltd, 2018)

The improvement of production and introduction of mass production ideology changed the organisational structure as well.

- Firstly, high-skilled masters were replaced with less-skilled and less expensive workers, since skill was integrated into machines.
- Secondly, fewer workers were needed to carry out routine and hard-working operations, since machines were executing some of the labour-intensive and routine work.

Even though the need for masters which perform operations was decreased, increased number of operators created a need for supervisors and managers. The growth of organisational structure, a complication of production, management, accounting and sales processes created a need in, for example, engineering, accounting, distribution, sales specialists.
Several decades after, the repletion of domestic markets pushed companies towards international markets. (Ritzer, 2011). Together with the development of transport and increased quality of life, it pushed some companies to move the production overseas, to countries, where taxes, wages, social and environmental requirements are lower than in U.S. or Europe. Other companies were pushed to constantly increase their efficiency in order to stay profitable. Some companies and countries focused on raw material supplies, others started processing materials, thus creating components, some companies switched to assembly operations, there were also companies who diversified their production in order to conquer new market segments.

In other words, the production of the twenty-first century was derived from thousands of inventions and ideas of thousands of persons. It was invented several thousand years ago and developed in Europe of Renaissance, improved in the U.S. in the eighteenth-twentieth centuries and reformed in Japan in the middle and the end of the twentieth century. The improvement will never stop, automation of production and management is now highly used worldwide, such improvements will be described a bit later in the current study.

## 1.2 Assembly types

Assembly production can be divided using several characteristics as shown in Figure 2. The most frequently used classifications are described in the current chapter.

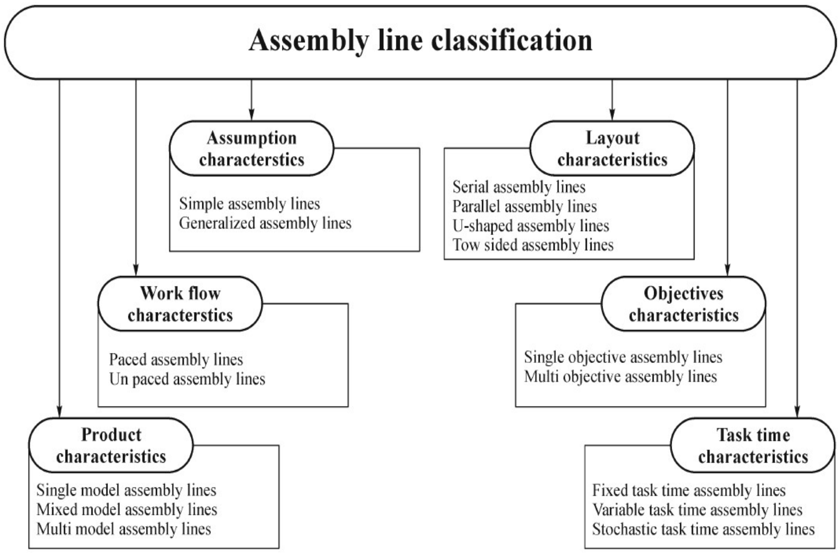


Figure 2 – Classification of an assembly line (Mirza, 2014)

### 1.2.1 Assembly by product characteristics

If a single product without any variations is produced, then it is called a single-model assembly line as illustrated in Figure 3.
Let us hold a mental experiment. The company manufactures three different products or three modifications of one product: such as Triangle, Square and Circle. The assembly line releases only single type of product during some time period, in our case it will be a week. At the beginning of week one the production order was released by the management. It states that during the week one company will produce 60 Triangles. After all Triangles were sent to the warehouse, a new order was released, requiring 60 Squares to be produced. Such method of manufacturing is called single-model production, when the only single product is produced.

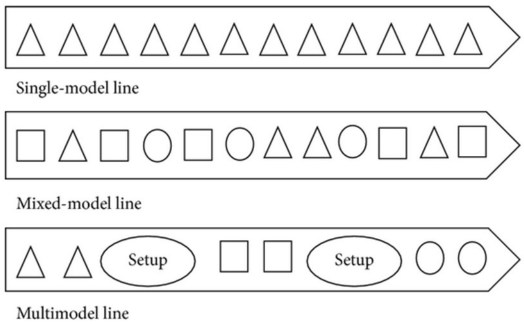


Figure 3 - Assembly lines, classified using product characteristic (Wang, Tu, Chen, 2015)

On Monday, week two, production shop received an order for 30 Squares, 20 Triangles and 10 Circles to be produced. The assembly shop is capable of producing all products together, so there are no major differences in assembly operations. Production steps of a mixed-model line can have small variations among each other, the operation time can also be different for different products or product modifications.

After several years, the design of products underwent several changes. It is not anymore possible to produce them without setting up the equipment. So if one production cell performed some operation on Square, it is needed to set up the equipment before the same cell can process Triangles or Circles. Shift supervisor got new production task, stating that ten batches of 2 Circles, 2 Squares and 2 Triangles should be assembled and released in the above order. All three products are processed by the production line, however they are not mixed anymore, each product requires a special setup, so each work cell performs different operations for non-similar products, thus the line consists of numerous single-line processes. This is called multi-model line. The more setups are performed, the less efficient is the production, since more time is wasted on setting the equipment up. Such waste can be minimised by decreasing the number of setups, thus with larger batches.

### 1.2.2 Assembly by workflow characteristics

Any assembly can be described as a flow-type line or non-flow-type line. The flow-type line is defined, in the first place, by the fact that all operations are performed by the same time intervals, this time is called takt time and is the average time between the start of production of two subsequent units. The operation time can also be an aliquot part of the takt time e.g. if takt time is 10 minutes, the process time can be equal to 2, 5 or 20 minutes and so on. However, it is very important to balance the line, so if task A takes 20 minutes when the takt time is 10 minutes, task A should be performed by two work cells at the same time, so the pace is still one product per 10 minutes.

The first type of flow-type line is a flow-type stationary line. With this method of organisation of assembly all products being processed remain at the same working place during the entire assembly process. Workers or brigades consistently pass from one product to the next in time intervals equal to the takt time. Workers or brigades perform the operation assigned to them. Such technique is used for the assembly of large and bulky products, when the conveyance is difficult. The flow-type stationary line allows uniform flow, short assembly cycle and high performance. It is used in mass production.

The second type is flow-type moving assembly. Which means that each worker has a specific task and work cell assigned, while the product is moving through the production line. This type of assembly can be based paced or unpaced.
In the first case, the worker releases the part after he/she complied all operations on the part.

In the second case, the worker is forced to perform all assigned tasks within the takt time. Sound or light signal is usually used to indicate the end of the takt so that workers will pass the product to the next station. Nowadays, constantly or periodically moving conveyors are used for determining the takt time.

The planning and control of material flow are not complicated due to well-organised product flow in both time and space, especially when operations are paced. Flow assembly reduces the duration of the production cycle, lowers the idle time between operations, increases the skill of assemblers and allows more opportunities for mechanisation and automation of assembly operations comparing to the non-flow assembly, which leads to a reduction in the labour intensity of assembly by 35-50% (Bespalov, 2014).

Due to the standardisation of processes and thorough balancing, the flow assembly has higher efficiency but less flexibility as compared with non-flow type. Thereby, it is commonly used in continuous or mass production.

The non-flow assembly can be stationary or moving. During non-flow stationary assembly product is fully assembled at one place, which is supplied with all needed components. Work cells are equipped with tools required for particular operations. The assembly can be executed with the division of labour or without it. During the division of labour the technological process is divided into subassemblies and main assembly. Such operations are performed in parallel; thus, the lead time is shorter as compared with the assembly without the division of labour.

A non-flow moving assembly is similar to the flow moving assembly and can also be performed in paced or unpaced way, however there are essential differences between non-flow and flow assemblies. With non-flow assembly the flow of products in space is not organised in a systematic way, however the flow in time can be planned and forecasted. Comparing to the flow assembly it is a more complex task to organise the product and material flow, bring all chaotic movements to the systematic order. Thus, the non-flow assembly is more suitable for flexible production and is used in job-shop, batch and mass production (Jampol'skij E.S., Solovej Z.I., 1975).

### 1.2.3 Assembly by layout characteristics

The layout of a production line as shown in Figure 4 is defined by technological processes, however much often the layout is based on what the company can afford. Often the production area is pre-defined by the company management or by the area of existing facilities.

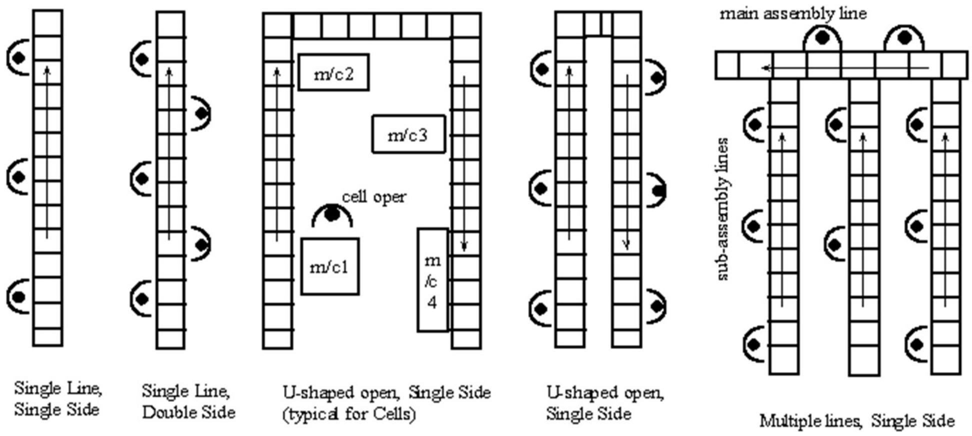


Figure 4 - Different shapes of an assembly line (Freeman, 2001)

Assembly line can be designed as a single line with workstations from one side. Workstations can be placed from both sides thus forming a double or two-sided line. Such layouts are called serial production/assembly line, since all operations are performed in series and the material flow goes from the beginning to the end of the line through all operations. It is important to state, that one of the most significant requirements of the design of production line is to allow single direction of the material flow, if it can be achieved. Production engineers try to eliminate backflow, which means the product must not return to the preceding workstation.

A u-shaped line allows saving floor space, adapting the layout to the most common factory shape – rectangular. To save more space workstations can be placed on the inside of U-shaped line, however this can make material handling more sophisticated if there is a need to deliver raw, especially bulky, materials to workstations. With small component size all material handling is carried out by means of conveyors (it can be the same conveyor which moves the product to be assembled) or by means of bins and trolleys, delivered to each workstation. It is possible to place all workstations on the outside of the U-shaped conveyor line, this allows easier access to workstations. Workstations can also be placed from both sides of the U-shaped conveyor, allowing denser distribution of workspaces regarding conveyor line length.

Assembly operations can be performed in parallel in order to increase the production capacity or reduce the lead time. Thus, parallel production/assembly line is formed. If same operations are performed by two parallel lines, the production becomes more immune to such problems as a raw material shortage, failure of equipment or injury of a worker. If one line is stopped, the other one will continue working, thus some part of the factory will perform the operation. Thereby, failure effect is different from the one in the single production line, which is, in many cases, easier to implement and balance as compared with the parallel line. However the failure at one of the stages will affect all subsequent operations, it can also affect all preceding operations as well, for example, if room for the stock is allowed, all preceding lines will stop due to the incapability to place processed components on the conveyor line, which is full.

The development of production pushed companies to look for new techniques which will allow producing with higher efficiency, fewer costs and with as fewer failures as possible. Such techniques allowed to increase the production reliability thus decreasing the possibility of downtimes. A new philosophy, known as Lean manufacturing became a new solution for the business world.

## 1.3 Lean manufacturing

### 1.3.1 History of Lean manufacturing

Although the term Lean appeared 30 years ago in the article called Triumph of the Lean Production System based on the master's thesis of MIT student John Krafcik, the origin of this philosophy dates back to the beginning of the twentieth century (Krafcik, 1988).

The success of the Ford company pushed the development of mass production, however it was clear that the efficiency of technological processes can be increased. One way to do it was waste elimination.

Frank Gilbreth an American engineer, also known as a pioneer of scientific management once noticed that a mason who builds a wall performs unnecessary motions: he leans over to take the next brick. (N., 2005; Urwick, 1949). After studying the operations which are required to build a wall Gilbreth developed a multilevel scaffold to keep the bricks on it. (Wood, 2003, pp. 49-64) This solution eliminated the need to lean over and decreased the number of movements from 18 to 5. The production rate increased from 120 blocks/hour to 350 blocks. (Nikitin, 2013). Afterwards, the term of work which adds no value to the final product was described as MUDA.

In My Life and Work (1922) Henry Ford depicted his thoughts about the waste. He writes
I believe that the average farmer puts to a really useful purpose only about 5% of the energy he expends [sic]... Not only is everything done by hand, but seldom is a thought given to a logical arrangement. A farmer doing his chores will walk up and down a rickety ladder a dozen times. He will carry water for years instead of putting in a few lengths of pipe. His whole idea, when there is extra work to do, is to hire extra men. He thinks of putting money into improvements as an expense... It is waste motion— waste effort— that makes farm prices high and profits low. (Ford, 1922)

However, the main role in the development of lean philosophy belongs to Toyota Motor Corp. It started in 1924, Japan, when Sakichi Toyoda invented a loom, which stopped itself when the lateral or the vertical threads ran out or broke, stopping the operation and eliminating any work added to a defective product (Mass W. & Robertson A, 1996). In 1934 company shifted from textile production to car manufacturing. (Toyota Company History from 1867 to 1939, 2010). Kiichiro Toyoda, the founder of Toyota Motor Corp, managed the casting of engines, he was continuously discovering problems related to the production. He recognised that many problems could be solved after a thorough study of each process. In 1936, Toyota won its first contract for the production of trucks for the Japanese government. New challenges appeared during the production of trucks. The need to solve them led Kiichiro Toyoda to

develop Kaizen improvement teams. One of the main tasks of such teams was a continuous study of all stages of production along with its technology and the introduction of methods for its improvement. (Masaaki, 2012)
In post-war Japan, the level of demand was low, thus it was not possible to use benefits of scale and reduce the cost of production. During his visit to the USA engineer of Toyota Motor Corp. Taiichi Ohno came to the conclusion that production should not be based on traditional push strategy, when the demand is forecasted and products are made to stock. Taiichi Ohno focused on pull strategy, when the production is driven by the actual sales (Ohno, 1988).

It was Taiichi Ohno who combined all advanced methods developed to increase the production efficiency and developed his own, unique system, which was called the Toyota Production System or TPS (Holweg, 2007). Based on the TPS, the lean manufacturing system includes many other methods to increase the efficiency of production.

The main principle of all lean improvements is based on eliminating three main sources of waste (Emiliani, 2007): Mura (unevenness), Muri (overburden) and Muda (waste). Taiichi Ohno defined waste as “anything other than the minimum amount of equipment, materials, parts, and working time essential to production” (Heizer, 2005).

### 1.3.2 Mura

Mura is the waste of unevenness, derived from a Japanese word 斑 meaning lack of uniformity; (Kenkyusha's New Japanese-English Dictionary, 2003) inequality, irregularity; nonuniformity. The main key is to schedule all operations by eliminating idle- and overtime (Liker, 2004).

Let us hold mental experiment. The company produces cars, a work shift is 8 hours long. It takes one hour to produce one car.
The production plan is different for each day, thus during the first day the real time to produce cars is five hours, this means that three hours or 37.5% of the working time is wasted. The same situation occurs during days 2,4 and 5 as illustrated in Figure 5. During the third day two hours of overtime are required to realise the production plan. It is important to mention that overtime wages are higher than the average ones. (Department of Labor, 2018) (Ylityo, Lisatyo ja Sunnuntaityo [Overwork, Additional Work and Sunday Work], 2018). Increased time of work increases the capacity, howevere the fatigue of workers will decrease their effectiveness by the end of the day.

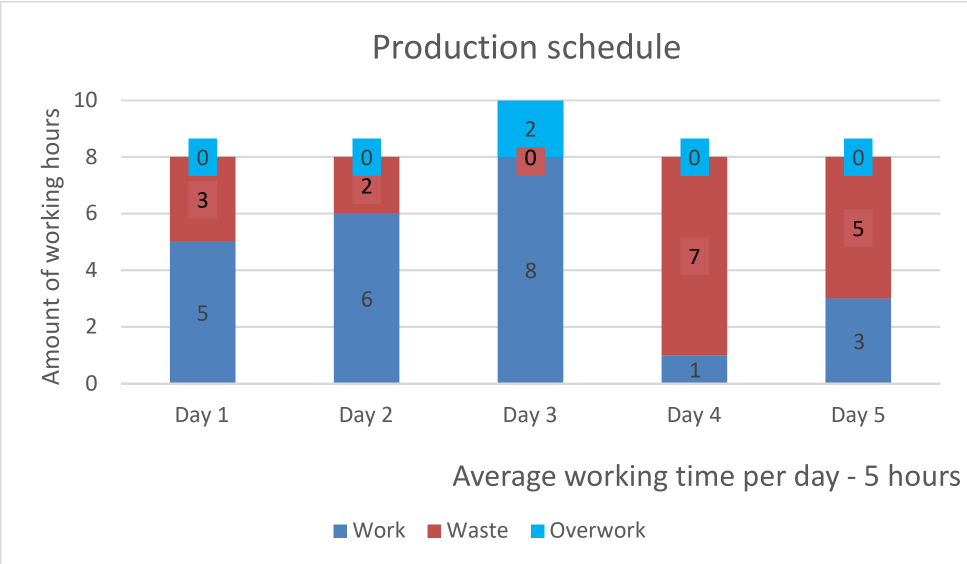

Figure 5 - Initial production schedule in an 8-hour shift

The total working time is 25 hours so that the company will produce 25 cars. Implying that the weekly number of working hours with this company is 40 and adding two hours of overtime to it, the efficiency can be calculated.

$$\frac{Total\ working\ time}{Weekly\ working\ time + Overtime} = \frac{25}{40+2} * 100\% = 59.5\%$$

It can be seen from the result of 59.5 % that the production can be improved. It is then rescheduled according to Lean strategy.

Now eight cars are to be produced each day as seen in Figure 6. There is no money wasted due to no tasks to be performed or due to the overwork, in other words, the unevenness is eliminated. The average working time is 8 hours per day, meaning that the total working time is 40 hours per week.

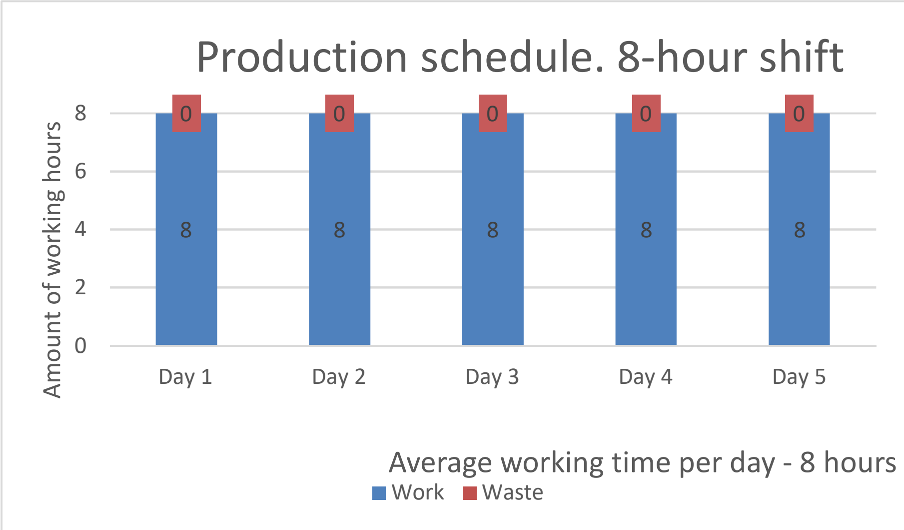


Figure 6 - Optimised production schedule, 8-hour shift

$$\frac{40}{40+0} * 100\% = 100\%$$

It may happen so that the company does not have enough orders to keep the production schedule at the level of 8 working hours per day, however the company still can find the optimal level to optimise the schedule as seen in Figure 7. Work shifts can then be shortened, so the company will eliminate expenditures on loafing workers and equipment which operates for no purpose.

$$\frac{25}{25+0} * 100\% = 100\%$$

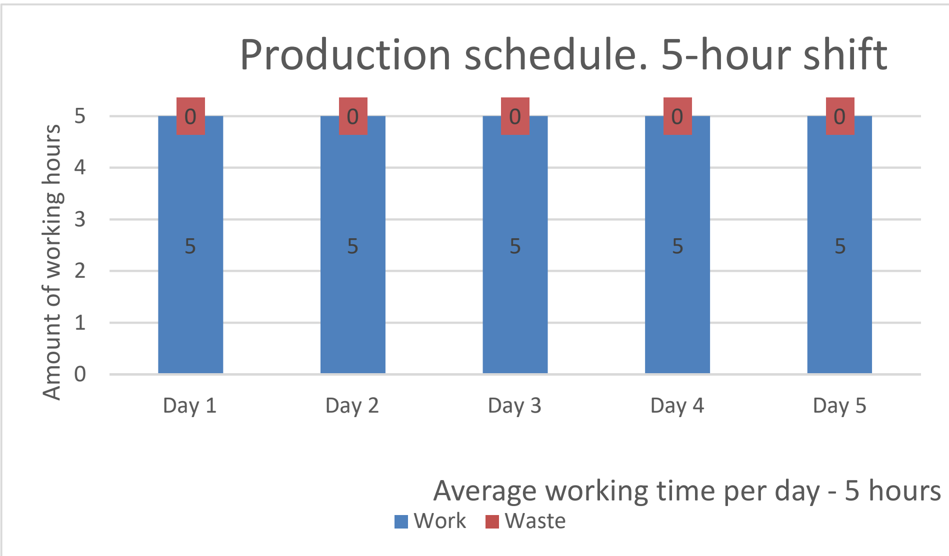


Figure 7 - Optimised production schedule, 5-hour shift

### 1.3.3 Muri

Muri is the waste of overburden, derived from a Japanese word 無理 meaning immoderation, unreasonableness, (Kenkyusha's New Japanese-English Dictionary, 2003). The main key is to relieve unnecessary stress to employees and processes. (Liker, 2004).

Muri is caused by unreliable equipment, fluctuating demand (Mura), poorly laid out workplaces, lack of skills, unclear instructions or poor technological process. The process of brick wall building, when worker leans over to pick up the brick is a good example of Muri. All processes should be studied and all unnecessary actions should be eliminated through the standardisation of processes. When standardised work is implemented to production the following results are observed:

- Higher quality of product and defect-based wastes are eliminated,
- Improved productivity due to better performance and fewer defects,
- Heightened employee morale (due to an examination of safety and ergonomics),
- Reduced costs (Liker, 2004).

### 1.3.4 Muda

Muda is derived from a Japanese word 無駄 meaning wastefulness, uselessness. (Kenkyusha's New Japanese-English Dictionary, 2003). It is a key concept of lean philosophy. The main methodology of waste reduction is to define which processes add value to the final product from an end-customers point of view, and then to eliminate all non-value-adding work (Liker, 2004).

According to Ford "nearly 5% of work adds value to the product and the rest is basically a waste" (Ford, 1922). Value added and non-value added time is shown in Figure 8.

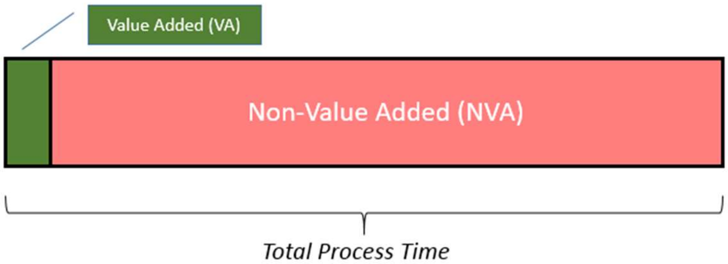


Figure 8 - Value-Adding analysis of operations performed during production (Six Sigma Material, 2018)

All non-value adding processes can be divided into two types as illustrated in Figure 9:

- Non-value-adding and not obligatory. Such activities reduce the profitability of the business and should be eliminated.
- Non-value-adding, but obligatory. Quality control can be an example of such process. Although it might not add value to the end-customer, quality control is often required to meet regulations and standards, e.g. laboratory checks in the food industry. Obligatory activities should be continuously optimised so that less time, material or energy is wasted.

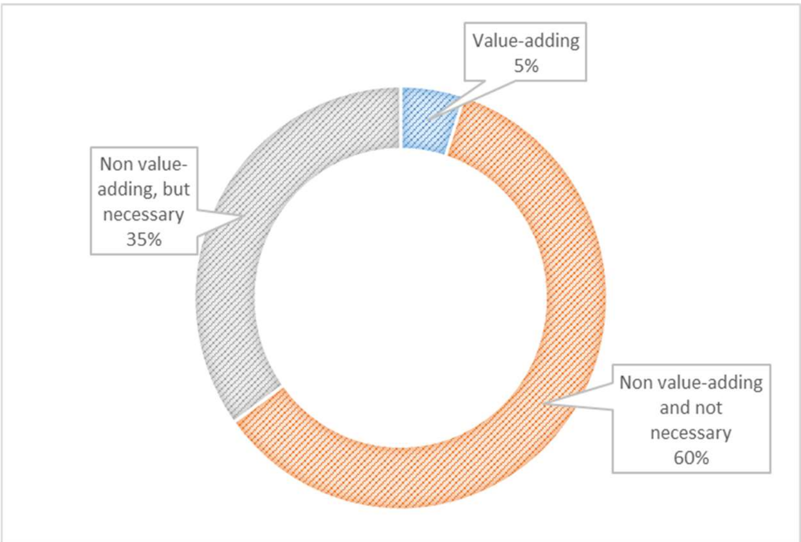


Figure 9 - Value-Adding analysis of operations performed during production (Hines, P. & Taylor, D., 2000)

All waste was divided into seven forms by Taiichi Ohno:

- Transport: unnecessarily moving things, equipment, parts, tools and materials from one location to another;
- Inventory: making more than customer demand, building up unnecessary stocks;
- Motion: unnecessary movement; people walking to get things which should be located closer to the point-of-use;
- Waiting: delays between operations because parts are missing. Stopped work: waiting for parts, machines, or people;
- Overproduction: making too much. Completing a task before it is needed. Making products that the customer has not ordered;
- Over-processing: duplicate or redundant operations, performing wasteful steps that are not required. Blind adherence to traditions;
- Defects: Failing to produce goods or services of right quality. Thus, the amount of rework or scrap is increased (Ohno, 1988).

The last type of waste was added to the list at a later date.

Skill or personnel underutilisation includes the following: failing to use skills and capabilities of the workforce, not listening to people, using their knowledge or learning from past mistakes/issues (Liker, 2004, p. 28).

When so-called lean-thinking is introduced to the business all processes should be analysed, after the management will understand all Muda, Mura and Muri activities changes should be implemented. It is important to perform analysis on a permanent basis, thus continuously improving the performance (Ohno, 1988).

### 1.3.5 Just-in-time

Just in time or JIT is a methodology used in TPS. The main principle can be described in an aforementioned way: if production schedule is defined, it is possible to organise material flow so that all materials, components and subassemblies will be delivered in right quantity to the right place and exactly by the right time to be manufactured, assembled or sold. Moreover, buffer stocks that “freeze” the company’s money should be eliminated. This concept is an important part of the Lean manufacturing philosophy.

### 1.3.6 Jidoka

Jidoka or autonomation is known as intelligent automation. Autonomation or pre-automation is a term used by production engineer of Toyota Motor Corp, Shigeo Shingo to describe one stage of transition from manual to fully automated work. Fully automated work is only possible if the machine can detect and correct flaws in its work, but the implementation of such machines is currently not cost-effective. However, 90% of benefits of full automation can obtained by autonomation or separating workers from machines and placing error-detecting mechanisms in-between (Ohno, 1988).

The first example of Jidoka is automated loom developed by Sakichi Toyoda, as it was mentioned above, the loom was designed to stop when the thread brakes. Thus, no work was added to defected products. According to Jidoka the defect should be noticed and fixed as soon as possible. All causes of the defect should be investigated in order such fault will never happen again.

Jidoka is highly used in JIT manufacturing, since the production is designed to have no time and material buffers. Such optimisation makes JIT production very effective, but very sensitive to any fault which can disrupt the production process. Jidoka introduces the automatic detection of defects and faults during manufacturing. The production is stopped if an error is detected, thus forcing instantaneous attention to the problem. Although halting slows down the production, it is used in order to detect problems and eliminate the spread of bad practices. (Balram, 2007). Kaizen is derived from Japanese word 改善 meaning “improvement” (Kenkyusha's New Japanese-English Dictionary, 2003) and developed by Taiichi Ohno. This practice requires permanent detecting, analysis and solving of any impediment that can occur. Often Kaizen is used along with 5S method, which helps to get to so-called root cause of any defect, fault or impediment. Investigating team can get to the root cause by asking the question “Why?” five times (Ohno, 1988). The number of iterations is not fixed so that it can vary depending on the situation. The last answer is always a process which caused the problem.

Example:

Why are we not able to produce more? We have no more capacity.
Why do we have no more capacity? Only half of the equipment is being used.
Why is only half of the equipment being used? The rest is broken.
Why the rest is broken?. The equipment is not maintained.
Why is the equipment not maintained? **Maintenance practices are not defined**.

### 1.3.7 Kanban

Kanban is a scheduled system developed by Taiichi Ohno and is widely used in lean and JIT manufacturing (Ohno, 1988).

One of the most important rules of Kanban system is limiting work-in-progress or WIP. The limit depends on the application and is usually set according to rough estimations. The effect of implementation of Kanban system is continuously analysed and the WIP limit is reduced as inefficiencies are found and eliminated.

#### 1.3.7.1. Kanban board

Kanban board illustrated Figure 10 and Figure 11 is a method used to visualise and schedule tasks. It has at least three columns for planned, in-progress and finished activities. Tasks are written on paper stickers and attached to the column according to the progress status (Kniberg, 2010). Let us hold a mental experiment. Some company has set WIP limit to be one task and one task has an in-progress status assigned, some activities are already performed and three tasks are still to be executed. Thus, the Kanban board will look like this:


Figure 10 - Kanban board. Step 1

When the task is carried out next planned activity can be performed and stickers are moved in accordance with the current status. In a way, tasks are pulled by the subsequent stage.
Kanban system pushes employees to focus on actual tasks, thereby helping to perform separate tasks faster and allowing to add value to the end-product in early stages of projects (Gross, 2003).

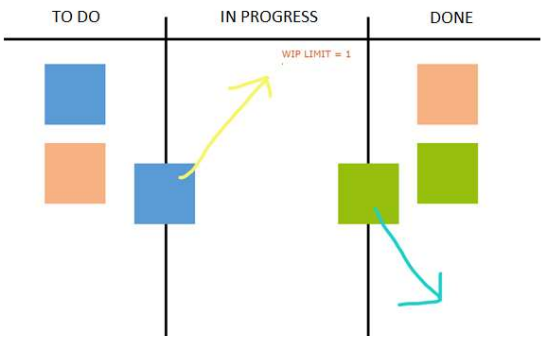


Figure 11 - Kanban board. Step 2

#### 1.3.7.2. Kanban card and three bin system

Each process can be brought to Kanban system shown in Figure 12. Every worker, every plant or every department has some amount of WIP limited by in accordance with Kanban. When current tasks are performed and the amount of WIP less that limit new tasks are assigned. In order the pull system will work three bin system is implemented (JD Edwards EnterpriseOne Applications Kanban Management Implementation Guide, 2018).

There are three bins which contain some amount of products. The first bin is located in the warehouse, the second is located in the factory and the last one is located at the store. When all products are sold an empty bin is delivered to the factory. Factory has its own bin filled with manufactured products, this bin is sent to the store. The factory, in its turn, sends the empty bin to the warehouse, which has its own bin filled with components. This bin is sent to the factory. The empty bin stays in the warehouse. The process is then repeated. In this way, each subsequent task is "pulling" work from the preceding one. Usually, Kanban bin has some red zone for safe-stock so that the demand can be still met during the period of time needed for supplies. Each bin has Kanban card attached, which contains all needed information about the content of bins.

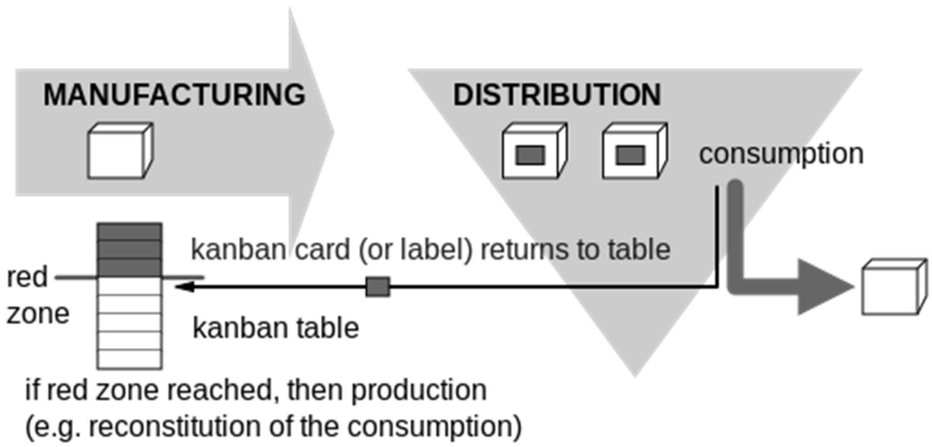


Figure 12 - Kanban bin system working principle (Waldner, 1992)

Three bin system allows easy and fast communication between different departments or workstations. Since the content of bins is used as a safe-stock, thus processes never run out of products.

## 1.4 Cooling system. Definition and operating principle.

### 1.4.1 Cooling system

The cooling system is "a system which cools something such as a building or engine" (Collins English Dictionary, 2018). A large amount of different cooling systems was invented by human beings, for example, refrigerator systems used in railway carriages to keep goods being transported cool, fridges used as a home appliance to store food and slow down the process of spoiling, cooling systems embedded in engines so that they are kept in the operating temperature range. However, the current study is focused on a cooling showcase production.

### 1.4.2 Display cabinet cooler

Cooling showcases or display cabinet coolers illustrated in Figure 13 are mainly used by grocery shops are designed to store food and beverages inside the shopping area. This is done for several reasons: products with short expiration date such as meat or low-temperature storage conditions such as ice-cream or soft drinks require such equipment to keep them in the shopping area. The showcase is designed in order to attract potential customers and to advertise brands using colourful logo stickers on the showcase's body

The body of the showcase cooler consists of two functional modules (I and II in Figure 13).


Figure 13 - The design of a display cabinet cooler

The upper part (I) with the access unrestricted from at least one side. It can be either an open front or glass-door design. This module is used to store goods. The lower part (II) is the "box" with the cooling equipment inside. This module is used to keep cold stored goods. This is the typical plug-In or Integral display cabinet due to the embedded cooling unit with internal condensate disposal. However, there is also another type of showcase coolers presented on the market – remote cabinet. Such cabinets are connected to the separate cooling unit. Thereby remote cabinets have larger storing volumes comparing to the plug-In systems of the same external dimensions. Due to such design the volume of the shopping compartment is used with higher efficiency.

### 1.4.3 Cooling system operating principle:

The required temperature of the air inside the cooler is kept constant due to the heat transfer process (Figure 14). The gas, called a *refrigerant* or *coolant* (typically hydrofluorocarbon-based, chlorofluorocarbon-based or propane) adsorbs the energy (in the form of heat) from the inside of the fridge and emits it to the atmosphere. (Refrigerators, 2018)

Firstly, the compressor constricts the gas, thus the pressure of the refrigerant rises, the energy of the gas increases.

The hot coolant is then pushed forward and goes through the radiator device which is usually designed to be outside of the cooling device's body. The gas exposed to the impact of the room temperature air starts transferring its heat to the atmosphere. During this step the refrigerant becomes liquid in so-called forced condensation process, the energy is transferred to the atmosphere during the liquefaction process.

The liquid then passes the expansion valve and enters the cooling compartment usually called *the chiller cabinet*. During this stage the liquid expands which causes the sudden pressure drop, the energy which was stored as pressure is used by the coolant for the vaporisation. The liquid becomes gas.

The refrigerant absorbs the heat of the air in the cooling compartment. The air inside cools down. During this phase the energy of the air in the chiller cabinet is transferred to the coolant.

The gas is then squeezed by the compressor, the temperature and the pressure are raised. It is done because the gas cannot flow from a cooler place to a hotter place without any work carried out. This work is performed by the compressor allowing the process of cooling to run continuously and repeatedly (Heat Transfer, 2018).

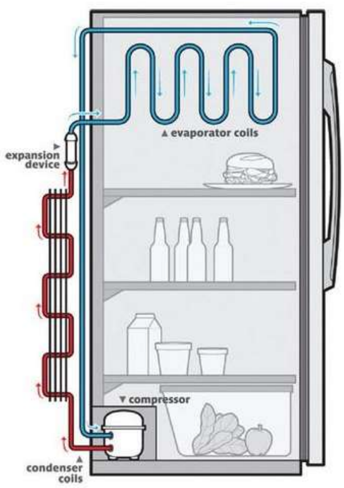


Figure 14 - Working principle of refrigerator

# 2 CONTRACTING PARTY

## 2.1 Commissioning company

The research project was performed at facilities and with the help of personnel of Finnish company Aste Finland Ltd (Figure 15) (hereinafter referred to as ASTE).

Figure 15 - Company logo (Promotional Coolers, 2018)

The company was founded in 2010 by five former employees of Helkama Group in order to develop, manufacture and sell high-quality plug-in display cabinets. All facilities of ASTE as well as its headquarters is located in Forssa, Finland. In 2017 the company became a subsidiary of a Belgian company DRU International NV. ASTE distributes its solutions throughout the Nordic region, in Central and Southern Europe, Russia and Australia. The company has such well-known partners as Carlsberg, Heineken, Unilever, Nestle, Hartwall and PepsiCo.

All production presented in display cabinet market can be roughly divided into two categories: mass production and custom design.

Mass production provides the customer with inexpensive standardised solutions using economies of scale. However, it allows only small or no variations in the design of an end-product. Customised production has significantly smaller volume comparing to the mass production, but unique

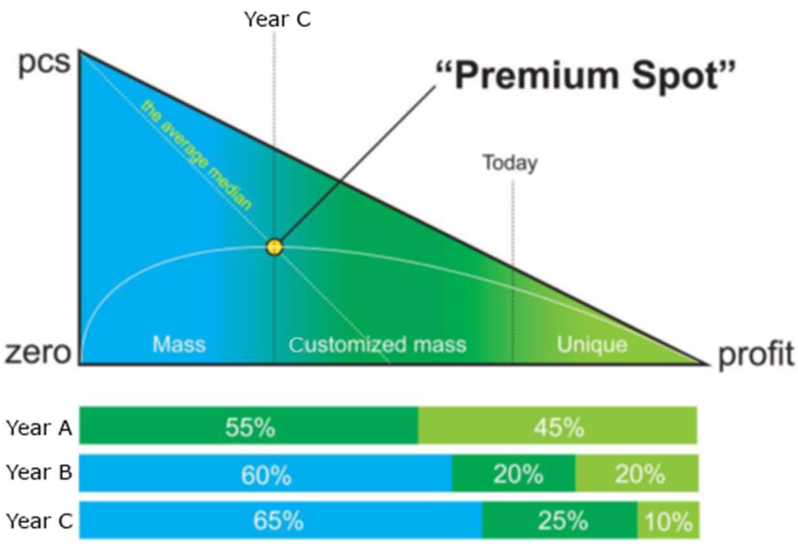


Figure 16 - Strategy of ASTE

solutions can be easily produced, since the production is much flexible. Custom-made units are usually more expensive than mass-produced, thus profit margin is noticeably higher. The aim of ASTE was to develop a hybrid solution to profit from advantages of both mass and custom production. The company provides its customers with mass-customised solutions and is moving to the “premium spot” as seen in Figure 16) meaning that shares of Mass, Customised mass and Unique products in the total production will be 65%, 25% and 10% respectively.

Financial records illustrated in Figure 17 show the growth of the company

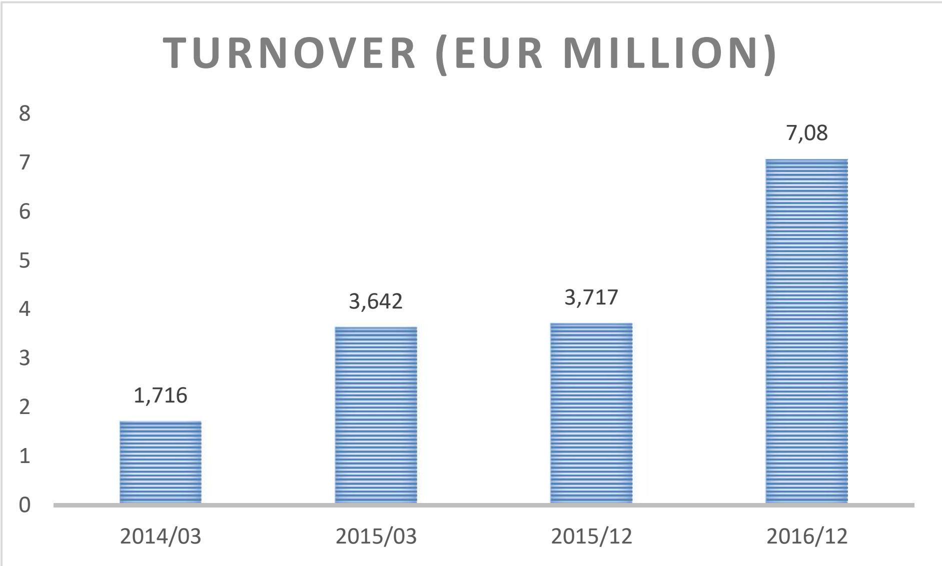


Figure 17 - Turnover of ASTE (Finder.fi, 2018)

### 2.1.1 Management

The management of ASTE (Figure 18, Figure 19, Figure 20, Figure 21, Figure 22) consists of professionals with deep knowledge of processes related to cooling systems: from the design and production to sales and marketing with cumulative experience of more than 100 years

Figure 18 - Jussi Salonen, CEO of ASTE

Figure 19 - Keijo Vaha, Sourcing Manager

Figure 20 - Janne Leppämäki, Design Manager

Figure 21 - Harri Järvinen, Development Manager

Figure 22 - Saku Pelto-Knuutila, Production Manager

### 2.1.2 Market

The European cooler market can be divided into five segments: hypermarkets and supermarkets, food and beverage industry, hard discount stores, independent shops and convenience stores and petrol stations as illustrated in Figure 23.

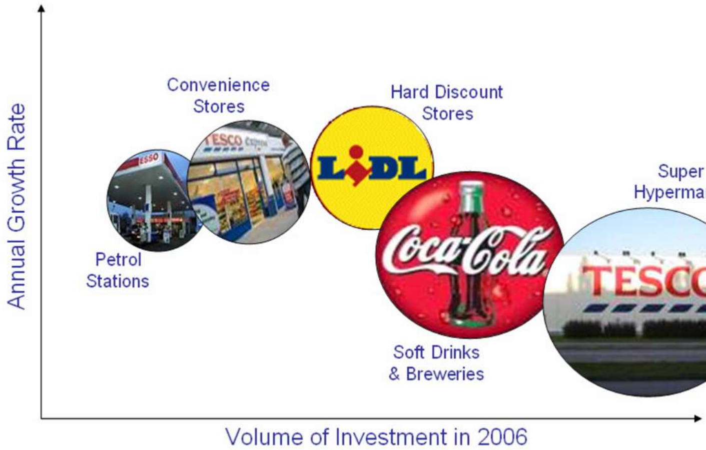


Figure 23 - Volume of investment to display cabinet market, 2006 (Frost & Sullivan, 2007)

Supermarkets and hypermarkets had the major share in investment in 2006 (Figure 23). Supermarkets dominated the food retail distribution in Europe. Since each supermarket has a large number of display cabinets, the share was dramatically increased when new stores were opened (Frost & Sullivan, 2007).

Market research (Frost & Sullivan, 2007) shows that soft drink companies were investing in showcase cabinets for advertising purposes, since a large amount of such cabinets is used in bars, cafes, nightclubs and restaurants.

The rise of convenience stores in the UK and hard discount stores across Europe, particularly in Germany, increased the volume of the display cabinet market (Frost & Sullivan, 2007).

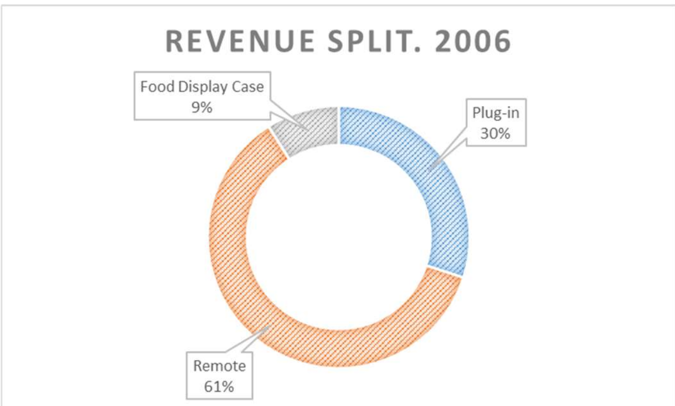


Figure 24 - European market for refrigerated display cabinets. Revenue split, 2006 (Frost & Sullivan, 2007)

In the year 2006 the demand for remote cabinets was 61% of all showcase coolers sold in Europe (Figure 24) and further growth was forecasted. The share of plug-in display cabinets was 30% (Frost & Sullivan, 2007).
Frost & Sullivan research (European Refrigerated Display Cabinet Markets, 2007) shows (Figure 25) that in 2006 Germany, France, Italy and UK shared 77% of the whole European market and Scandinavian countries shared less than 9%.

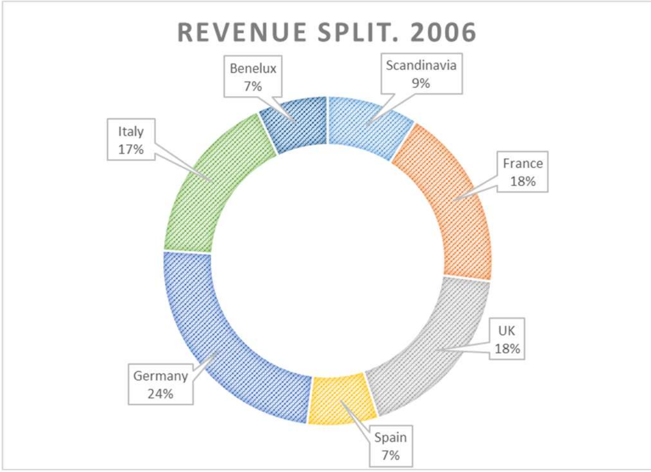


Figure 25 - European market for refrigerated display cabinets. Revenue split by region (Europe), 2006 (Frost & Sullivan, 2007)

Results of market research conducted in 2008-2009 (ASTE FINLAND Oy, 2013) shows that the market capacity of European and CIS countries was 1.43 million in 2008 (Figure 26). It should be noted, that not only new facilities require showcase coolers, since broken coolers are removed and outdated solutions are replaced with new ones during the renovation of stores.

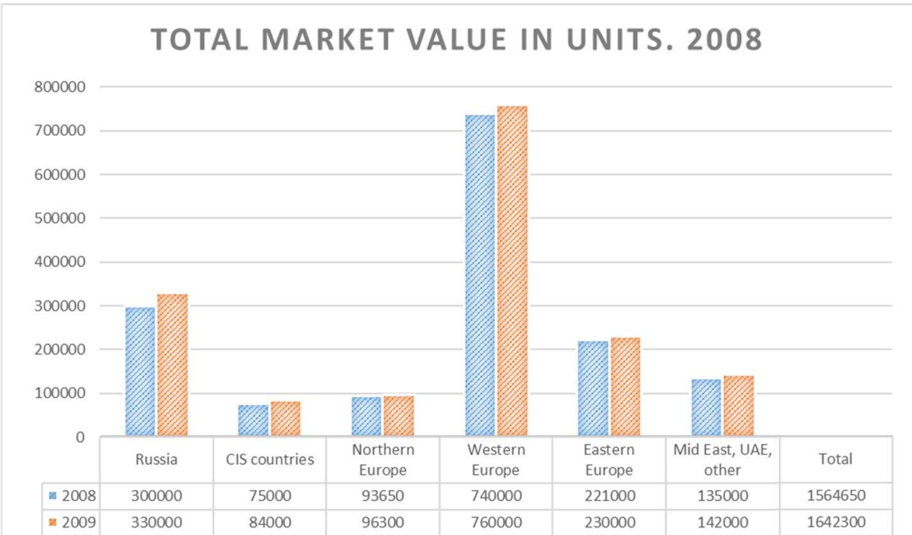


Figure 26 - World market for refrigerated display cabinets, 2008 (ASTE FINLAND Oy, 2013)

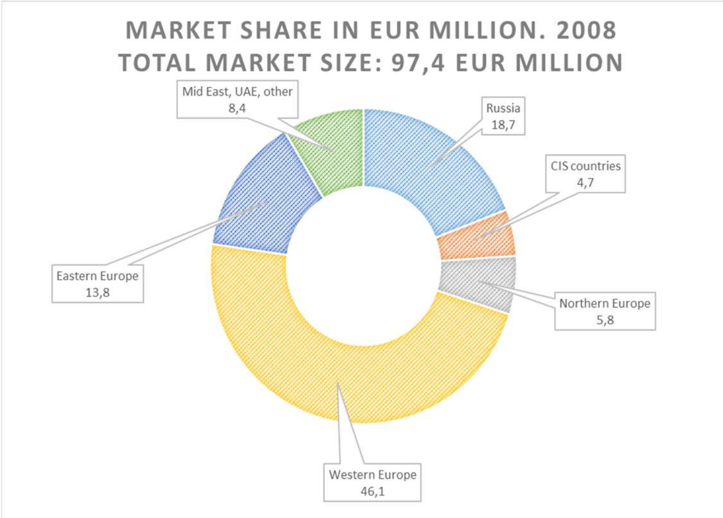


Figure 28 - World market for refrigerated display cabinets. Market share by regions, 2008 (ASTE FINLAND Oy, 2013)

The research of European business-to-business display cabinet market (ASTE FINLAND Oy, 2013) shows that total available market or TAM will be divided among three main types of commercial coolers. The forecast of total average European market split (Figure 28) shows that glass door coolers and open front coolers will represent 80% of total market share (ASTE FINLAND Oy, 2018).

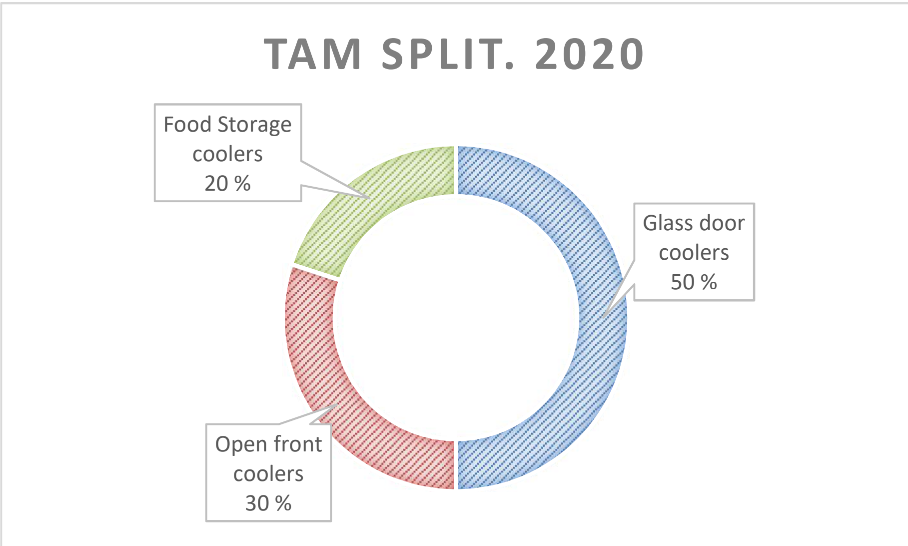


Figure 27 - European market for refrigerated display cabinets. Total average market split, 2020 (ASTE FINLAND Oy, 2013)

### 2.1.3 Benchmarking

The table (Appendix 1) represents the results of research conducted by ASTE (2013). It can be seen that Iarp which became part of the Epta Group in 2013 had the largest total capacity equal to 700 000 of products, however according to Frost & Sullivan (2007) such companies as SFA, Ügur, Klimasan entered the European market with aggressive price policies, offering low-cost products. As it was mentioned above, soft drinks & beverage companies were the second investors in display cabinet market after super & hypermarkets (Frost & Sullivan, 2007). Due to this, partners of such large companies as The Coca-Cola Company and PepsiCo Inc. are very strong competitors with high demand in the US.

### 2.1.4 Tendencies of cooler market

Development of the design in order to increase the convenience of the device usage, to improve storing conditions and to lower the laboriousness of device installation, maintenance and repair. In addition, market research (Frost & Sullivan, 2007) shows that open front models are getting more popular due to the ease of the access to goods stored.

More products tend to have so-called bio-fresh compartments which allow extending the shelf life of goods stored in fresh, non-frozen conditions (-2°C… +2°C) (ASTE FINLAND Oy, 2018).

Control switches are moved from the cooling chambers to the outside control panels. Working mode colour representation is introduced, sound notifications are used to inform the operator about the failure or usage instructions violation. Sophisticated software is used to control the temperature and thus allow to lower the energy consumption through the more efficient use of energy (ASTE FINLAND Oy, 2018).

Transparent materials are more widely used in the design of shelves, sides, doors and other components. The tempered glass or polymer materials are used in such designs (ASTE FINLAND Oy, 2018).

New designs tend to use both pipe and air cooling systems, when even and constant temperature conditions are maintained by the combination of traditional cooling system and the cool air, which flows through the cooling compartment. Ventilation is also used with radiator devices to allow faster heat dissipation.

Embedded deodorators are used to eliminate the unpleasant smell. Such deodorators are either automated or remotely controlled by the operator e.g. the grocery store worker (ASTE FINLAND Oy, 2018). Cold accumulators are introduced to the design of cooling devices to keep stored goods at the low temperature when the compressor is not working, to stabilise temperature conditions during its cyclic operation and to allow fast cooling of new goods being inserted. In the past years it was a common practice to use only artificial cold accumulators, however during cold seasons and especially in countries with cold climate it is wise to use natural cold accumulators, which uses cold climate conditions to the benefit of energy savings. Such natural cold accumulator designs appear in the most recent designs of coolers (Shahov V.A & Kozlovtsev A.P, 2015). In addition, the use of night curtains becomes a common practice. Such curtain keeps cold inside the storing compartment of the open front cooler during the night, thus lowering the energy consumption. It allows the end-users i.e. convenience stores, petrol stations, supermarkets to decrease their operating costs (ASTE FINLAND Oy, 2018).

Technological processes of production, device design, component materials, coolant and power consumption are changed to correspond the ideology of environmentally friendly design and to satisfy environmental regulations and to benefit from government support programmes. In addition, bactericidal coating of the storing compartment is being implemented to help users maintain a healthy storage space, study (Kapmann, De Clerck, Kohn, Patchala, Langerock, Kreyenschmidt, 2007) shows lower contamination of refrigerator surfaces treated with silver compounds compared to the untreated material: “This [study] indicates that the silver-based antimicrobial … the material used in refrigerators … protects the inner walls of the refrigerator and helps to prevent them being a hot spot for contaminants that could be transferred upon contact with food”.

The fusion of the device’s and building’s interior ’s designs becomes a common practice. Cooling devices become more customised to correspond the need of users and, in case of shopfront coolers, food industry companies: led lightning and illuminated logos are introduced to the design to attract the buyer and promote brands or particular products.

There is a trend in the B2B market: customers require quick response, especially during the Jan-Aug period, when there is the largest demand for the cooling systems. The typical lead time is 4-8 weeks according to ASTE reports (Order Report, 2018; 2017).

## 2.2 Future focus of ASTE

The strategy of ASTE is based on technology and design improvements with a slogan: "Create top-of-mind and lead (not follow) newest trend and technologies!".

New technologies will help ASTE to compete with other companies, making products and production techniques more efficient. Moreover, continuous implementation of green technologies will ensure a longer lifespan and lower energy consumption, this will allow products to meet environmental regulations, it will also endorse the reputation of a reliable partner, which responds to customer's demand with comprehension.

ASTE will continue developing modular products in order to meet the wishes of the client and allow customisation. Thus providing customers with the easily adjustable sizing of products and the highest visibility in-store.

## 2.3 Current production

### 2.3.1 Product families

The product range of ASTE (Appendix 2) can be divided into four broad directions or series: AVO, CELIT, SUBSTER, and AF. However, there are several principles of how all products are designed. The main focus of product developers is concentrated on modular design. Since the strategy of ASTE is to produce in "premium spot" and benefit from both mass and custom production advantages, it is important for the company to devise flexible platforms which allow unproblematic customisation along with standardised production techniques which can be performed on the same equipment by the same workers. It is essential to note that overwhelming majority of ASTE products is designed to contain bottles and cans with beverages, however some models can be used to store chilled food, ice-cream and snacks.

# 3 PRODUCTION AND TECHNOLOGICAL PROCESS

## 3.1 Production

Current production facility (Figure 29, Appendix 3) is divided into three compartments. Office and work-related welfare premises (A), production and R&D (B), warehouse (C).

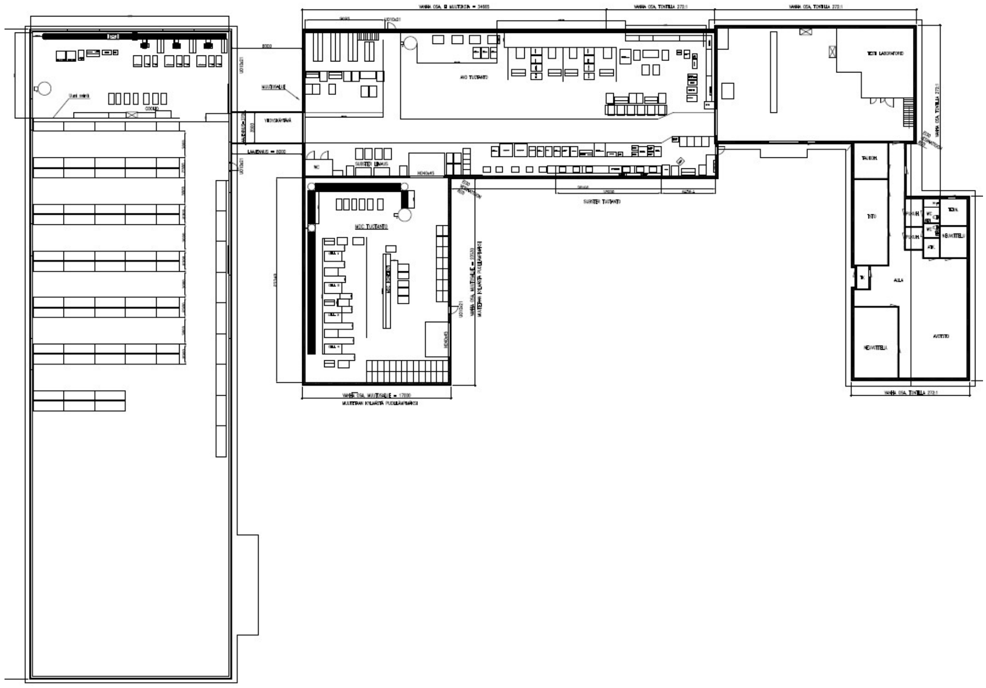

Figure 29 - Factory layout

- The total workshop area is 1400 m$^2$.
- Total warehouse area is 1700 m$^2$.

### 3.1.1 Workshop

Production of ASTE is located in four separate compartments of one building. (Appendix 3, Appendix 4, Appendix 5, Appendix 6, Appendix 7). Shop B1 (Appendix 4) is used as R&D, service and cutting area. Shop B2 (Appendix 5) is utilised for production of AVO and SUBSTER as well as a pre-assembly area for electronic components and radiators. Production of CELIT is located in Shop B3 (Appendix 6) and has its own unloading point for pre-made cooler bodies. Shop B4 (Appendix 7) is used for the production of COOLIO.

ASTE performs only assembly operations with pre-shaped components, thence no heavy equipment is used for production. Operations are performed by humans with the help of pneumatically or electrically driven tools, thus the production can be classified as a mechanised assembly.

All AVO coolers are produced in batches by dint of single-model line, with the typical batch size of 40, 80 and 120 units.

### 3.1.2 Tools and equipment

#### 3.1.2.1. Tools

##### 3.1.2.1.1. Overview

Since was the majority of all joints used to fix components in assemblies is temporary screw- or bolt-type connection, one of the most frequently used tools is a screwdriver. Cordless electric screwdrivers are used for basic connections and pneumatic impact screwdrivers are used to fix glass sides of AVO Harmony products.

##### 3.1.2.1.2. Glueing tools

Few operations require permanent fixing with the help of glue. Both assembly adhesive and hot glue are used (Figure 30. Figure 31, Figure 32). Some operations require the use of cutters, knives, pliers and rubber hammers.

Figure 30 - Adhesive applicator gun (Expressgrass, 2018)


Figure 31 - Cordless Caulk and Adhesive Gun (U.S.A., 2018)


Figure 32 - Extrusion Glue Gun (Bühnen GmbH & Co., 2018)

3.1.2.2. Equipment

3.1.2.2.1. Brazing equipment

The design of cassettes requires brazing of pipes after all components of the cooling system are installed, thus each production line has brazing equipment (Figure 33) and certified worker assigned to perform this

Figure 33 - Brazing equipment (Profi Schweiss Shop, 2018)

operation.

3.1.2.2.2. Evacuation and filling equipment

After the cooling system is brazed a vacuum pump (Figure 34, Figure 35) is used to evacuate the cooling system of atmospheric pressure and moisture.

Figure 34 - Vacuum pump (CPS Products Inc., 2018)

Figure 35 - Filling equipment (L. P. Gas Engineers & Consultants, 2018)

### 3.1.2.2.3. Testing equipment

Each cassette should pass several quality checks before it can be joined with other sub-assemblies.

All brazed connections are inspected for gas leakage (Figure 36). Only if there is no gas escaping cooling system, this quality check is passed.

The second quality test is performed with the help of electrical testing equipment (Figure 37), which checks if the system is operating correctly and end-users will not get any electrical injuries.
No special equipment is required for the last check, which is performed before the display cabinet is packed. The cooler is connected to the mains and operates for several minutes, thus ASTE is ascertained that the end-product operates properly.

Figure 36 - Gas leak detector (Smartsensor, 2018)

Figure 37 - Electrical testing equipment (Zhenhuan, 2018)

### 3.1.2.2.4. Packing equipment

After the cooler passes final check it is wrapped with the use of the stretch-wrapping machine.

Then the end-product is strapped to be fully fixed and ready for transportation. Both hand-tools and automated machines are used for this operation (Figure 38. Figure 39, Figure 40).

Figure 38 - Stretch Wrapping Machine (Machine Solution, 2018)

Figure 39 - Automatic strapping machine (Dynaric, Inc., 2018)

Figure 40 - Cordless strapping machine (May Dong Dai, 2018)

### 3.1.3 Material handling

The majority of components come on euro pallets and forklift trucks are used to deliver them to work cells. Small components can fit in boxes which can be easily moved by hands. No special tools are used to lift components to be attached to the assembly, however, since the weight of cassette can reach 76 kg, cassettes are moved with the help of wheels attached to their bottom. Moreover, before the cassette is placed on the pallet a special device is attached to the bottom of the pallet, so workers can move pallet by pushing it. After cooler is tested it is moved with the help of manual pallet truck.

Gravity conveyors (Figure 41) are used for the ease of movement of COOLIO and CELIT products. It can be seen from the layout of CELIT line (Appendix 6) that main assembly cells are placed beside the conveyor. The body of a cooler is placed on the inclinable pneumatic (Figure 42) table. The table is then returned to a horizontal position forming and worker performs operations on the cooler. The table is then set to horizontal position and assembled display cabinet is shifted back to the conveyor.

Manual pallet trucks (Figure 43) are used to move inter-operational materials such as components of sub-assemblies.

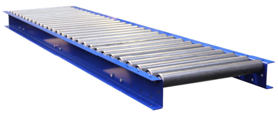

Figure 41 - Gravity roller conveyor ( KBR Machinery Conveyor Sections / JRM Holdings Limited, 2018)

Figure 42 - Pneumatic table (RND Automation and Enginnering, LLC, 2018)

Figure 43 - Pallet Truck (Pallet Trucks UK, 2018)

### 3.1.4 Quality

The amount of defects is small and is mainly caused by supplier's components which are damaged. All components undergo visual inspection before being assembled, however some defects, for example wrong hole positions are found during cassette assembly or main assembly operations, thus both component sub-assembly and joining time are wasted

## 3.2 Sample product

Since the study was conducted for the main product line, the cooler produced in the largest quantity was chosen as a sample product.

### 3.2.1 AVO Harmony 135-60

### 3.2.2 Product description. Sample product parameters.

AVO Harmony 135-60 (hereinafter, “AVOH 135-60”, “135-60”) is an open front cooler with full-glass sidewalls, which can be performed in white, black or grey (Figure 44). The display cabinet can be equipped with stickers with brand logos depicted on them. There are several reasons why it was chosen as a sample product (Jampol'skij E.S., Solovej Z.I., 1975):

- The amount of sample products to be released prevails in the annual plan,
- The amount of total labour input represents a significant part of total labour input,
- The design of AVOH 135-60 is almost similar to AVO Harmony 135-50, AVO Harmony 135-87 and AVO Harmony 170-54,
- Less than 10% of assembly operations are different from AVO Harmony 145-60 and AVO Harmony 145-87,
- Less than 35% of assembly operations are different from AVO Standard and AVO Wood models.

Figure 44 - AVO Harmony 135-60

### 3.2.3 Assembly operations.

#### 3.2.3.1. Cassette assembly

Appendix 8 depicts all components which are used to assemble one 135-60 unit. Operations in orange boxes represent main phases of production, namely assembly, cleaning and adjustment of stickers, packing. Each phase has different components and sub-assemblies which should be joined together in order to complete the phase.

The first component to be assembled is cassette, which in its turn is assembled from:

- Evaporator fan plate or front fan plate/fan plate,
- Condenser fan plate or back ventilator panel/back vent,
- Cassette body or insulation box,
- Bottom plate or bottom,
- Condenser or radiator, which is brazed in another shop before it enters the assembly,
- Evaporator, which comes from the supplier,
- Sensor plate with control unit or sensor panel,
- Compressor or comp,
- Other components.

Some components are, in their turn, assembled from smaller parts which are represented in green.

#### 3.2.3.2. Main assembly

The cassette is pushed to main assembly cell and is then joined with:

- Top panel or top,
- Back wall or back panel/back,
- Glass sidewalls or glasses,
- Curtain plate or curtain which allows the end-customer to use night curtain in order to save energy,
- Front grill panel or front grill,
- Two or three shelves: the amount depends on the will of the customer,
- Other components.

Glasses are fixed by branded fasteners or FB. The front grill is fixed by rigid branded fasteners or FBR.

### 3.2.4 Non-assembly operations.

#### 3.2.4.1. Cleaning and Sticker attachment

During this phase several stickers with customer logo are attached to the display cabinet, then serial number sticker (hereinafter, “serial number”, “sticker”, “serial no”, “serial №”, “serial number”) is attached to the wall of storing compartment. ASTE sticker with the company logo is placed on the top panel. Power cord and product manual are put in storing compartment.

#### 3.2.4.2. Packing

To prevent any damage of coolers during transportation four corners made from polyurethane foam are used. Smaller polyurethane corners are laid between each shelf and glass to restrict any movements. The product is then wrapped with stretch wrap.
Two stickers with all needed information for shipping are placed on the stretch wrap (Figure 45).
Finally, cooler is strapped with two strap bands and placed in the storage area, where it waits for the warehouse worker to pick take it.

Figure 45 - Packed units

### 3.2.5 Production scheme

Appendix 9 represents current production operations in a schematic way. Rectangles represent main steps performed by workers (yellow) and by machines without supervision (orange). Hexagons represent components and sub-assemblies used at a particular step. Blue hexagons represent so-called pre-operations, which represent operations, which are carried out proactively for the whole batch, e.g. cutting plastic LED covers in large quantities before the production will start. Purple hexagons represent components which are reused after the display cabinet is released.

The green colour is used for accompanying document which contains information about the particular product which should be produced. The red colour is used to indicate special components related to

- transportation and components e.g. polyurethane corners or timber pallet;
- promotion of ASTE e.g. sticker with ASTE logo on it;
- service and maintenance e.g. power cord, serial number sticker.

It can be noted from the diagram that there is one grey rectangle. Since some customer order coolers without stickers this operation is optional.

## 3.3 AVO shop layout. Personnel

### 3.3.1 Layout

AVO production is located in Shop B2 and is the main production line according to the strategy of ASTE. The area of AVO production shop is 350 $m^2$ and contains work cells for all operation, required in assembly, except for radiator brazing, cutting and control unit firmware installation operations.

Appendix 10 (N.B. Picture is not up to scale) depicts how production steps are performed in current conditions in accordance to factory layout. The diagram shows inter-operational flow.

There is large corner table on which the cassette is assembled and tested. The cassette is then placed on a pallet and moved to main assembly cell. N.B., the diagram depicts one cell for the ease of representation and understanding, however AVO line can have up to four cells working).

After the main assembly is finished, the cooler is moved to washing area, where it is cleaned from grease and dust. Shelves and stickers are then attached. After the serial number is affixed the display cooler is packed and put to storing area.

There is a blue translucent box in the scheme which does not represent the real working area, it represents all pre-operations which are performed in other shops.

Green arrows represent the flow of product being assembled. Red arrows show the flow of sub-assemblies. Blue arrow represents the outflow. Violet arrows symbolise flow of “pre-work” components.

### 3.3.2 Personnel

There were eight workers performing operations in AVO shop when the research project started.

Shift supervisor was performing brazing, evacuation and filling operations as well as controlling the production and solving problems. Two employees were attached to main assembly work cells. Other five workers were performing pre-operations, sub-assemblies, washing, sticker affixing and packing operations. When some component was missing, e.g. the cassette, operators of successive workstation were performing other work in order to use the idle time for work. The team of 8 workers was releasing an average of 26 AVOH 135-60 per day.

## 3.4 Time study

### 3.4.1 Definition of time study

In order to understand how production is performed and detect the bottleneck there a time study was conducted.

According to British Standard Institute time study has been defined as “The application of techniques designed to establish the time for a qualified worker to carry out a specified job at a defined level of performance.” (BS 3138 (1992).

### 3.4.2 Preparation and realisation

Each production step was broken down into the smallest operations called sub-operations before the study was performed.

A stopwatch was used to measure the time. It was important to take several time measurements from each operation: three times for each sub-operation and ten times for production step only. In order to reduce the stress of workers being observed, the study was executed from some distance and the observer pretended like another operation is being researched.

The research was conducted with no hitches, however, it is important to state that each worker has own pace affected by age, physical and mental conditions and skill. After the research was performed, all collected data was put in order and the average time was calculated for each sub-operation and each production step (Appendix 10). Production scheme (Appendix 9) was updated (Appendix 11).

Finally, outcomes as shown in Table 2 were presented to the management, the reliability of the results was proven by the production manager and the shift supervisor. It was discovered that such operations as led cover cutting and price tag cutting should not be taken into account due to changes in the technological process.Each operation is described in a detailed way in Appendix 12, average time for each operation look like this:

Table 2 - Time obtained during the time-study

| | |
|---|---|
| Bottom | 01:35 |
| Insulation | 10:00 |
| Compressor | 02:30 |
| Sensor plate | 01:40 |
| Fan plate | 02:25 |
| Cassette | 07:31 |
| Evacuation pre-work | 02:54 |
| Evacuation post-work | 02:15 |
| Filling | 00:08 |
| Leakage inspection | 00:20 |
| LED Converter | 01:30 |
| Back Vent | 01:54 |
| Cassette Final Assy | 04:00 |
| Test | 02:30 |
| Curtain plate | 04:06 |
| Back wall | 05:25 |
| Top plate | 02:54 |
| Front grill | 02:22 |
| Shelf | 01:19 |
| Ceiling | 01:38 |
| Washing | 02:30 |
| Stickers | 07:15 |
| Packing | 05:25 |
| FBR | 00:21 |
| FB | 00:04 |
| Serial No. | 00:30 |
| Price Tag prep | 00:15 |
| Pre Test | 02:00 |
| Post Test | 00:30 |
| Cutting cell | 00:30 |
| 25 LED prep | 03:30 |
| Socket preassy | 00:10 |

### 3.4.3 Allowances

It is a common practice to add various allowances to the normal time: Performance rating or PRF is used to compensate for the difference in pace of workers performing same operations. The rating of 106% was used.

#### 3.4.3.1. Rest and personal allowances

Rest and personal allowances or RPA are used in order to allow the worker to relieve physiological and psychological stress, to recover from fatigue. Standard rest allowance or RA is 4%. Personal allowance or PA includes time for smoking, drinking water, washing hands and other basic needs. The allowance depends on how labour-intensive is the task performed by the employee and on the sex, thus basic allowance is 5% for male workers and 7% for female workers (Anil, Kumar, Suresh, 2008). The allowance of 7% was used to correspond the needs of both.

#### 3.4.3.2. Contingency allowance

Contingency allowance or CA is intended to compensate the worker for the time to prepare workplace, to obtain necessary tools, to prepare and maintain the equipment, to clean the place after work is performed. This allowance is also used to cover time spent during replacement of a broken tool or during short power failures. This allowance depends on technological process and normally does not exceed 5% (Anil, Kumar, Suresh, 2008). Due to the low amount of sophisticated equipment and flexibility of production line, the allowance of 3% was used.

### 3.4.3.3. Total allowance:

$$Total\ allowance = TA = PRF + RA + PA + CA$$
$$= 106\% + 4\% + 7\% + 3\% = 120\%$$
$$ST = Observed\ time\ \times Time\ allowance\ = OT \times TA$$
$$= Standard\ time$$

Observed time was then multiplied by 1.2 to get standard time for each operation (Table 3).

Table 3 - Allowance calculation for each operation

| Operation name | Time | PRF | RA | RA | CA | TA | Standard Time |
|---|---|---|---|---|---|---|---|
| Bottom | 01:35 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 01:54 |
| Insulation | 10:00 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 12:00 |
| Compressor | 02:30 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 03:00 |
| Sensor plate | 01:40 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 02:00 |
| Fan plate | 02:25 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 02:54 |
| Cassette | 07:31 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 09:01 |
| Evacuation pre-work | 02:54 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 03:29 |
| Evacuation post-work | 02:15 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 02:42 |
| Filling | 00:08 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:10 |
| Leakage inspection | 00:20 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:24 |
| LED Converter | 01:30 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 01:48 |
| Back Vent | 01:54 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 02:17 |
| Cassette Final Assy | 04:00 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 04:48 |
| Test | 02:30 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 03:00 |
| Curtain plate | 04:06 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 04:56 |
| Back wall | 05:25 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 06:30 |
| Top plate | 02:54 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 03:29 |
| Front grill | 02:22 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 02:50 |
| Shelf | 01:19 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 01:35 |
| Ceiling | 01:38 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 01:57 |
| Washing | 02:30 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 03:00 |
| Stickers | 07:15 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 08:42 |
| Packing | 05:25 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 06:30 |
| FBR | 00:21 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:25 |
| FB | 00:04 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:05 |
| Serial No. | 00:30 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:36 |
| Price Tag prep | 00:15 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:18 |
| Pre Test | 02:00 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 02:24 |
| Post Test | 00:30 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:36 |
| Cutting cell | 00:30 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:36 |
| 25 LED prep | 03:30 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 04:12 |
| Socket preassy | 00:10 | 106,00% | 4,00% | 7,00% | 3,00% | 120,00% | 00:12 |

Calculated values were used to define total production time of one 135-60 (Chapter 3.4.4.)

### 3.4.4 Minimal lead time. DNA

So-called DNA-diagram was created for 135-60 (Appendix 13). The timeline: each row indicates the time period of 30 seconds. Thus two rows symbolise 60 seconds or a minute.

The diagram is used for theoretical and approximate calculations and has a distinct difference from the reality: since the step of the timeline is 30 seconds, all values were rounded up. For instance, if the operation takes 1:54 seconds, it will be represented by four cells or two minutes, thus the diagram will not take 6 seconds into account.

Columns represent tasks performed by workers or machines. Each operation has its own colour and name assign and the production step at which certain component is required is defined by the colour.

Yellow area at the end of the operation represents 20% allowance, however the representation obeys one rule: if the observed time for the operation is 42 seconds or 2 cells, the total time will be

$$ST = OT \times TA = 42\ sec \times 120\% = 54\ sec$$

Since the observed time and the total time are represented by the same amount of cells, the allowance is not indicated by yellow colour.

From the DNA diagram we can see that minimal lead time is 85 minutes (Figure 48). The total theoretical time to produce one unit is obtained by simple calculations and is equal to 118.5 minutes and includes 13.5 minutes of machine time. However, it does not take into account “pre-work” time which is 4.82 min for one 135-60.

Table 4 - Main values obtained with the help of DNA-diagram

| | |
|---|---|
| Minimal lead time | 85 minutes |
| Main time | 118.5 minutes |
| Pre-work time | 4.82 minutes |
| Unit time | 123.32 minutes |

### 3.4.5 Total working time

The operator of AVO line has to work 8 hours per day according to the contract. A lunch break allowance of 30 minutes is added to 8 hours. Moreover, the policy of ASTE obliges every worker to have two coffee breaks 12 minutes each. The allowance of 1 minute was added to each break to compensate for the time it takes for the operator to reach the workplace.

$$Tot.\,daily\,working\,time\,(\mathrm{min}) = \\ = Tot.\,hours \times 60 \\ - \; C.\,break\,time \times C.\,breaks\,tot. - Allow. \times Breaks\,tot. \\ = \\ = 8\,h \times 60 - 12\,\mathrm{min} \times 2 \; - 1\,\mathrm{min} \times 3 \; = 453\,minutes$$

Thus, total working time used in for calculations was 453 minutes.

### 3.4.6 Number of workers. Method I

The next step of the research project was to investigate how much workers does ASTE need to produce the pre-defined amount of 135-60.

The amount of AVOH 135-60 which one employee can produce is obtained by diving daily working time by total production time

$$Capacity\ of\ labor = \frac{Daily\ working\ time}{Unit\ time} = \frac{453\ min}{123.32\ min} = 3.673\ \frac{pcs}{day \times per}$$

The number of workers needed to produce a certain amount of units was calculated according to aforementioned values.

10 units per day:

$$Tot.amount\ of\ workers = \frac{Amount\ of\ units\ to\ be\ produced \times (Unit\ time)}{Tot.daily\ working\ time} = \frac{10\ pcs\ \times (123.32\ min)}{453\ min} = \frac{1234}{453} = 2.7 = 3\ workers$$

Thus, three operators can produce 10 AVOH 135-60 per day.

20 units per day

$$\text{Tot. number of workers} = \frac{2467}{453} = 5.5 \rightarrow 6\ workers$$

30 units per day

$$\text{Tot. number of workers} = \frac{3700}{453} = 8.2 \rightarrow 9\ workers$$

40 units per day

$$\text{Tot. number of workers} = \frac{4933}{453} = 10.8 \rightarrow 11\ workers$$

50 units per day

$$\text{Tot. number of workers} = \frac{6166}{453} = 13.6 \rightarrow 14\ workers$$

60 units per day

$$\text{Tot. number of workers} = \frac{7400}{453} = 16.3 \rightarrow 17\ workers$$

## 3.5 Bottlenecks detected in the production

When the research project started two bottlenecks were detected in the production of the sample product.

The first one was the evacuation equipment, or simply vacuum pump, which creates a vacuum in the cooling system before it is filled with the refrigerant. The approach of the contracting party is so that the evacuation must last at least 10 minutes of machine time. The allowance of 30 seconds was used to assure that the time to connect and disconnect hoses is considered. Since it takes 10.5 minutes to perform evacuation operation for the sample product, the maximum of parts that can be produced per day is the number of working minutes per day divided by the time it takes for the product to undergo this operation.

$$Production\ rate = \frac{\text{Tot. daily working time}}{\text{Operation time}} = \frac{453\ min}{10.5\ min} = 43.4\ units\ per\ day$$

However, if we consider each working day, it takes time for the first cooler to proceed all the operations until it reaches the evacuation and in the same way it takes time for the last cooler produced to proceed all workstations until the end product is ready to be moved to the warehouse, thus the production flow will change.

It takes 20 minutes for the product to reach the evacuation station and 54 minutes to become the end product after the operation is performed.

$$Realistic\ production\ rate = \frac{Available\ daily\ working\ time}{Operation\ time} = \frac{453\ min - 20\ min - 54\ min}{10.5\ min} = \frac{379\ min}{10.5\ min} = 36.1\ units\ per\ day$$

The second bottleneck is defined by the capacity of main assembly cells. Since it takes 24 minutes to perform main assembly operation for the sample product, the maximum of parts that can be produced per day is the number of working minutes per day divided by the time it takes for the worker to execute the main assembly operation.

$$Production\ rate = \frac{453\ min}{24\ min} = 18.875\ units\ per\ day$$

The more assembly cells exist, the less time each subsequent cell has in case of nonparallel operations after and before it. It is easy to prove that if washing, applying stickers and packing takes, for example, 19 minutes and can only be performed in series, the first assembly cell should finish the operation at least 19 minutes before the workday ends, the second cell should then release the cooler 38 minutes before the workday ends. So the second cell has 19 minutes less time than the first cell.

$$Realistic\ production\ rate = \frac{453\ min - 42\ min - 19\ min}{24\ min} = 16.3\ units\ per\ day$$

$$392\ min - 19\ min = 373\ min$$

The third cell will have 38 minutes less time than the first one. The same calculations can be applied to the operational time of work cells before

$$392\ min - 42\ min = 350\ min$$

Calculations allow understanding which operations are closer to the bottleneck point. The theoretical possibility that an operation is a bottleneck is defined by two factors: number of cells, which perform a certain task in parallel and the operation time. The lower is the first one and the higher is the second one, the more likely production operation is a bottleneck. Table 5 depicts a list of operations sorted from the most-likely to be or become a bottleneck to the less-likely. Note that the result for each component does not depend on other components, moreover, the calculations are based on the principle described in the previous paragraph and do not take into account the stock made during previous working days.

Table 5 - Bottleneck analysis

| Operation name | Number of Cells | Comp/day | 135-60/day |
|---|---|---|---|
| Insulation | 1 | 31 | 31 |
| Evacuation | 1 | 36 | 36 |
| Cassette | 1 | 37 | 37 |
| Stickers | 1 | 43 | 43 |
| Back wall | 1 | 57 | 57 |
| Packing | 1 | 57 | 57 |
| Main Assembly | 4 | 64 | 64 |
| Curtain plate | 1 | 75 | 75 |
| Cassette Final Assy | 1 | 77 | 77 |
| Evacuation pre-work | 1 | 106 | 106 |
| Top plate | 1 | 106 | 106 |
| Shelf | 1 | 234 | 117 |
| Compressor | 1 | 123 | 123 |
| Washing | 1 | 123 | 123 |
| Fan plate | 1 | 128 | 128 |
| Front grill | 1 | 130 | 130 |
| Evacuation post-work | 1 | 137 | 137 |
| Test | 1 | 148 | 148 |
| Pre Test | 1 | 154 | 154 |
| Back Vent | 1 | 161 | 161 |
| Sensor plate | 1 | 185 | 185 |
| Ceiling | 1 | 189 | 189 |
| Bottom | 1 | 195 | 195 |
| LED Converter | 1 | 205 | 205 |
| FBR | 4 | 3572 | 446 |
| Price Tag prep | 1 | 1227 | 613 |
| Serial No. | 1 | 614 | 614 |
| Post Test | 1 | 614 | 614 |
| Cutting cell | 1 | 614 | 614 |
| 25 LED prep | 1 | 88 | 733 |
| Leakage inspection | 1 | 921 | 921 |
| FB | 4 | 19628 | 1635 |
| Socket preassy | 1 | 1869 | 1869 |
| Filling | 1 | 2301 | 2301 |

## 3.6 The performance problem

The calculations were then compared with the current situation
As it was mentioned above, eight workers release 26 units per day, since the unit time is computed and is equal it is possible to estimate production rate for eight workers.

$$Estimated\ production\ rate = \frac{Tot.daily\ working\ time\ \times Amount\ of\ workers}{Unit\ time} = \frac{453\,\mathrm{min}\ \times\ 8\,per}{123.32\,min} = 29\ units\ per\ day$$

It can be seen, that the performance of workers is lower than the rated capacity, thus, the operations assigned to operators should be rearranged in the most optimal way.
Moreover, the technological process of assembly operations can be investigated to find any possibility of improvement. Such improvements as well as bottleneck optimisation are considered in Chapter 4.

# 4 CASE I. OPTIMISATION OF THE CURRENT PRODUCTION

The research described in Chapter 3 showed that the current production could be optimised. The requirement of the research project was to develop solution allowing for manufacturing of 15000 units per year or 60 units per day, thus all improvements considered the desirable production level of 60 products per day.

## 4.1 Bottleneck analysis

The analysis as seen in Figure 49 shows that the insulation assembly would require some amount of parallel work for the production rates exceeding 31 units per day. However, insulation does not require any special equipment and can be performed at a normal work cell, if the number of workers is increased. However, such operations as evacuation, packing, main assembly, evacuation pre-work, test, leakage inspection and filling require special equipment. In other words, the increase in the number of workers will help until the machine capacity is reached. Three ways of development can be considered:

- Investing in more efficient equipment,
- Doubling the equipment,
- Optimising the technological process.

### 4.1.1 Insulation

The design analysis of the design and production process of the insulation box was performed (ASTE FINLAND Oy, 2018). According to the analysis the design cannot be changed without causing harm to modularity and the production practices allow less than 1% reduction of time. However, as it was stated above, the insulation box assembly can be performed with the help of common tools, thus the operation should be executed in parallel allowing more than 60 parts performed per day, moreover, the operation can be performed by more than two workers, which allows flexible production rates.

### 4.1.2 Evacuation

The evacuation equipment used at the AVO shop allows releasing 36 AVOH 135-60 per day. In order to make the decision the following calculations were performed.

The maximum production flow is 60 products per day or one cooler produced every 7.55 minutes.

$$Cycle\ time = \frac{453\ min}{60\ pts} = 7.55\ min$$

Since, neither more powerful equipment, nor changes in the process can decrease the time this process (ASTE FINLAND Oy, 2018), it was decided to increase the capacity. Thus, secondary evacuation equipment was introduced to the design of the production process (Chapter 4.2).

It can be seen that two pumps are enough to achieve such production rates.

$$Production\ rate = \frac{453\ min - 20\ min - 54\ min}{10.5\ min \times 2} = \frac{379\ min}{10.5\ min \times 2} = 72.2\ parts\ per\ day$$

All operations are optimised to correspond the production flow, aforementioned calculations show that one vacuum pump has enough capacity to provide the flow up to 30 products per day. The second pump is necessary to assure the production of 40-60 products per day.

### 4.1.3 Main assembly

Two main assembly cells were used in production when the time study was conducted, however AVO shop is equipped with four cells.

Since the number of cells is 4, we can calculate the maximum production rate for main assembly cells

$$The\ maximum\ production\ rate = 16\ units\ per\ day\ \times 4 = 64\ units\ per\ day$$

Thus, the number of active main assembly cells should be increased to four.

### 4.1.4 Cassette

The current production techniques allow to perform 37 cassette assembly operations per day, the analysis (ASTE FINLAND Oy, 2018) showed no improvements, which can be implemented in short-term, thus it was decided to imply parallel performance by two workers. Such performance allows producing more than 60 units per day.

### 4.1.5 Sticker attachment

The sticker attachment is a routine operation requiring high attention since customer stickers are one of the most visible parts of display cabinet cooler. The study does not consider forcing workers to perform sticking faster a practical solution, since the quality can drop, however such practices can be gently used to improve the performance of operators gradually. It was designed so, that the operation of attachment of stickers should be performed in parallel, which will allow maximum of 86 units released per day.

### 4.1.6 Back wall

Releasing 57 back walls per day in current conditions is possible. The optimisation which allows reducing operation time by 6% should be considered a priority solution. However it is not possible to change the design of the current product at the moment, thus the back wall assembly operation should be assigned to two workers, the load can be spread either even, in other words 30 and 30 parts or in any other way which allows achieving desired production rate.

### 4.1.7 Packing

The time study (Appendix 12/4) shows that the packing operation can be separated, in other words the stretch wrapping or packing (film) and strapping or packing (strap) can be performed by different workers. The standard time for each operation was calculated.

$$\text{Packing (film) ST} = \text{OT} \times \text{TA}$$
$$= 02 \text{ min } 48 \text{ sec} \times 120\ \% = 3 \text{ min } 22\ sec$$

$$\text{Packing (strap) ST} = \text{OT} \times \text{TA}$$
$$= 02 \text{ min } 37 \text{ sec} \times 120\ \% = 3 \text{ min } 09\ sec$$

$$Production\ rate = \frac{371.63\ min}{3.36\ min} = 110\ units\ per\ day$$

Packing film operation was considered in calculations, since it takes more time to wrap the part than to strap. The result of 110 units per day exceeds desired production rate, meaning that the packing is not a bottleneck anymore.

## 4.2 Process optimisation

### 4.2.1 Curtain plate

The time study showed that several operations performed during curtain assembly could be optimised. Such operations are described below, and the optimised solution is stated. The procedure of curtain sub-assembly consists of several steps (described in a more detailed way in Appendix 12/6)

Step 1. The worker puts the curtain on the table (Figure 46),

Step 2. He/she places handle on top of the curtain metal plank (Figure 46),

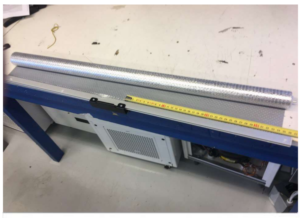

Figure 47 - Curtain plate assembly. Steps 2 and 3

Step 3. Tape meter is used to place handle exactly in the middle of the plank,

Step 4. The handle is attached to the curtain with screwdrivers (Figure 47),

Figure 46 - Curtain plate assembly. Step 4

Step 5. The curtain is joined with the curtain holding cover,

Step 6. The retrieving/returning spring is tightened by revolving the metal bar around its axis with pliers,

Step 7. The metal bar is fixed and curtain sub-assembly is attached to the curtain metal plate (Figure 48).

Figure 48 - Curtain plate assembly. Step 7

There are several processes which can be optimised:

- Step 3. Fixture can be used to eliminate the process of position assuring the use of tape meter and reduce operational time.
- Step 6. The curtain holding cover has a small mass, hence it can not resist the moment created by the worker, when tightening the spring. So the worker holds the cover with one hand while tightening the spring with another one, which was observed during the production). However, human being's wrist can not revolve by 360° thus it creates problems while tightening the spring. Due to the anatomy of human it is needed to loosen the grip, so the position of the wrist can be changed, during this moment pliers usually slip, and the spring is returned to the initial position. The worker should start step 6 again.

#### 4.2.1.1. Step 3. Solution

A fixture (Figure 49) was designed to ease positioning of components. Moreover, the fixture is universal so that it could be used in sub-assemblies of all coolers produced in the researched production shop. To correspond such requirements several positioning holes were drilled in the fixture baseplate.

Figure 49 - Developed solution

The fixing plank (Figure 50) is positioned in such way: it has two bolts which fit in drilled holes. The surface of the wooden hole is supported by the metal hub to increase the durability of the fixture.

Fixing planks are not interchangeable, thence colour coding is used to eliminate the possibility of mistake.

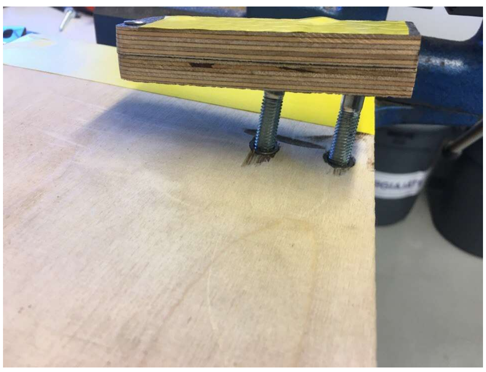

Figure 50 - Fixing plank

Two metal stoppers (Figure 51) are used for part positioning. They also carry out support function when the screwdriver is used. The indent (Figure 51) is used to allow the positioning of the handle.

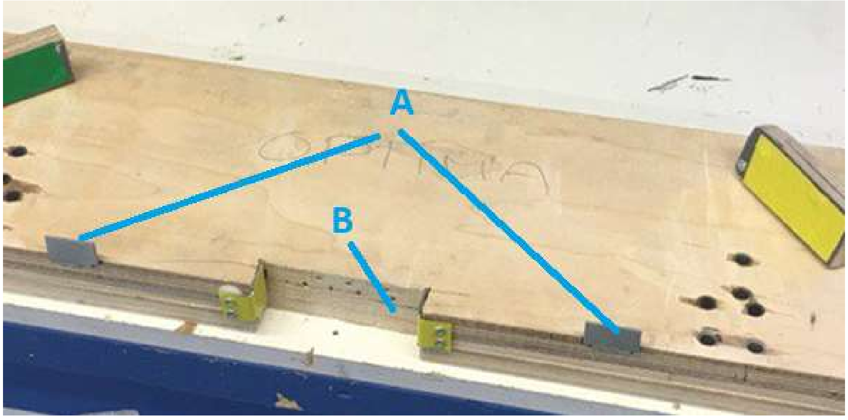


Figure 51 - Design of the fixture. A - Metal stopper. B - Indent

The time study (Table 10) showed that it takes four minutes six seconds for the worker to perform the curtain sub-assembly without the fixture, and it takes three minutes and fifty seconds when the fixture is used. So, the total operational time is decreased by 16 seconds on average.

Figure 52 - Solution in use

#### 4.2.1.2. Step 6. Solution

The spring can be tightened when the curtain holding cover is already attached to the curtain metal plate (Figure 53). The metal plate has greater mass prior to the cover and resists the moment created. Thence, the worker does not need to use his hand for part holding and it becomes easier to change the position of the wrist. The time study shows (Appendix 12/6) that due to the dramatic decrease of pliers slippage the average time to perform curtain sub-assembly operation has decreased from three minutes fifty seconds to three minutes thirty seconds.

Total time saved is 20 seconds.

Figure 53 - Step 6. Solution. Curtain is attached to metal plate

### 4.2.2 Production optimisation

#### 4.2.2.1. Number of workers. Method II

The thought experiment was conducted and results were represented in the form of a diagram (Appendix 16). This diagram s based on DNA diagram (Appendix 13) and represents how production steps can be distributed among workers in an optimised way. A legend diagram (Appendix 15) represents some part of the working day and is explained in details, however several important comments should be stated.

The diagram is based on DNA-diagram and optimised in order to arrange production tasks in the most efficient way.

The diagram step is 30 seconds, however, since the diagram is only used to estimate the number of workers needed and the research project does not set goals for the diagram to be used as production schedule, such variations of time can be neglected.

Each operation has its own colour and codename from 3 letters, the full codename list is stated in Appendix 14. Production schedule optimisation. Codename on the left represents the inflow and the index number of component used. Codename on the right indicated the outflow and the index number of operation in which this component is used. Codenames are used to show inter-operational flow, the number indicates the index number of component, thus if it is the first component produced the number is 1, if 1023 similar components were produced before, the number will be 1024.

Six diagrams were developed allowing a unique solution for 10, 20, 30, 40, 50 and 60 units to be released per one day. For each production rate production operations were assigned to workers according to several requirements based on principles of lean and in accordance with current production situation and technological processes. Such requirements are stated below.

1. The idle time should be minimal

2. The worker should perform the minimum number of different tasks per day. During one-day worker should perform tasks at the minimum number of workstations

Tasks for each worker should be as convenient in the concept of order as possible, that is the list of tasks should be as even as possible, if several tasks are repeatedly executed, the number of operations per repetition should remain same.

Example (Table 6): from two tasks lists, task list for worker one will be chosen as more even and logical.

Table 6 - Task list

| Worker 1 | Worker 2 |
|---|---|
| Four curtain plates | Six curtain plates |
| Four back panels | Two back panels |
| Four curtain plates | Two curtain plates |
| Four back panels | Seven back panels |
| Four curtain plates | Four curtain plates |
| Four back panels | Three back panels |

3. The worker can perform the task only if the previous one is finished

4. The worker should perform the task during the machine time if the machine can operate without human supervision.

5. All preliminary operations (cutting cells, led preparation, price tag preparation) should be performed before the first component of such operation is needed in the production if possible. E.g. all cells should be cut before the first Top sub-assembly will require cell. However, the most priority task was to decrease the number of workers to the minimal amount required.

Diagrams (Appendix 16) represent a theoretical solution for production optimisation.

The first half of each diagram represents so-called Day 0 when no components exist at all, so the production starts from pre-work and sub-assemblies.

The second half or Day X represents any day after Day 0, so the amount of stock remains the same each day.

Breaks for coffee and lunch are not shown. The time of coffee break can be used, for example, to perform machine operations which do not require human supervision, however, the pace becomes unstable and the order of tasks become too chaotic which puts pressure on workers. Thus, breaks are not considered in calculations.

Moreover, according to principles of mass production (Pine, 1999), each operation should obey takt time and the takt time is defined by:

- Bottlenecks, if the capacity limit is reached;
- Production schedule, if the capacity limit is not reached yet.

Thus, in order to stabilise production and eliminate unevenness, faster operations should be slowed down. In case of AVO line, coffee breaks should not be used to speed up the production.

It is important to state several limitations of the technological process and production itself. Some operations cannot be executed if the preceding operation is not performed yet. For example, the main assembly cannot be started if the cassette is not released yet. Workers of AVO line prefer to perform pre-work before main operations start. Moreover, it is not rational to split some pre-work operations. For instance, worker A cuts cells for top plate assembly in a different shop. It is practical to cut all cells and bring them to a workplace, as opposed to splitting this operation and spend time and energy on numerous movements between two shops. Some operations cannot be executed in parallel, since they require unique equipment to be performed, for example, the usage of the stretch wrapping machine, it can pack only one unit at a time.
All facts mentioned above influence the amount of workforce needed.

#### 4.2.2.2. Results

The number of workers needed to release a specific amount of AVOH 135-60 was compared using the results obtained by two aforementioned methods. The comparison is illustrated in Table 7.

Table 7 - Number of workers calculated by Method I (Chapter 3.4.6) and Method II

| 135-60 (pcs) | Labor (pers.) | |
|---|---|---|
| | The method I Theoretical/Realistic | Method II Day0/DayX |
| 10 | 2,7/3 | 3/3 |
| 20 | 5,5/6 | 6/6 |
| 30 | 8,2/9 | 9/9 |
| 40 | 10,8/11 | 12/11 |
| 50 | 13,6/14 | 15/14 |
| 60 | 16,3/17 | 18/17 |

It can be seen that the maximum deviation between results is less than 15%, however, when the production becomes larger the number of workers becomes different for Day0 and DayX. Moreover, as it can be seen from both theoretical values and production diagram Appendix 16, the capacity allows producing more units with the same number of workers, particularly in case of continuous production.

$$\text{Daily capacity of labour} = \\ = \text{Amount of days} \\ \times \text{Number of workers x } Capacity\ of\ worker = \\ = 1\,day \times 17\,per \times 3.673\,\frac{pcs}{day \times per} = 61.829\,units$$

Thus the production allows further optimisation.

## 4.3 Further activities. Instructions.

### 4.3.1 Production optimisation

Since the study provides relevant data about AVOH 135-60 production, in particular, time study, it can be used in order to optimise production planning.

Results of time study should be introduced to the scheduling module of ERP system, thus allowing better planning. Moreover, the schedule will allow warehouse workers to estimate the need for components with an accuracy almost to the minute, this, in turn, will decrease idle time.

In order to increase thoroughness of planning time different activities can be performed.

#### 4.3.1.1. Method I. Factor table

Values of most parameters which are needed for planning, such as lead time or unit time can be obtained from factor table, which compares each article with the sample product. The difference is represented by values and is calculated by the coefficient formula.

Total coefficient formula:

$$K = K_1 + K_2 + K_3 \dots K_n$$

$K_1$, $K_2$, $K_3$ –mass, quantity and complexity coefficients and $K_n$ is a coefficient, which considers any feature of the product being compared. For example in the production of machinery $K_n$ takes into consideration the accuracy of machines being compared.

The mass factor is determined by the undermentioned formula:

$$K_1 = \sqrt[3]{\left(\frac{Q_x}{Q}\right)^2},$$

where Q and $Q_x$ – a mass of sample product and compared product.

Quantity coefficient is obtained using following formula:

$$\frac{N}{N_x},$$

where N and $N_x$ – annual quantity of sample and compared products to be released. In practice, values from the coefficient table (Table 8) are used, however the table does not take into account any radical change in the technological process.

Table 8 - Coefficient table (Jampol'skij E.S., Solovej Z.I., 1975)

| $\frac{N}{N_x}$ | $K_2$ | $\frac{N}{N_x}$ | $K_2$ | $\frac{N}{N_x}$ | $K_2$ |
|---|---|---|---|---|---|
| 0,5 | 0,97 | 2,0 | 1,12 | 6,5 | 1,3 |
| 0,75 | 0,99 | 2,2 | 1,13 | 7,0 | 1,31 |
| 1,0 | 1,00 | 2,5 | 1,15 | 7,5 | 1,32 |
| 1,1 | 1,01 | 3,0 | 1,17 | 8,0 | 1,32 |
| 1,2 | 1,03 | 3,5 | 1,20 | 8,5 | 1,34 |
| 1,3 | 1,05 | 4,0 | 1,22 | 9,0 | 1,35 |
| 1,4 | 1,06 | 4,5 | 1,23 | 9,5 | 1,36 |
| 1,5 | 1,07 | 5,0 | 1,25 | 10,0 | 1,37 |
| 1,6 | 1,08 | 5,5 | 1,27 | | |
| 1,8 | 1,10 | 6,0 | 1,28 | | |

When new products are released, sample product might be reconsidered according to following requirements:

$$0{,}5Q_x < Q < 2Q_x$$
$$0{,}1N_x < N < 10N_x$$

Complexity coefficient $K_3$ is defined by the researcher in accordance with technological design and production process of the product being compared. It makes sense to develop this coefficient together with design and production specialists.

More coefficients can be used depending on the production.

Table 9 – Factor table

| Current production plan | | | | Developed production plan | | | | |
|---|---|---|---|---|---|---|---|---|
| Product | Qty (pcs) | Mass of one unit (kg) | Mass of all units (t) | $K_1$ | $K_2$ | $K_3$ | K | Qty (pcs) |
| 135-60 | 7000 | 110 | 770 | 1 | 1 | 1 | 1 | 7000 |
| 135-87 | 3000 | 100 | 300 | 0.94 | 1.14 | 1.2 | 1.28 | 3852 |
| 145-60 | 800 | 200 | 160 | 1.49 | 1.345 | 1.3 | 2.6 | 2083 |
| 145-87 | 720 | 50 | 50,4 | 0.74 | 1.375 | 1.8 | 1.8 | 1319 |
| Total | 11520 | | 1280,4 | | | | | 14255 |

Quantity received by such calculations (Table 9) is then used for further planning. It should be borne in mind that total mass of units stated in current production plan is not changed. All further calculations should use this value and not the conditional value obtained from developed production plan.

#### 4.3.1.2. Method II. Time study

In order to increase the exactness of planning, time study should be performed for every single product of AVO family. Obtained values should be introduced to ERP system to allow exact production planning.

### 4.3.2 Pre-Work

The amount of work, which can be accomplished by suppliers should be performed in this way, if it is cost-efficient. For example, cells for top assembly can be already cut by the supplier.

### 4.3.3 Equipment and material handling

All inter-operational material handling is performed manually and the introduction of the conveying system will reduce fatigue of workers.

For heavy parts, such as glass sidewalls, special handling equipment can be used, which, in turn, will also reduce the tiredness of employees.

ERP system should be fully integrated into production allowing to automate material handling and providing better control over production.

### 4.3.4 Tools and work cells

Brand-new tools have a very small difference as compared with tools used in ASTE at the moment, therefore it is impractical to upgrade tools at present. However, jigs and fixtures similar to the one described in Chapter 4.2 should be developed in order to decrease the time of operations and decrease fatigue of workers.

All operations should be standardised and instructions must be introduced to workers.

### 4.3.5 Employees, social life.

It a common knowledge that the quality of work affects the performance. (Aketch, J. R.; Odera, O; Chepkuto, P.; Okaka, O., 2012) (Salavati, A.; Maghsoudi, K.; Kaveh, H. , 2013) The employee should know and feel that he or she contributes to the common good. The current strategy of ASTE is to show that it is more than a company, it is a family, and it is important to keep motivating workers and maintain a friendly environment.
Moreover, it is important to keep work conditions at a decent level: temperature, humidity, lighting, furniture and noise are parameters which influence the productivity of work according to (Shruti Sehgal, 2012)

### 4.3.6 Quality

Transportation and storing practices should be revised in order to understand the cause of damaged components. Sheet metal parts can be covered with plastic film in order to protect them from scratches. However, the use of protective materials will increase component cost, thus the cost-effect should be considered. Such quality control practices as leak inspection and electrical testing provide sufficient control level and require no improvement.

### 4.3.7 Safety

The amount of accidents is very low at the moment due to developed safety policies of ASTE and also due to the low danger level of technological processes, however sheet metal parts can also be a threat due to sharp edges. Even though workers have safety card, which confirms their knowledge about work safety, it is necessary to maintain the consciousness of labourers and hold briefings to provide them with safety instructions.

# 5 CASE II. FACTORY EXTENSION

## 5.1 Industry study

The factory extension is next logical step of production development. The design of totally new AVO shop was created in accordance with the need of company, in particular, plan to produce 15000 units per year. The solution is based on improvements suggested in Chapter 4. Moreover, new features were intruded to the design to allow higher efficiency of work.

First and foremost, the research of production of such well-known companies as BMW, Opel, Toyota, Ford, Bentley, Mercedes was conducted. Nowadays there are numerous videos with factory tours on the Internet ([YouCarPress], 2018) ([Alpha SQUAD official], 2017) it is more than enough to understand how production is organised.

Such research allowed to see how material handling is performed, especially how the product is conveyed trough the production line. Videos provide information on how work is automated and which equipment is used to decrease fatigue of employees.

Then, production of Electrolux, Manor, Cabjaks, Mariholodmash, Bosh, Saip, Mr. Breeze, Megatek, Walton was researched using the same source of information. Aforementioned companies manufacture cooling systems, from industrial coolers and display cabinets to water coolers and household refrigerators.

Video material provides important information about equipment and technological processes involved in the production of cooling systems.

- The outcomes of research can be described as a list of following statements:
- Producers tend to automate production.
- Operations which cannot be automated are mechanised.
- Producers tend to eliminate operations which cannot be mechanised.
- Conveyor systems are general product handling means.
- When the use of conveyor is not efficient or is prohibited, automated vehicles are used to handle components or finished goods.
- Fixtures are used to decrease the time needed to place components.
- Tool balancers are used to decrease tool pick and release time.
- Tool balancers, exoskeletons and bulk material handling equipment are used to reduce fatigue of workers.
- Integrated ERP systems with barcode readers for components are used to increase the transparency of production, to eliminate pilferages.

- Kanban bin method is used to ease material handling and eliminate idle time. Usually bins are linked to barcode system.
- The pace of workers is restricted, this eliminating unevenness and forcing workers to operate with high efficiency. The takt time is restricted by conveyor speed and the size of work cell or by the amount of time between periodical movements of the conveyor.

Level of automation in assembly production of cooling systems is low. The fact is that tolerances used in such production are not tight enough and sometimes brute force is needed to adjust components. Therefore, the implementation of robots will require sophisticated equipment, tighter tolerances and stricter quality control or completely new design of the product which will allow automating most of the tasks which are performed manually. All aforementioned actions require large investments, moreover, tighter tolerances will increase raw material and equipment cost, because of stricter requirements. In fact, current automation equipment cannot replace human workers, for some operations it is still more efficient to use human labour (Ohno, 1988). It can also be seen that large amount of assembly operations of BMW, Mercedes or Toyota, such as interior assembly or bumper assembly are performed by humans due to the same reasons.

## 5.2 Technological process

It was important to reconsider working principles before the layout was designed, since changes in technological process can affect production and shop layout.

### 5.2.1 Tools.

It was considered that all heavy tools like screwdrivers and pneumatic guns would be attached to tool balancers as seen in Figure 54 and Figure 55 in order to decrease fatigue of workers.


Figure 54 - Tool balancer (EXPRESS ASSEMBLY PRODUCTS, LLC, 2018)

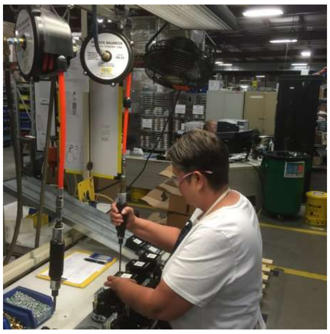

Figure 55 - Tool balancer in use (JSG Industrial Systems Pty Ltd, 2018)

All workstations are designed to have bins similar to the ones illustrated in Figure 56 for small components such as screws or cable ties. The implementation of such bins will help to keep workplace in order and to ease the access to frequently used components. The implementation of glass handling equipment as seen in Figure 57 will reduce labour intensity of main assembly operation. Moreover, the use of such equipment will allow attaching glass faster due to easier positioning and will eliminate glass braking which occurs when the glass slips out of the hands of a worker.

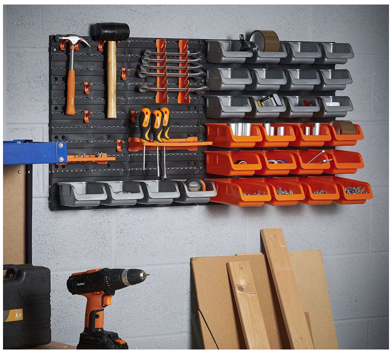

Figure 56 - Bins attached to the wall (Vonhaus, 2018)

Figure 57 - Glass handling equipment (Sofokus Oy, 2018)

### 5.2.2 Automation

In order to decrease the number of workers and process time and increase the capacity of production line several machines were chosen to be introduced to the new design.

#### 5.2.2.1. Evacuation equipment.

Automated systems as illustrated in Figure 58 can evacuate and fill the cooling system with higher speed and safety as compared with manual solutions. Moreover, such machines can handle more than one cooling system at the same time.

Figure 58 - Gas charging machine (GALILEO TP PROCESS EQUIPMENT, 2018)

#### 5.2.2.2. Stretch wrapping machine

The current situation is so that wrapping is performed by semi-automated solution and the worker stands near stretch wrapping machine while it operates. Nowadays fully automated solutions as seen in Figure 59 which are attached to the conveyor exist, the operating rate of automated wrapping equipment is more than 120 loads per hour.

Figure 59 - Stretch wrapping machine (DNC, 2018)

#### 5.2.2.3. Strapping machine

Introduction of the automated strapping machine depicted in Figure 60 eliminates the need for manual work; thus it can affect the number of employees needed. Solutions presented on the market operate with higher efficiency than humans and can release up to 80 pallets per hour.

Figure 60 - Strapping machine (Humboldt Verpackungstechnik GMBH, 2018)

### 5.2.3 Pre-Work

It was considered that cell cutting is not performed by ASTE anymore, thus this operation was not taken into account. Socket preassembly operation was combined with back vent assembly. All other pre-work operations remained the same.

### 5.2.4 Material handling

It was decided to separate production line into four nominal parts.

- The first part, called unit A, where cassette assembly is performed.
- The second part, called unit B, where main assembly, washing and sticker attachment are carried out.
- The third part, called unit C, where sub-assembly work is carried out.
- The fourth part, called unit D, where the assembled product is packed.

The use of paced conveyor line was considered by the researcher and by the management of ASTE as the most suitable for this case. As it was mentioned above, setting the pace of production will enable easier planning and better control over it. The idleness of workers will be eliminated to a certain extent solving the problem of unevenness.

Type of conveying system was chosen to correspond technological process of each unit. All operations except main assembly, washing, sticker application and packing are performed at the table level, this means that the conveyor line should be divided into at least three different parts:

- Table level for units A and C;
- Floor level for unit B;
- Near floor level for unit D.

#### 5.2.4.1. Tabletop conveyor.

The use of belt conveyor (Figure 61, Figure 62) was considered the best solution, since all operations can be performed on the work surface of the conveyor, this will eliminate the need to move part being processed from the conveyor therefore decreasing production time and labour intensity. The conveyor is meant to move periodically, thus setting the pace for the production.

Figure 61 - Belt conveyor (Connect Automation, 2018)

Figure 62 - Tabletop conveyor with worktables (LM MANUTENTIONS INC, 2018)

#### 5.2.4.2. Floor level conveyor

The floor conveyor as illustrated in Figure 63 was chosen as the most suitable solutions for main assembly, washing and sticker attachment operations. Such conveyors are used in automobile production. Floor conveyor is wide belt conveyor line installed on the floor level. It allows workers to unrestricted access to products being processed, since the surface of the conveyor is used as a usual floor as seen in Figure 64 and Figure 65. Moreover, such line sets the pace of workers, since the conveyor is constantly moving and thus the operation should be performed before the product will reach the next work cell.

Figure 63 - Floor conveyor (ERBG System Kft., 2018)

Figure 64 - Volkswagen production. Floor conveyor (AFT Automatisierungs- und Fördertechnik GmbH & Co. KG, 2018)

Figure 65 - BMW production. Floor conveyor (BMW AG, 2018)

#### 5.2.4.3. Near floor level conveyor

As it can be seen from above-stated pictures of wrapping and strapping machines, they usually require some near floor level conveyor illustrated in Figure 66, however it does not affect any operation performed by human workers and depends on the machine used. Thence the design of this conveyor was considered after the technological process was finalised and the quotation from the manufacturer was received. Since the product is already assembled and conveyor surface is used only for moving the product, the use of roller conveyor is considered the best solutions for unit

Figure 66 - Near floor level conveyor (Scaletronic ApS, 2018)

D.

### 5.2.5 Assembly work

A small-scale time study was conducted for operations which require component handling to investigate possible improvements due to the design of tabletop conveyor. The standard time for each operation was updated according to results of time study as seen in Table 10. The reason why observed time is decreased was investigated. Observed time has changed for following operations:

Table 10 - Updated time for operations

| Operation name | Old time | New time | Savings | Reason |
|---|---|---|---|---|
| Back panel | 05:25 | 05:12 | 00:13 | Material handling |
| Cassette | 08:00 | 07:30 | 00:30 | Material handling |
| Ceiling | 01:38 | 01:21 | 00:17 | Material handling |
| Compressor | 02:30 | 02:11 | 00:19 | Material handling |
| Curtain | 04:06 | 03:30 | 00:36 | Fixture |
| Fan plate | 02:25 | 02:20 | 00:05 | Material handling |
| Front grill plate | 02:22 | 02:20 | 00:02 | Material handling |
| Main assembly | 20:00 | 18:20 | 01:40 | Material and heavy component handling |
| Sensor plate | 01:40 | 01:38 | 00:02 | Material handling |
| Shelf | 01:19 | 01:17 | 00:02 | Material handling |
| Top plate | 02:54 | 02:43 | 00:11 | Material handling |

Time study shows that there is no effect on other operations, however it is necessary to remember that the research was carried out in conditions resembling conveyor line, but not identical. Thus real-time can differ from the estimated one.

Appendix 17 represents an observed and standard time for each operation.

Obtained results were used for further calculations. The unique codename was assigned to each operation (Appendix 18). Note that M, S and P stand for main, sub and packing operations respectively.

### 5.2.6 Takt time

In order to calculate takt time required daily capacity should be defined. Since the desired capacity is 15000 units per year and the number of workdays is approximately 250 per year, we can easily obtain required daily capacity value using following formula

$$Daily\ capacity = \frac{Yearly\ capacity}{Av.amount\ of\ workdays\ per\ year} = \frac{15000\ pcs}{250\ days}$$
$$= 60\ units\ per\ day$$

Since we know the number of working minutes per day, we can calculate the time between releasing of two subsequent units, in other words, the takt time.

$$Takt\ time = \frac{Daily\ working\ time}{Daily\ capacity} = \frac{453\ min}{60\ pcs} = 7.55\ \mathrm{min.}$$

The takt time which allows producing exactly 60 products per day is 7 minutes 33 seconds. Due to the different operation principle of tabletop and floor conveyor, the maximum time of operations which can be performed by a worker is different. It is 7 minutes and 20 seconds for tabletop work cells, thus time allowance for conveyor movement is 13 seconds.

Since floor conveyor is constantly moving no allowance is used for conveyor movements and the maximum time is 7 minutes and 30 seconds.

Two solutions based on different production strategies were developed.

## 5.3 Solution I

The solution I or Layout I was developed in order to simplify material flow and separate assembly line from preassembly line. Thus, operations were divided into two groups: preassembly or sub-operations and assembly or main operations. Operations were combined according to several rules listed from highest priority to lowest:

- Main operations must be separated from subassembly tasks (Appendix 18),
- No backflow is allowed,
- Operations can be split if technological process allows splitting and the material flow remains logical or when operation time exceeds takt time,
- The idle time should be minimised,
- The material flow should remain logical.

### 5.3.1 Workcells

The theoretical number of workers can be easily determined by dividing unit time (without machine time) by the takt time. (Note that calculations neglect table conveyor movement)

$$N.of\ employees = \frac{Unit\ time - Machine\ time}{Takt\ time} = \frac{107{,}16\ min}{7.55\ min} = 14.1946 \rightarrow 15\ workers$$

It is essential to remember that operations M1-M11 and S1-S19 (Appendix 18) are performed at table level and operations M12-M15 are carried out when the product is on the surface of the floor conveyor. Thus the total amount of working time is 35 minutes for main table-level operations, 38 minutes for sub operations and 34 minutes for floor level operations and production processes are separated. The idle time depends on tact time and total time for operations. Even rough calculations show that 34, 35 or 38 cannot be divided by 7.55 without a remainder.

$$\frac{35}{7.55} = 4.636 \qquad \frac{34}{7.55} = 4.5$$

This means that it is not possible to eliminate idle times if tact time or total operational time will remain constant.

All aforementioned calculations lead to the conclusion that the solution will require more than 15 workers due to the separation of production processes. After combining operations, assigning them to particular work cells and putting the information in order, workcell table (Appendix 19) was obtained. The design requires 16 workers in order to manufacture 60 products per day. Note that cells 2m, 16p and 17p require space but do not require human worker, since operations are performed by machines.

### 5.3.2 Production line

#### 5.3.2.1. Conveyor section

Tabletop conveyor cells are designed to be 1500 mm long and 900 mm wide, which allows handling any components used in the production of AHO Harmony units. The height is designed to correspond to the current height of working tables and is 850 mm.

Moving floor conveyor cells are designed to be 10 mm long allowing operators of two adjacent to work without interfering with each other. The width of the conveyor is 2.7 m and is designed to comprise enough space for two workers and one unit.

#### 5.3.2.2. Production

Appendix 20 and Appendix 21 represent the layout of this design. Note, that names of operations are stated in blue. The production line starts from two separate ends of the conveyor where all components needed for cassette assembly operation are produced. Then the cassette proceeds through cells 1-9, after all serial no is attached the unit is packed and sent to the warehouse.

Side conveyor system is designed for cells 10-16. The line has several junction points, where components are sorted and then delivered to the work cell, where such components are used. Note that names of these components are stated in red near to the conveyor section they will be delivered to.

#### 5.3.2.3. Performance

The total amount of work was calculated and analysed, the results can be seen in Table 11. Since the production is paced and takt time is 7.55 minutes the idle time can be calculated as the difference between the amount of human labour and the takt time. Layout efficiency is 89.89% which means the amount of total daily working time used and 10.11% of time wasted.

Table 11 - Layout I. Performance

| Layout I | | | |
|---|---|---|---|
| Amount of work | 2.00.30 | | |
| Amount of human labour | 1.54.30 | Idle tot. | 0.11.51 |
| Max total time | 1.57.15 | Idle avg. | 0.00.44 |
| Workers tot. | 16 | | |
| | | Efficiency | 89,89 % |

## 5.4 Solution II

Solution II or Layout was developed in order to increase production efficiency by minimising idle time.
As in the case of the first solution, operations were divided into two groups: preassembly or sub-operations and assembly or main operations.
Operations were combined in obedience to several rules listed from highest priority to lowest:

- The idle time should be minimised;
- If technological process allows performing parallel operations while unit undergoes some machine process, e.g. electrical testing, such operations should be performed.
- Operations can be split if technological process allows splitting and the material flow remains logical or when operation time exceeds takt time;
- The material flow should remain logical; the amount of backflow should be minimised or eliminated, if possible.

### 5.4.1 Workcells

After operations were combined and assigned to assigning them to specific work cells, the information was systemised and presented in the form of a table (Appendix 22)
As it can be seen from the table the second solution requires 15 workers to release 60 products per day.

### 5.4.2 Production line

#### 5.4.2.1. Conveyor section

Tabletop conveyor cells are designed to be 1500 mm long and 1350 mm wide, which allows to perform work from both sides of the conveyor and handle two separate components. The height is designed to correspond to the current height of working tables and is 850 mm.
The design of moving floor conveyor is similar to the one of solution I.

Production line layouts with operation names (Appendix 23) and dimensions (Appendix 24) were created.

#### 5.4.2.2. Production

Appendix 23 and Appendix 24 depict the layout of this design. The principle of indication of processes and components is similar to the one used in Appendix 20.
The production consists of two lines:
Primary line, where cells 1-9, 15m and 16 m are placed.
Secondary line, with cells 10-15, which works in the same way as a secondary line of solution I. The line has one sorting point in order to separate components used in different production steps.
However, the main difference from the first solution is the size of tabletop production cells. With the length of and the width of, each section allows to perform work from, both sides of the conveyor, moreover it allows handling of larger materials.

#### 5.4.2.3. Performance

The efficiency of production is higher as compared with the efficiency of Layout I due to the fact that subassemblies are not separated from main assemblies, which allows decreasing idle time as illustrated in Table 12.

Table 12 - Layout II. Performance

Layout II

| | | | |
|---|---|---|---|
| Amount of work | 1.58.34 | | |
| Amount of human labour | 1.54.30 | Idle tot. | 0.06.14 |
| Max total time | 1.55.15 | Idle avg. | 0.00.25 |
| Workers tot. | 15 | | |
| | | Efficiency | 94,59 % |

## 5.5 Benchmarking

Several parameters stated in benchmarking table (Table 13) were compared allowing to understand the best application for each solution.

Table 13 - Benchmarking table

| Parameter | Solution I | Solution II |
|---|---|---|
| Number of workers | 16 | 15 |
| Area | 480 $m^2$ | 340 $m^2$ |
| Complexity | High | Medium |
| Flexibility | Low | Low |
| Material and product flow | Logical | Complex |
| The main line | More cells | Wider cells |
| Secondary line | More cells | Wider cells |
| Packing equipment | Same | Same |
| Production rate (pcs/year) | 15000 | 15000 |
| Reliability | Medium | Medium |
| Cost | Higher | Lower |
| Efficiency | 89.89% | 94.59% |

### 5.5.1 Number of workers

Solution II requires fewer workers than solution I. The number of workers affects direct fixed costs of production, since the company needs to pay salaries and insurance contributions. Moreover, number of workers affects costs indirectly, each worker requires working cell, tools, parking place, food. Thus, layout II represents a more cost-effective solution.

### 5.5.2 Area

The total area of the layout is smaller, allowing to save money on construction. Moreover, smaller production shop will require less lighting, heating, ventilation and cleaning as compared with larger shops. In other words, it will need less money to be maintained and used.

### 5.5.3 Complexity

The complexity of each solution is defined by the number of conveyor lines and their shape, the least complex solution is one straight production line with uniform conveyor along its entire length. Solution II represents less complex solution due to a smaller amount of junction and sorting points as compared with the solution I.

### 5.5.4 Flexibility

Both solutions are designed to correspond needs of current production of AVO products. Thus, solutions are optimised for the technological process being used and the scenario when processes are changed drastically is not taken into account. Thereby, both solutions do not allow tangible flexibility

### 5.5.5 Material and product flow

The first solution allows to separate main and sub-operations, thus allowing more logical flow, however the need to sort subcomponents before they are delivered to particular work cell increases the complexity. The flow of the second solution is less logical as compared with the first one due to the backflow.

### 5.5.6 Main and Secondary lines

The second solution is designed with fewer conveyor sections than the first one, however such sections are wider. Both solutions increase the flexibility of the line.

### 5.5.7 Packing equipment and production rate

Stretch wrapping and strapping machines are designed in order to correspond to the production rate of 15000 units per year and are similar for both layouts, thus there is no difference between packing equipment.

### 5.5.8 Reliability

High level of optimisation increases the production efficiency, however only if there are no faults in the production. If some work cell stops working, the whole production is affected by this incident. Thus, it is necessary to create small buffer stock before each production step. Such stock can be created by the implementation of Kanban bin system.

### 5.5.9 Cost

The cost of packing equipment and the cost of conveyor section is almost similar for both solutions, however solution I require more conveyor sections, it also requires more sorting equipment as compared with solution II. Therefore, the cost is higher for a solution I.

### 5.5.10 Efficiency

The efficiency of Layout I is smaller as compared with the one of Layout II due to the separation of production processes. The effect of process separation was described in detail in Chapter 4.3.1

## 5.6 Results

Layout I and layout II were presented to the management of ASTE, some changes were suggested. Such changes are listed below:

- Allow more flexibility of production line;
- Separate sub-operations from main operations;
-

The final solution was developed in order to correspond new requirements.

## 5.7 Final solution

### 5.7.1 Workcells and conveyor sections

The design of workflow is based on the one of Layout I. Main operations are separated from subassemblies. All sub-operations are designed to be performed at the usual working table and subassemblies are delivered to main cells with the help of trolleys, both the use of AGVs[1] and manually driven trolleys was considered. The Kanban bin system was considered to be introduced to the production line. Small stock before operations will be created with the help of the same trolleys. It is important to state that sub-operations are not divided into parts, since it is ineffective to move unfinished components from one table to another. Tasks with operation time which exceeds takt time were designed to be performed in parallel, thus, if two workers assemble insulation boxes, two units are processed in 15 minutes, meaning that unit is released each takt. It is important to develop such production schedule, so similar parts are not released simultaneously, instead one unit is released per takt.

### 5.7.2 Production line

#### 5.7.2.1. Conveyor section

The layout I was chosen as a basis for final layout (Appendix 26, Appendix 27) since it allows separation of main and sub-operations. The length of table conveyor section was increased to 2000 mm; the width was designed to be 1200mm. The total area was increased to 825 $m^2$ in order to enhance the flexibility of the production shop. Floor conveyor of unit B was enlarged in order to allow higher flexibility of the production line.

The design of unit A was changed: the number of work cells was changed from five to seven. The length and width of floor conveyor were changed to 15 m and 5 m respectively which allows allocating more workers if the technological process will be changed. Moreover, the shape of the conveyor was changed from straight line to L-shaped line, since it allows to use shop area with higher efficiency. Subassembly operations were combined to allow smaller idle times and more logical inter-operational flow (Appendix 25). The number of subassembly cells was increased to eight in order to allow workspace for additional operations. All sub-operations are designed to be performed at the universal working table which is 1500 wide, 700 mm deep and 850 mm high. Unit C is completely separated from other units, which allows higher flexibility.

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[1] AGV or Automated Guided Vehicle – fully automated means of transportation. AGVs are used in production for material handling and allow reduction in the number of workers and increased efficiency of works, since humans do not participate in transportation of material.

#### 5.7.2.2. Production

The shop is designed to contain two separate production areas:

- conveyor line for main operations and packing, where cells 1-9, 18m and 19m are placed
- subassembly area with universal worktables depicted in Figure 67, where cells 10-17 are placed

Figure 67 - Universal worktable (EquipMax, Inc, 2018)

#### 5.7.2.3. Performance

The efficiency of the final solution shown in Table 14 is similar to the one of Layout I, since subassemblies are separated from main operations. However, the efficiency was considered satisfactory, since the layout allows both relatively high efficiency and high flexibility.

Table 14 - Final Layout. Performance

| Final Layout | | | |
|---|---|---|---|
| Amount of work | 2.15.05 | | |
| Amount of human labour | 1.54.30 | Idle tot. | 0.11.51 |
| Max total time | 1.57.15 | Idle avg. | 0.00.44 |
| Workers tot. | 16 | | |
| | | Efficiency | 89,89 % |

## 5.8 Outcome

The layout of the final solution (Appendix 26, Appendix 27) allows significantly higher flexibility due to larger conveyor cells, an increased amount of work cells and buffer stock before each operation. In this way, the production line will be able to produce units with a different design even if it requires major changes of technological process. Moreover, the production will be more reliable and less susceptible to faults and component shortages. The flexibility of design allows long-term usage of the production line and ability to handle products which will be designed in future.

# 6 INVESTMENT CALCULATION

## 6.1 Theory

The attractiveness of investment project for potential funders and partners is defined by several values, basically these values are used to define how much and how fast the project will return investments. Such values should be briefly explained in order to proceed to calculations. Note that the research project is focused on one production shop, in other words, any amount of money accountable to other objects, whether it be the salary of management or warehouse equipment amortisation cost.

### 6.1.1 Assets

In financial accounting, an asset means any economic resource owned or controlled by a company.
All assets can be divided into two parts, current assets and non-current assets.
Current assets are expected to be sold or consumed within one year and include following items:

- Cash and cash equivalents,
- Prepaid expenses,
- Marketable securities,
- Accounts receivable,
- Inventory (O'Sullivan, Arthur; Sheffrin, Steven M., 2003).

Non-current or long-term assets are expected to be productive for more than one year. Such assets are
Tangible fixed assets or physical property, meaning machinery, buildings and vehicles;
Intangible fixed assets or non-physical property, meaning trademarks, rights of use, internet domain names, licensing, lease and franchise agreements, service and employment contracts;
Goodwill, which is nominal value describing business connections of the company, such as trademark, customer network or reputation (Downes, John; Goodman, Jordan Elliot, 2003).

### 6.1.2 Liabilities

Liability means any economic value which should be transferred by the company to another company as a result of past transactions or events. Examples of liabilities are accrued expenses, taxes payable, accounts payable, long-term bonds or pension obligations (Australian Accounting Standards Board, 2018).

### 6.1.3 Equity

Equity is the difference between assets and liabilities.

$$Equity = Assets - Liabilities$$

It defines the amount of any economic value either negative or positive of anything owned by a company (Hervé Stolowy; Michel Lebas, 2006).

### 6.1.4 Costs

The company pays money to cover electricity or to buy raw materials, all such expenditures are called costs or expenses and can be direct or indirect. Both direct and indirect costs can be fixed, which are not affected by the number of units produced eg. rent of factory compartments or variable, which are affected by the number of produced units e.g raw material cost. If no products are produced, variable costs are equal to zero (O'Sullivan, Arthur; Sheffrin, Steven M., 2003).

Indirect costs mean amount of money spent on administrative and security needs and not directly accountable to cost object, in the case of the research project, the production. Such expenses will include equipment maintenance cost, equipment insurance, tools and inventory.
Direct costs are directly attributable to object. Thus, such salaries, components, electricity, water, packing or shipping are direct costs of production.

### 6.1.5 Amortisation, depreciation and depletion

Since very few assets can be used forever, each asset has its own life cycle, during which an asset is used. The cost of an asset is spread over the life cycle. Usually, depreciation, amortisation and depletion rates are different for different assets, and are stated in tax codes defined by the government. In Finland it is defined in Tuloverolaki (Tuloverolaki 1992/1535, 2018).

#### 6.1.5.1. Depreciation

Depreciation is the practice of spreading tangible asset over its useful life, thus it is used for equipment, buildings, furniture, vehicles, tools and land (O'Sullivan, Arthur; Sheffrin, Steven M., 2003).

#### 6.1.5.2. Amortisation

Amortisation describes the expensing of fixed assets over their useful life and is used for patents and trademarks, franchise agreements, copyrights and bonds (O'Sullivan, Arthur; Sheffrin, Steven M., 2003).

#### 6.1.5.3. Depletion

It used in business dealing with natural resources. The lifecycle of an oil well is defined by the amount of oil which can be pumped out of it, the total cost of equipment and its setup is spread over the useful life period (Raymond H. Peterson, New York).

Since only tangible assets are considered in the design of production line and the useful life for tools and equipment is four years, the depreciation rate can be calculated. It is equal to 25% per year (Tuloverolaki 1992/1535, 2018).

### 6.1.6 Taxes and interest

Taxes are fees which companies and individuals paid to a government entity such as regional or national, in order to fund its activities.

#### 6.1.6.1. VAT

VAT or value-added tax defines the amount of money withdrawn to a governmental budget. VAT is applicable to value of the product, labour or service which is created at all production steps. As a result, the final user of product or service pays VAT applied to the full value of such product or service.

Table 15 - VAT rates in Finland (VERO, 2018)

| | |
|---|---|
| 24% | the general rate: most goods and services |
| 14% | a reduced rate: food, animal feed, restaurant and catering services |
| 10% | a reduced rate: books, pharmaceutical products, physical exercise services, film showings, entrance to cultural and entertainment events, passenger transport services, accommodation services, operations relating to TV and public broadcasting against a fee |

The general rate of VAT in Finland is 24% (Table 15) meaning that net price of the product is 100 EUR, the customer will pay EUR 124 for it. $Price = Net\ price * (100\% + VAT) = 100\ EUR * 124\% = EUR\ 124$ At the end of each accounting period, the amount of VAT received and VAT paid is summed up. If the value is negative, the company have paid more VAT than received and can initiate a procedure for reimbursement (Australian Accounting Standards Board, 2018).

### 6.1.6.2. Corporate tax

Corporate tax defines the part of revenue contributed to the government and is 20%.

Salary taxes, contributions and other payments

The employer pays some amount of money to support employees, such contributions include life and unemployment insurances. Table 16 depicts common contributions paid by companies to factory workers, rates are average for Finland.

The table shows the average monthly cost of annual bonuses and holiday payments since it is covered by the employer and is important for investment calculations.

Table 16 - Contributions paid by Finnish employers (BusinessFinland Oy, 2018)

**Pension contribution (average 18%)**

**Employment accident insurance according to risk and the size of the company (average 0.9%)**

**Unemployment insurance (1.0%)**

For companies with total wages over € 2044500, unemployment insurance 3.9%

**Group life insurance (average 0.07%)**

**Employer's social security contribution (2.12%)**

**Monthly cost for annual bonus and holiday pay (15.9%)**

### 6.1.6.3. Interest

Interest is the amount of money charged by a lender from a borrower charged for the privilege of borrowing anything which has an economic value.

For example, if the company has borrowed EUR 100 from the bank with the interest of 10% and the duration of the loan is one year, the total amount of money, which will be paid to a back will be EUR 110.

The interest in Finland is defined by two values EURIBOR and loan interest defined by the bank. EURIBOR or Euro Interbank Offered Rate is an interest reference rate based on rates of 44 European banks called panel banks. It is calculated for different loan periods from 1 week to 12 months, after the period is over, the interest can be recalculated in accordance with current EURIBOR value. Base EURIBOR rate for the first half of 2018 is -0.25%. (Bank of Finland, 2018)

Each bank has own interest rate, which can vary from loan to loan depending on its size, credit history of borrower, financial and political situation. Typical corporate loan interests are 2-10% for Nordea bank (Nordea Bank AB (publ), Finnish Branch, 2018).

The interest of 10% was used for calculations.

### 6.1.7 Cash flow

Cash flow takes into account cash and cash-equivalents and is equal to the difference between cash inflow and cash outflow. Information on operating, investing and financing cash flow shows financial performance, liquidity and flexibility of company over an accounting period (O'Sullivan, Arthur; Sheffrin, Steven M., 2003).

### 6.1.8 TVM and discounting

The concept of TVM or time value of money was developed by Leonardo Fibonacci in 1202 (Griff, M, 2014) and is used in modern financial operations. The value of money received today is bigger than the value of money which will be received tomorrow. It is based on the premise that everyone prefers to get a certain amount of money today than the same amount in the future, all other things being equal.
Discounting is used in investment calculations to define the value of cash flow at the exact moment of time. Two basic discounting operations exist:

- Compounding, which is used to calculate the value of today's cash flow in the future. Discounting, which is used to define today's value of future cash flow.
- Investment computation for the final layout presented in the current study requires discounting calculations. The formula of discounting is

$$PV = \frac{FV}{(1+i)^n} \text{ (Investopedia, LLC, 2018), where}$$

PV means present value or the value of money at the present time;
FV stands for the future value of the value of money at a certain point in the future;
i stands for the discount rate, which depends on base rate for the issuer, award for country risks for holders of equity instruments and other economic values which are not considered in the current research project;
N means a number of periods between in present date and future date.

### 6.1.9 Net present value

Net present value or NPV is used in investment projects to calculate the value of cash flow cast to the present day. It takes into an account invested capital or IC and cash flow or CF.

$$NPV = -IC + \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} \text{ (Khan, M. Y., 1993)}$$

NPV can be interpreted as the value added by the project or overall profit of the investor.
Since NPV is an absolute value, it cannot be used for comparison of two investment projects with different investment capital.

### 6.1.10 WACC

Weighted average cost of capital is the average interest rate of all company's sources of financing. The calculation takes into account the specific weight of each source of financing.
Weighted average cost of capital is calculated as

$$c = \left(\frac{E}{K}\right) \times y + \left(\frac{D}{K}\right) \times b(1-t) \text{ (Investopedia, LLC, 2018), where}$$

C stands for WACC;
y is required or expected a return on equity;
b means the cost of borrowed funds;
t is income tax rate for the company;
Note that all values stated above are measured in percentages,
D stands for the amount of all borrowed funds;
E means total equity;
K is total invested capital;
Note that D, E, and K are measured in currency units.
If capital can be divided into several parts with their own cost and return values, each part is calculated separately within one formula.

### 6.1.11 Earnings

#### 6.1.11.1. Turnover

Turnover represents the amount of money that comes into the business, in other words it represents total sales value (Bodie, Zane; Alex Kane; Alan J. Marcus, 2004).

$$Turnover\ (simplified) = Unit\ price \times Amount\ of\ units\ sold\ \text{(Bodie, Zane; Alex Kane; Alan J. Marcus, 2004)}$$

#### 6.1.11.2. Gross profit

Gross profit means the amount of money received by the company after variable costs are taken into account. In other words, gross profit is the difference between total sales and costs of production.

$$Gross\ profit = Turnover - Variable\ Costs\ \text{(Horngren, Charles, 2011)}$$

#### 6.1.11.3. Gross margin

Gross margin is used to determine the gap between the amount of money received when products are sold and the amount of money spent to produce such products. It is measured in percentages and shows how profitable is to produce goods sold by the company.

$$Gross\ margin = \frac{Gross\ profit}{Turnover}\ \text{(Horngren, Charles, 2011)}$$

#### 6.1.11.4. EBITDA

EBITDA stands for earnings before interest, taxation, depreciation and amortisation and is the amount of money company receive from sold goods after the company pays for production, labour and administrative needs. EBITDA is the difference between gross profit and fixed costs (Investopedia, LLC., 2018).

$$EBITDA = Turnover - Variable\ Costs - Fixed\ costs$$

6.1.11.5. EBIT

EBIT of earnings before interest takes into account depreciation, amortisation and depletion of equipment, building, tools and vehicles. (Investopedia, LLC, 2018).

$$EBIT = Turnover - Variable\ Costs - Fixed\ costs - Depreciation - Amortization - Depletion$$

6.1.11.6. EBT

EBT is the amount of money received by the company after all costs, as well as depreciation, amortisation, depletion and debt servicing are taken into account (Investopedia, LLC, 2018).

$$EBT = Turnover - Variable\ Costs - Fixed\ costs - Depreciation - Amortization - Depletion - Interest$$

6.1.11.7. Net profit

EBT is the value which is subjected to the corporate tax, after the amount after the tax is deducted is a real profit of the company or the project the company receives a net profit (Hervé Stolowy; Michel Lebas, 2006).

$$Net\ profit = Turnover - Variable\ Costs - Fixed\ costs - Depreciation - Amortization - Depletion - Interest - Taxes$$

6.1.11.8. Net profit margin

Net profit margin is used to calculate the ratio of net profit to revenue of the company. Generally, it means how much money company earns from its total revenue (Investopedia, LLC, 2018).

$$Net\ profit\ margin = \frac{Net\ profit}{Turnover}$$

### 6.1.12 Project performance parameters

#### 6.1.12.1. Payback period

Payback period or PP describes the amount of time necessary to ensure that the revenues generated by investment project will cover investment costs, in other words, it is period of time before the project will reach a break-even point. PP is calculated using following formula:

$$Payback\ period = \frac{Initial\ investment}{Cash\ flow\ per\ period}\ \text{(Williams, J. R, 2012)}$$

For example, if total investment is EUR 100 EUR and cash flow is + EUR 50 per year, the payback time of project will be two years.
PP is used to compare different investment projects or to evaluate the certain project. If payback period is less than the useful life of the project, it can be accepted, if pp exceeds useful lifetime, the project is unprofitable and should be rejected.
However, pp formula does not take into account time value of money, in order to obtain real payback time more thorough computations are performed.

#### 6.1.12.2. Discounted payback period

Discounted payback period or DPP is the amount of time it will take for the investment project to reach a break-even point. It is the period of time in which the net present value of the project will become equal to zero.

$$DPP\ = n\ at\ which \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} > -IC_{t=0}\ \text{(Altair Software Company, 2018)}$$, where

n stands for the number of accounting periods;
$CF_t$ is the cash flow during period t;
i means discount rate;
$IC_0$ stands for initial capital at t = 0;
DPP is widely used to calculate payback periods for investment projects in countries with unstable political, tax and legislation systems, moreover the importance of DPP is defined by stability of demand for the result of investment and is essential for industries with short product life.
However, DPP and PP do not take into account cash flow after the payback time, thus the profit created by the project is not considered.

### 6.1.12.3. The internal rate of return

The internal rate of return or IRR is used to calculate the profitability of investment project and is described as interest rate at which NPV is equal to zero. In other words, it is the amount of money which the project will return after a certain period of time. For example, if IRR is 1500% for one year, and the amount of investments is equal to EUR 100, the profit of the project will be equal to EUR 1500.

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} - \sum_{t=0}^{n} \frac{IC_t}{(1+IRR)^t} = 0 \text{ (Investopedia, LLC, 2018)},$$

Since the interest is determined by the cost of capital or WACC, internal rate of return is compared to it.
If IRR > WACC, the project is profitable and can be accepted,
If IRR < WACC, the project is unprofitable and should be rejected.
IRR is commonly used for evaluation of investment projects; however, it has several disadvantages due to the mathematical formula.
The formula considers that positive cash flow is reinvested at the rate equal to IRR, thus, the closer IRR is to the level of reinvestments, the more realistic value is.
IRR is a relative value, thus the absolute result in currency units cannot be obtained.
If the cash inflow and outflow alternate it could occur so, that the project will have several IRR, thereby, the investment decision cannot be made only by using IRR value.

## 6.2 Finalizing the equipment

After tax and interest rates were obtained, the total cost of tools and equipment for final layout was calculated.

### 6.2.1 Work cell cost

Work cells were divided into several groups according to the technological process.
Such groups are:

- Subassembly working cells,
- Table conveyor cells,
- Main assembly cells,
- Washing cells,
- Stickers cells,
- Unique tools.

Prices are provided by Etra Oy.

Each cell is designed to have a working table with rails to install lamps, tool balancers, storage trays and chargers. The design takes into account trash bin, tool balancer, Kanban bins for components, trolley to carry bins and standard tools such as screwdriver, cutters and pliers.

#### 6.2.1.1. Table conveyor cells

Since the conveyor is used as working surface, there is no need in the working table, that is the only difference between the design of table conveyor and subassembly cell. Note that rails are still used to carry lamps, tool balancers and containers.

Table 17 - Table conveyor working cell price

Table conveyor working cell

| Name | Quantity | Price | Total |
|---|---|---|---|
| Screwdriver | 1 | 157,00 EUR | 157,00 EUR |
| Cutters | 1 | 21,00 EUR | 21,00 EUR |
| Pliers | 1 | 15,40 EUR | 15,40 EUR |
| Storage tray small | 2 | 3,35 EUR | 6,70 EUR |
| Storage tray medium | 1 | 4,65 EUR | 4,65 EUR |
| Storage tray large | 1 | 5,10 EUR | 5,10 EUR |
| Container small 14l | 2 | 13,20 EUR | 26,40 EUR |
| Container medium 40l | 1 | 23,00 EUR | 23,00 EUR |
| Container large 54l | 1 | 24,90 EUR | 24,90 EUR |
| Bin trolley | 1 | 315,00 EUR | 315,00 EUR |
| Tube module | 1 | 129,00 EUR | 129,00 EUR |
| Bin rail | 2 | 19,89 EUR | 39,78 EUR |
| Lamp and balancer holder | 1 | 117,00 EUR | 117,00 EUR |
| Lamp | 1 | 200,00 EUR | 200,00 EUR |
| Power rail | 1 | 200,00 EUR | 200,00 EUR |
| Tool balancer | 1 | 49,90 EUR | 49,90 EUR |
| Trash bin 35l | 1 | 11,50 EUR | 11,50 EUR |
| | | Total | 1 346,33 EUR |
| Conveyor cell | 7 | | 9 424,31 EUR |
| | Alv | 24% | 11 686,14 EUR |

#### 6.2.1.2. Main assembly cells

Working table and rails are not required for main assembly cell design, however universal trolleys which are used as mobile working tables to carry tools and small components. Each main assembly cell requires rubber hammer for adjustment of logo cap.

Table 18 - Main assembly cell price

Main assembly cell

| Name | Quantity | Price | Total |
|---|---|---|---|
| Screwdriver | 2 | 157,00 EUR | 314,00 EUR |
| Cutters | 1 | 21,00 EUR | 21,00 EUR |
| Pliers | 1 | 15,40 EUR | 15,40 EUR |
| Storage tray small | 2 | 3,35 EUR | 6,70 EUR |
| Storage tray medium | 1 | 4,65 EUR | 4,65 EUR |
| Storage tray large | 1 | 5,10 EUR | 5,10 EUR |
| Container small 14l | 2 | 13,20 EUR | 26,40 EUR |
| Container medium 40l | 1 | 23,00 EUR | 23,00 EUR |
| Container large 54l | 1 | 24,90 EUR | 24,90 EUR |
| Bin trolley | 1 | 315,00 EUR | 315,00 EUR |
| Universal trolley | 1 | 510,00 EUR | 510,00 EUR |
| Tool balancer for screwdriver | 1 | 49,90 EUR | 49,90 EUR |
| Rubber hammer | 1 | 80,00 EUR | 80,00 EUR |
| Tool balancer for pneumatic screwdriver | 1 | 52,00 EUR | 52,00 EUR |
| Trash bin 35l | 1 | 11,50 EUR | 11,50 EUR |
| | | Total | 1 459,55 EUR |
| Main assembly cell | 3 | | 4 378,65 EUR |
| | Alv | 24 % | 5 429,53 EUR |

### 6.2.1.3. Washing cells

Since washing cell requires only one tool, such as a bottle with washing liquid, costs are calculated for one tool balancer, Kanban trolley with bins, storage trays, universal trolley and trash bin only.

Table 19 - Washing cell price

Washing cell

| Name | Quantity | Price | Total |
|---|---|---|---|
| Storage tray small | 2 | 3,35 EUR | 6,70 EUR |
| Storage tray medium | 1 | 4,65 EUR | 4,65 EUR |
| Storage tray large | 1 | 5,10 EUR | 5,10 EUR |
| Container small 14l | 2 | 13,20 EUR | 26,40 EUR |
| Container medium 40l | 1 | 23,00 EUR | 23,00 EUR |
| Container large 54l | 1 | 24,90 EUR | 24,90 EUR |
| Bin trolley | 1 | 315,00 EUR | 315,00 EUR |
| Universal trolley | 1 | 510,00 EUR | 510,00 EUR |
| Trash bin 35l | 1 | 11,50 EUR | 11,50 EUR |
| Tool balancer | 1 | 49,90 EUR | 49,90 EUR |
| | | Total | 960,70 EUR |
| Washing cell | 1 | | 960,70 EUR |
| | Alv | 24% | 1 191,27 EUR |

### 6.2.1.4. Stickers cell

The design of stickers cell is similar to the one of washing cell, however special trolley I used to carry stickers.

Table 20 - Stickers cell price

| Name | Quantity | Price | Total |
|---|---|---|---|
| Storage tray small | 2 | 3,35 EUR | 6,70 EUR |
| Storage tray medium | 1 | 4,65 EUR | 4,65 EUR |
| Storage tray large | 1 | 5,10 EUR | 5,10 EUR |
| Container small 14l | 2 | 13,20 EUR | 26,40 EUR |
| Container medium 40l | 1 | 23,00 EUR | 23,00 EUR |
| Container large 54l | 1 | 24,90 EUR | 24,90 EUR |
| Bin trolley | 1 | 315,00 EUR | 315,00 EUR |
| Trolley for stickers | 1 | 860,00 EUR | 860,00 EUR |
| Trash bin 35l | 1 | 11,50 EUR | 11,50 EUR |
| | | Total | 1 277,25 EUR |
| Stickers cell | 1 | | 1 277,25 EUR |
| | Alv | 24 % | 1 583,79 EUR |

### 6.2.1.5. Unique tools

Unique tools are those used in specific operations, for example pneumatic riveting tool or vacuum glass holders in the main assembly, hot glue gun in shelf and ceiling assembly. Calculations also take into account chargers and batteries for electric tools and manual packing tools to allow packing operations in case of packing equipment failure.

Table 21 - Unique tools cost

Unique tools

| Name | Quantity | Price | Total |
|---|---|---|---|
| Angle impact screwdriver | 1 | 156,00 EUR | 156,00 EUR |
| Hot glue gun | 1 | 750,00 EUR | 750,00 EUR |
| Adhesive glue gun (manual) | 3 | 10,00 EUR | 30,00 EUR |
| Adhesive glue gun (electric) | 1 | 200,00 EUR | 200,00 EUR |
| Charger | 10 | 42,50 EUR | 425,00 EUR |
| Battery | 20 | 29,00 EUR | 580,00 EUR |
| Strapping machine electric | 1 | 2 280,00 EUR | 2 280,00 EUR |
| Manual stretch wrapper | 1 | 42,00 EUR | 42,00 EUR |
| Strapping trolley | 1 | 260,00 EUR | 260,00 EUR |
| Tool balancer | 6 | 49,90 EUR | 299,40 EUR |
| Pneumatic impact screwdriver | 1 | 230,00 EUR | 230,00 EUR |
| Gas leak detector | 1 | 200,00 EUR | 200,00 EUR |
| Pneumatic riveting tool | 2 | 1 570,00 EUR | 3 140,00 EUR |
| Vacuum holder for glass | 2 | 3 000,00 EUR | 6 000,00 EUR |
| Pallet truck | 2 | 310,00 EUR | 620,00 EUR |
| | | Total | 15 212,40 EUR |
| | Alv | 24% | 18 863,38 EUR |

## 6.3 Total cost

The cost of tools was combined with the cost of equipment required (ASTE FINLAND Oy, 2018)
The total cost of tools is EUR 57 881.71 as illustrated in Table 22.

Table 22 – Total tool cost

| Name | Cost |
|---|---|
| Sub-Assy working cells | 19 664,71 EUR |
| Table conveyor working cells | 11 686,14 EUR |
| Main assembly cells | 5 429,53 EUR |
| Washing cells | 960,70 EUR |
| Stickers cells | 1 277,25 EUR |
| Unique tools | 18 863,38 EUR |
| Total | 57 881,71 EUR |

The total cost of equipment is EUR 920 000 as seen in Table 23. Note that given values are not real.

Table 23 - Total cost

| | |
|---|---|
| 14m conveyor section | 192 300,00 EUR |
| Hydraulic table and roller conveyor | 133 200,00 EUR |
| Curve conveyor | 136 500,00 EUR |
| Floor conveyor | 200 000,00 EUR |
| Filling/evacuation equipment | 12 000,00 EUR |
| Electrical testing machine | 96 000,00 EUR |
| Wrapping machine and strapping machine | 150 000,00 EUR |
| Total | 920 000,00 EUR |

The solution developed in current research was compared with doubling of the production. Since AVO shop releases 30 units per day with 12 workers, installing the same equipment and hiring 12 more workers will provide ASTE with the desirable capacity of 60 units per day. The cost of doubling of current production was considered to be EUR 620 000.

## 6.4 Investment project analysis

### 6.4.1 The background

Since final solution does not consider changes in the design of product or cost and price of one unit, the revenue and variable costs will remain same for both solutions. The final design will require more power to operate due to electrically driven conveyors, thus the fixed cost of energy will be lower for doubling solution.

The difference between two solutions is the amount of investment capital required, number of workers and amount of electricity used as illustrated in Table 24.

Table 24 - Difference between solutions

| Difference | Final solution | Doubling solution |
|---|---|---|
| Investment capital | EUR 920 000<br>(EUR 1 million loan) | EUR 620 000<br>(EUR 700 000 loan) |
| Number of workers | 16 | 24 |
| Cost of energy (year) | 15000 | 5000 |

Several other premises were considered in order to perform financial analysis:

- Cost of one unit - EUR 80
- Price of one unit – EUR 200
- Cost of one worker – EUR 2058 per month
- Production rate - 15000 units per year
- WACC – 5%
- Taxes – 24% VAT and 20% Corporate tax
- Depreciation rate – 25% per year
- Inventory turnover – one day
- Account payable – 30 days
- Account receivable – 30 days
- Interest – 10%

The values provided in the current chapter were used for financial calculations. Three scenarios were developed in order to investigate the strength of projects as seen in Table 25.

Table 25 - Scenarios for investment project analysis

| | Common | Optimist | Pessimist |
|---|---|---|---|
| Sales volume | 0,0% | 30,0% | -10,0% |
| Price | 0,0% | 5,0% | -5,0% |
| Variable cost | 0,0% | -5,0% | 5,0% |
| Fixed cost | 0,0% | -10,0% | 10,0% |
| Capital cost | 0,0% | -15,0% | 15,0% |

Financial reports were created (Appendix 29, Appendix 30) and presented to the management.

### 6.4.2 Comparison between final layout and doubling the existing production

As it was mentioned above, the solution developed in the current research project do not affect the productivity of the factory. In other words, the output to input ratio is not changed, which means that variable costs and income remain the same. The financial advantage of the layout comes from its flexibility and number of workers, since the flexibility is an abstract concept, solutions were compared based on the expenses of the company. Due to no design changes, the difference between layouts comes mainly from the salary difference. Since the number of workers is 24 for doubling and 16 for the final solution, the difference can be calculated as illustrated in Figure 68.

$$Cost\ of\ workers: 8\ (per)\ x\ 12\ (month)\ x\ EUR\ 2058\ = EUR\ 197568$$

Since the conveyor line requires more electricity, which costs EUR 10 000 more as compared with doubling solution, the total amount of money saved will be EUR 187 568.

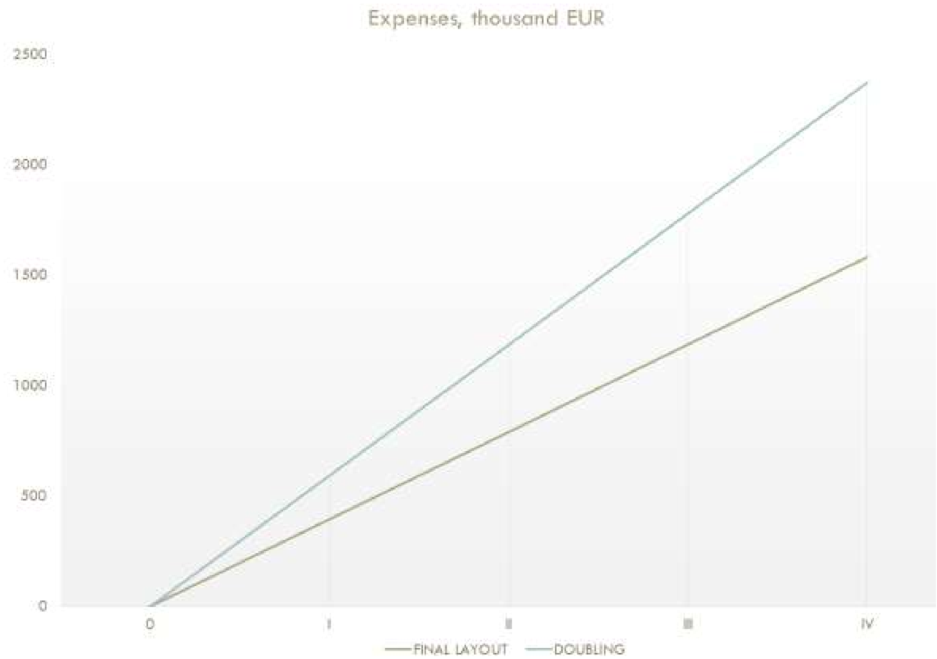



Figure 68 - Salary expenses

Table 26 - Comparison of investment projects

| Parameter | Final solution | Doubling solution |
|---|---|---|
| IC | Higher | Lower |
| IRR | Lower | Higher |
| NPV | Higher | Lower |
| PP | Longer | Shorter |
| DPP | Longer | Shorter |
| Expenses | Lower | Higher |
| Net profit | Higher | Lower |
| Profitability | Higher | Lower |
| Use | Long-term | Short term |

Both investment projects are highly profitable even in the pessimistic case. The break-even point is reached before the equipment is depreciated. However, since the payback period is affected by the amount of investment, PP and DPP values are lower for doubling solution. The IRR is higher for doubling solution due to smaller investment capital required.

The doubling solution is preferable if short-term planning is considered, since the production line requires less money to be launched and the project is paid back in one operating quarter.

The final solution is more profitable and is preferable for long-term operation so that the company can benefit from smaller expenses due to the smaller number of workers as can be seen in Figure 69.

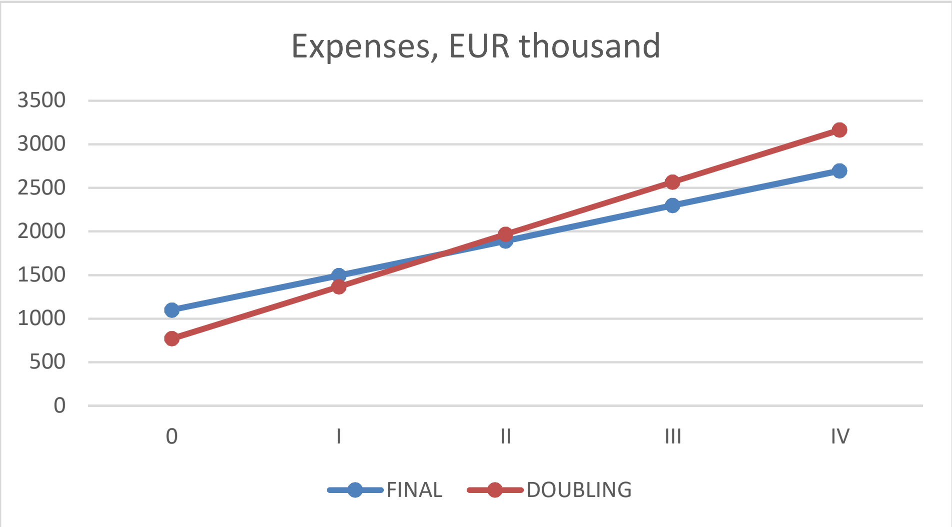



Figure 69 - Investment and fixed expenses

# 7 CONCLUSION

The results of the research project were presented in the form of different techniques allowing optimisation of the current production and a proposal of production shop for factory extension. After optimisation techniques were implemented into production the production rate was increased from 26 to 30 units per day. The management of Aste Finland Oy got a clear understanding of the relationship between the number of workers and production rates and limitations of the current production, such an understanding allows for easier production planning and a better respond to the demand.

The proposal of factory extension contains information on the equipment and tools, such as the exact solutions, their prices and suppliers, the number of workers required, the most important issue, however, was the investment analysis for the extension project and a comparison of the proposed solution to the doubling of the existing production. Such an analysis showed the attractiveness of investments, moreover the solution will save EUR 187.6 thousand each year due to the fact that smaller number of workers is required for production. The solution takes into account future development of the company such as increased production rates and the development of the product line.

Since current research project was focused on one production line it only considered the production of a sample product, thus the following tasks are the subjects for further studies:

- Production development of CELIT, SUBSTER, COOLIO, AF and other products,
- Optimisation and automation of warehousing system,
- Integration of ERP system to production,
- Implementation of design for assembly or DFA methods in order to optimise the production

Appendix 1. COMPETITOR BENCHMARKING

| Company name | Market Countries | Capacity x 1000 upright/total | Competitive Advantage | Impact on ASTE (areas) |
|---|---|---|---|---|
| Frigoglass | Norway, China, Greece, US, Germany,<br>Kenya, Philippines, Russia, Poland,<br>Australia, France, Malaysia | 250 / 250 | Creativity<br>Large size<br>Part of Coca-Cola family | Russia<br>Benelux<br>Poland |
| Iarp | Italy | 100 / 700 | A wide range of products<br>Technical director<br>Design (plastic design) | Italy<br>Spain<br>France |
| Carrier (Gamko) (Linde) | USA<br>Hungary<br>Netherlands (Gamko) | 40 / 150 | Strong US background<br>Resources, cooperation with PepsiCo<br>Price | Hungary<br>Italy<br>Denmark |
| Klimasan | Turkey | 100 / 300 | Price<br>Production technology and capacity | CIS<br>Bulgaria<br>former Yugoslavia |
| Ügur | Turkey | 70 / 150 | Price<br>Technology | CIS<br>Bulgaria<br>Western<br>Europe wholesale |
| Vestfrost | Denmark | 50 / 500 | Quality<br>Price<br>New products | Germany<br>Benelux<br>Italy<br>Denmark |
| Caravel (Derby) (Gramm) | Denmark | 35 / 250 | Design<br>Price | Denmark<br>UK<br>Benelux<br>Germany, Norway |
| AHT/SFA | Austria<br>Germany<br>Turkey<br>Thailand | 70/300 | Product range | Benelux<br>Italy<br>UK<br>Austria |
| Coreco | Spain | | Laboratory approved by CC and PepsiCo<br>Functionality in Southern Europe<br>Product range | Spain<br>Portugal |
| Inter Technica | Ukraine | | Price<br>Located close to the Russian market | Russia<br>Ukraine<br>Baltic countries |
| Liebherr | Germany<br>Romania | 60/400 | Quality | Western Europe |

Appendix 2. PRODUCT FAMILIES

Appendix 2/1. SUBSTER SERIES

The SUBSTER product family is formed by two model-types or three models performed in white, black or grey colour.
SUBSTER SR85 and SR100 are open top coolers designed to fulfil basic sales and marketing needs. Transparent sides made from acryl allow 360°- visibility. The structure allows either stacking its contents or dumping them inside.


Figure A 1 - SUBSTER SR85


Figure A 2 - SUBSTER SR100

SUBSTER SR150 is build using the same platform, however it is higher than SR85 and SR100, moreover it is open-cooler. The transparent acrylic body allows an unrestricted view. Bottles and cans ar e placed on adjustable shelves.


Figure A 3 - SUBSTER SR150

Appendix 2/2. CELIT SERIES

CELIT product family can be divided into two categories: CELIT MDC and CELIT LUMO.
CELIT MDC. MDC family is represented by MDC40R, MDC60R, MDC50, MDC60, MDC87, MDC100 and MDC120. Digits stand for the width of the cooler in cm and R stands for Slim Retro design.

Figure A 4 - MDC40R

Figure A 5 - MDC60R

All coolers use modular design and consists of two main units. The body with one glass door or two with adjustable shelves defines outer dimensions of the cooler and how much goods it can contain. The cooling unit, which is placed on top of the body defines the power of the cooling system, thus determining the temperature range and the energy consumption. The upper panel contains stickers depicting company logos, the panel can be replaced with the digital screen.


Figure A 6 - MDC products

CELIT LUMO is a wine and HoReCa[2] cooler with the round-edge design. The wine has different storing conditions, thus the operating temperature of LUMO cooler is higher as compared with beverage coolers, therefore wine cooler is sold under a separate brand name.

Figure A 7 - CELIT LUMO

[2] Syllabic abbreviation of the words **Ho**tel/**Re**staurant/**Ca**fé used in Europe for the food service industry (Eurostat, 2018).

AF product family consists of AF25, AF39, AF50, AF65, AF80, AF90, AF200, where the number stands for the width in cm. AF coolers are glass-door display cabinets mainly designed for bars and restaurants, some models, for example AF50, are designed to be placed on the table, some models such as AF39, are designed to be placed on the floor.

Figure A 8 – AF25


Figure A 9 - AF39

Figure A 10 - AF50

Figure A 11 - AF80

Figure A 12 - AF90

Figure A 13 - AF200

AVO is the main product family and consists of a wide range of coolers. AVO series can be divided into CT, Optima, Festival, Standard, Harmony and MAXI product lines.
AVO CT is professional countertop coolers designed for POS areas and HoReCa sector. The cooler has transparent front cover or door, which allows the access to the storing compartment. ASTE provides its customers with AVO CT60, CT100, 2D Lounge and Optima which can be performed in white or black colour. The design of Optima allows using of wooden walls.

Figure A 14 - AVO CT60

Figure A 15 - AVO CT100


Figure A 16 - AVO 2D


Figure A 17 - Optima 90

Figure A 18 - Optima 90 Wood

Avo Festival is a unique solution developed for public events, the cooler body is placed inside the hardcover with wheels allowing to transport coolers without any damage.

AVO Standard line consists of open front coolers.

The storing compartment is placed on top of the standard cooling unit called cassette, which allows to customise the product and provide customers with cardboard, wooden or glass body. Models which are based on AVO Standard are named this way: AVO [Type] [Height]-[Width], e.g. AVO

Figure A 19 - AVO Festival 1


Figure A 20 - AVO Festival 2

Figure A 21 - AVO WOOD 145-55

Figure A 22 - AVO WOOD 180-58


Figure A 23 - AVO Standard


Figure A 24 - AVO Standard G. Can be black or white


Figure A 25 - AVO Carton Valio

Figure A 26 - AVO Carton Juice

The design of AVO Harmony evolved from AVO Standard. The storing compartment is placed on top of same cooling unit; however, sidewalls are made of glass. The top panel can be equipped with the illuminating panel for a logo of a company. Improved design allows customising both height and width of coolers, thus providing customers with wide range of solutions. AVO Harmony consists of 6 models.

AVO MAXI is a special product developed to store a large number of goods. Such display cabinets are significantly higher and wider. A larger

Figure A 27 - AVO Harmony 135-50 can be either white, black or grey

Figure A 28 - AVO Harmony 135-60. Can be either white, black or grey

Figure A 29 - AVO Harmony 135-87. Can be black or grey

Figure A 30 - AVO Harmony 145-60


Figure A 31 - AVO Harmony 145-87

Figure A 32 - AVO Harmony 170-54. Can be black or grey

version of the standard cassette is used to form the base of its body. Large illuminated logo panel is attached to the top to allow high visibility for shop visitors.


Figure A 33 - AVO MAXI 200-120. Can be white or black

Due to the modular design, fully customised solutions can be developed allowing customers get exactly what they want.

Figure A 34 - AVO Station. 1

Figure A 35 - AVO Station. 2

Parent company DRU uses production volumes of ASTE to outsource some part of its production. In particular, at the moment ASTE makes COOLIO.

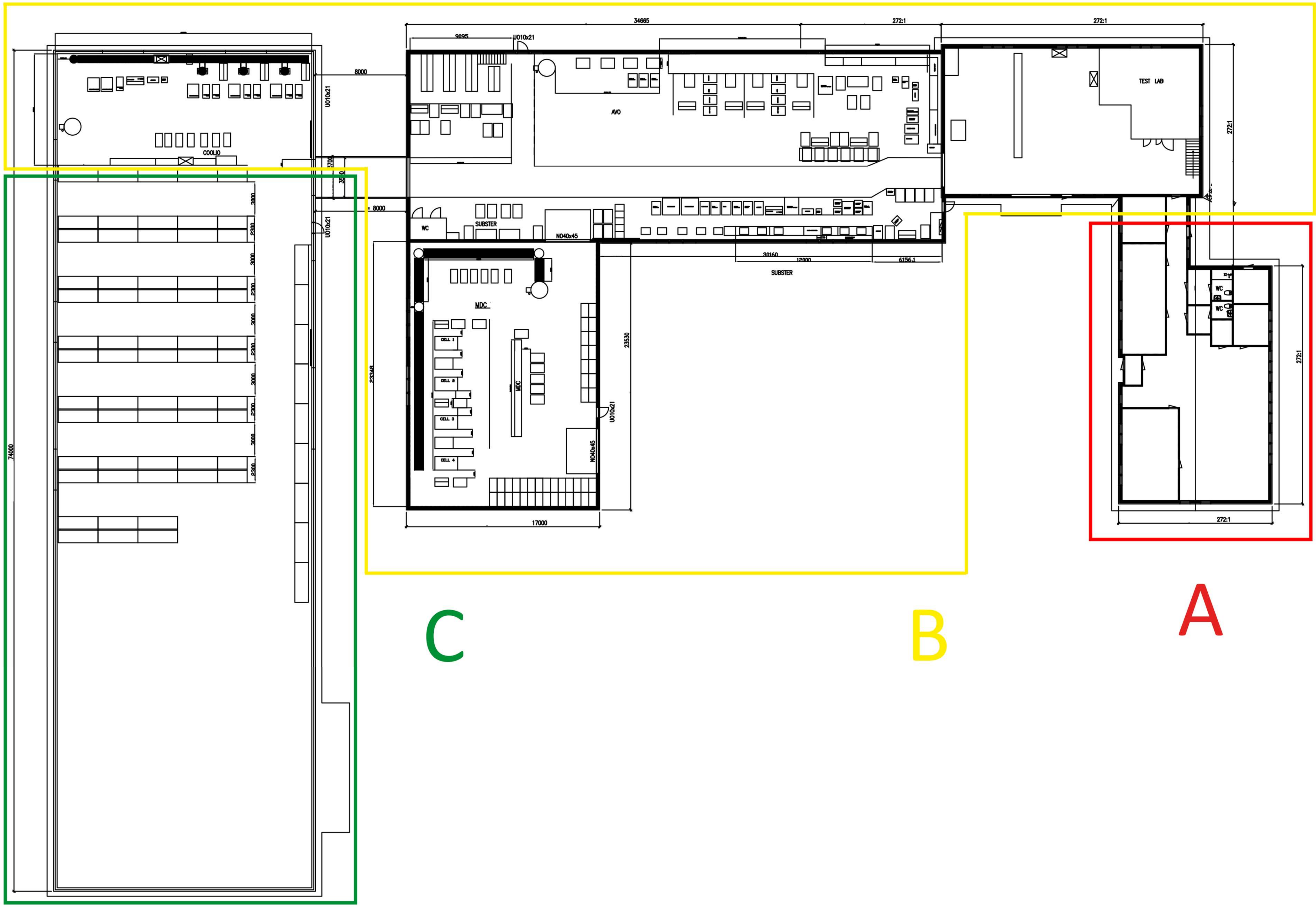
COOLIO is a bottom cooling unit which forms a platform for five different types of display cabinets, it can be used for both open front and open-top coolers.
Such design allows customers to order branded carton or plastic body of custom shapes (see Fig. 55, Fig. 56)

Figure A 36 – COOLIO Cassette

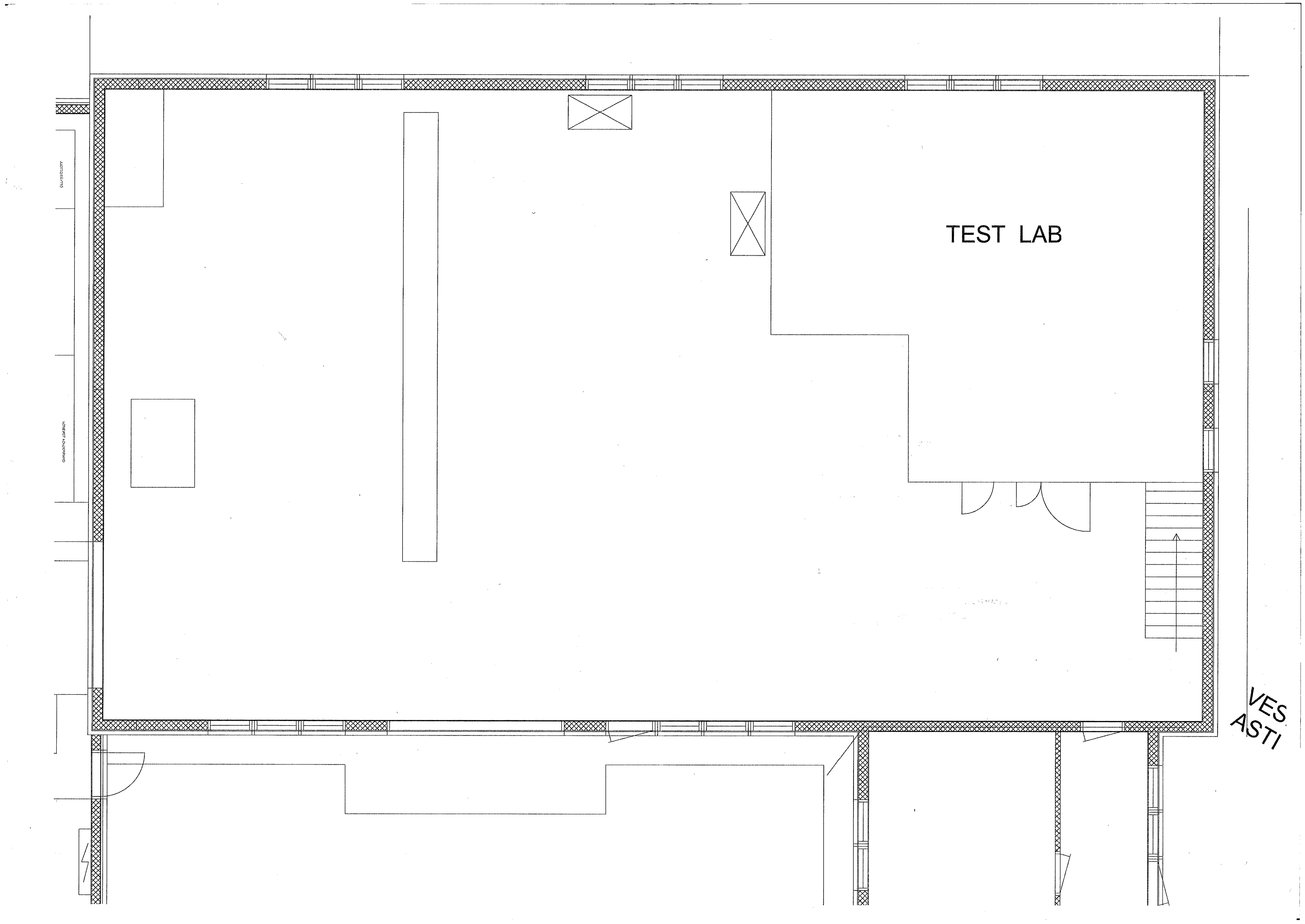

Figure A 37 - COOLIO solutions


Figure A 38 - Products based on COOLIO Cassette

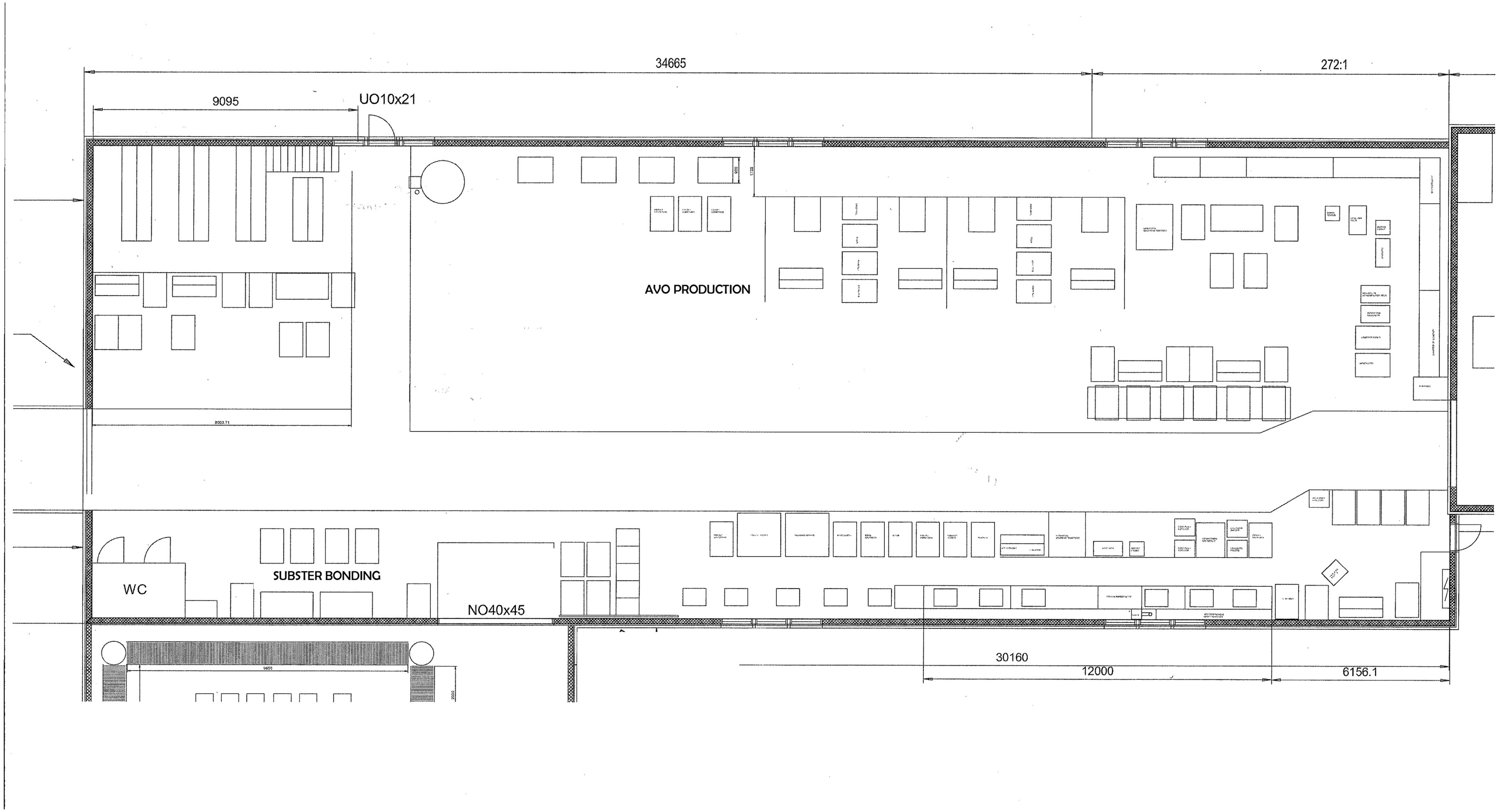
Appendix 3. FACTORY LAYOUT



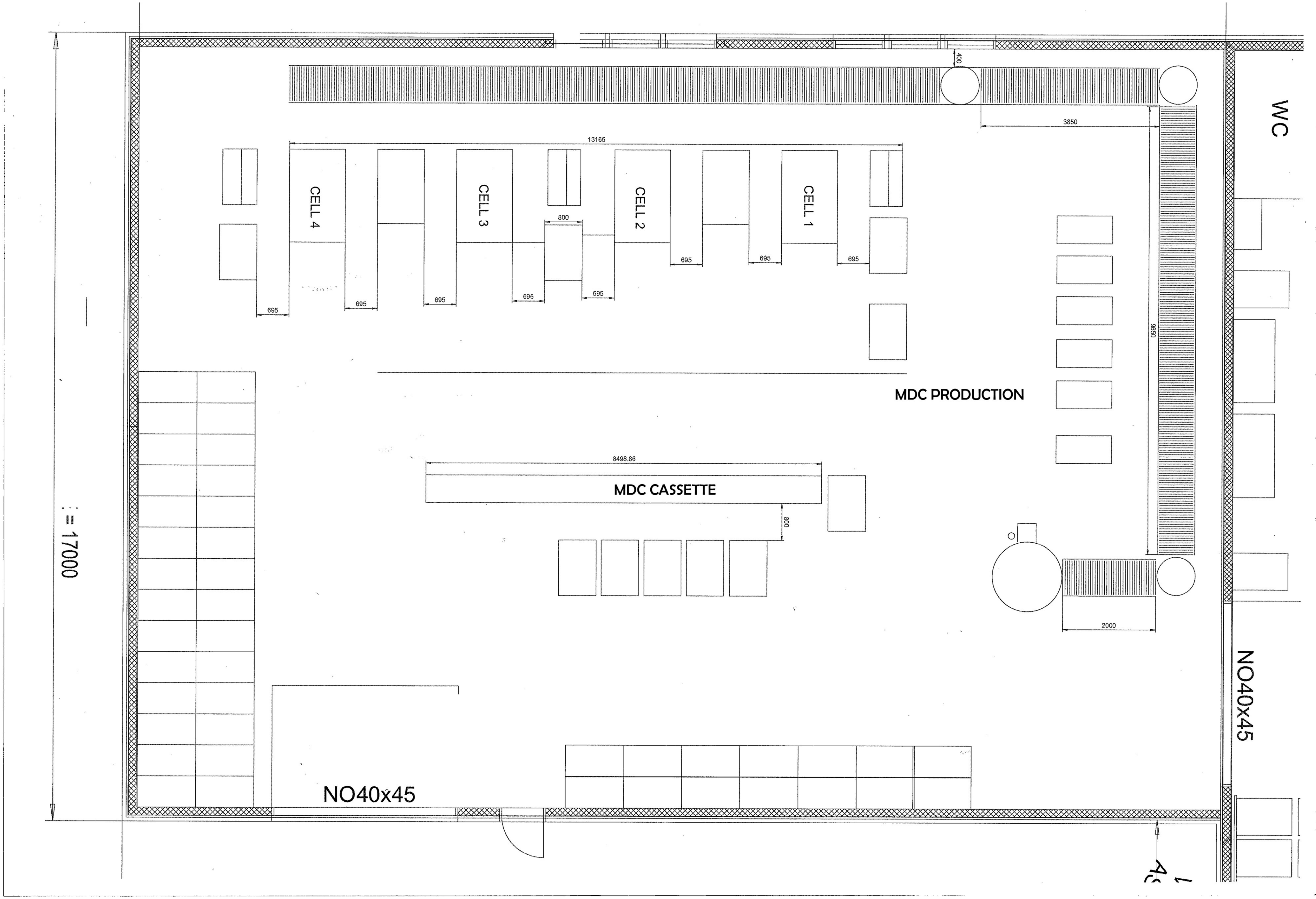
Appendix 4. SHOP B1



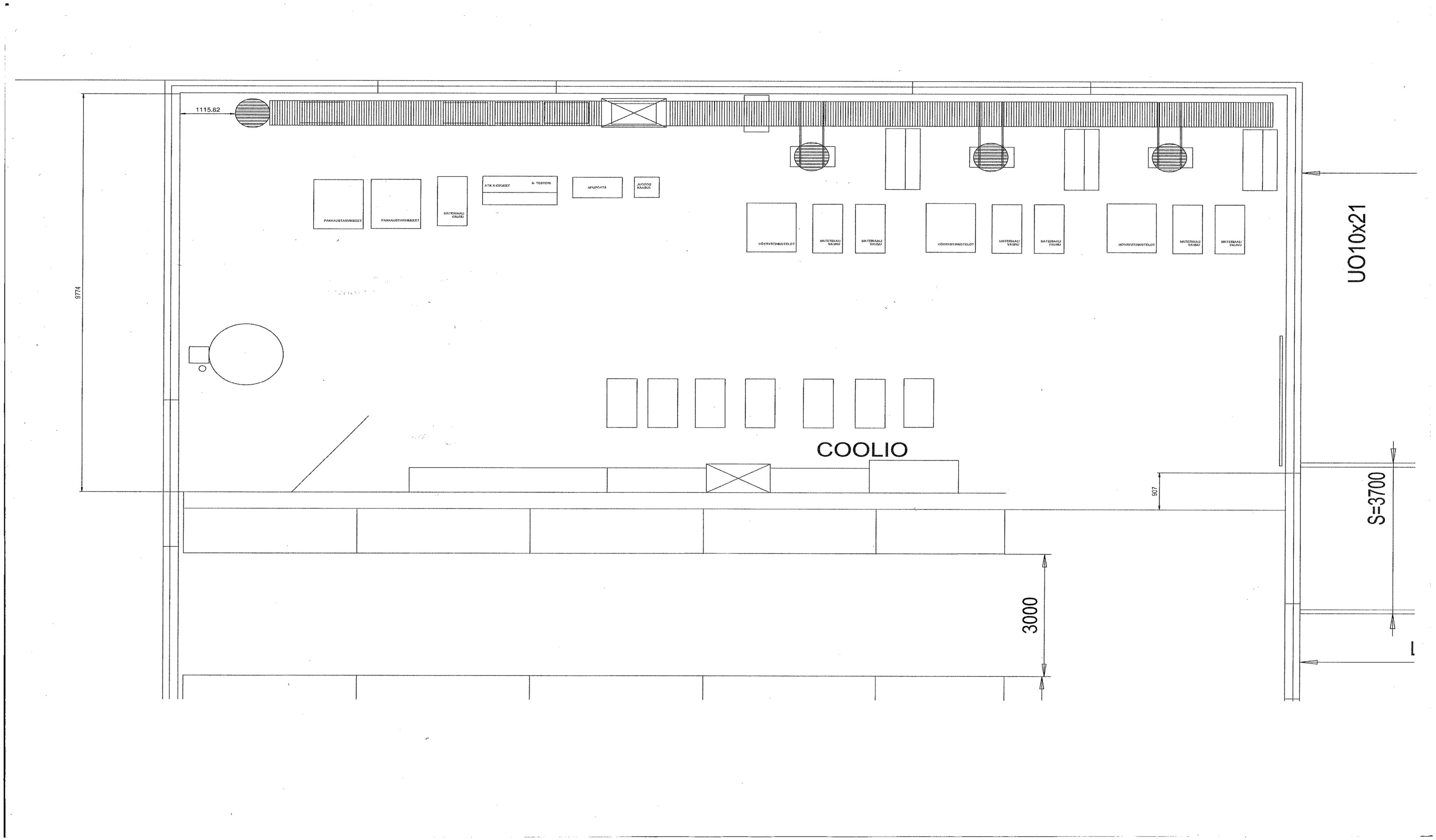
Appendix 5. SHOP B2



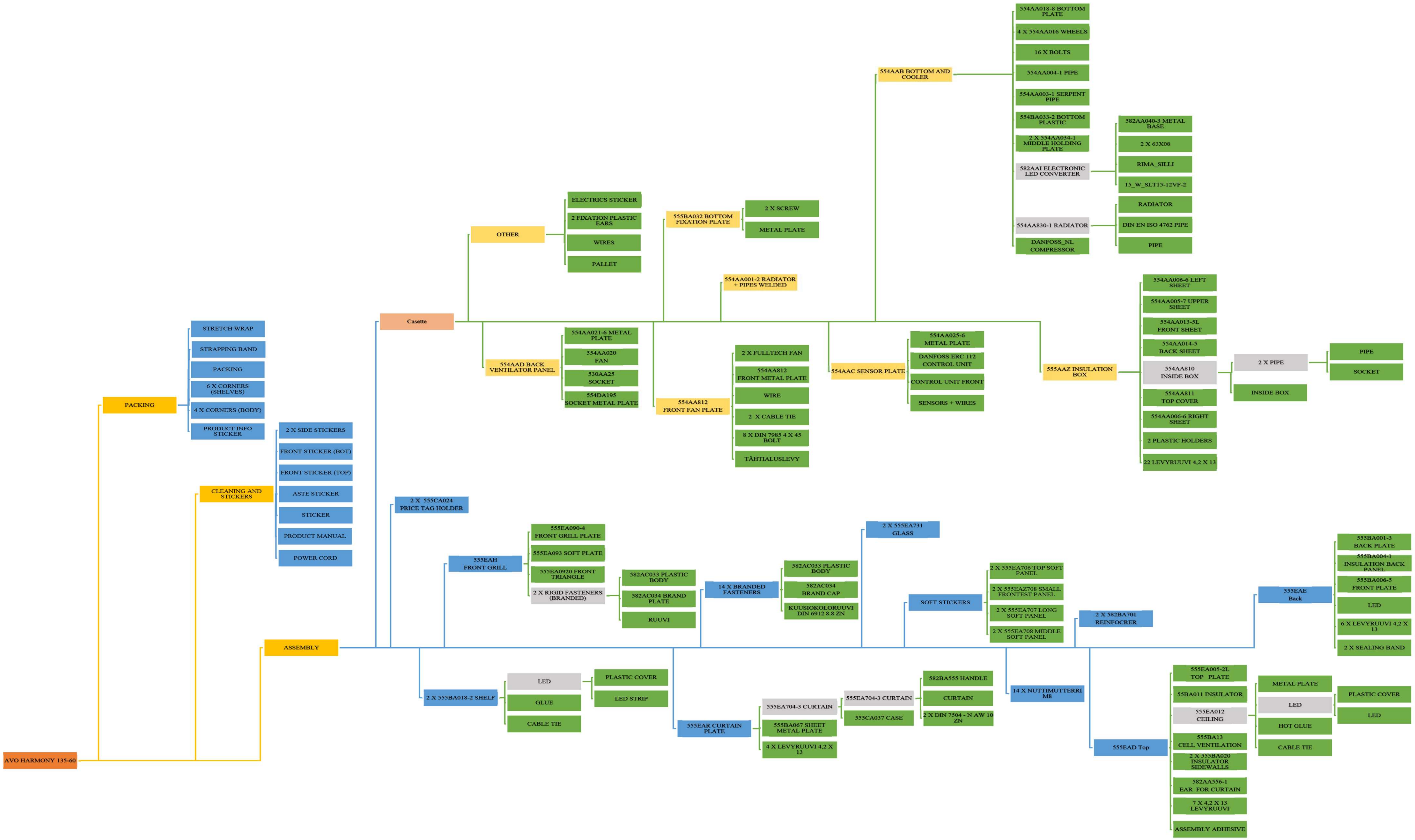
Appendix 6. SHOP B3



Appendix 7. SHOP B4



Appendix 8/1. SAMPLE PRODUCT. COMPONENTS

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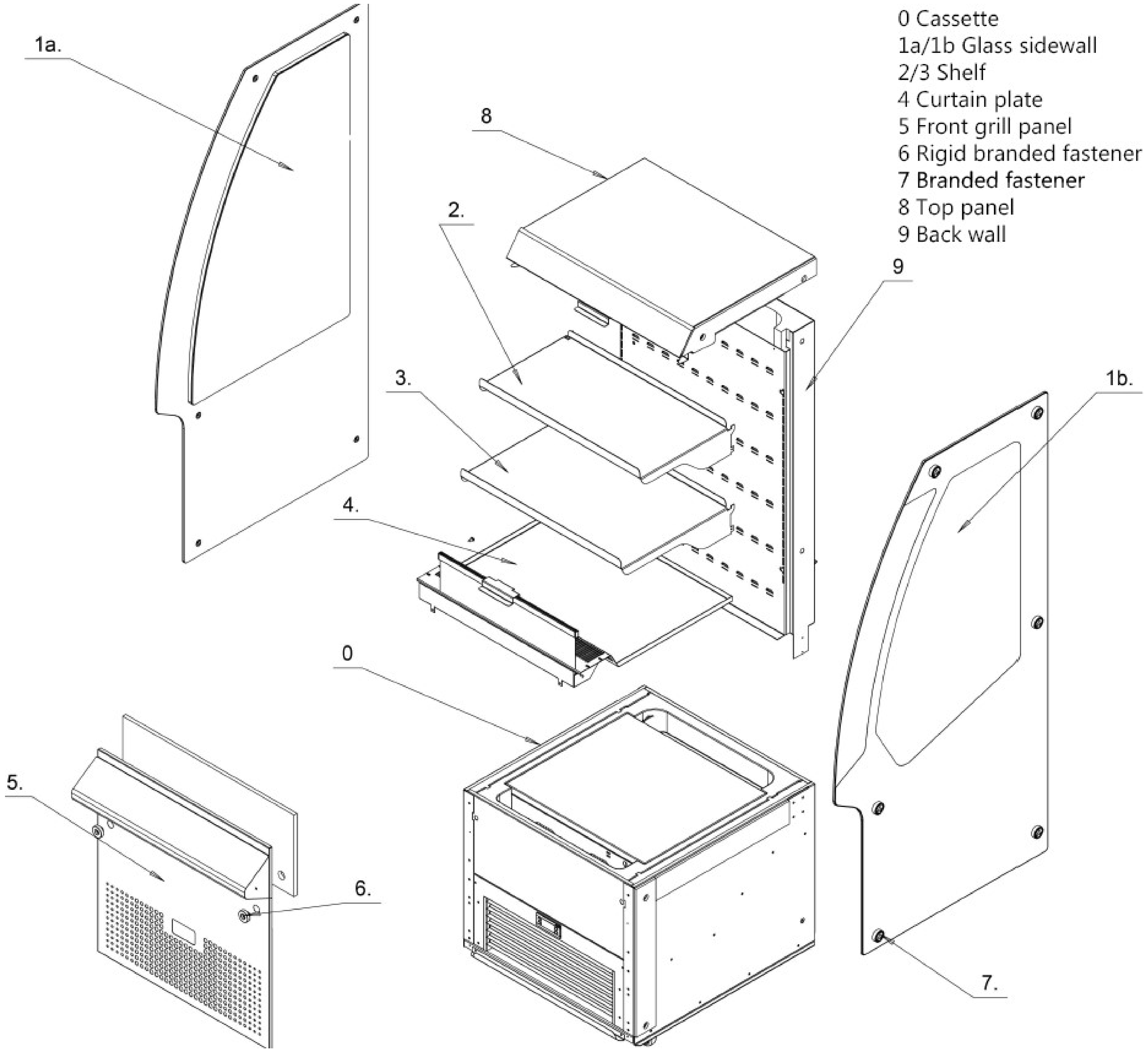
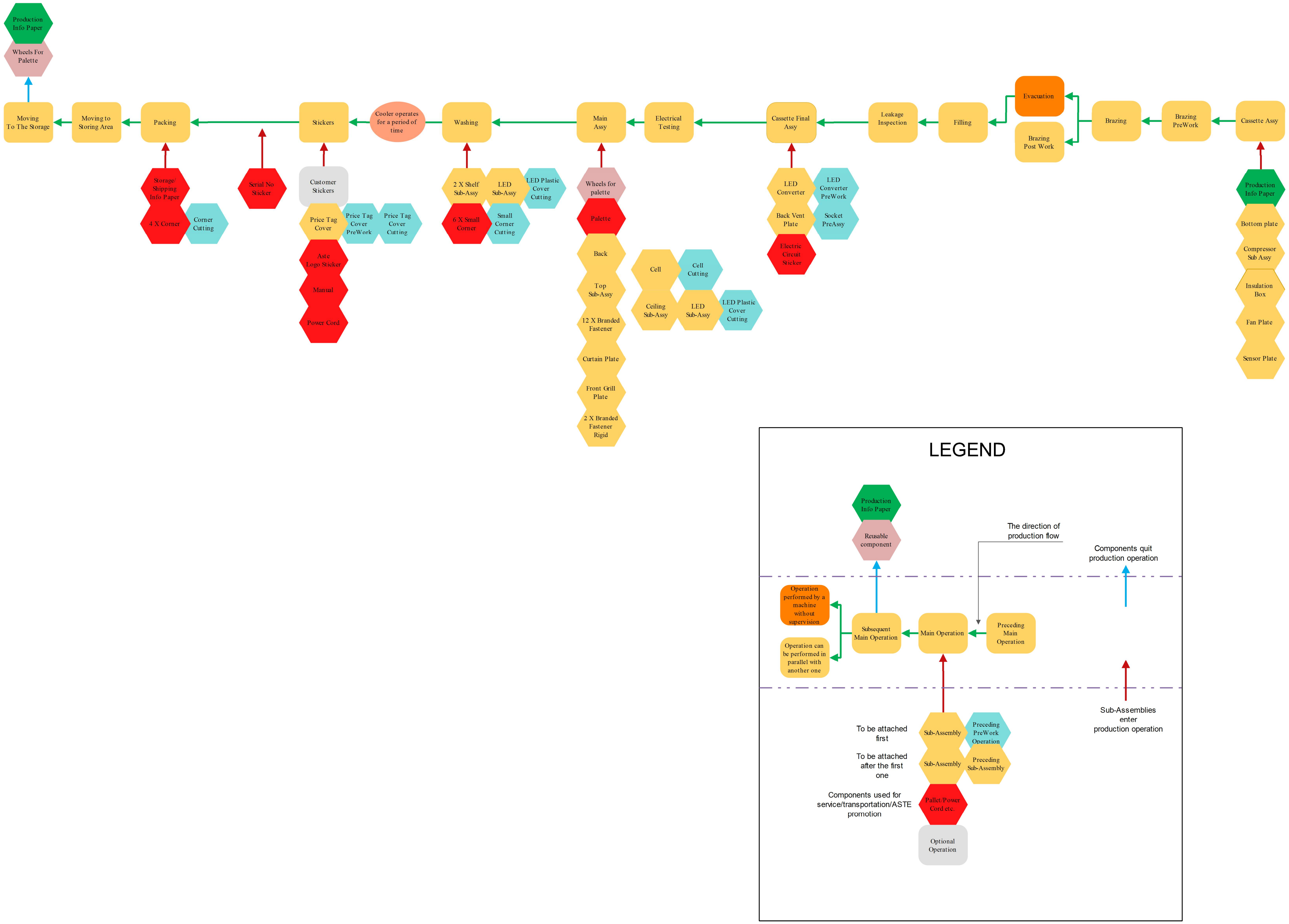
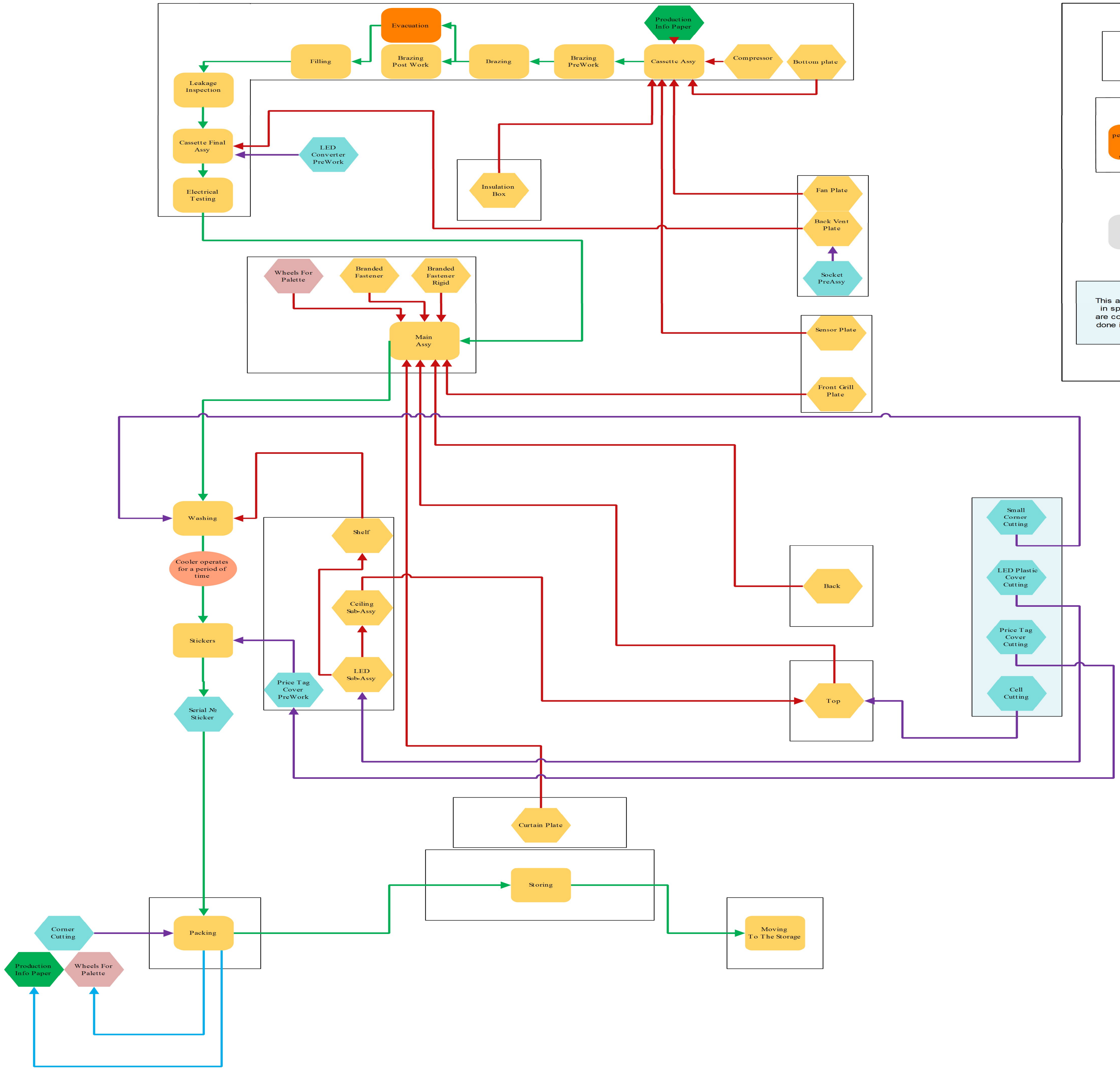


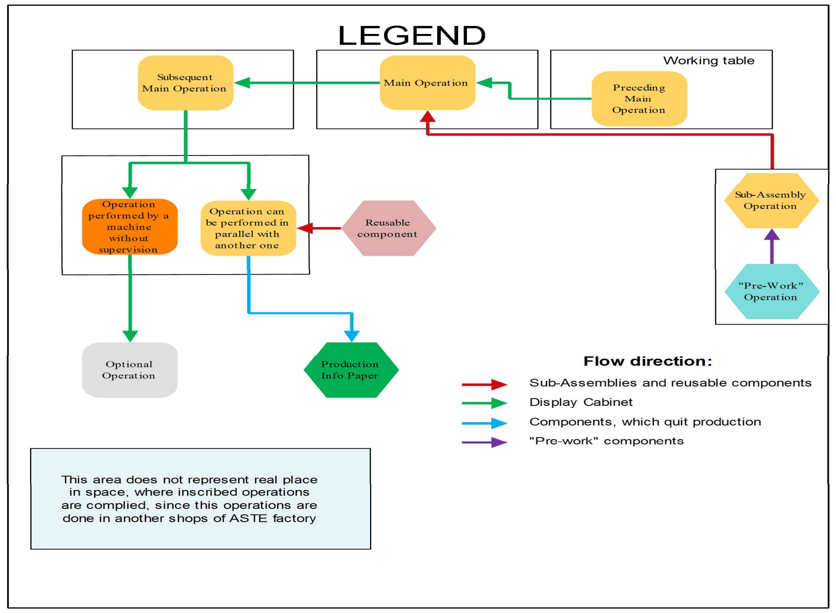

0 Cassette
1a/1b Glass sidewall
2/3 Shelf
4 Curtain plate
5 Front grill panel
6 Rigid branded fastener
7 Branded fastener
8 Top panel
9 Back wall

Appendix 9. PRODUCTION SCHEME

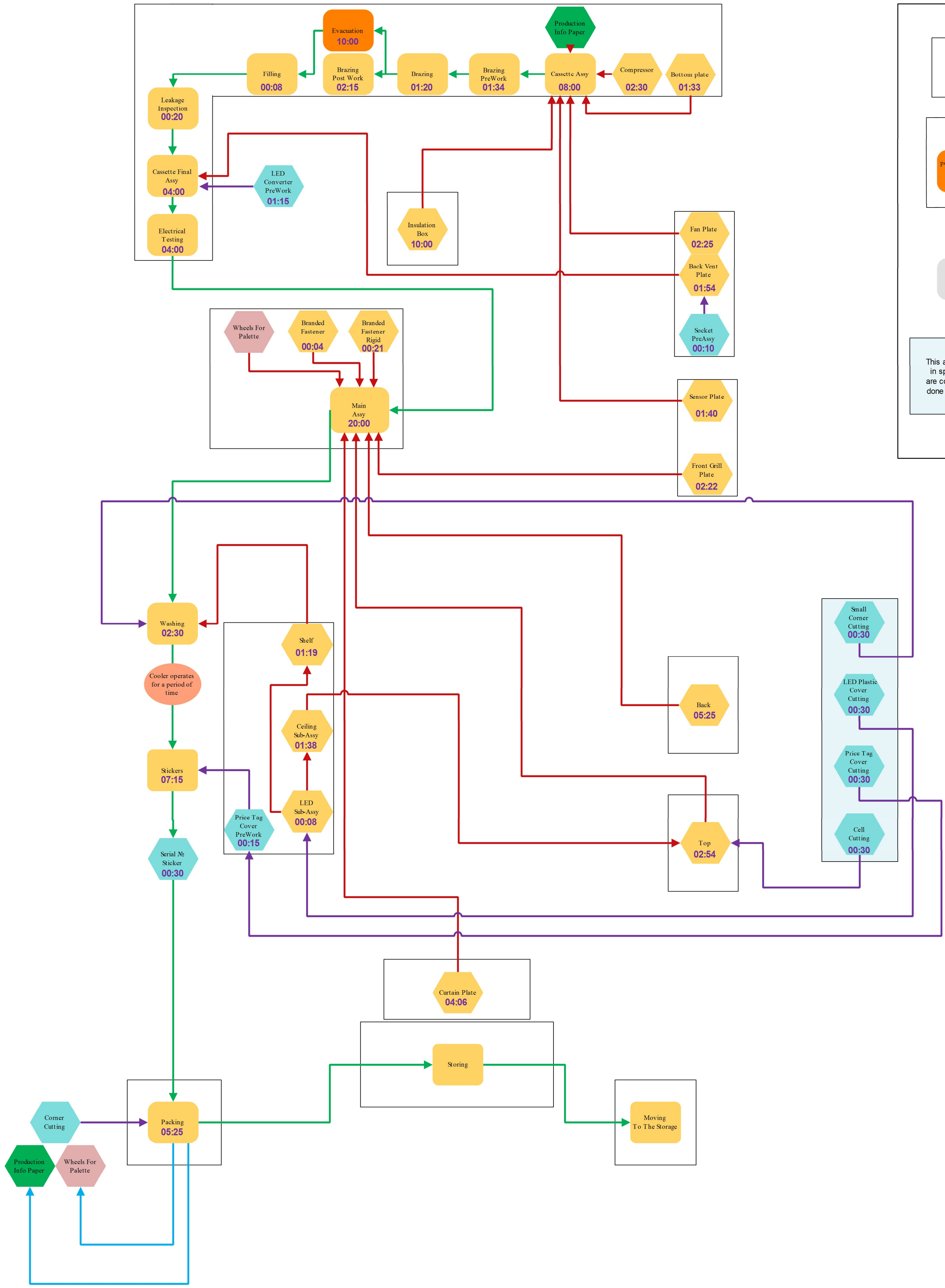


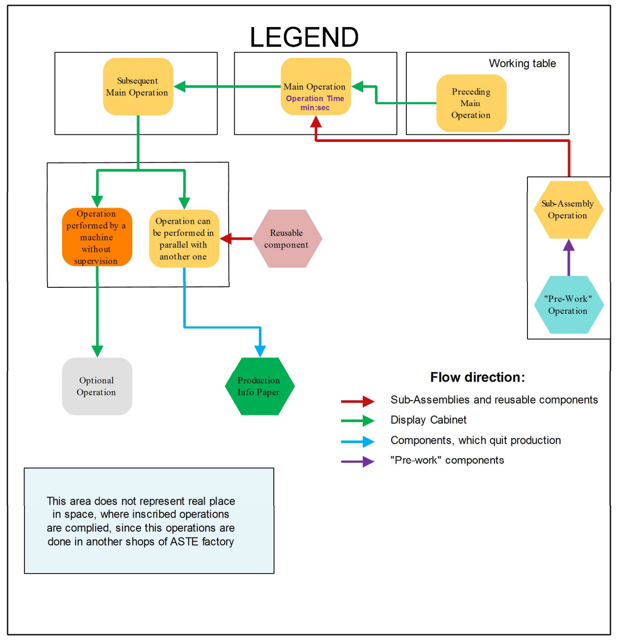
Appendix 10. PRODUCTION SCHEME AND LAYOUT



Appendix 11. PRODUCTION SCHEME AND LAYOUT. TIME



Appendix 12/1. RESULTS OF TIME STUDY

Back Vent Plate

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take plate | 00:00 | 00:00 | 00:00 | |
| Put plate | 00:03 | 00:03 | 00:03 | 00:03 |
| Take vent | 00:10 | 00:04 | 00:06 | 00:04 |
| Wire | 00:15 | 00:24 | 00:33 | 00:17 |
| Put wire | 00:27 | 00:30 | 00:42 | 00:09 |
| Take cover | 00:28 | 00:31 | 00:46 | 00:02 |
| Put cover | 00:30 | 00:38 | 00:53 | 00:05 |
| Take screwdriver | 00:35 | 00:41 | 00:55 | 00:03 |
| Tighten screw 1 | 00:45 | 00:45 | 01:01 | 00:07 |
| Tighten screw 2 | 00:51 | 00:52 | 01:05 | 00:06 |
| Tighten screw 3 | 00:57 | 01:02 | 01:20 | 00:10 |
| Tighten screw 4 | 01:02 | 01:09 | 01:26 | 00:06 |
| Put screwdriver | 01:04 | 01:12 | 01:28 | 00:02 |
| Take plate | 01:06 | 01:13 | 01:31 | 00:02 |
| Put plate | 01:10 | 01:16 | 01:35 | 00:04 |
| Take screwdriver | 01:12 | 01:17 | 01:36 | 00:01 |
| Tighten screw 1 | 01:18 | 01:23 | 01:37 | 00:04 |
| Tighten screw 2 | 01:24 | 01:28 | 01:46 | 00:07 |
| Put screwdriver | 01:25 | 01:29 | 01:47 | 00:01 |
| Put | 01:28 | 01:30 | 01:48 | 00:02 |

Results of other measutements

| № | Time |
|---|---|
| 1 | 01:54 |
| 2 | 01:43 |
| 3 | 01:47 |
| 4 | 02:38 |
| 5 | 02:12 |
| 6 | 01:43 |
| 7 | 02:21 |
| 9 | 01:33 |
| 9 | 01:59 |
| 10 | 02:10 |
| Average time to assemble Back Vent Plate | 01:54 |

Bottom

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take bottom plate | 00:00 | 00:00 | 00:00 | |
| Put | 00:03 | 00:07 | 00:04 | 00:05 |
| Put wheels to the table | 00:13 | 00:15 | 00:08 | 00:07 |
| Take bolts | 00:22 | 00:30 | 00:10 | 00:09 |
| Put bolts | 00:45 | 00:35 | 00:12 | 00:10 |
| Take screwdriver | 00:46 | 00:36 | 00:13 | 00:01 |
| Tighten bolt 1 | 00:47 | 00:38 | 00:14 | 00:02 |
| Tighten bolt 2 | 00:49 | 00:40 | 00:15 | 00:02 |
| Tighten bolt 3 | 00:51 | 00:43 | 00:17 | 00:02 |
| Tighten bolt 4 | 00:53 | 00:45 | 00:21 | 00:03 |
| Tighten bolt 5 | 00:55 | 00:49 | 00:25 | 00:03 |
| Tighten bolt 6 | 00:57 | 00:52 | 00:29 | 00:03 |
| Tighten bolt 7 | 01:00 | 00:56 | 00:33 | 00:04 |
| Tighten bolt 8 | 01:03 | 01:00 | 00:40 | 00:05 |
| Tighten bolt 9 | 01:05 | 01:05 | 00:43 | 00:03 |
| Tighten bolt 10 | 01:08 | 01:09 | 00:45 | 00:03 |
| Tighten bolt 11 | 01:12 | 01:12 | 00:50 | 00:04 |
| Tighten bolt 12 | 01:15 | 01:15 | 00:52 | 00:03 |
| Tighten bolt 13 | 01:23 | 01:19 | 00:57 | 00:06 |
| Tighten bolt 14 | 01:26 | 01:24 | 01:05 | 00:05 |
| Tighten bolt 15 | 01:29 | 01:35 | 01:07 | 00:05 |
| Tighten bolt 16 | 01:33 | 01:40 | 01:10 | 00:04 |
| Put screwdriver | 01:34 | 01:41 | 01:11 | 00:01 |
| Put component to the tray | 01:38 | 01:47 | 01:14 | 00:05 |

Results of other measutements

| № | Time |
|---|---|
| 1 | 01:38 |
| 2 | 01:47 |
| 3 | 01:40 |
| 4 | 01:40 |
| 5 | 01:25 |
| 6 | 01:40 |
| 7 | 01:35 |
| 9 | 01:20 |
| 9 | 01:28 |
| 10 | 01:38 |
| Average time to assemble Bottom Plate | 01:35 |

Back plate

| Operation name | Time | | | A |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Take back plate | 00:05 | 00:03 | 00:08 | |
| Put back plate | 00:10 | 00:10 | 00:23 | |
| Take insulation | 00:15 | 00:20 | 00:30 | |
| Put insulation | 00:26 | 00:25 | 00:39 | |
| Take front plate | 00:38 | 00:38 | 00:52 | |
| Put front plate | 00:40 | 00:42 | 00:56 | |
| Apply rubber line 1 | 01:04 | 01:15 | 01:26 | |
| Apply rubber line 2 | 01:28 | 01:28 | 01:36 | |
| Take cutters | 01:29 | 01:29 | 01:37 | |
| Cut | 01:38 | 01:30 | 01:40 | |
| Put cutters | 01:40 | 01:31 | 01:43 | |
| Take wires | 01:45 | 01:40 | 02:00 | |
| Unscrew 1 | 01:56 | 01:50 | 02:20 | |
| Unscrew 2 | 02:09 | 01:59 | 02:35 | |
| Put led connector 1 | 02:21 | 02:01 | 02:40 | |
| Tigthen 1 | 02:33 | 02:14 | 02:53 | |
| Put led connector 2 | 02:49 | 02:27 | 03:08 | |
| Tigthen 2 | 03:00 | 02:41 | 03:20 | |
| Put led connector 3 | 03:29 | 02:54 | 03:33 | |
| Tigthen 3 | 03:35 | 03:09 | 03:40 | |
| Put led connector 4 | 03:48 | 03:11 | 03:48 | |
| Tigthen 4 | 03:56 | 03:20 | 03:58 | |
| Take wrench | 04:02 | 03:23 | 04:16 | |
| Tigthen 1 | 04:05 | 03:27 | 04:21 | |
| Tigthen 2 | 04:12 | 03:29 | 04:23 | |
| Tigthen 3 | 04:18 | 03:33 | 04:27 | |
| Tigthen 4 | 04:27 | 03:36 | 04:30 | |
| Put fastener back | 04:29 | 03:38 | 04:35 | |
| Put on the back | 04:38 | 03:47 | 04:40 | |
| Align | 05:13 | 04:06 | 04:50 | |
| Take screwdriver | 05:14 | 04:07 | 04:52 | |
| Tighten screw 1 | 05:19 | 04:10 | 04:59 | |
| Tighten screw 2 | 05:24 | 04:16 | 05:07 | |
| Tighten screw 3 | 05:31 | 04:25 | 05:16 | |
| Tighten screw 4 | 05:48 | 04:34 | 05:22 | |
| Put | 06:05 | 04:43 | 05:35 | |

Results of other measutements

| № | Time |
|---|---|
| 1 | 05:59 |
| 2 | 04:55 |
| 3 | 05:42 |
| 4 | 05:08 |
| 5 | 05:54 |
| 6 | 04:57 |
| 7 | 05:22 |
| 9 | 05:38 |
| 9 | 05:15 |
| 10 | 05:08 |
| Average time to assemble Top Plate | 05:25 |

Cassette

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| START | 00:00 | 00:00 | 00:00 | |
| Take bottom | 00:03 | 00:05 | 00:02 | 00:03 |
| Take screws | 00:05 | 00:15 | 00:04 | 00:05 |
| Take screwdriwer | 00:12 | 00:16 | 00:08 | 00:04 |
| Tighten screw 1 | 00:14 | 00:17 | 00:10 | 00:02 |
| Tighten screw 2 | 00:15 | 00:19 | 00:12 | 00:02 |
| Take wire | 00:20 | 00:25 | 00:16 | 00:05 |
| Take screwdriver | 00:22 | 00:26 | 00:18 | 00:02 |
| Tighten screw 1 | 00:24 | 00:29 | 00:20 | 00:02 |
| Put screwdriver | 00:28 | 00:30 | 00:22 | 00:02 |
| Take metal plates | 00:37 | 00:35 | 00:25 | 00:06 |
| Take plastic cover | 00:44 | 00:40 | 00:45 | 00:11 |
| Take glue gun | 00:45 | 00:44 | 00:48 | 00:03 |
| Apply glue | 00:50 | 00:50 | 00:52 | 00:05 |
| Put glue gun | 00:51 | 00:51 | 00:53 | 00:01 |
| Hold | 00:54 | 00:58 | 00:54 | 00:04 |
| Take compressor | 01:05 | 01:10 | 01:04 | 00:11 |
| Put leg 1 | 01:12 | 01:18 | 01:10 | 00:07 |
| Put leg 2 | 01:20 | 01:20 | 01:12 | 00:04 |
| Put leg 3 | 01:30 | 01:25 | 01:18 | 00:07 |
| Put leg 4 | 01:35 | 01:29 | 01:20 | 00:04 |
| Put metal pipe 1 to leg 1 | 01:40 | 01:34 | 01:22 | 00:04 |
| Put metal pipe 2 to leg 2 | 01:43 | 01:36 | 01:25 | 00:03 |
| Put metal pipe 3 to leg 3 | 01:46 | 01:38 | 01:28 | 00:03 |
| Put metal pipe 4 to leg 4 | 01:48 | 01:49 | 01:30 | 00:05 |
| Turn | 01:52 | 01:49 | 01:33 | 00:02 |
| Take wire | 01:55 | 01:50 | 01:35 | 00:02 |
| Join components | 02:03 | 01:56 | 01:38 | 00:06 |
| Put | 02:25 | 02:00 | 01:42 | 00:10 |
| Take | 02:31 | 02:07 | 01:49 | 00:07 |
| Put black component | 02:34 | 02:11 | 01:53 | 00:04 |
| Take holder | 02:30 | 02:15 | 01:57 | 00:01 |
| Adjust | 02:33 | 02:28 | 02:01 | 00:07 |
| Take screwdriver | 02:35 | 02:30 | 02:14 | 00:06 |
| Tighten screw 1 | 02:38 | 02:34 | 02:18 | 00:04 |
| Tighten screw 2 | 02:40 | 02:38 | 02:22 | 00:03 |
| Put screwdriver | 02:41 | 02:39 | 02:28 | 00:03 |
| Take component a | 02:44 | 02:42 | 02:32 | 00:03 |
| Put component a | 02:51 | 03:01 | 02:53 | 00:16 |
| Take screwdriver | 02:55 | 03:02 | 02:57 | 00:03 |
| Tighten screw 1 | 02:56 | 03:03 | 02:59 | 00:01 |
| Put screwdriver | 02:58 | 03:10 | 03:06 | 00:05 |
| Take compressor | 03:00 | 03:11 | 03:08 | 00:02 |
| Take bolts | 03:02 | 03:12 | 03:10 | 00:02 |
| Put bolts | 03:30 | 03:18 | 03:13 | 00:12 |
| Place compressor | 03:46 | 03:21 | 03:15 | 00:07 |
| Take pneumatic screwdriver | 03:54 | 03:25 | 03:20 | 00:06 |
| Tighten bolt 1 | 04:14 | 03:27 | 03:45 | 00:16 |
| Tighten bolt 2 | 04:16 | 03:29 | 03:59 | 00:06 |
| Tighten bolt 3 | 04:19 | 03:31 | 04:15 | 00:07 |
| Tighten bolt 4 | 05:00 | 03:34 | 04:20 | 00:16 |
| Put pneumatic screwdriver | 05:02 | 03:38 | 04:21 | 00:02 |
| Turn | 05:03 | 03:46 | 04:22 | 00:03 |
| Take pliers | 05:04 | 03:53 | 04:22 | 00:03 |
| Deform | 05:05 | 03:58 | 04:23 | 00:02 |
| Put pliers | 05:09 | 03:59 | 04:25 | 00:02 |
| Take radiator | 05:10 | 04:09 | 04:25 | 00:04 |
| Place radiator | 05:11 | 04:11 | 04:30 | 00:03 |
| Bend pipes | 05:16 | 04:29 | 04:41 | 00:11 |
| Take sensor plate | 05:34 | 04:38 | 04:53 | 00:13 |
| Wire operation uncoil | 05:42 | 04:52 | 05:15 | 00:15 |
| Place comp | 05:48 | 04:55 | 05:20 | 00:05 |
| Take screwdriver | 05:51 | 04:59 | 05:24 | 00:04 |
| Tighten screw 1 | 05:58 | 05:02 | 05:28 | 00:05 |
| Tighten screw 2 | 06:00 | 05:05 | 05:31 | 00:03 |
| Tighten screw 3 | 06:04 | 05:08 | 05:33 | 00:03 |
| Tighten screw 4 | 06:07 | 05:12 | 05:35 | 00:03 |
| Tighten screw 5 | 06:09 | 05:18 | 05:36 | 00:03 |
| Tighten screw 6 | 06:17 | 05:22 | 05:39 | 00:05 |
| Put screwdriver | 06:18 | 05:23 | 05:42 | 00:02 |
| Take bottom fixing plate | 06:22 | 05:26 | 05:45 | 00:03 |
| Place comp | 06:25 | 05:29 | 05:48 | 00:03 |
| Take screwdriver | 06:26 | 05:30 | 05:49 | 00:01 |
| Tighten screw 1 | 06:28 | 05:32 | 05:50 | 00:02 |
| Tighten screw 2 | 06:30 | 05:34 | 05:52 | 00:02 |
| Tighten screw 3 | 06:32 | 05:36 | 05:54 | 00:02 |
| Put screwdriver | 06:33 | 05:38 | 05:56 | 00:02 |
| Take insulation assy | 06:37 | 05:44 | 06:00 | 00:05 |
| Put to the table | 06:40 | 05:49 | 06:04 | 00:04 |
| Put sensors | 06:55 | 05:52 | 06:25 | 00:13 |
| Put assy | 07:05 | 05:56 | 06:28 | 00:06 |
| Take screwdriver | 07:07 | 06:00 | 06:32 | 00:03 |
| Tighten screw 1 | 07:11 | 06:04 | 06:35 | 00:04 |
| Tighten screw 2 | 07:12 | 06:08 | 06:38 | 00:03 |
| Tighten screw 3 | 07:15 | 06:12 | 06:42 | 00:04 |
| Tighten screw 4 | 07:18 | 06:14 | 06:44 | 00:02 |
| Tighten screw 5 | 07:22 | 06:18 | 06:48 | 00:04 |
| Tighten screw 6 | 07:26 | 06:22 | 06:53 | 00:04 |
| Tighten screw 7 | 07:29 | 06:25 | 06:59 | 00:04 |
| Tighten screw 8 | 07:33 | 06:31 | 07:00 | 00:04 |
| Tighten screw 9 | 07:36 | 06:34 | 07:08 | 00:05 |
| Tighten screw 10 | 07:39 | 06:39 | 07:12 | 00:04 |
| Tighten screw 11 | 07:42 | 06:43 | 07:15 | 00:03 |
| Tighten screw 12 | 07:45 | 06:46 | 07:18 | 00:03 |
| Tighten screw 13 | 07:48 | 06:52 | 07:22 | 00:04 |
| Tighten screw 14 | 07:54 | 06:55 | 07:28 | 00:05 |
| Put screwdriver | 08:00 | 07:15 | 07:30 | 00:09 |
| Turn | 08:02 | 07:17 | 07:49 | 00:08 |
| Take fan plate | 08:20 | 07:17 | 07:51 | 00:07 |
| Put | 08:25 | 07:42 | 08:13 | 00:17 |
| Take big rad | 08:40 | 07:53 | 08:20 | 00:11 |
| Turn pipe | 08:48 | 07:58 | 08:26 | 00:06 |
| Unwind small pipe | 08:55 | 08:00 | 08:30 | 00:04 |
| Put small pipe | 09:09 | 08:05 | 08:35 | 00:08 |
| Reel up | 09:22 | 08:22 | 08:52 | 00:16 |
| Take cutters | 09:41 | 09:15 | 09:02 | 00:27 |
| Take cable tie | 09:51 | 09:20 | 09:05 | 00:06 |
| Cut | 09:53 | 09:26 | 09:11 | 00:05 |
| Put cutters | 09:54 | 09:27 | 09:21 | 00:04 |
| Put sensors | 10:05 | 09:30 | 09:32 | 00:08 |
| Put wires | 10:12 | 09:33 | 09:45 | 00:08 |
| Paper | 10:33 | 09:36 | 09:53 | 00:11 |

Results of other meausurements

| № | Time |
|---|---|
| 1 | 09:37 |
| 2 | 10:08 |
| 3 | 09:32 |
| 4 | 09:50 |
| 5 | 10:16 |
| 6 | 09:33 |
| 7 | 10:11 |
| 9 | 10:20 |
| 9 | 09:43 |
| 10 | 10:56 |
| Average time to assemble Cassette | 10:01 |
| Average time to assemble Compressor | 02:30 |
| Average time to assemble Cassette w/o Compressor | 07:31 |

Cassette final

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take vent | 00:00 | 00:00 | 00:00 | |
| Join cables | 00:08 | 00:09 | 00:06 | 00:08 |
| Fix cables | 00:31 | 00:16 | 00:15 | 00:13 |
| Put gum | 00:42 | 00:20 | 00:20 | 00:07 |
| Put LED Converter | 00:47 | 00:23 | 00:21 | 00:03 |
| Take screwdriver | 00:49 | 00:26 | 00:23 | 00:02 |
| Tighten screw 1 | 00:52 | 00:27 | 00:25 | 00:02 |
| Put screwdriver | 00:55 | 00:30 | 00:26 | 00:02 |
| Put wire | 01:00 | 00:35 | 00:28 | 00:04 |
| Take screwdriver | 01:03 | 00:46 | 00:30 | 00:05 |
| Tighten screw 1 | 01:09 | 00:48 | 00:31 | 00:03 |
| Tighten screw 2 | 01:15 | 00:59 | 00:32 | 00:06 |
| Tighten screw 3 | 01:26 | 01:05 | 00:35 | 00:07 |
| Put inside | 01:32 | 01:16 | 00:43 | 00:08 |
| Join cables | 01:42 | 01:24 | 00:48 | 00:08 |
| Take cutters | 01:46 | 01:30 | 00:52 | 00:05 |
| Take screwdriver | 01:50 | 01:36 | 00:56 | 00:05 |
| Tighten screw 1 | 01:56 | 01:41 | 00:59 | 00:05 |
| Tighten screw 2 | 02:03 | 01:48 | 01:02 | 00:06 |
| Tighten screw 3 | 02:08 | 01:54 | 01:05 | 00:05 |
| Tighten screw 4 | 02:10 | 02:00 | 01:15 | 00:06 |
| Tighten screw 5 | 02:15 | 02:03 | 01:18 | 00:04 |
| Tighten screw 6 | 02:21 | 02:07 | 01:23 | 00:05 |
| Put screwdriver | 02:26 | 02:10 | 01:25 | 00:03 |
| Take top insulation | 02:32 | 02:13 | 01:30 | 00:05 |
| Place | 02:43 | 02:20 | 01:45 | 00:11 |
| Take rubber | 02:49 | 02:25 | 01:51 | 00:06 |
| Apply rubber | 02:54 | 02:35 | 02:04 | 00:09 |
| Take cutters | 02:59 | 02:38 | 02:06 | 00:03 |
| Cut | 03:03 | 02:42 | 02:12 | 00:05 |
| Put cutters | 03:05 | 02:46 | 02:14 | 00:03 |
| Apply rubber (middle) | 03:12 | 02:50 | 02:34 | 00:10 |
| Put wire for LED | 03:18 | 03:09 | 02:45 | 00:12 |
| Take cutters | 03:26 | 03:13 | 02:51 | 00:06 |
| Cut | 03:32 | 03:16 | 02:53 | 00:04 |
| Put cutters | 03:38 | 03:25 | 03:02 | 00:08 |
| Inspect | 03:40 | 03:32 | 03:10 | 00:06 |
| Cut | 03:55 | 03:40 | 03:25 | 00:13 |
| Put cutters | 03:59 | 03:45 | 03:28 | 00:04 |
| Inspect | 04:05 | 03:50 | 03:32 | 00:05 |
| Put | 04:10 | 03:56 | 03:45 | 00:08 |

Results of other meausurements

| № | Time |
|---|---|
| 1 | 04:10 |
| 2 | 04:17 |
| 3 | 04:00 |
| 4 | 03:20 |
| 5 | 04:16 |
| 6 | 03:15 |
| 7 | 03:12 |
| 9 | 04:25 |
| 9 | 04:30 |
| 10 | 04:42 |
| Average time to perform Cassette Final Assembly | 04:00 |

Appendix 12/3. RESULTS OF TIME STUDY

Prefilling

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Take paper | 00:00 | 00:00 | 00:00 | 00:00 |
| Write | 00:03 | 00:05 | 00:06 | 00:01 |
| Put wires | 00:04 | 00:09 | 00:11 | 00:00 |
| Take off cap from pipe | 00:08 | 00:16 | 01:47 | 00:01 |
| Put pipe | 00:10 | 00:18 | 01:53 | 00:01 |
| Fix | 00:12 | 00:24 | 01:57 | 00:01 |
| Take bender | 00:14 | 00:31 | 02:00 | 00:01 |
| Bend 90° | 00:16 | 00:33 | 00:23 | 00:01 |
| Put bender | 00:17 | 00:34 | 00:24 | 00:00 |
| Take small wires | 00:18 | 00:35 | 02:04 | 00:00 |
| Adjust wires | 00:20 | 00:45 | 02:28 | 00:01 |
| Put into the pipe with big cyl | 00:44 | 01:44 | 02:35 | 00:08 |
| Take brazer | 01:08 | 02:39 | 04:15 | 00:08 |
| Set fire | 01:11 | 03:22 | 05:02 | 00:01 |
| Braze left pipe 1 | 01:24 | 03:26 | 05:03 | 00:04 |
| Braze left pipe 2 | 01:30 | 03:40 | 05:10 | 00:02 |
| Braze right pipe 1 | 01:46 | 03:59 | 05:15 | 00:05 |
| Braze right pipe 2 | 01:50 | 04:04 | 05:27 | 00:01 |
| Braze right pipes 3 and 4 | 02:08 | 02:49 | 03:43 | 00:06 |
| Put brazer | 02:10 | 02:50 | 03:48 | 00:01 |
| Inspect with mirros | 02:20 | 04:02 | 03:52 | 00:03 |
| Clean with air | 02:35 | 04:26 | 03:54 | 00:05 |
| Attach nipple | 02:47 | 04:43 | 04:32 | 00:04 |
| Start evatuaction | 02:54 | 05:00 | | 00:02 |
| Take wire connectors | 03:55 | 05:41 | 07:04 | 00:20 |
| Put wires | 04:35 | 06:02 | 08:05 | 00:13 |
| Take screwdriver | 04:39 | 06:03 | 08:08 | 00:01 |
| Tighten screw 1 | 04:46 | 06:06 | 08:14 | 00:02 |
| Tighten screw 2 | 04:50 | 06:13 | 08:18 | 00:01 |
| Put screwdriver | 04:53 | 06:15 | 08:20 | 00:01 |
| Take cable tie | 04:59 | 06:20 | 08:26 | 00:02 |
| Put cable tie 1 | 05:03 | 06:22 | 08:35 | 00:01 |
| Put cable tie 2 | 05:10 | 06:30 | 08:40 | 00:02 |
| Take pliers | 05:15 | 06:40 | 08:45 | 00:02 |
| cut | 05:17 | 06:43 | 08:48 | 00:01 |
| Cut cable tie 1 | 05:21 | 06:45 | 08:49 | 00:01 |
| Cut cable tie 2 | 05:21 | 06:49 | 08:50 | 00:00 |
| Put pliers | 05:23 | 06:52 | 08:52 | 00:01 |
| Put cables | 05:33 | 06:59 | 08:51 | 00:03 |
| Put | 05:33 | 07:00 | 09:02 | 00:00 |
| | | together | | |

Results of other measutements

| № | Time |
|---|---|
| 1 | 05:16 |
| 2 | 04:00 |
| 3 | 04:20 |
| 4 | 05:10 |
| 5 | 04:16 |
| 6 | 04:32 |
| 7 | 04:20 |
| 9 | 05:34 |
| 9 | 05:25 |
| 10 | 05:20 |
| Average time to perform operation | 05:09 |
| Average time to perfrom Pre-Work | 0:02:54 |
| Average time to perform Post-Work | 0:02:15 |

Main assembly

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take pallet | 00:00 | 00:00 | 00:00 | |
| Put wheels | 00:02 | 00:02 | 00:02 | 00:02 |
| Put on the pallet | 00:05 | 00:05 | 00:06 | 00:03 |
| Take to the place | 00:15 | 00:16 | 00:18 | 00:11 |
| Take paper away | 00:17 | 00:18 | 00:20 | 00:02 |
| Take back sub-assy | 00:45 | 00:49 | 00:53 | 00:31 |
| Put back sub-assy | 01:00 | 01:05 | 01:11 | 00:16 |
| Connect wires | 01:01 | 01:06 | 01:12 | 00:01 |
| Take screwdriver | 01:03 | 01:08 | 01:15 | 00:02 |
| Tighten screw 1 | 01:24 | 01:31 | 01:40 | 00:23 |
| Tighten screw 2 | 01:31 | 01:39 | 01:48 | 00:08 |
| Tighten screw 3 | 01:45 | 01:54 | 02:05 | 00:15 |
| Tighten screw 4 | 01:51 | 02:01 | 02:12 | 00:07 |
| Tighten screw 5 | 01:53 | 02:03 | 02:14 | 00:02 |
| Tighten screw 6 | 01:55 | 02:05 | 02:17 | 00:02 |
| Tighten screw 7 | 01:58 | 02:08 | 02:20 | 00:03 |
| Put screwdriver | 02:00 | 02:10 | 02:23 | 00:02 |
| Test led | 02:03 | 02:14 | 02:26 | 00:03 |
| Take corners | 02:38 | 02:52 | 03:08 | 00:38 |
| Take screwdriver | 02:48 | 03:02 | 03:20 | 00:11 |
| Tighten screw 1 | 02:54 | 03:09 | 03:27 | 00:07 |
| Tighten screw 2 | 02:58 | 03:13 | 03:31 | 00:04 |
| Tighten screw 3 | 03:03 | 03:19 | 03:37 | 00:05 |
| Tighten screw 4 | 03:06 | 03:22 | 03:41 | 00:03 |
| Put screwdriver | 03:10 | 03:26 | 03:46 | 00:04 |
| Take top sub-assy | 03:30 | 03:48 | 04:09 | 00:22 |
| Place top sub-assy | 03:45 | 04:04 | 04:27 | 00:16 |
| Connect LED | 03:55 | 04:15 | 04:39 | 00:11 |
| Take screwdriver | 03:58 | 04:18 | 04:43 | 00:03 |
| Tighten screw 1 | 04:00 | 04:21 | 04:45 | 00:02 |
| Tighten screw 2 | 04:11 | 04:33 | 04:58 | 00:12 |
| Tighten screw 3 | 04:17 | 04:39 | 05:05 | 00:07 |
| Tighten screw 4 | 04:28 | 04:51 | 05:18 | 00:12 |
| Tighten screw 5 | 04:33 | 04:56 | 05:24 | 00:05 |
| Tighten screw 6 | 04:42 | 05:06 | 05:35 | 00:10 |
| Tighten screw 7 | 04:51 | 05:16 | 05:46 | 00:10 |
| Put screwdriver | 04:53 | 05:18 | 05:48 | 00:02 |
| Take rivets | 04:55 | 05:20 | 05:50 | 00:02 |
| Take pneumatic gun | 05:00 | 05:26 | 05:56 | 00:05 |
| Put rivet 1 | 05:03 | 05:29 | 06:00 | 00:03 |
| Put rivet 2 | 05:06 | 05:32 | 06:04 | 00:03 |
| Put rivet 3 | 05:10 | 05:37 | 06:08 | 00:04 |
| Put rivet 4 | 05:18 | 05:45 | 06:18 | 00:09 |
| Put rivet 5 | 05:26 | 05:54 | 06:27 | 00:09 |
| Put rivet 6 | 05:29 | 05:57 | 06:31 | 00:03 |
| Put rivet 7 | 05:32 | 06:01 | 06:34 | 00:03 |
| Put rivet 8 | 05:45 | 06:15 | 06:50 | 00:14 |
| Put rivet 9 | 05:51 | 06:21 | 06:57 | 00:07 |
| Put rivet 10 | 05:56 | 06:27 | 07:03 | 00:05 |
| Put rivet 11 | 06:02 | 06:33 | 07:10 | 00:07 |
| Put rivet 12 | 06:15 | 06:47 | 07:26 | 00:14 |
| Put pneumatic gun | 06:26 | 06:59 | 07:39 | 00:12 |
| Take stickers | 07:10 | 07:47 | 08:31 | 00:48 |
| Put soft sticker 1 | 07:36 | 08:15 | 09:02 | 00:28 |
| Put soft sticker 2 | 08:08 | 08:50 | 09:40 | 00:35 |
| Put soft sticker 3 | 08:26 | 09:10 | 10:01 | 00:20 |
| Put soft sticker 4 | 08:33 | 09:17 | 10:09 | 00:08 |
| Put soft sticker 1a | 08:50 | 09:36 | 10:30 | 00:19 |
| Put soft sticker 2a | 09:00 | 09:46 | 10:42 | 00:11 |
| Put soft sticker 3a | 09:10 | 09:57 | 10:53 | 00:11 |
| Put soft sticker 4a | 09:20 | 10:08 | 11:05 | 00:11 |
| Take Branded Fasteners | 09:42 | 10:32 | 11:31 | 00:24 |
| Put Branded Fasteners | 09:45 | 10:35 | 11:35 | 00:03 |
| Prepare glass | 10:00 | 10:52 | 11:53 | 00:16 |
| Take glass | 10:23 | 11:17 | 12:20 | 00:25 |
| Put glass | 10:42 | 11:37 | 12:43 | 00:21 |
| Take screwdriver | 10:44 | 11:39 | 12:45 | 00:02 |
| Tighten screw 1 | 10:54 | 11:50 | 12:57 | 00:11 |
| Tighten screw 2 | 11:03 | 12:00 | 13:08 | 00:10 |
| Tighten screw 3 | 11:11 | 12:09 | 13:17 | 00:09 |
| Tighten screw 4 | 11:23 | 12:22 | 13:31 | 00:13 |
| Tighten screw 5 | 11:36 | 12:36 | 13:47 | 00:14 |
| Tighten screw 6 | 11:45 | 12:46 | 13:58 | 00:10 |
| Put screwdriver | 11:50 | 12:51 | 14:04 | 00:05 |
| Prepare glass | 12:13 | 13:16 | 14:31 | 00:25 |
| Take glass | 12:54 | 14:01 | 15:20 | 00:45 |
| Put glass | 13:15 | 14:23 | 15:45 | 00:23 |
| Take screwdriver | 13:25 | 14:34 | 15:56 | 00:11 |
| Tighten screw 1 | 13:28 | 14:37 | 16:00 | 00:03 |
| Tighten screw 2 | 13:33 | 14:43 | 16:06 | 00:05 |
| Tighten screw 3 | 13:45 | 14:56 | 16:20 | 00:13 |
| Tighten screw 4 | 13:53 | 15:05 | 16:30 | 00:09 |
| Tighten screw 5 | 14:00 | 15:12 | 16:38 | 00:08 |
| Tighten screw 6 | 14:06 | 15:19 | 16:45 | 00:07 |
| Put screwdriver | 14:10 | 15:23 | 16:50 | 00:04 |
| Take curtain sub-assy | 14:50 | 16:07 | 17:37 | 00:44 |
| Put floor | 15:00 | 16:17 | 17:49 | 00:11 |
| Screw | 15:06 | 16:24 | 17:56 | 00:07 |
| Tighten screw 1 | 15:10 | 16:28 | 18:01 | 00:04 |
| Tighten screw 2 | 15:15 | 16:34 | 18:07 | 00:05 |
| Take front grill sub-assy | 15:30 | 16:50 | 18:25 | 00:16 |
| Put front gril sub-assy | 15:35 | 16:55 | 18:31 | 00:05 |
| Take Branded Fasteners | 15:40 | 17:01 | 18:37 | 00:05 |
| Tigthen 1 | 15:44 | 17:05 | 18:42 | 00:04 |
| Tigthen 2 | 15:58 | 17:20 | 18:58 | 00:15 |
| Take caps | 16:05 | 17:28 | 19:07 | 00:08 |
| Take hammer | 16:10 | 17:33 | 19:12 | 00:05 |
| Put cap 1 | 16:19 | 17:43 | 19:23 | 00:10 |
| Put cap 2 | 16:23 | 17:48 | 19:28 | 00:04 |
| Put cap 3 | 16:30 | 17:55 | 19:36 | 00:08 |
| Put cap 4 | 16:40 | 18:06 | 19:48 | 00:11 |
| Put cap 5 | 16:47 | 18:14 | 19:56 | 00:08 |
| Put cap 6 | 16:54 | 18:21 | 20:05 | 00:08 |
| Put cap 1a | 17:05 | 18:33 | 20:18 | 00:12 |
| Put cap 2a | 17:19 | 18:48 | 20:34 | 00:15 |
| Put cap 3a | 17:24 | 18:54 | 20:40 | 00:05 |
| Put cap 4a | 17:33 | 19:04 | 20:51 | 00:10 |
| Put cap 5a | 17:47 | 19:19 | 21:08 | 00:15 |
| Put cap 6a | 17:53 | 19:25 | 21:15 | 00:07 |
| Put hammer | 17:54 | 19:26 | 21:16 | 00:01 |
| Check | 18:10 | 19:44 | 21:35 | 00:17 |
| Adjust | 18:24 | 19:59 | 21:52 | 00:15 |
| Write | 18:31 | 20:07 | 22:00 | 00:08 |
| Deliver | 18:45 | 20:12 | 22:06 | 00:08 |

Results of other measutements

| № | Time |
|---|---|
| 1 | 16:00 |
| 2 | 19:00 |
| 3 | 22:00 |
| 4 | 22:00 |
| 5 | 23:00 |
| 6 | 13:00 |
| 7 | 13:00 |
| 9 | 31:00 |
| 9 | 21:00 |
| 10 | 19:00 |
| Average time to perform Main Assembly | 20:00 |

Appendix 12/4. RESULTS OF TIME STUDY

Stickers

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take side sticker | 00:00 | 00:00 | 00:00 | |
| Splash | 00:05 | 00:05 | 00:10 | 00:07 |
| Stick | 00:50 | 00:50 | 01:00 | 00:47 |
| Smooth out | 01:10 | 01:15 | 01:20 | 00:22 |
| Wipe with towel | 01:49 | 01:38 | 01:49 | 00:30 |
| Take side sticker | 02:30 | 01:40 | 02:05 | 00:20 |
| Splash | 02:40 | 01:45 | 02:10 | 00:07 |
| Stick | 03:06 | 02:15 | 02:30 | 00:25 |
| Smooth out | 03:32 | 02:35 | 02:59 | 00:25 |
| Wipe with towel | 03:50 | 02:50 | 03:05 | 00:13 |
| Take top sticker | 04:05 | 03:33 | 03:30 | 00:28 |
| Splash | 04:10 | 03:36 | 03:45 | 00:08 |
| Stick | 04:25 | 03:54 | 03:50 | 00:13 |
| Smooth out | 04:45 | 04:10 | 04:00 | 00:15 |
| Wipe with towel | 04:50 | 04:20 | 04:20 | 00:12 |
| Take middle sticker | 05:00 | 04:33 | 04:38 | 00:14 |
| Splash | 05:05 | 04:37 | 04:40 | 00:04 |
| Stick | 05:13 | 04:49 | 04:55 | 00:12 |
| Smooth out | 05:22 | 05:00 | 05:05 | 00:10 |
| Wipe with towel | 05:30 | 05:16 | 05:15 | 00:11 |
| Take bottom sticker | 05:35 | 05:20 | 05:21 | 00:05 |
| Splash | 05:38 | 05:25 | 05:23 | 00:03 |
| Stick | 05:50 | 05:29 | 05:40 | 00:11 |
| Smooth out | 06:13 | 05:52 | 06:06 | 00:24 |
| Wipe with towel | 06:50 | 06:30 | 06:34 | 00:34 |
| Manual | 07:00 | 06:43 | 06:40 | 00:10 |
| Take power cable | 07:10 | 07:00 | 06:50 | 00:12 |
| Take sticker top aste | 07:14 | 07:01 | 06:55 | 00:03 |
| Put | 07:18 | 07:02 | 07:00 | 00:03 |
| Apply | 07:20 | 07:15 | 07:04 | 00:06 |
| Take price tags | 07:20 | 07:16 | 07:07 | 00:01 |
| Fix price tag 1 | 07:21 | 07:20 | 07:08 | 00:02 |
| Fix price tag 2 | 07:22 | 07:21 | 07:09 | 00:01 |
| Finish | 07:23 | 07:23 | 07:10 | 00:01 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 06:49 |
| | 2 | 07:55 |
| | 3 | 06:38 |
| | 4 | 07:35 |
| | 5 | 07:11 |
| | 6 | 07:20 |
| | 7 | 07:30 |
| | 9 | 06:47 |
| | 9 | 07:19 |
| | 10 | 07:19 |
| Average time to affix stickers | | 07:15 |

Packing

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Unplug | 00:01 | 00:03 | 00:03 | 00:02 |
| Take pallet truck | 00:05 | 00:10 | 00:10 | 00:06 |
| Lift | 00:12 | 00:15 | 00:24 | 00:09 |
| Place | 00:19 | 00:20 | 00:26 | 00:05 |
| Lower | 00:26 | 00:25 | 00:27 | 00:04 |
| Take the paper off | 00:40 | 00:27 | 00:30 | 00:06 |
| Take top cover | 01:03 | 00:35 | 00:37 | 00:13 |
| Put cover | 01:08 | 00:40 | 00:40 | 00:04 |
| Take 4 corners | 01:23 | 00:45 | 00:44 | 00:08 |
| Put corner 1 | 01:25 | 00:50 | 00:46 | 00:03 |
| Put corner 2 | 01:31 | 00:57 | 00:57 | 00:08 |
| Put corner 3 | 01:47 | 01:03 | 01:49 | 00:25 |
| Put corner 4 | 01:53 | 01:05 | 01:56 | 00:05 |
| Put film. Wrapping starts | 02:00 | 01:15 | 02:00 | 00:07 |
| Apply sticker 1 | 03:00 | 02:09 | 02:32 | 00:49 |
| Apply sticker 2 | 03:06 | 02:26 | 02:38 | 00:10 |
| End. Wrapping ends | 03:11 | 02:25 | 02:48 | 00:05 |
| Apply upper corner 1 | 03:28 | 02:47 | 03:06 | 00:19 |
| Apply upper corner 2 | 03:33 | 02:46 | 03:09 | 00:02 |
| Put line | 03:53 | 02:59 | 03:28 | 00:17 |
| Cut | 04:00 | 03:15 | 03:36 | 00:10 |
| Put line | 04:21 | 03:32 | 03:50 | 00:17 |
| Cut | 04:28 | 03:43 | 04:05 | 00:11 |
| Take pallet truck | 04:45 | 03:55 | 04:18 | 00:14 |
| Lift | 04:58 | 04:02 | 04:27 | 00:10 |
| Take the product | 05:00 | 04:03 | 04:30 | 00:02 |
| Put | 05:10 | 04:10 | 04:34 | 00:07 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 04:25 |
| | 2 | 05:01 |
| | 3 | 05:30 |
| | 4 | 07:35 |
| | 5 | 06:12 |
| | 6 | 05:35 |
| | 7 | 05:40 |
| | 9 | 06:18 |
| | 9 | 04:50 |
| | 10 | 05:27 |
| Average time to perform packing | | 05:25 |
| Packing (film) | | 02:48 |
| Packing (strap) | | 02:37 |

Shelf w/o pre-LED time

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Take ceiling | 00:03 | 00:02 | 00:02 | 00:02 |
| Put | 00:06 | 00:05 | 00:06 | 00:03 |
| Take LED | 00:07 | 00:06 | 00:08 | 00:01 |
| Take glue gun | 00:10 | 00:08 | 00:10 | 00:02 |
| Apply glue | 00:15 | 00:14 | 00:18 | 00:06 |
| Put glue gun | 00:25 | 00:22 | 00:30 | 00:10 |
| Join together | 00:33 | 00:55 | 00:48 | 00:20 |
| Take plastic holder | 00:36 | 00:56 | 00:52 | 00:03 |
| Take cable tie | 00:38 | 00:58 | 00:53 | 00:02 |
| Put and ajust the wire | 00:40 | 01:00 | 01:01 | 00:04 |
| Take pliers | 00:53 | 01:25 | 01:02 | 00:13 |
| Cut | 00:56 | 01:29 | 01:04 | 00:03 |
| Put pliers | 00:57 | 01:31 | 01:05 | 00:01 |
| Put | 00:59 | 01:35 | 01:07 | 00:03 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 01:32 |
| | 2 | 01:00 |
| | 3 | 00:59 |
| | 4 | 00:58 |
| | 5 | 01:21 |
| | 6 | 01:45 |
| | 7 | 01:25 |
| | 9 | 01:30 |
| | 9 | 01:33 |
| | 10 | 01:22 |
| Average time to assemble Shelf | | 01:19 |

Sensor plate

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take sensor plate | 00:00 | 00:00 | 00:00 | |
| Put rubber line | 00:06 | 00:05 | 00:08 | 00:06 |
| Turn | 00:10 | 00:12 | 00:10 | 00:04 |
| Take control panel | 00:15 | 00:16 | 00:14 | 00:04 |
| Take wire | 00:19 | 00:21 | 00:22 | 00:06 |
| Put wire | 00:21 | 00:22 | 00:23 | 00:01 |
| Take pliers | 00:28 | 00:30 | 00:26 | 00:06 |
| Cut | 00:31 | 00:33 | 00:28 | 00:03 |
| Put pliers back | 00:34 | 00:35 | 00:29 | 00:02 |
| Take wire | 00:37 | 00:36 | 00:32 | 00:02 |
| Put wire | 00:41 | 00:40 | 00:36 | 00:04 |
| Take pliers | 00:42 | 00:48 | 00:38 | 00:04 |
| Take wire | 00:43 | 00:50 | 00:39 | 00:01 |
| Cut | 00:47 | 00:58 | 00:45 | 00:06 |
| Put pliers back | 00:48 | 01:00 | 00:46 | 00:01 |
| Put wire | 00:50 | 01:02 | 00:48 | 00:02 |
| Put control panel | 00:52 | 01:03 | 00:50 | 00:02 |
| Put front panel | 01:02 | 01:07 | 01:00 | 00:08 |
| Take screwdriver | 01:10 | 01:16 | 01:09 | 00:09 |
| Put screwdriver | 01:20 | 01:25 | 01:18 | 00:09 |
| Fasten screw 1 | 01:20 | 01:25 | 01:18 | 00:09 |
| Reel up wires | 01:30 | 01:36 | 01:28 | 00:10 |
| Put | 01:35 | 01:41 | 01:33 | 00:05 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 01:20 |
| | 2 | 01:35 |
| | 3 | 01:41 |
| | 4 | 01:10 |
| | 5 | 01:59 |
| | 6 | 01:49 |
| | 7 | 01:30 |
| | 9 | 01:50 |
| | 9 | 01:55 |
| | 10 | 02:01 |
| Average time to assemble Sensor Plate | | 01:40 |

Insulation

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Take ins | 00:03 | 00:12 | 00:30 | 00:15 |
| Take pipes | 00:07 | 00:30 | 00:45 | 00:12 |
| Put pipe 1 | 00:24 | 00:40 | 00:51 | 00:11 |
| Put pipe 2 | 00:27 | 00:53 | 01:00 | 00:08 |
| Take sheet cover | 00:46 | 01:07 | 01:18 | 00:18 |
| Place | 00:55 | 01:27 | 01:30 | 00:13 |
| Bend | 01:03 | 01:40 | 01:54 | 00:15 |
| Take front and back | 01:28 | 01:52 | 02:30 | 00:25 |
| Place front | 01:51 | 02:02 | 03:22 | 00:28 |
| Place back | 02:02 | 02:13 | 03:55 | 00:18 |
| Take sidewall 1 | 02:09 | 02:18 | 04:24 | 00:14 |
| Take sidewall 2 | 02:13 | 02:20 | 04:36 | 00:06 |
| Put sidewall 1 | 02:31 | 02:30 | 05:00 | 00:17 |
| Put sidewall 2 | 02:48 | 02:40 | 05:12 | 00:13 |
| Take ears | 05:15 | 02:50 | 05:17 | 00:54 |
| Place | 05:32 | 03:08 | 05:26 | 00:15 |
| Take front and back | 06:21 | 03:25 | 05:41 | 00:27 |
| Take screwdriver | 06:32 | 03:45 | 05:46 | 00:12 |
| Tighten screw 1 | 06:42 | 03:58 | 05:53 | 00:10 |
| Tighten screw 2 | 06:45 | 04:05 | 06:00 | 00:06 |
| Tighten screw 1 | 06:47 | 04:13 | 06:10 | 00:07 |
| Tighten screw 2 | 06:57 | 04:20 | 06:29 | 00:12 |
| Tighten screw 3 | 07:07 | 04:28 | 06:46 | 00:11 |
| Tighten screw 4 | 07:10 | 04:43 | 06:58 | 00:10 |
| Tighten screw 5 | 07:22 | 04:58 | 07:24 | 00:18 |
| Tighten screw 6 | 07:34 | 05:30 | 07:43 | 00:21 |
| Tighten screw 7 | 07:41 | 05:53 | 07:58 | 00:15 |
| Tighten screw 8 | 07:49 | 06:02 | 08:17 | 00:13 |
| Tighten screw 9 | 07:57 | 06:15 | 08:31 | 00:12 |
| Tighten screw 10 | 08:02 | 06:28 | 08:50 | 00:12 |
| Tighten screw 11 | 08:04 | 06:43 | 10:58 | 00:48 |
| Tighten screw 12 | 08:07 | 08:15 | 11:07 | 00:35 |
| Tighten screw 13 | 08:09 | 08:20 | 11:22 | 00:07 |
| Tighten screw 14 | 08:11 | 08:37 | 11:43 | 00:14 |
| Tighten screw 15 | 08:14 | 08:43 | 12:00 | 00:08 |
| Tighten screw 16 | 08:17 | 09:07 | 12:14 | 00:14 |
| Put screwdriver | 08:20 | 09:55 | 12:29 | 00:22 |
| Put Insulation | 08:21 | 10:00 | 12:38 | 00:05 |

Results of other measutements

| № | Time |
|---|---|
| 1 | 10:45 |
| 2 | 08:46 |
| 3 | 10:55 |
| 4 | 10:31 |
| 5 | 10:32 |
| 6 | 10:05 |
| 7 | 10:21 |
| 9 | 09:30 |
| 9 | 08:32 |
| 10 | 09:08 |
| Average time to assemble Insulation | 10:00 |

Fastener Branded Rigid

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| FBR | 00:00 | 00:00 | 00:00 | |
| Take plastic | 00:01 | 00:01 | 00:02 | 00:01 |
| Take bolt | 00:03 | 00:04 | 00:05 | 00:03 |
| Join | 00:05 | 00:06 | 00:08 | 00:02 |
| Take cap | 00:09 | 00:10 | 00:12 | 00:04 |
| Take hammer | 00:10 | 00:12 | 00:13 | 00:01 |
| Hammer | 00:18 | 00:14 | 00:15 | 00:04 |
| Put hammer | 00:19 | 00:17 | 00:20 | 00:03 |
| Put | 00:21 | 00:19 | 00:23 | 00:02 |

Results of other measutements

| № | Time |
|---|---|
| 1 | 00:21 |
| 2 | 00:22 |
| 3 | 00:21 |
| 4 | 00:18 |
| 5 | 00:19 |
| 6 | 00:20 |
| 7 | 00:20 |
| 9 | 00:21 |
| 9 | 00:21 |
| 10 | 00:22 |
| Average time to assemble FBR | 00:21 |

20,5 sec

Price Tag

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take price tag cover | 00:00 | 00:00 | 00:00 | |
| Clean from sawdust | 00:01 | 00:02 | 00:01 | 00:01 |
| Take price tag | 00:10 | 00:08 | 00:04 | 00:06 |
| Join | 00:14 | 00:15 | 00:12 | 00:06 |
| Put | 00:15 | 00:17 | 00:13 | 00:01 |

Results of other measutements

| № | Time |
|---|---|
| 1 | 00:11 |
| 2 | 00:16 |
| 3 | 00:13 |
| 4 | 00:14 |
| 5 | 00:10 |
| 6 | 00:09 |
| 7 | 00:16 |
| 9 | 00:21 |
| 9 | 00:18 |
| 10 | 00:22 |
| Average time to assemble Price Tag | 00:15 |

15 sec

Fastener Branded

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Take bolt | 00:01 | 00:02 | 00:01 | 00:01 |
| Put | 00:02 | 00:05 | 00:02 | 00:02 |
| Take plastic | 00:03 | 00:06 | 00:03 | 00:01 |
| Join | 00:05 | 00:07 | 00:04 | 00:01 |

According to 400 measurements

| Average time to assemble FB | 3,75 | sec |
|---|---|---|

Fan plate

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Take plate | 00:06 | 00:02 | 00:03 | 00:04 |
| Take 2 vents | 00:11 | 00:06 | 00:05 | 00:04 |
| Place wires | 00:40 | 00:09 | 00:11 | 00:13 |
| Take bolt | 00:45 | 00:23 | 00:17 | 00:08 |
| Place bolt 1 | 00:47 | 00:30 | 00:26 | 00:06 |
| Place bolt 2 | 00:49 | 00:32 | 00:32 | 00:03 |
| Place bolt 3 | 00:51 | 00:35 | 00:34 | 00:02 |
| Place bolt 4 | 00:54 | 00:37 | 00:41 | 00:04 |
| Place bolt 5 | 00:58 | 00:48 | 00:43 | 00:06 |
| Place bolt 6 | 01:01 | 00:53 | 00:53 | 00:06 |
| Place bolt 7 | 01:03 | 00:55 | 00:57 | 00:03 |
| Take tähti | 01:04 | 01:00 | 01:03 | 00:04 |
| Place bolt 8 | 01:05 | 01:04 | 01:09 | 00:04 |
| Take screwdriver | 01:08 | 01:08 | 01:13 | 00:04 |
| Tighten screw 1 | 01:10 | 01:14 | 01:18 | 00:04 |
| Tighten screw 2 | 01:18 | 01:18 | 01:23 | 00:06 |
| Tighten screw 3 | 01:25 | 01:22 | 01:25 | 00:04 |
| Tighten screw 4 | 01:30 | 01:26 | 01:29 | 00:04 |
| Tighten screw 5 | 01:41 | 01:29 | 01:34 | 00:06 |
| Tighten screw 6 | 01:53 | 01:34 | 01:38 | 00:07 |
| Tighten screw 7 | 02:00 | 01:37 | 01:42 | 00:05 |
| Tighten screw 8 | 02:05 | 01:40 | 01:44 | 00:03 |
| Put screwdriver | 02:08 | 01:42 | 01:48 | 00:03 |
| Take cable tie 1 | 02:13 | 01:54 | 01:51 | 00:07 |
| Take cable tie 2 | 02:18 | 01:59 | 02:09 | 00:09 |
| Take cutters | 02:20 | 02:04 | 02:10 | 00:03 |
| Cut cable tie 1 | 02:25 | 02:09 | 02:12 | 00:04 |
| Cut cable tie 2 | 02:30 | 02:12 | 02:15 | 00:04 |
| Place cutters | 02:33 | 02:18 | 02:20 | 00:05 |
| Reel up the wire | 02:41 | 02:24 | 02:29 | 00:08 |
| Put | 02:45 | 02:28 | 02:30 | 00:03 |

Results of other measutements

| № | Time |
|---|---|
| 1 | 02:28 |
| 2 | 02:55 |
| 3 | 02:30 |
| 4 | 02:13 |
| 5 | 02:05 |
| 6 | 02:00 |
| 7 | 02:30 |
| 9 | 02:38 |
| 9 | 02:12 |
| 10 | 02:09 |
| Average time to assemble Fan Plate | 02:25 |

Front Grill Plate

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take plate | 00:05 | 00:06 | 00:04 | |
| Take corner | 00:07 | 00:09 | 00:15 | 00:05 |
| Put | 00:10 | 00:30 | 00:20 | 00:10 |
| Align | 00:21 | 00:40 | 00:31 | 00:11 |
| Take screwdriver | 00:28 | 00:42 | 00:34 | 00:04 |
| Tigthen screw 1 | 00:37 | 00:45 | 00:39 | 00:06 |
| Tigthen screw 2 | 00:44 | 00:50 | 00:41 | 00:05 |
| Tigthen screw 3 | 00:49 | 00:55 | 00:46 | 00:05 |
| Tigthen screw 4 | 00:53 | 01:00 | 00:52 | 00:05 |
| Tigthen screw 5 | 00:57 | 01:03 | 01:00 | 00:05 |
| Tigthen screw 6 | 01:03 | 01:09 | 01:03 | 00:05 |
| Put screwdriver | 01:04 | 01:11 | 01:05 | 00:02 |
| Take soft panel | 01:10 | 01:26 | 01:09 | 00:08 |
| Take knife | 01:11 | 01:28 | 01:13 | 00:02 |
| Cut | 01:45 | 01:58 | 01:31 | 00:27 |
| Put knife | 01:48 | 02:00 | 01:33 | 00:02 |
| Stick | 02:43 | 02:02 | 01:54 | 00:26 |
| Put | 02:52 | 02:07 | 01:58 | 00:06 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 01:50 |
| | 2 | 02:00 |
| | 3 | 02:30 |
| | 4 | 02:45 |
| | 5 | 02:10 |
| | 6 | 02:21 |
| | 7 | 02:33 |
| | 9 | 02:45 |
| | 9 | 02:05 |
| | 10 | 02:45 |
| Average time to assemble Front Grill Plate | | 02:22 |

Ceiling w/o pre-LED time

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Take ceiling | 00:07 | 00:06 | 00:04 | 00:06 |
| Put | 00:09 | 00:09 | 00:06 | 00:02 |
| Take LED | 00:11 | 00:11 | 00:09 | 00:02 |
| Take glue gun | 00:15 | 00:16 | 00:14 | 00:05 |
| Apply glue | 00:21 | 00:37 | 00:38 | 00:17 |
| Put glue gun | 00:23 | 00:38 | 00:39 | 00:01 |
| Join together | 00:45 | 00:39 | 00:40 | 00:08 |
| Take plastic holder | 00:50 | 00:45 | 00:47 | 00:06 |
| Take cable tie | 00:55 | 00:53 | 00:59 | 00:08 |
| Put and ajust the wire | 01:26 | 01:22 | 01:25 | 00:29 |
| Take pliers | 01:27 | 01:23 | 01:26 | 00:01 |
| Cut | 01:34 | 01:24 | 01:28 | 00:03 |
| Put pliers | 01:36 | 01:25 | 01:29 | 00:01 |
| Put | 01:45 | 01:28 | 01:32 | 00:05 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 01:32 |
| | 2 | 02:00 |
| | 3 | 01:40 |
| | 4 | 02:05 |
| | 5 | 01:21 |
| | 6 | 01:45 |
| | 7 | 01:25 |
| | 9 | 01:30 |
| | 9 | 01:33 |
| | 10 | 01:35 |
| Average time to assemble Ceiling | | 01:38 |

Curtain plate

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Start | 00:00 | 00:00 | 00:00 | |
| Take curtain | 00:03 | 00:06 | 00:06 | 00:05 |
| Place | 00:05 | 00:07 | 00:17 | 00:05 |
| Take handle | 00:08 | 00:15 | 00:25 | 00:06 |
| Place | 00:21 | 00:28 | 00:28 | 00:10 |
| Take screwdriver | 00:22 | 00:31 | 00:46 | 00:07 |
| Take screws | 00:25 | 00:48 | 00:48 | 00:07 |
| Tigthen screw 1 | 00:29 | 00:51 | 01:01 | 00:07 |
| Tigthen screw 2 | 01:05 | 00:55 | 01:12 | 00:17 |
| Put screwdriver | 01:06 | 01:23 | 01:14 | 00:10 |
| Take metal | 01:09 | 01:30 | 01:20 | 00:05 |
| Take pilers | 01:10 | 01:32 | 01:30 | 00:04 |
| Deform | 01:24 | 01:35 | 01:40 | 00:09 |
| Put pilers | 01:25 | 01:36 | 01:58 | 00:07 |
| Put curtain | 01:40 | 01:51 | 02:02 | 00:11 |
| Take pilers | 01:44 | 01:55 | 02:10 | 00:05 |
| Turn | 02:00 | 05:20 | 02:40 | 01:24 |
| Deform | 02:15 | 05:30 | 02:55 | 00:13 |
| Put pilers | 02:23 | 05:31 | 02:57 | 00:04 |
| Place sheet metal | 02:31 | 06:05 | 03:20 | 00:22 |
| Take screwdriver | 02:35 | 06:08 | 03:25 | 00:04 |
| Take screws | 02:55 | 06:10 | 03:27 | 00:08 |
| Tigthen screw 1 | 03:00 | 06:12 | 03:31 | 00:04 |
| Tigthen screw 2 | 03:02 | 06:17 | 03:36 | 00:04 |
| Tigthen screw 3 | 03:35 | 06:32 | 03:47 | 00:20 |
| Tigthen screw 4 | 03:43 | 06:40 | 03:56 | 00:08 |
| Put screwdriver | 03:48 | 06:41 | 04:03 | 00:04 |
| Check | 03:55 | 06:45 | 04:05 | 00:04 |
| Put | 04:00 | 06:51 | 04:10 | 00:05 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 04:10 |
| | 2 | 04:18 |
| | 3 | 03:50 |
| | 4 | 03:40 |
| | 5 | 03:15 |
| | 6 | 04:30 |
| | 7 | 03:30 |
| | 9 | 04:20 |
| | 9 | 03:18 |
| | 10 | 03:30 |
| Average time to assemble Curtain Plate | | 04:06 |

Top plate

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Top | 00:00 | 00:00 | 00:00 | |
| Take top | 00:04 | 00:04 | 00:02 | 00:03 |
| Put | 00:06 | 00:07 | 00:04 | 00:02 |
| Take hinge | 00:11 | 00:08 | 00:06 | 00:03 |
| Take glue gun | 00:14 | 00:10 | 00:10 | 00:03 |
| Apply glue | 00:18 | 00:14 | 00:12 | 00:03 |
| Put glue gun | 00:21 | 00:15 | 00:13 | 00:02 |
| Put hinge | 00:25 | 00:20 | 00:23 | 00:06 |
| Hold | 00:31 | 00:27 | 00:31 | 00:07 |
| Take glue gun | 00:37 | 00:29 | 00:35 | 00:04 |
| Apply glue | 00:50 | 00:44 | 00:56 | 00:16 |
| Put glue gun | 00:52 | 00:47 | 00:59 | 00:03 |
| Take insulation | 00:54 | 00:53 | 01:00 | 00:03 |
| Put insulation | 01:02 | 01:11 | 01:08 | 00:11 |
| Adjust and hold | 01:15 | 01:20 | 01:18 | 00:11 |
| Take side | 01:20 | 01:21 | 01:22 | 00:03 |
| Put to the table | 01:24 | 01:25 | 01:28 | 00:05 |
| Take glue gun | 01:27 | 01:27 | 01:30 | 00:02 |
| Apply glue | 01:30 | 01:31 | 01:35 | 00:04 |
| Put glue gun | 01:35 | 01:34 | 01:38 | 00:04 |
| Take side panels | 01:42 | 01:38 | 01:40 | 00:04 |
| Put side panel 1 | 01:47 | 01:44 | 01:46 | 00:06 |
| Put side panel 2 | 01:53 | 01:46 | 01:55 | 00:06 |
| Bend 1 | 01:54 | 02:04 | 01:57 | 00:07 |
| Bend 2 | 01:54 | 02:04 | 01:57 | 00:00 |
| Bend 3 | 01:56 | 02:07 | 01:58 | 00:02 |
| Bend 4 | 01:56 | 02:07 | 01:58 | 00:00 |
| Take cell | 01:59 | 02:11 | 02:04 | 00:04 |
| Put cell | 02:05 | 02:14 | 02:11 | 00:05 |
| Cut | 02:16 | 02:21 | 02:16 | 00:08 |
| Place | 02:23 | 02:22 | 02:29 | 00:07 |
| Take ceil | 02:30 | 02:43 | 02:35 | 00:11 |
| Put | 02:32 | 02:45 | 02:38 | 00:02 |
| Take screwdriver | 02:38 | 02:46 | 02:52 | 00:07 |
| Tigthen screw 1 | 02:45 | 02:53 | 02:58 | 00:07 |
| Tigthen screw 2 | 02:57 | 03:01 | 03:05 | 00:09 |
| Tigthen screw 3 | 03:06 | 03:10 | 03:16 | 00:10 |
| Tigthen screw 4 | 03:11 | 03:18 | 03:26 | 00:08 |
| Take screwdriver (manual) | 03:18 | 03:32 | 03:47 | 00:14 |
| hold and screw | 03:29 | 03:39 | 03:56 | 00:09 |
| Tigthen screw 1 | 03:33 | 03:41 | 04:03 | 00:04 |
| Tigthen screw 2 | 03:43 | 03:50 | 04:10 | 00:09 |
| Put screwdriver (manual) | 03:47 | 03:55 | 04:11 | 00:03 |
| Bend 1 | 03:50 | 04:01 | 04:12 | 00:03 |
| Bend 2 | 03:51 | 04:03 | 04:12 | 00:01 |
| Take screwdriver | 03:56 | 04:05 | 04:20 | 00:05 |
| Tigthen screw 1 | 03:58 | 04:11 | 04:23 | 00:04 |
| Tigthen screw 2 | 04:14 | 04:13 | 04:31 | 00:09 |
| Put screwdriver | 04:15 | 04:14 | 04:32 | 00:01 |
| Put | 04:19 | 04:16 | 04:35 | 00:03 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 02:47 |
| | 2 | 02:29 |
| | 3 | 02:35 |
| | 4 | 02:13 |
| | 5 | 02:30 |
| | 6 | 02:30 |
| | 7 | 02:15 |
| | 9 | 02:40 |
| | 9 | 02:08 |
| | 10 | 02:27 |
| Average time to assemble Top Plate | | 02:54 |

Other operations

| Operation name | Time | Time | |
|---|---|---|---|
| Cell cutting | 30 | 00:30 | |
| Evacuation | 1000 | 10:00 | |
| Filling | 8 | 00:08 | |
| Leak inspection | 20 | 00:20 | |
| Led converter | 115 | 01:15 | |
| Led cover cutting | 30 | 00:30 | |
| Led preparation | 8 | 00:08 | |
| PostTest | 30 | 00:30 | |
| PreTest | 200 | 02:00 | |
| Price Tag | 14,67 | 00:15 | |
| Price tag cutting | 30 | 00:30 | |
| Serial no | 25 | 00:25 | |
| Test | 200 | 02:00 | Machine time |
| Washing | 230 | 02:30 | Machine time |

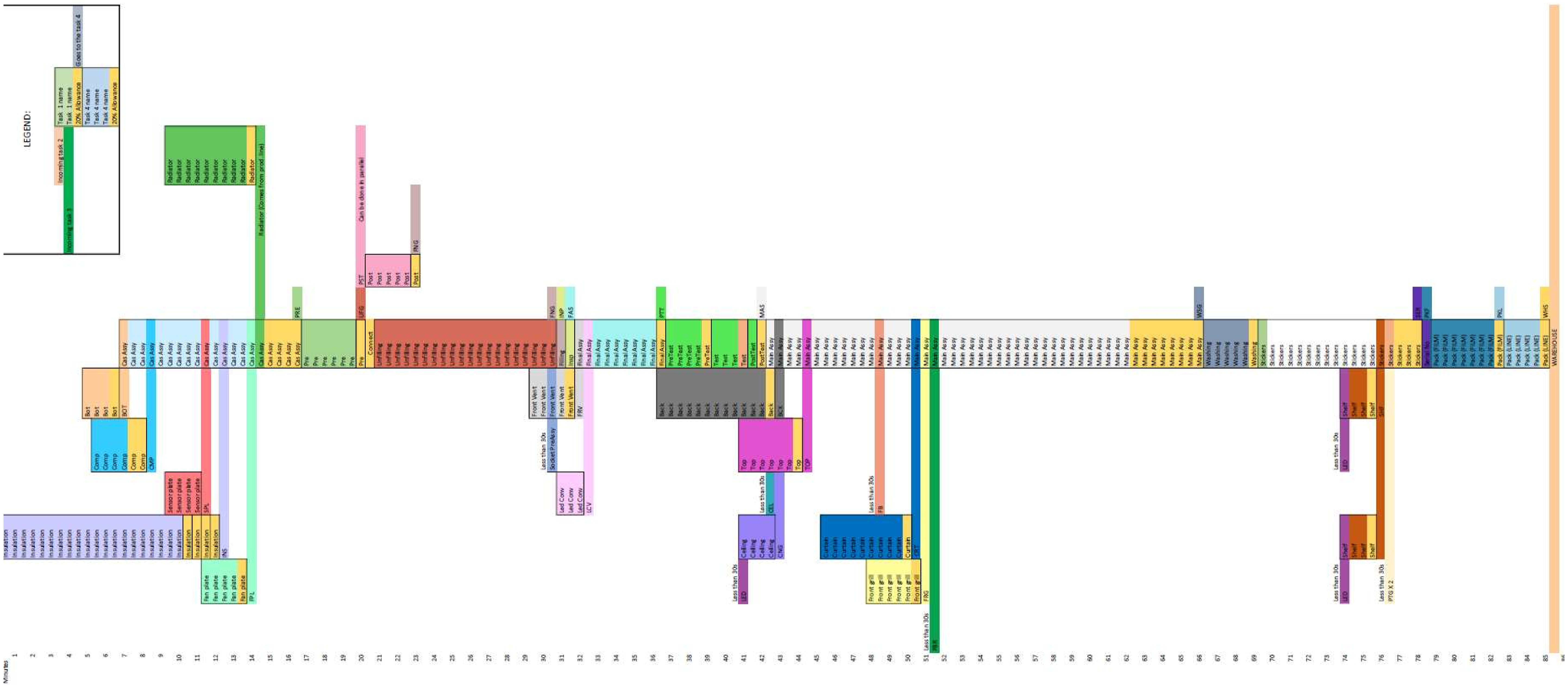
Socket PreAssy

| Operation name | Time | | | Average time |
|---|---|---|---|---|
| Take socket part 1 | 00:00 | 00:00 | 00:00 | |
| Fix socket in jig | 00:01 | 00:01 | 00:01 | 00:01 |
| Take socket part 2 | 00:02 | 00:03 | 00:02 | 00:01 |
| Take fixing tool | 00:03 | 00:05 | 00:04 | 00:02 |
| Press | 00:04 | 00:08 | 00:06 | 00:02 |
| Put fixing tool | 00:09 | 00:09 | 00:08 | 00:03 |
| Put | 00:11 | 00:10 | 00:09 | 00:01 |

Results of other measutements

| | № | Time |
|---|---|---|
| | 1 | 00:06 |
| | 2 | 00:09 |
| | 3 | 00:10 |
| | 4 | 00:11 |
| | 5 | 00:10 |
| | 6 | 00:10 |
| | 7 | 00:09 |
| | 9 | 00:09 |
| | 9 | 00:13 |
| | 10 | 00:11 |
| Average time to assemble Socket | | 00:10 |

Appendix 13. DNA DIAGRAM



Appendix 14. CODENAME LIST

| | |
|---|---|
| CMP | Compressor |
| BCK | Back plate |
| BCV | Back ventilation plate |
| CAS | Cassette assembly |
| FAS | Cassette final assembly |
| CNG | Ceiling |
| CEL | Cell cutting |
| CRT | Curtain plate |
| EVA | Evacuation |
| PRE | Evacuation pre-work |
| FPL | Fan plate |
| FB | Fastener branded |
| FBR | Fastener branded rigid |
| FNG | Filling |
| FRG | Front grill plate |
| INS | Insulation box |
| INP | Lean inspection |
| LCV | LED converter |
| LED | LED preparation |
| MAS | Main assembly |
| PKL | Packing (strapping) |
| PKF | Packing (wrapping) |
| PTT | Pre-Test |
| SPL | Sensor plate |
| SER | Serial no. |
| SHF | Shelf |
| SPA | Socket preassembly |
| TOP | Top plate |
| WHS | Warehouse |
| WSG | Washing |

# Appendix 15. LEGEND DIAGRAM

| Time (mm:ss) | | | | WORKER 1 |
|---|---|---|---|---|
| 00:00 | | | | |
| 00:30,0 | | | 30 sec | Preceding operation done by worker 1 |
| 01:00,0 | | | | Preceding operation |
| 01:30,0 | | | | Preceding operation |
| 02:00,0 | | | | Preceding operation |
| 02:30,0 | | | | Worker 1 starts performing operation |
| 03:00,0 | | | | Operation |
| 03:30,0 | | | | Operation |
| 04:00,0 | Index number of component to be used | Name of component to be used at this exact | | Operation |
| 04:30,0 | | | | Operation |
| 05:00,0 | Index number of component to be used | Name of component to be used at this exact | | Operation |
| 05:30,0 | | | | Operation |
| 06:00,0 | | | | Operation |
| 06:30,0 | Index number of component to be used | Name of component to be used at this exact | | Operation |
| 07:00,0 | | | | Operation |
| 07:30,0 | Index number of component to be used | Name of component to be used at this exact | | Operation |
| 08:00,0 | | | | Operation |
| 08:30,0 | | | | Operation |
| 09:00,0 | | | | Operation |
| 09:30,0 | | | | Operation |
| 10:00,0 | | | | Operation |
| 10:30,0 | | | | Total allowance |
| 11:00,0 | | | | Total allowance |
| 11:30,0 | | | | Total allowance |
| 12:00,0 | | | Index number of component released | Worker 1 finishes performing operation |
| 12:30,0 | | | | Next operation performed by worker 1 |
| | | | | The end of working day |

Appendix 16. PRODUCTION SCHEDULE DIAGRAMS

The appendix is represented as an pdf file (Production schedule diagrams.pdf) attached to the research project document

Appendix 17. RESULTS OF TIME STUDY. CONVEYOR

| Operation name | Observed time | Allowance | | | | Standard time |
|---|---|---|---|---|---|---|
| | | PRF | RA | Pa | CA | |
| Back panel | 05:12 | 106% | 4% | 7% | 3% | 06:14 |
| Back vent | 01:54 | 106% | 4% | 7% | 3% | 02:17 |
| Bottom | 01:35 | 106% | 4% | 7% | 3% | 01:53 |
| Cassette | 07:30 | 106% | 4% | 7% | 3% | 09:01 |
| Cassette final | 04:00 | 106% | 4% | 7% | 3% | 04:48 |
| Ceiling w/o pre-LED time | 01:21 | 106% | 4% | 7% | 3% | 01:37 |
| Compressor | 02:11 | 106% | 4% | 7% | 3% | 02:37 |
| Curtain plate | 03:30 | 106% | 4% | 7% | 3% | 04:12 |
| Fan plate | 02:20 | 106% | 4% | 7% | 3% | 02:48 |
| Front Grill Plate | 02:20 | 106% | 4% | 7% | 3% | 02:48 |
| Insulation | 10:00 | 106% | 4% | 7% | 3% | 12:00 |
| Evacuation | 10:00 | | | | | 10:00 |
| Test | 02:30 | | | | | 02:30 |
| Washing | 02:30 | 106% | 4% | 7% | 3% | 03:00 |
| Main assembly | 18:20 | 106% | 4% | 7% | 3% | 22:00 |
| Packing | 05:25 | 106% | 4% | 7% | 3% | 06:30 |
| Price Tag | 00:15 | 106% | 4% | 7% | 3% | 00:18 |
| Socket PreAssy | 00:10 | 106% | 4% | 7% | 3% | 00:12 |
| Evacuation pre-work | 02:54 | 106% | 4% | 7% | 3% | 03:29 |
| Evacuation post-work | 02:15 | 106% | 4% | 7% | 3% | 02:42 |
| Leak inspection | 00:20 | 106% | 4% | 7% | 3% | 00:24 |
| Sensor plate | 01:38 | 106% | 4% | 7% | 3% | 01:58 |
| Shelf w/o pre-LED time | 01:17 | 106% | 4% | 7% | 3% | 01:32 |
| Stickers | 07:15 | 106% | 4% | 7% | 3% | 08:42 |
| Led converter | 01:15 | 106% | 4% | 7% | 3% | 01:30 |
| Top plate | 02:43 | 106% | 4% | 7% | 3% | 03:16 |
| Led preparation | 00:08 | 106% | 4% | 7% | 3% | 00:10 |
| Filling | 00:08 | 106% | 4% | 7% | 3% | 00:10 |
| Fastener Branded | 00:05 | 106% | 4% | 7% | 3% | 00:06 |
| Fastener Branded Rigid | 00:21 | 106% | 4% | 7% | 3% | 00:25 |

## Appendix 18. CODENAMES OF OPERATIONS

| List of main operations | No |
|---|---|
| Cassette | M1 |
| Evacuation pre-work | M2 |
| Connection allowance | M3 |
| Evacuation | M4 |
| Evacuation post-work | M5 |
| Filling | M6 |
| Leak inspection | M7 |
| Cassette final | M8 |
| PreTest | M9 |
| Test | M10 |
| PostTest | M11 |
| Main assembly | M12 |
| Washing | M13 |
| Stickers | M14 |
| Serial no | M15 |

| List of sub operations | No |
|---|---|
| Back plate | S1 |
| Back vent | S2 |
| Bottom | S3 |
| Ceiling w/o pre-LED time | S4 |
| Compressor | S5 |
| Curtain plate | S6 |
| Fan plate | S7 |
| Fastener Branded | S8 |
| Fastener Branded Rigid | S9 |
| Front Grill Plate | S10 |
| Insulation | S11 |
| Led converter | S12 |
| Led preparation | S13 |
| Packing | S14 |
| Price Tag | S15 |
| Sensor plate | S16 |
| Shelf w/o pre-LED time | S17 |
| Socket PreAssy | S18 |
| Top plate | S19 |

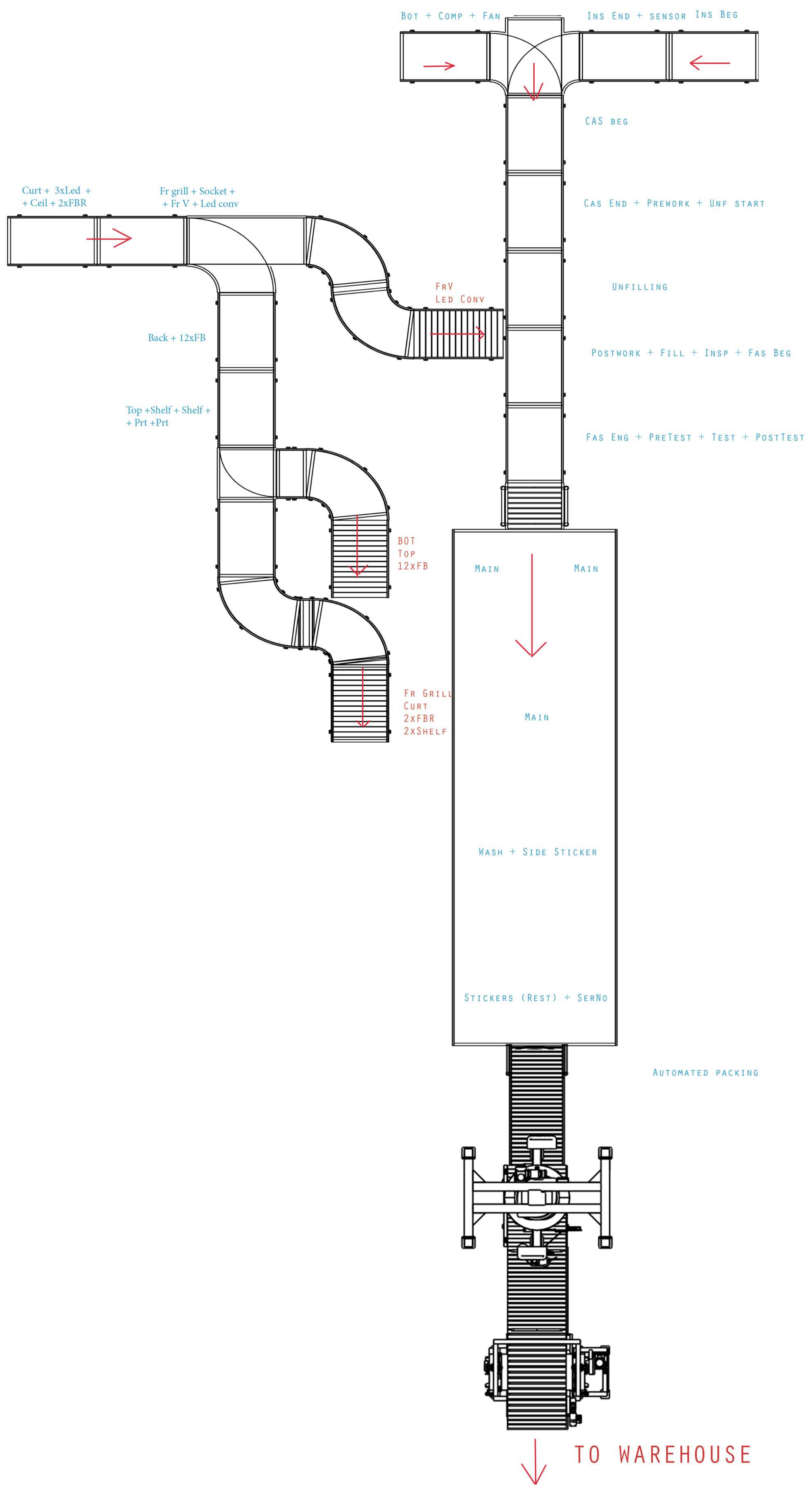
| List of machine operations | No |
|---|---|
| Back plate | M4 |
| Stretch Wrapping | P1 |
| Strapping | P2 |

Appendix 19. LAYOUT I. WORKCELL TABLE

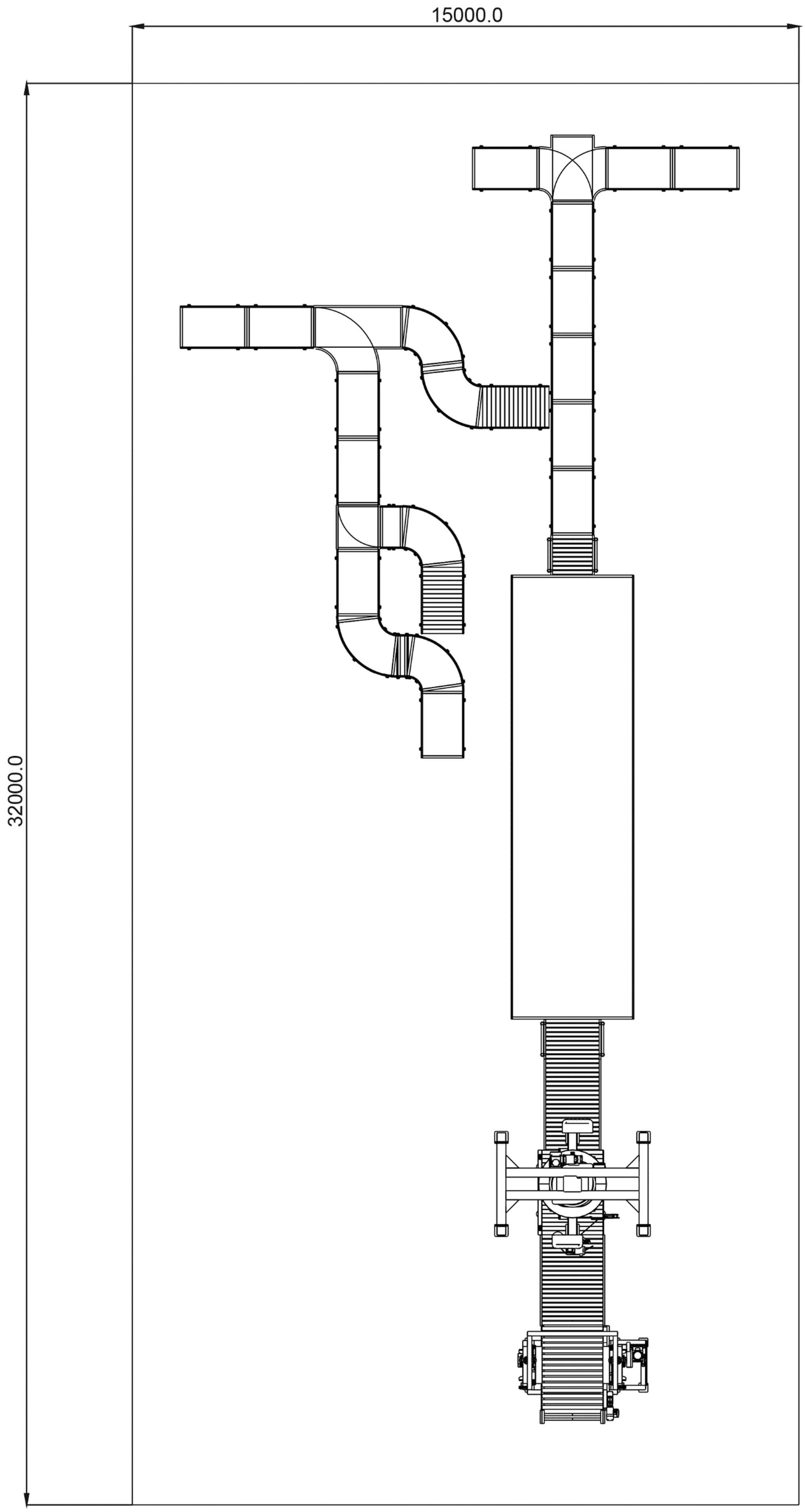
| Cell number | Operations | Time |
|---|---|---|
| Cell 1 | M1 (7:00) | 07:00 |
| Cell 2 | M1 (2:00) +M2+M3 | 05:39 |
| Cell 2m | M4 | 07:20 |
| Cell 3 | M5(M4 2:30 parallel)+M6+M7+M8 (3:00) | 06:15 |
| Cell 4 | M8 (1:48)+M9+M10+M11 | 04:48 (06:48) |
| Cell 5 | M12 (7:30) | 07:30 |
| Cell 6 | M12 (7:00) | 07:00 |
| Cell 7 | M12 (7:30) | 07:30 |
| Cell 8 | M13+M14 (2:45) | 05:45 |
| Cell 9 | M14 (5:57) + M15 | 06:27 |
| Cell 10 | S11 (7:00) | 07:00 |
| Cell 11 | S11(3:00)+S16 | 06:58 |
| Cell 12 | S3+S5+S7 | 07:19 |
| Cell 13 | S6+S4+3xS13+2xS9 | 07:08 |
| Cell 14 | S1+12xS8 | 07:08 |
| Cell 15 | 2xS17+S19+2xS15 | 06:56 |
| Cell 16 | S10+S18+S2+S12 | 06:47 |
| Cell 16m | P1 | 02:00 |
| Cell 17m | P2 | 02:00 |

Appendix 20. LAYOUT I. OPERATIONS AND MATERIAL FLOW

LAYOUT I

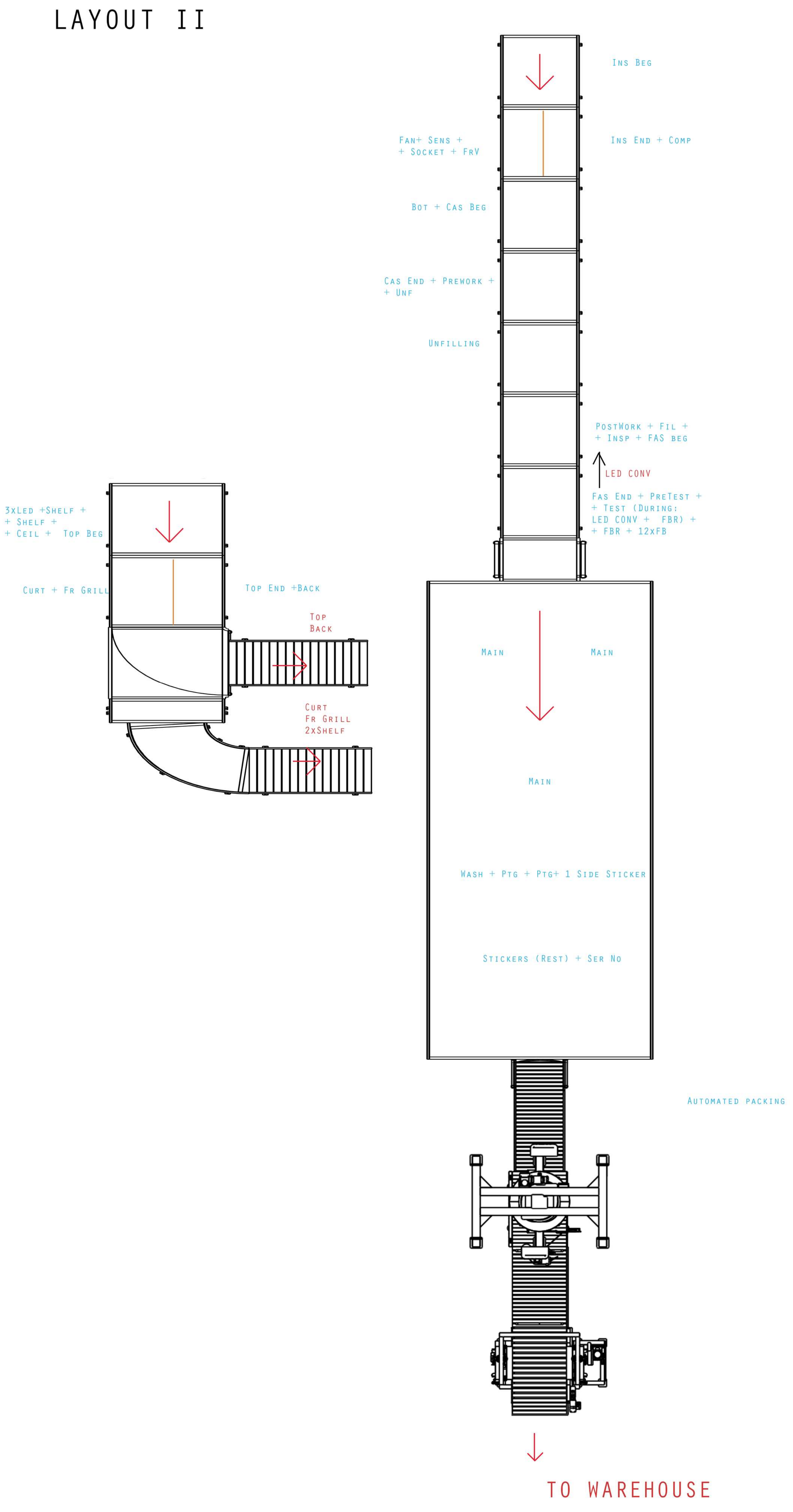


Appendix 21. LAYOUT I. DIMENSIONS

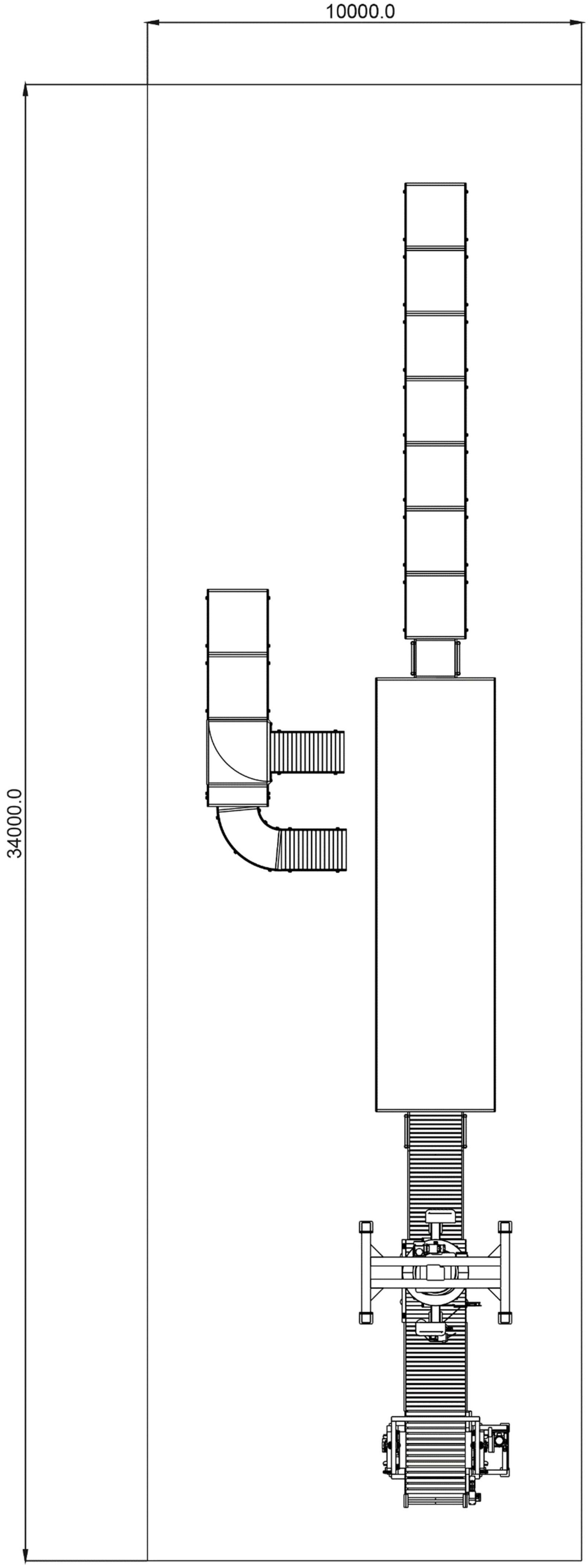


Appendix 22. LAYOUT II. WORKCELL TABLE

| Cell number | Operations | Time |
|---|---|---|
| Cell 1 | S3+M1 (5:20) | 07:14 |
| Cell 2 | M1 (3:40) +M2+M3 | 07:19 |
| Cell 2m | M4 (7:33 with conveyor moving time) | 07:20 |
| Cell 3 | M5(While M4 2:27)+M6+M7+M8 (3:00) | 07:15 |
| Cell 4 | M8 (1:48)+M9+M10 (While S12+S9)+S9+12xS8+M11 | 07:01 (07:07) |
| Cell 5 | M12 (7:30) | 07:30 |
| Cell 6 | M12 (7:00) | 07:00 |
| Cell 7 | M12 (7:30) | 07:30 |
| Cell 8 | M13++2xS15+M14 (2:45) | 05:54 |
| Cell 9 | M14 (5:57) + M15 | 06:54 |
| Cell 10 | S7+S16+S18+S2 | 07:14 |
| Cell 11 | S4+2xS17+3xS13+S19 (2:09) | 07:19 |
| Cell 12 | S1+S19(1:06) | 07:20 |
| Cell 13 | S6+S10 | 07:00 |
| Cell 14 | S11 (7:20) | 07:20 |
| Cell 15 | S11 (4:40)+S5 | 07:17 |
| Cell 15m | P1 | 02:00 |
| Cell 16m | P2 | 02:00 |


LAYOUT II
Ins Beg
Fan+ Sens +
+ Socket + FrV
Ins End + Comp
Bot + Cas Beg
Cas End + Prework +
+ Unf
Unfilling
PostWork + Fil +
+ Insp + FAS beg
LED CONV
Fas End + PreTest +
+ Test (During:
LED CONV + FBR) +
+ FBR + 12xFB
3xLed +Shelf +
+ Shelf +
+ Ceil + Top Beg
Curt + Fr Grill
Top End +Back
Top
Back
Curt
Fr Grill
2xShelf
Main
Main
Main
Wash + Ptg + Ptg+ 1 Side Sticker
Stickers (Rest) + Ser No
Automated packing
TO WAREHOUSE

Appendix 24. LAYOUT II. DIMENSIONS

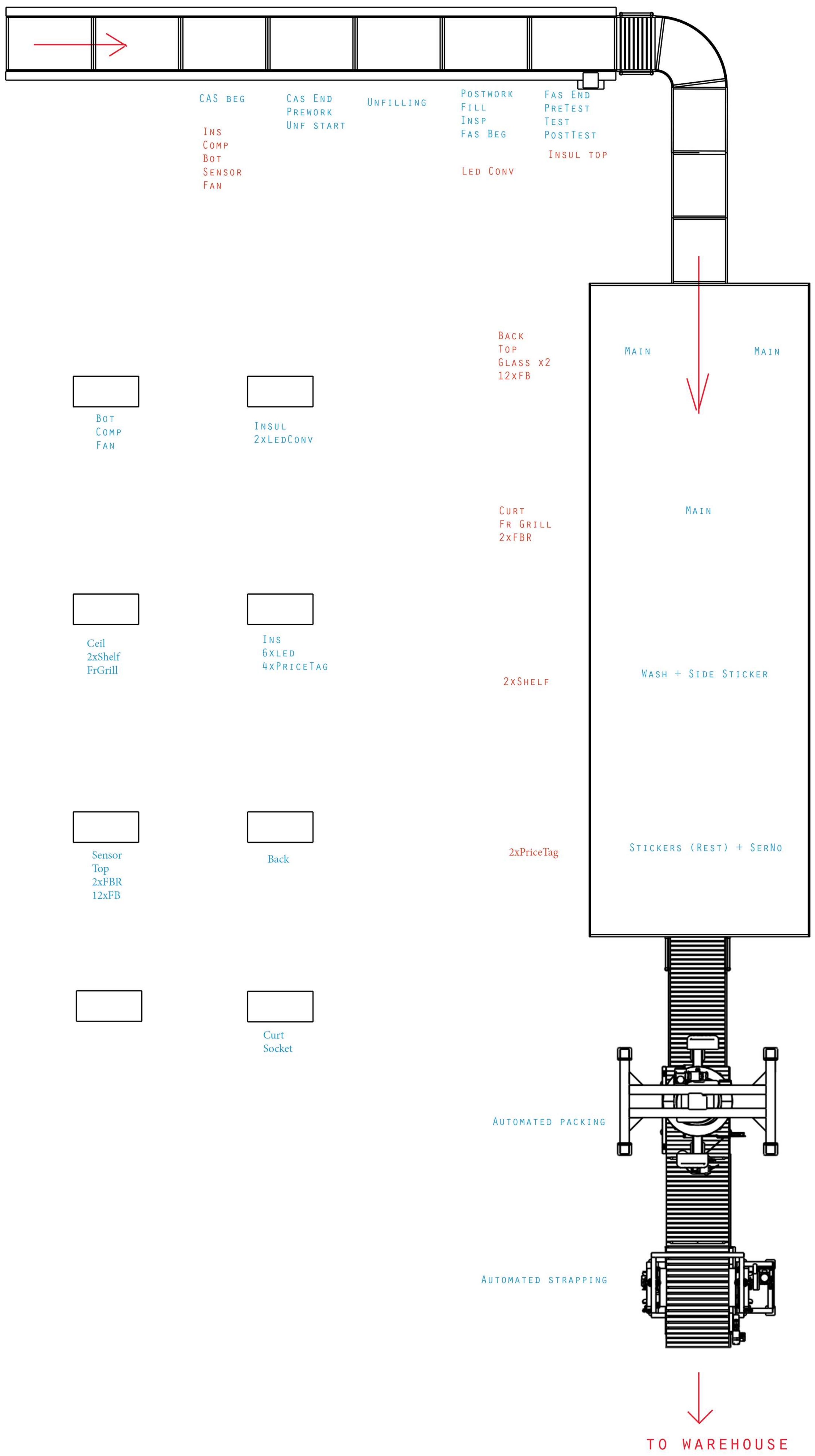


Appendix 25. FINAL LAYOUT. WORKCELL TABLE

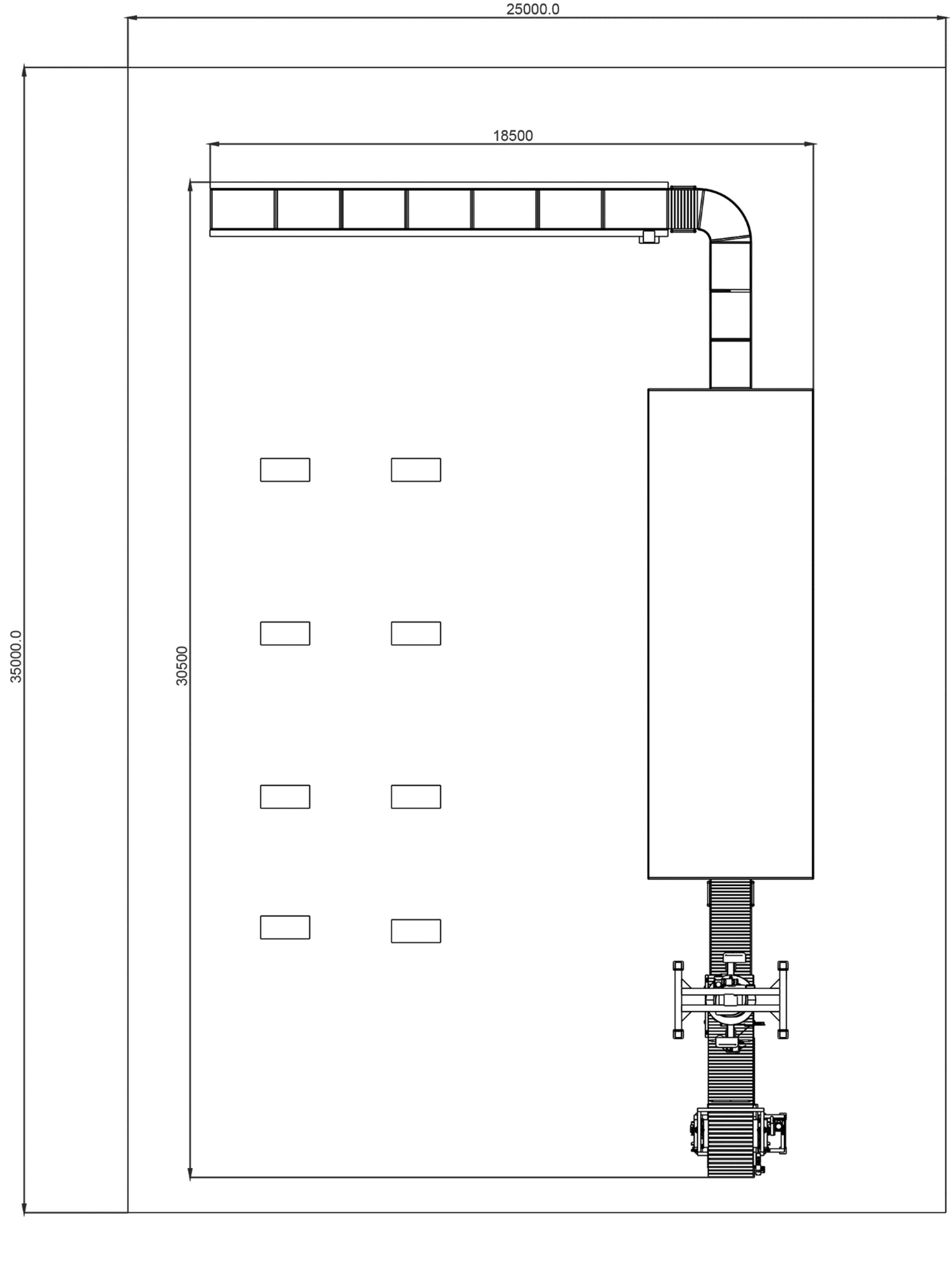
| Cell number | Operations | Time |
|---|---|---|
| Cell 1 | M1 (7:00) | 07.00 |
| Cell 2 | M1 (2:00) +M2+M3 | 05.39 |
| Cell 2m | M4 (7:33 with conveyor moving time) | 07.20 |
| Cell 3 | M5(While M4 2:30)+M6+M7+M8 (3:00) | 06.15 |
| Cell 4 | M8 (1:48)+M9+M10+M11 | 04.48 06.48 |
| Cell 5 | M12 (7:30) | 07.30 |
| Cell 6 | M12 (7:00) | 07.00 |
| Cell 7 | M12 (7:30) | 07.30 |
| Cell 8 | M13+M14 (2:45) | 05.45 |
| Cell 9 | M14 (5:57) + M15 | 06.27 |
| Cell 10 | S3+S5+S7 | 07.19 |
| Cell 11 | S11+2xS12 (Double) | 15.00 |
| Cell 12 | S4+2xS17+S10 | 07.29 |
| Cell 13 | S11+6xS13+4xS15 (Double) | 14.10 |
| Cell 14 | S16+S19+2xS8+12xS9 | 06.57 |
| Cell 15 | S1 | 06.14 |
| Cell 16 | S6+S19+S2 | 06.41 |
| Cell 17 | Reserve | 00.00 |
| Cell 18m | P1 | 02.00 |
| Cell 19m | P2 | 02.00 |

Appendix 26. FINAL LAYOUT. OPERATIONS AND MATERIAL FLOW

# FINAL LAYOUT



Appendix 27. FINAL LAYOUT. DIMENSION



# Project summary

## Brief information about project

| | |
|---|---|
| Company name | ASTE |
| Project name | Final solution |

## Project stages

| | Investment | Ong. activity | |
|---|---|---|---|
| Beginning | 01/07/18 | 01/01/19 | |
| Duration | 2 | 24 | quart. |
| End | 31/12/18 | 31/12/24 | |

## Project efficiency

| | | | |
|---|---|---|---|
| NPV | EUR, thousand | 11 595 | |
| IRR | %% | 171,8% | |
| PP | years | 1,3 | profitable |
| DPP | years | 1,3 | profitable |

## Scenario table

| | NPV | IRR | PP | DPP |
|---|---|---|---|---|
| Common scenario | 11 595 | 171,8% | 5,0 | 5,0 |
| Optimistic scenario | 18 169 | 345,3% | 4,0 | 4,0 |
| Pessimistic scenario | 8 713 | 113,8% | 6,0 | 7,0 |

## Income statement

| EUR, thousand | Total | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|---|
| Income | 14 569 | 2 422 | 2 425 | 2 427 | 2 429 | 2 432 | 2 434 |
| Variable expenditures | (3 629) | (605) | (605) | (605) | (605) | (605) | (605) |
| **Profit margin** | **10 940** | **1 817** | **1 820** | **1 822** | **1 825** | **1 827** | **1 829** |
| *Margin/revenue* | | *75,0%* | *75,1%* | *75,1%* | *75,1%* | *75,1%* | *75,2%* |
| Fixed Expenditure | (73) | (12) | (12) | (12) | (12) | (12) | (12) |
| Salary and other | (2 375) | (399) | (395) | (395) | (395) | (395) | (395) |
| **EBITDA** | **8 492** | **1 406** | **1 412** | **1 415** | **1 417** | **1 420** | **1 422** |
| *EBITDA/revenue* | | *58,1%* | *58,3%* | *58,3%* | *58,3%* | *58,4%* | *58,4%* |
| Depreciation | (887) | (222) | (222) | (222) | (222) | - | - |
| **EBIT** | **7 605** | **1 184** | **1 191** | **1 193** | **1 196** | **1 420** | **1 422** |
| *EBIT/revenue* | | *48,9%* | *49,1%* | *49,2%* | *49,2%* | *58,4%* | *58,4%* |
| Debt servicing | (27) | (27) | - | - | - | - | - |
| **EBT** | **7 578** | **1 157** | **1 191** | **1 193** | **1 196** | **1 420** | **1 422** |
| *EBT/revenue* | | *47,8%* | *49,1%* | *49,2%* | *49,2%* | *58,4%* | *58,4%* |
| Corporate tax | (1 516) | (231) | (238) | (239) | (239) | (284) | (284) |
| **Net profit** | **6 062** | **925** | **953** | **954** | **956** | **1 136** | **1 138** |
| *Net profit/revenue* | | *38,2%* | *39,3%* | *39,3%* | *39,4%* | *46,7%* | *46,7%* |

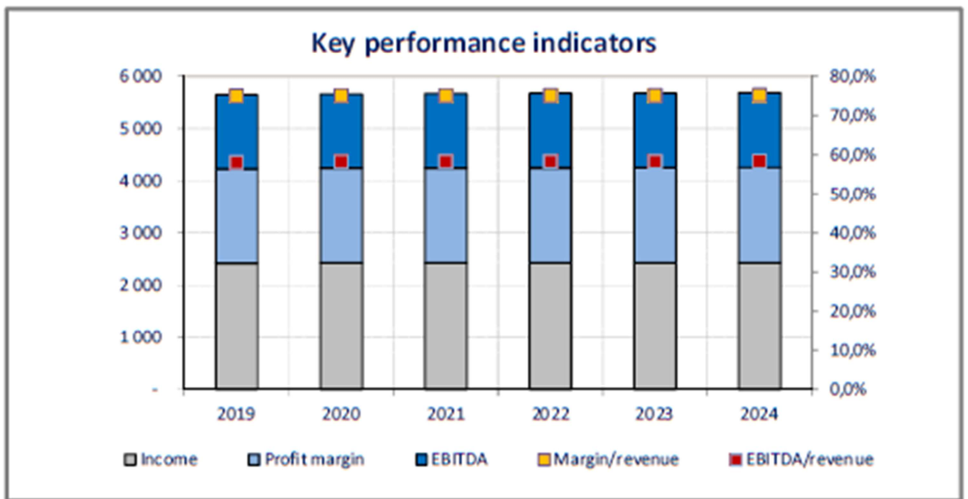
## Balance

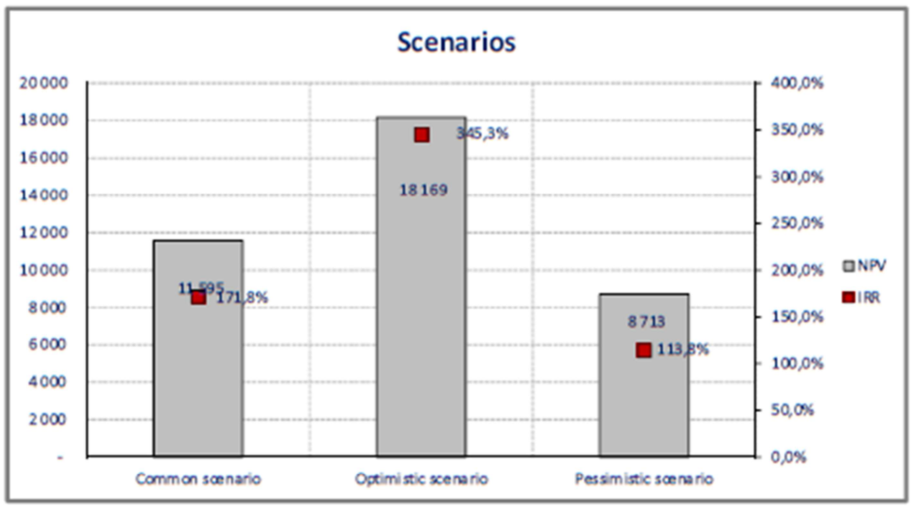
| EUR, thousand | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| Assets | | | | | | |
| Current Assets | 428 | 1 603 | 2 779 | 3 958 | 5 105 | 6 243 |
| Non-current Assets | 665 | 444 | 222 | - | - | - |
| **Total Assets** | **1 093** | **2 046** | **3 001** | **3 958** | **5 105** | **6 243** |
| Obligations and Capital | | | | | | |
| Current Obligations | 168 | 168 | 168 | 169 | 180 | 180 |
| long-term Obligations | - | - | - | - | - | - |
| Capital and reserves | 925 | 1 878 | 2 832 | 3 789 | 4 925 | 6 062 |
| **Total Obligations and Capital** | **1 093** | **2 046** | **3 001** | **3 958** | **5 105** | **6 243** |

## Cash Flow Statement

| EUR, thousand | Total | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|---|
| Operational activities | | | | | | | |
| Cash In | 18 065 | 3 003 | 3 006 | 3 009 | 3 012 | 3 015 | 3 018 |
| Cash Out | (10 695) | (1 448) | (1 832) | (1 833) | (1 834) | (1 868) | (1 880) |
| **Cash Flow** | **7 370** | **1 555** | **1 175** | **1 177** | **1 178** | **1 147** | **1 138** |
| Financial activities | | | | | | | |
| Cash In | - | - | - | - | - | - | - |
| Cash Out | (1 127) | (1 127) | - | - | - | - | - |
| **Cash Flow** | **(1 127)** | **(1 127)** | - | - | - | - | - |
| **Net change in cash** | **6 243** | **428** | **1 175** | **1 177** | **1 178** | **1 147** | **1 138** |
| Saldo in the beginning of period | | - | 428 | 1 603 | 2 779 | 3 958 | 5 105 |
| Saldo at the end of period | | 428 | 1 603 | 2 779 | 3 958 | 5 105 | 6 243 |

## Graphs and diagrams



# Project summary

## Brief information about project

| | |
|---|---|
| Company name | ASTE |
| Project name | Doubling solution |

## Project stages

| | Investment | Ong. activity | |
|---|---|---|---|
| Beginning | 01/07/18 | 01/01/19 | |
| Duration | 2 | 24 | quart. |

## Project efficiency

| | | | |
|---|---|---|---|
| NPV | EUR, thousand | 10 614 | |
| IRR | %% | 3762,7% | |
| PP | years | 0,8 | profitable |
| DPP | years | 0,8 | profitable |

## Scenario table

| | NPV | IRR | PP | DPP |
|---|---|---|---|---|
| Common scenario | 10 614 | 3762,7% | 3,0 | 3,0 |
| Optimistic scenario | 17 085 | 10844,8% | 3,0 | 3,0 |
| Pessimistic scenario | 7 835 | 1887,5% | 3,0 | 3,0 |

## Income statement

| EUR, thousand | Total | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|---|
| Income | 14 569 | 2 422 | 2 425 | 2 427 | 2 429 | 2 432 | 2 434 |
| Variable expenditures | (3 629) | (605) | (605) | (605) | (605) | (605) | (605) |
| **Profit margin** | **10 940** | **1 817** | **1 820** | **1 822** | **1 825** | **1 827** | **1 829** |
| *Margin/revenue* | | *75,0%* | *75,1%* | *75,1%* | *75,1%* | *75,1%* | *75,2%* |
| Fixed Expenditure | (24) | (4) | (4) | (4) | (4) | (4) | (4) |
| Salary and other | (3 562) | (599) | (593) | (593) | (593) | (593) | (593) |
| **EBITDA** | **7 353** | **1 215** | **1 223** | **1 225** | **1 228** | **1 230** | **1 233** |
| *EBITDA/revenue* | | *50,1%* | *50,4%* | *50,5%* | *50,5%* | *50,6%* | *50,6%* |
| Depreciation | (89) | (22) | (22) | (22) | (22) | - | - |
| **EBIT** | **7 265** | **1 192** | **1 201** | **1 203** | **1 206** | **1 230** | **1 233** |
| *EBIT/revenue* | | *49,2%* | *49,5%* | *49,6%* | *49,6%* | *50,6%* | *50,6%* |
| Debt servicing | (20) | (20) | - | - | - | - | - |
| **EBT** | **7 245** | **1 172** | **1 201** | **1 203** | **1 206** | **1 230** | **1 233** |
| *EBT/revenue* | | *48,4%* | *49,5%* | *49,6%* | *49,6%* | *50,6%* | *50,6%* |
| Corporate tax | (1 449) | (234) | (240) | (241) | (241) | (246) | (247) |
| **Net profit** | **5 796** | **938** | **961** | **963** | **964** | **984** | **986** |
| *Net profit/revenue* | | *38,7%* | *39,6%* | *39,7%* | *39,7%* | *40,5%* | *40,5%* |

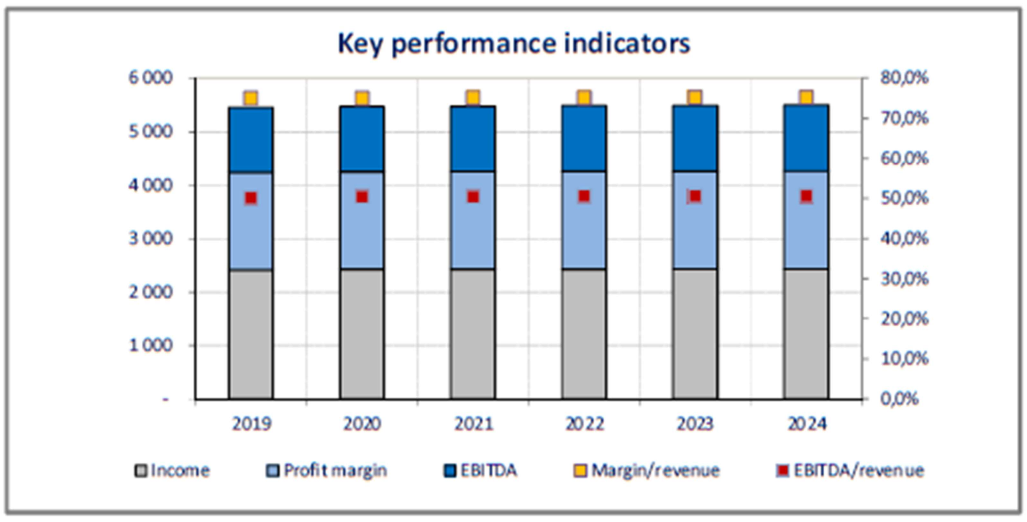
## Balance

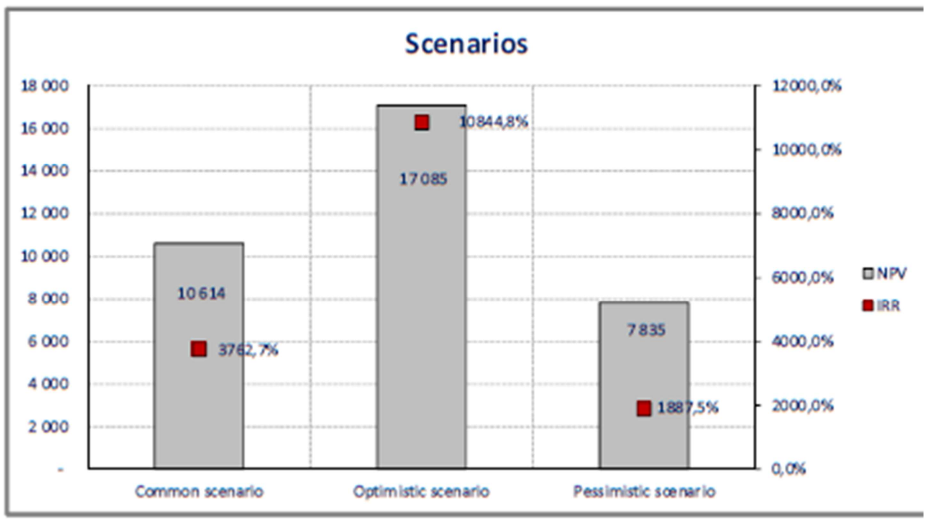
| EUR, thousand | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| Assets | | | | | | |
| Current Assets | 1 040 | 2 023 | 3 008 | 3 995 | 4 981 | 5 967 |
| Non-current Assets | 67 | 44 | 22 | - | - | - |
| **Total Assets** | **1 106** | **2 068** | **3 030** | **3 995** | **4 981** | **5 967** |
| Obligations and Capital | | | | | | |
| Current Obligations | 169 | 169 | 169 | 170 | 171 | 171 |
| long-term Obligations | - | - | - | - | - | - |
| Capital and reserves | 938 | 1 899 | 2 861 | 3 826 | 4 810 | 5 796 |
| **Total Obligations and Capital** | **1 106** | **2 068** | **3 030** | **3 995** | **4 981** | **5 967** |

## Cash Flow Statement

| EUR, thousand | Total | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|---|
| Operational activities | | | | | | | |
| Cash In | 18 065 | 3 003 | 3 006 | 3 009 | 3 012 | 3 015 | 3 018 |
| Cash Out | (11 968) | (1 833) | (2 023) | (2 024) | (2 025) | (2 030) | (2 032) |
| **Cash Flow** | **6 097** | **1 170** | **983** | **985** | **987** | **986** | **986** |
| Financial activities | | | | | | | |
| Cash In | - | - | - | - | - | - | - |
| Cash Out | (130) | (130) | - | - | - | - | - |
| **Cash Flow** | **(130)** | **(130)** | - | - | - | - | - |
| **Net change in cash** | **5 967** | **1 040** | **983** | **985** | **987** | **986** | **986** |
| Saldo in the beginning of period | | - | 1 040 | 2 023 | 3 008 | 3 995 | 4 981 |
| Saldo at the end of period | | 1 040 | 2 023 | 3 008 | 3 995 | 4 981 | 5 967 |

## Graphs and diagrams



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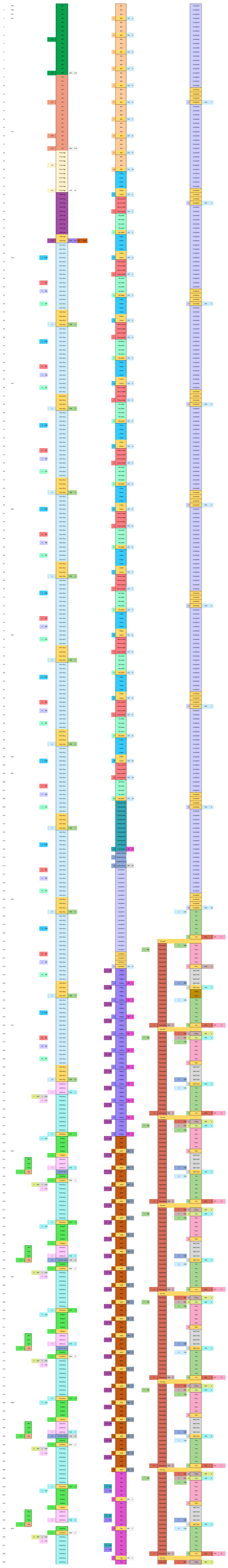
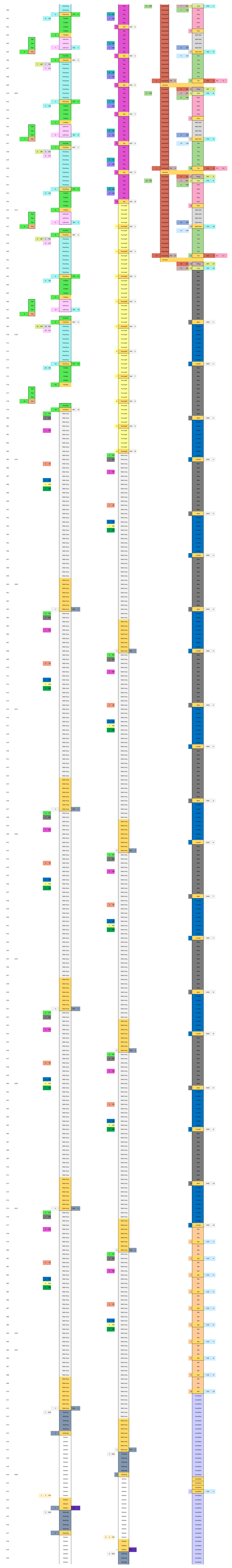
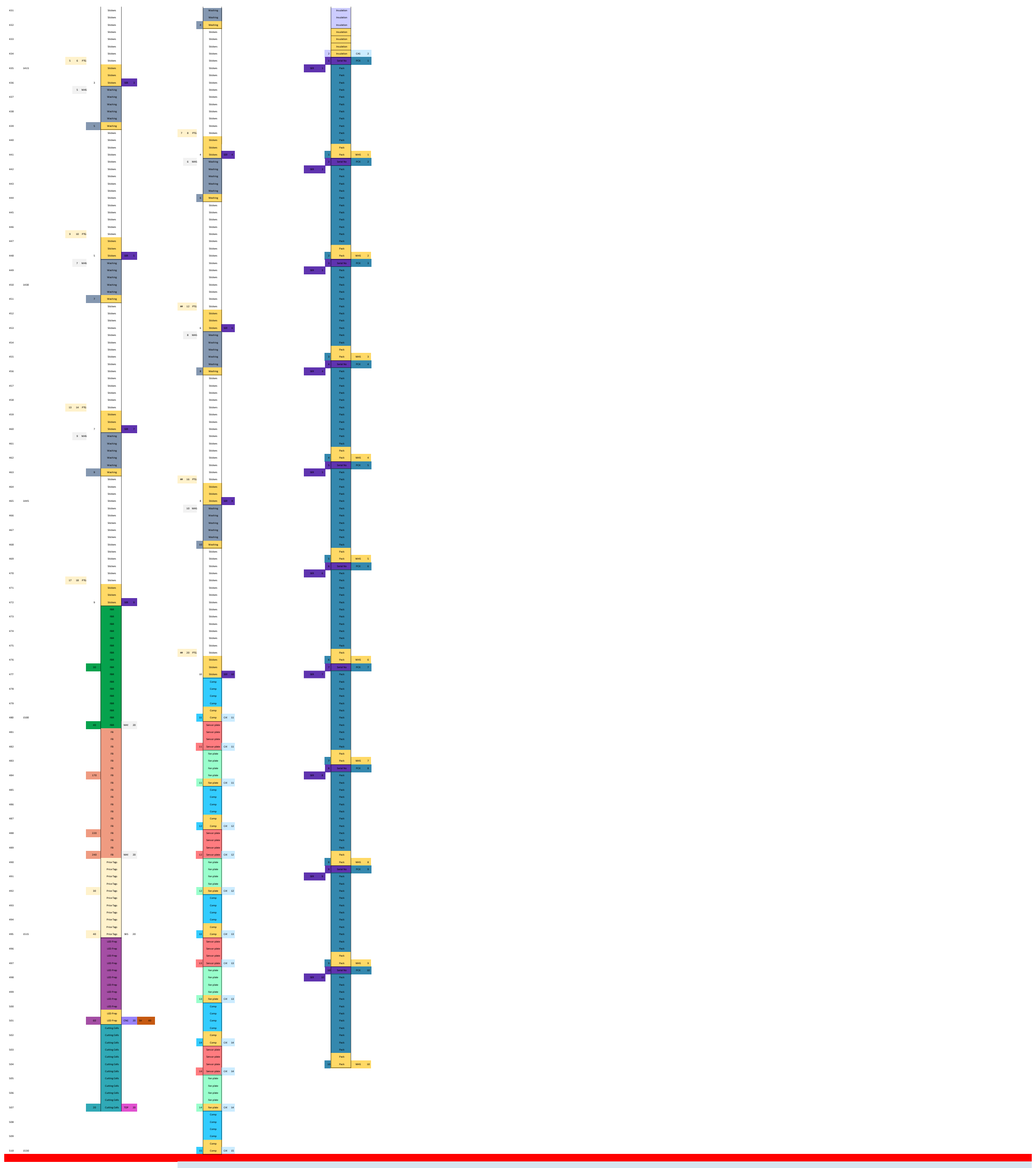
Production Schedule Diagrams

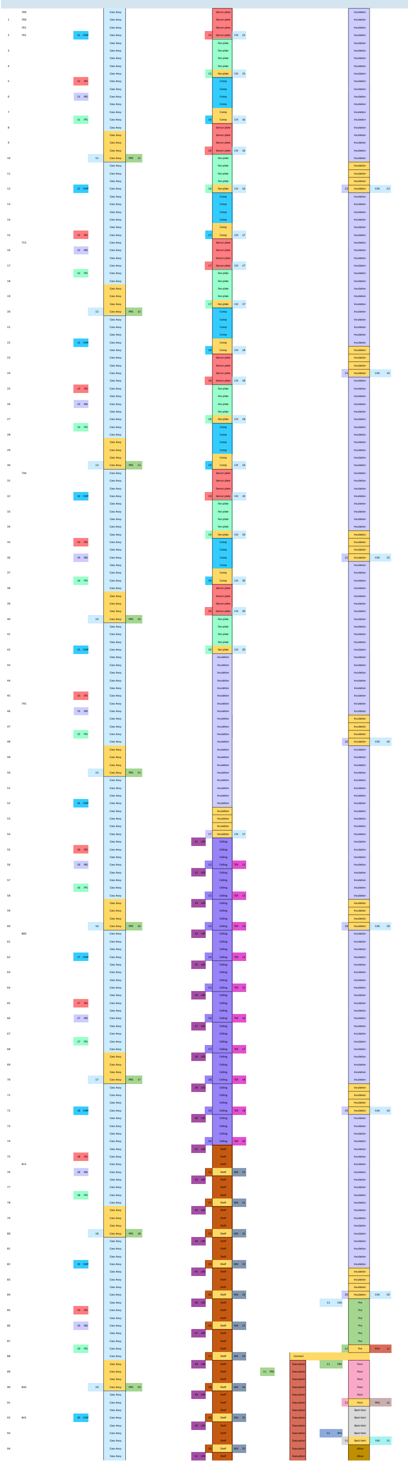
DAY 0 10 Units/day

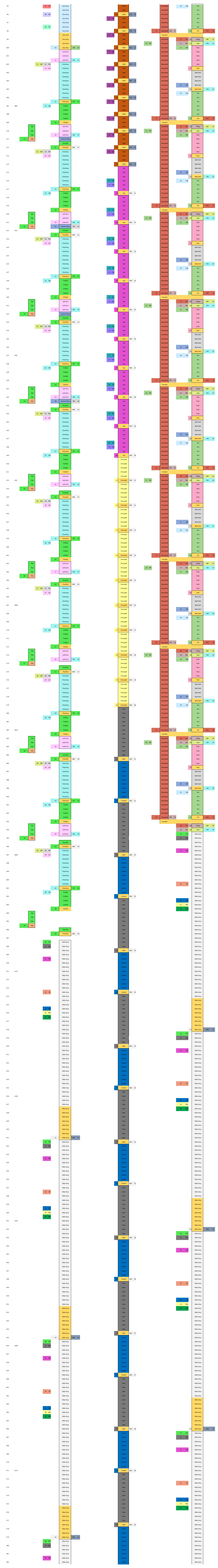


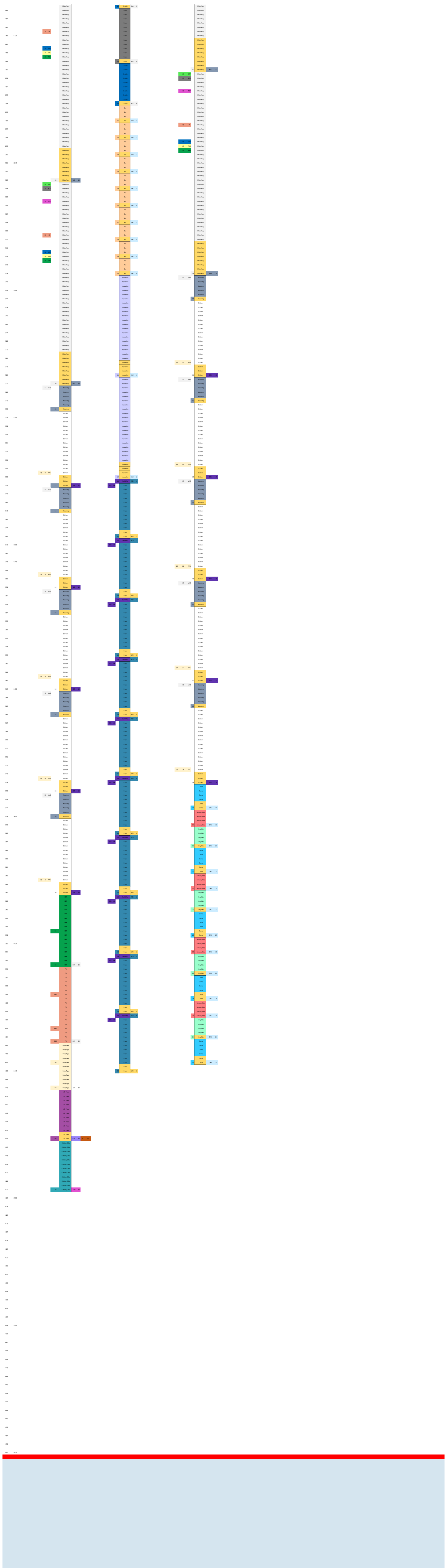




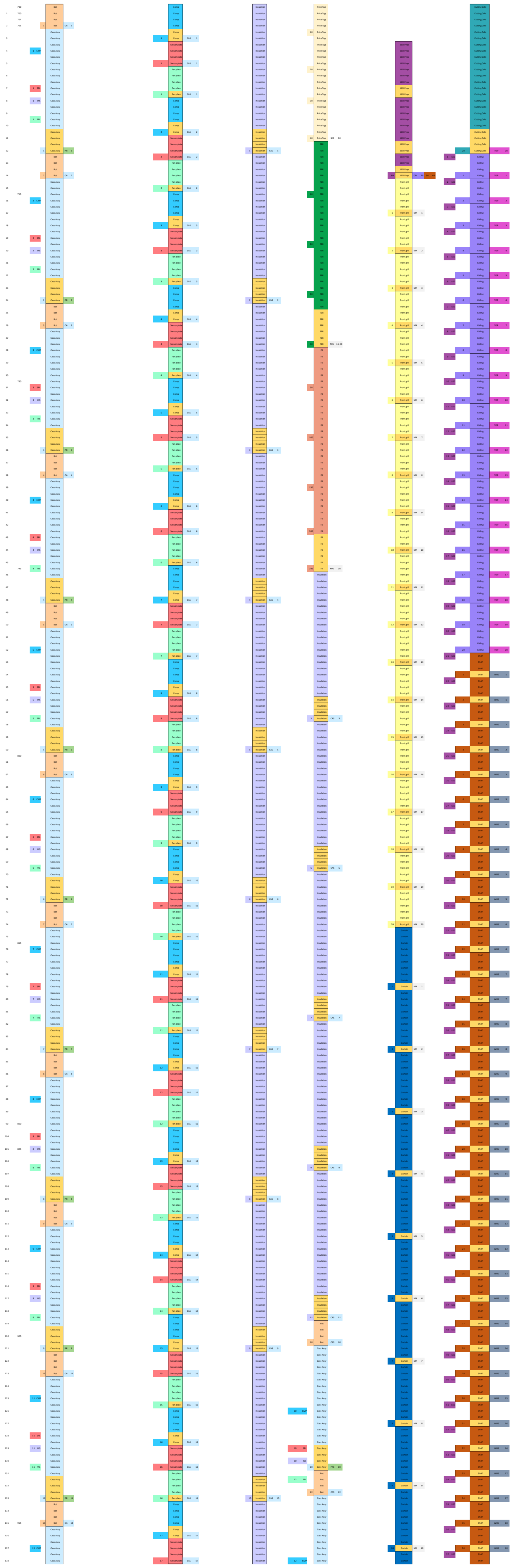
**DAY X**

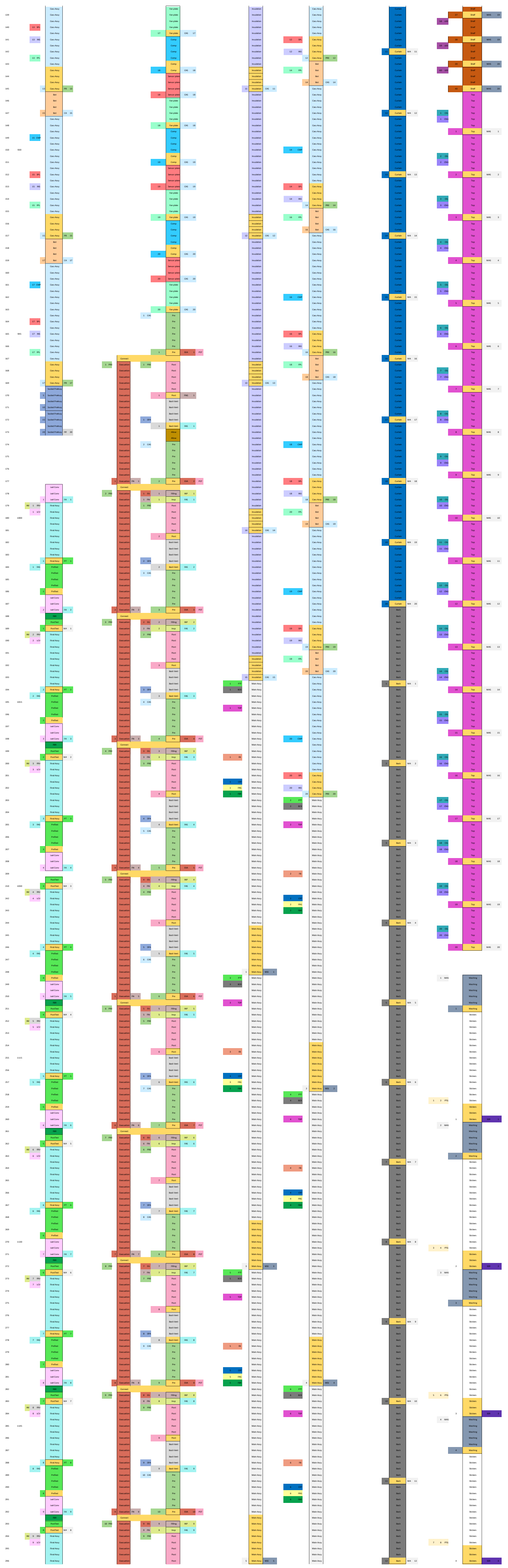


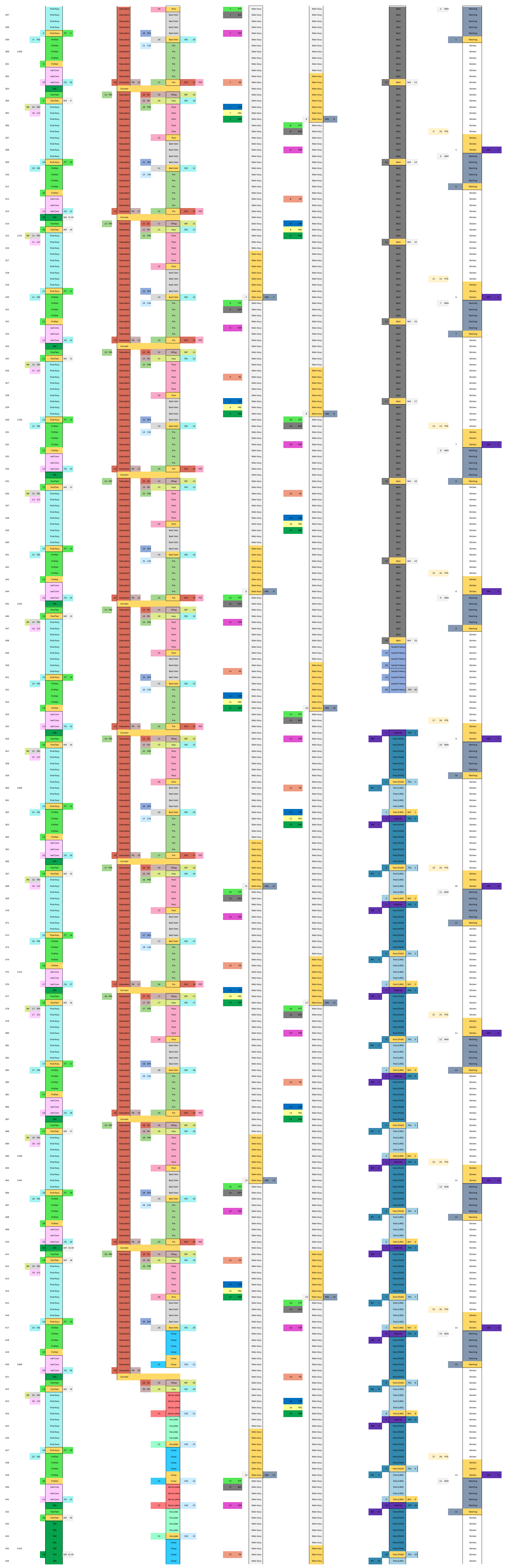




DAY 0 20 Units/day



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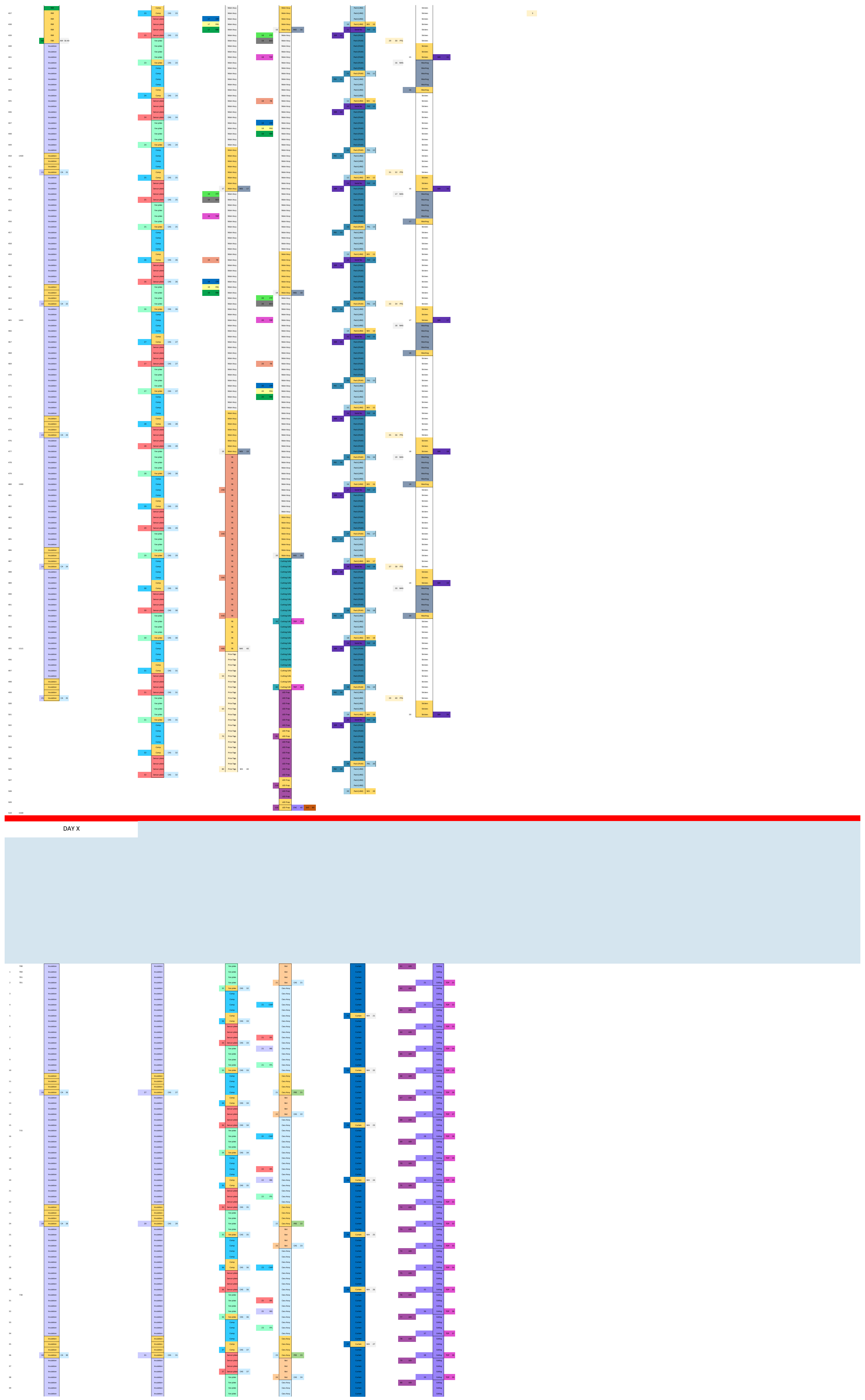
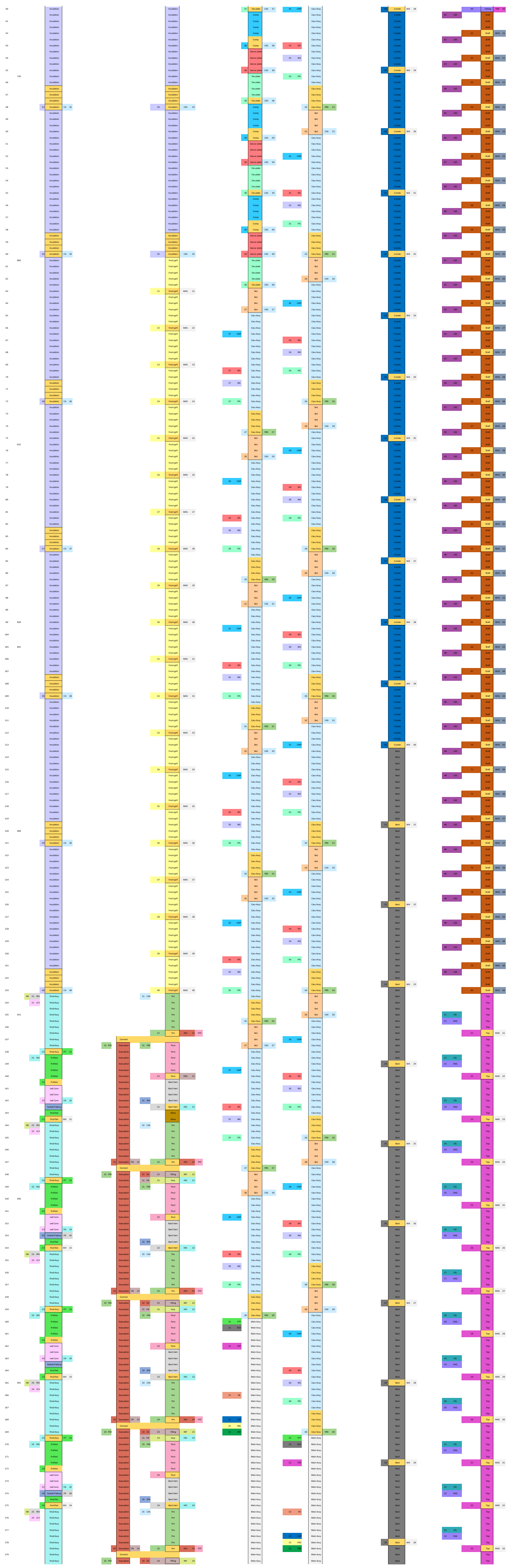
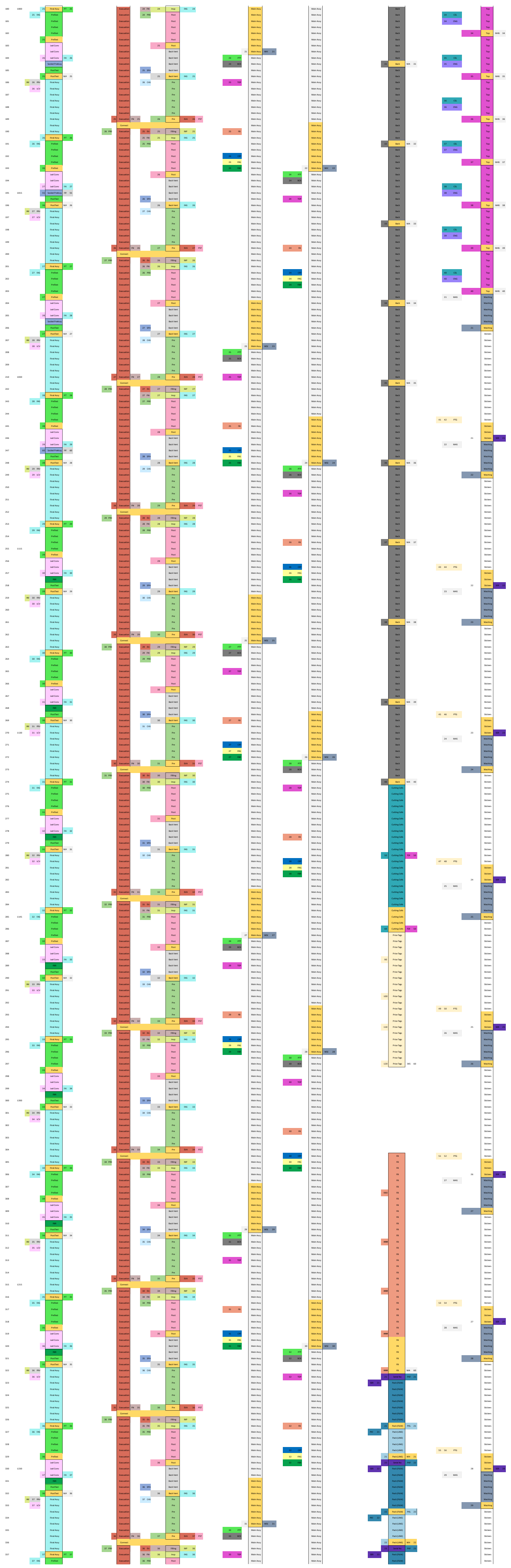
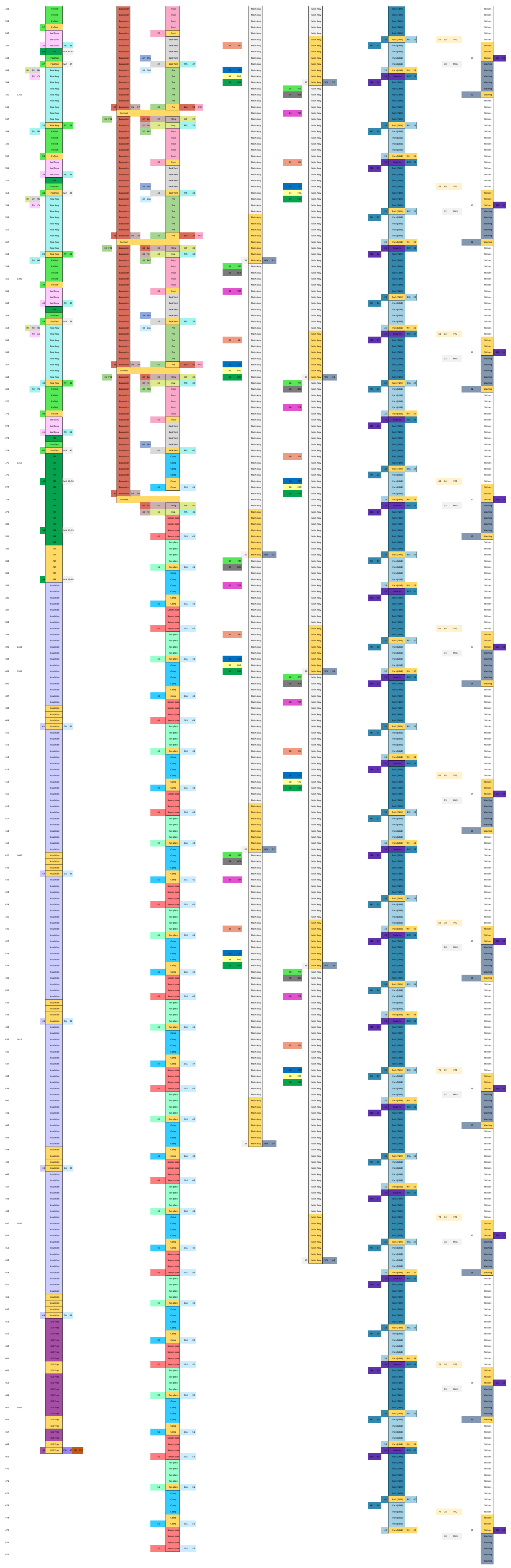
Back Vent
Pre
Filling
Insp
Main Assy


DAY X







| | | | | | |
|---|---|---|---|---|---|
| 478 | | | 40 | Washing | |
| 479 | | | | Stickers | |
| | | | | Stickers | |
| 480 | 1500 | | | Stickers | |
| | | | | Stickers | |
| 481 | | | | Stickers | |
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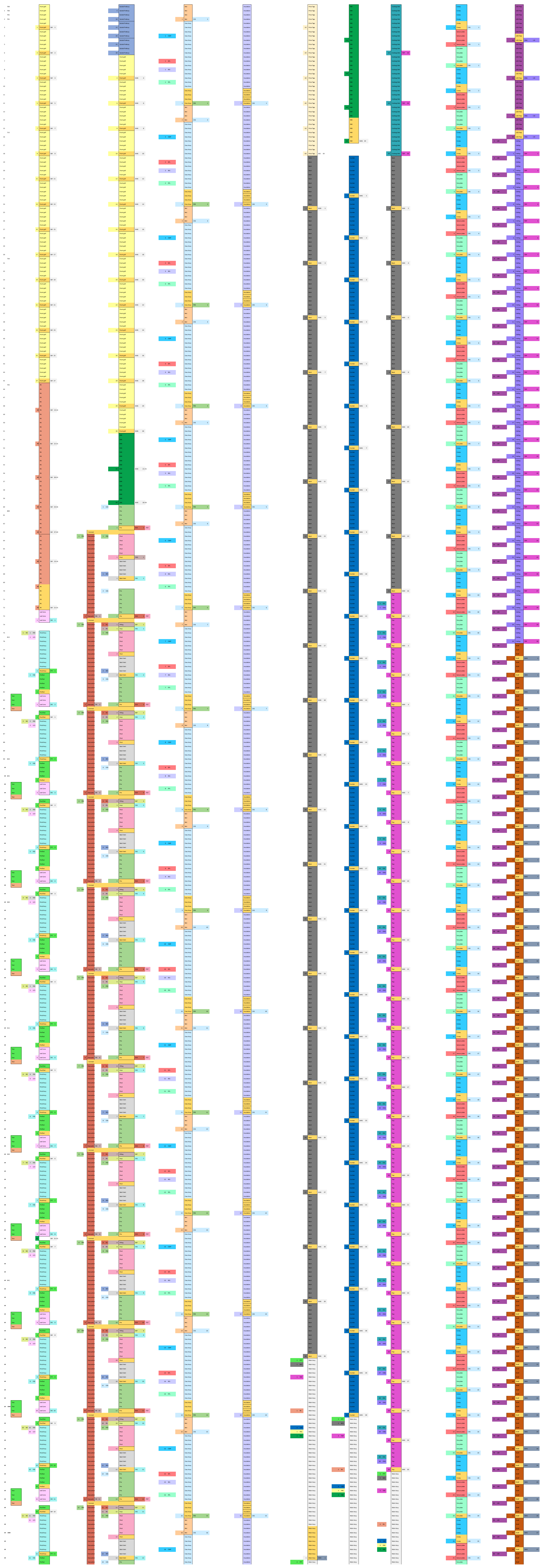
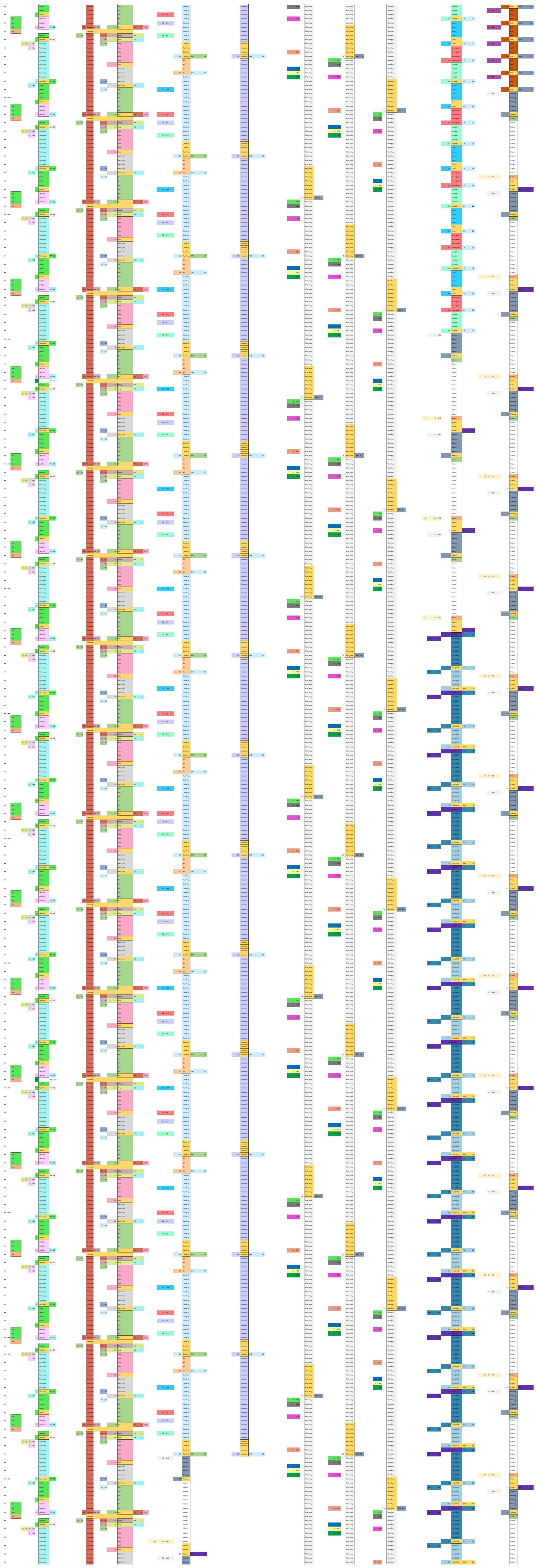
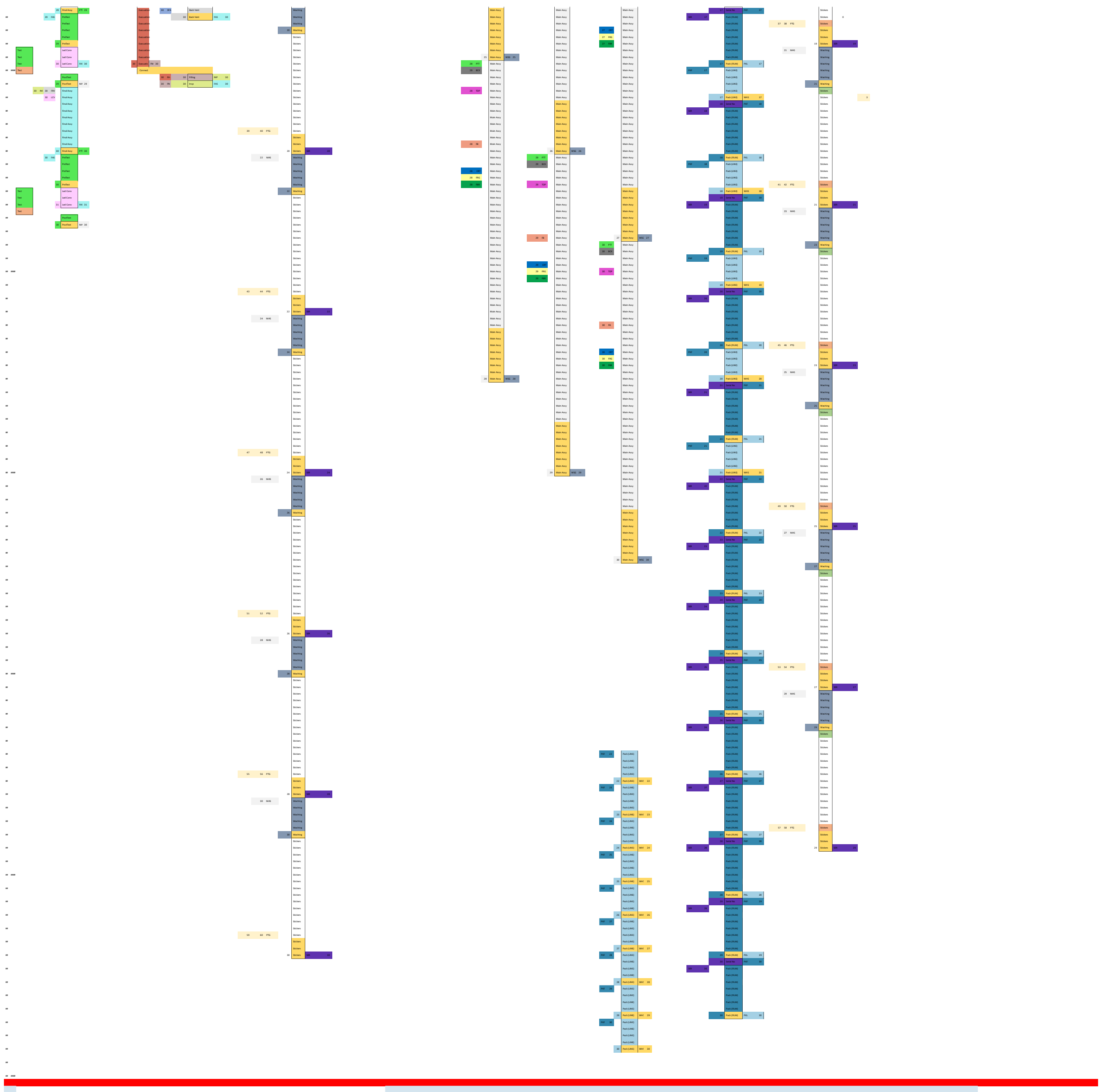
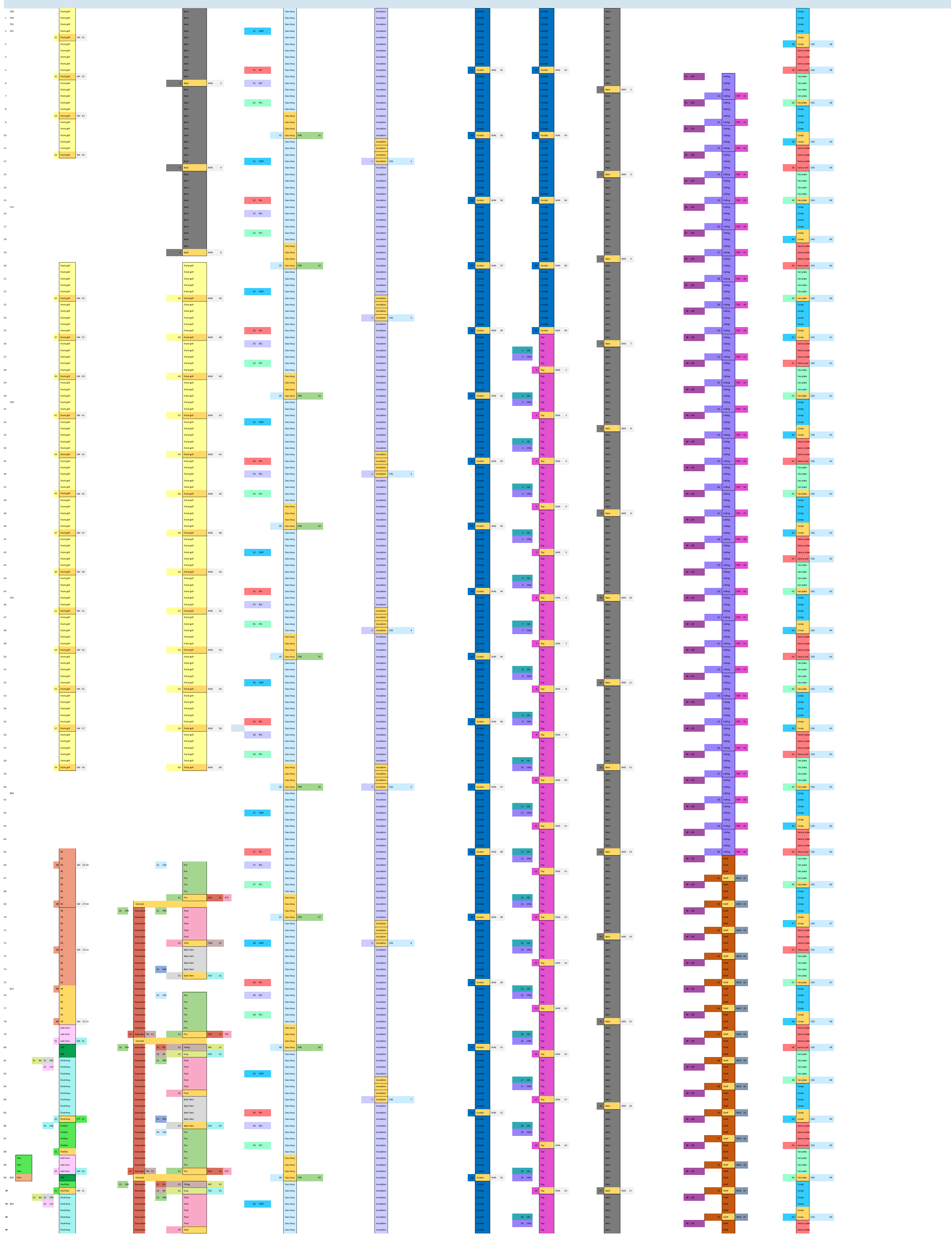
DAY 0 30 Units/day

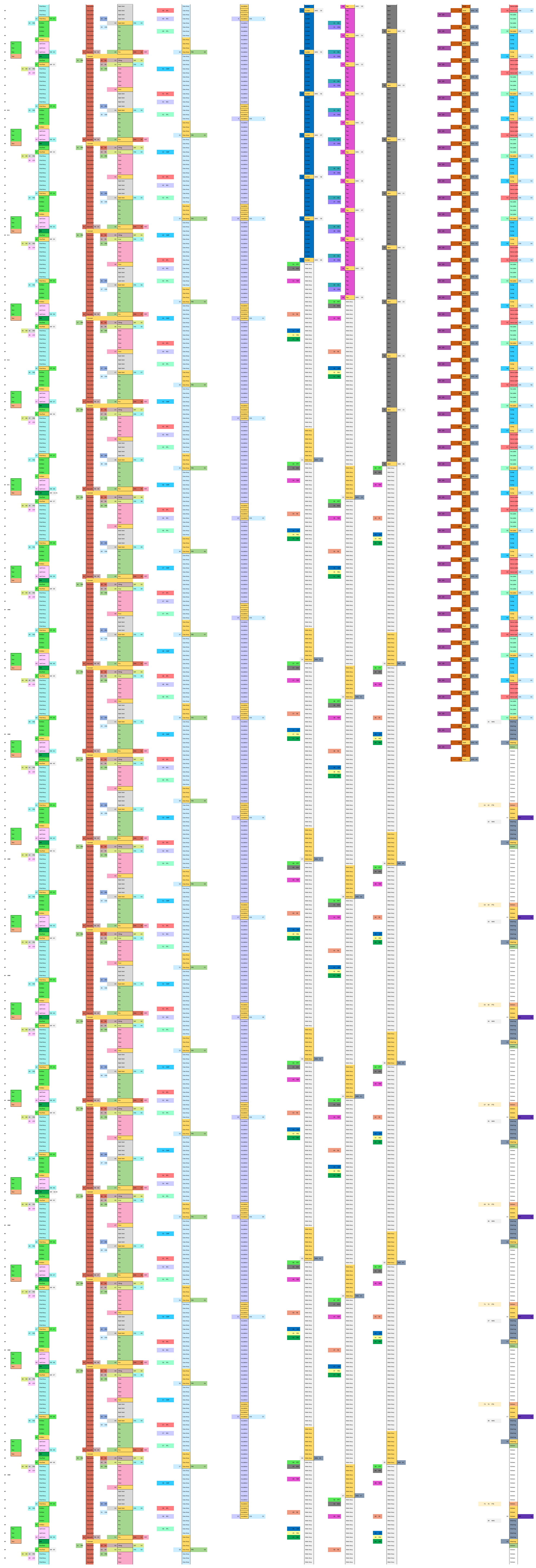


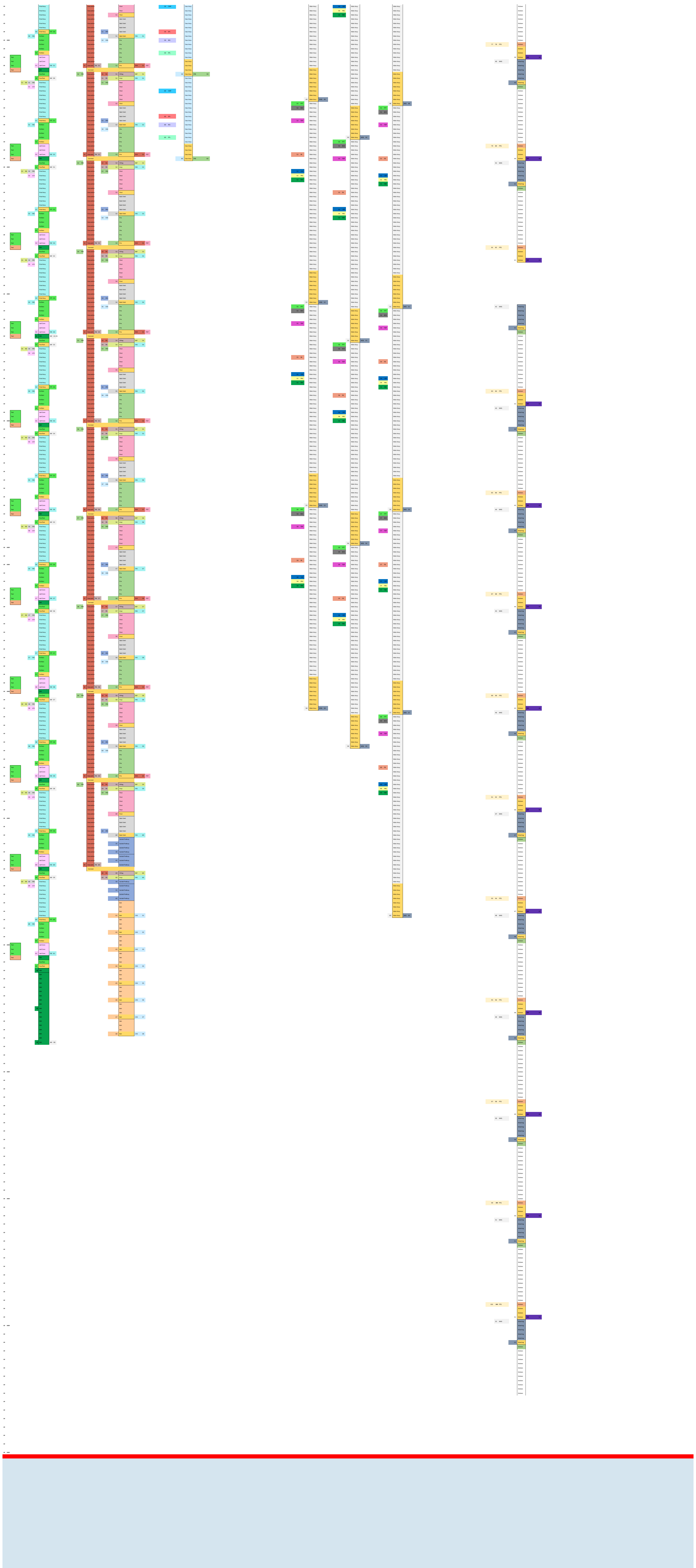




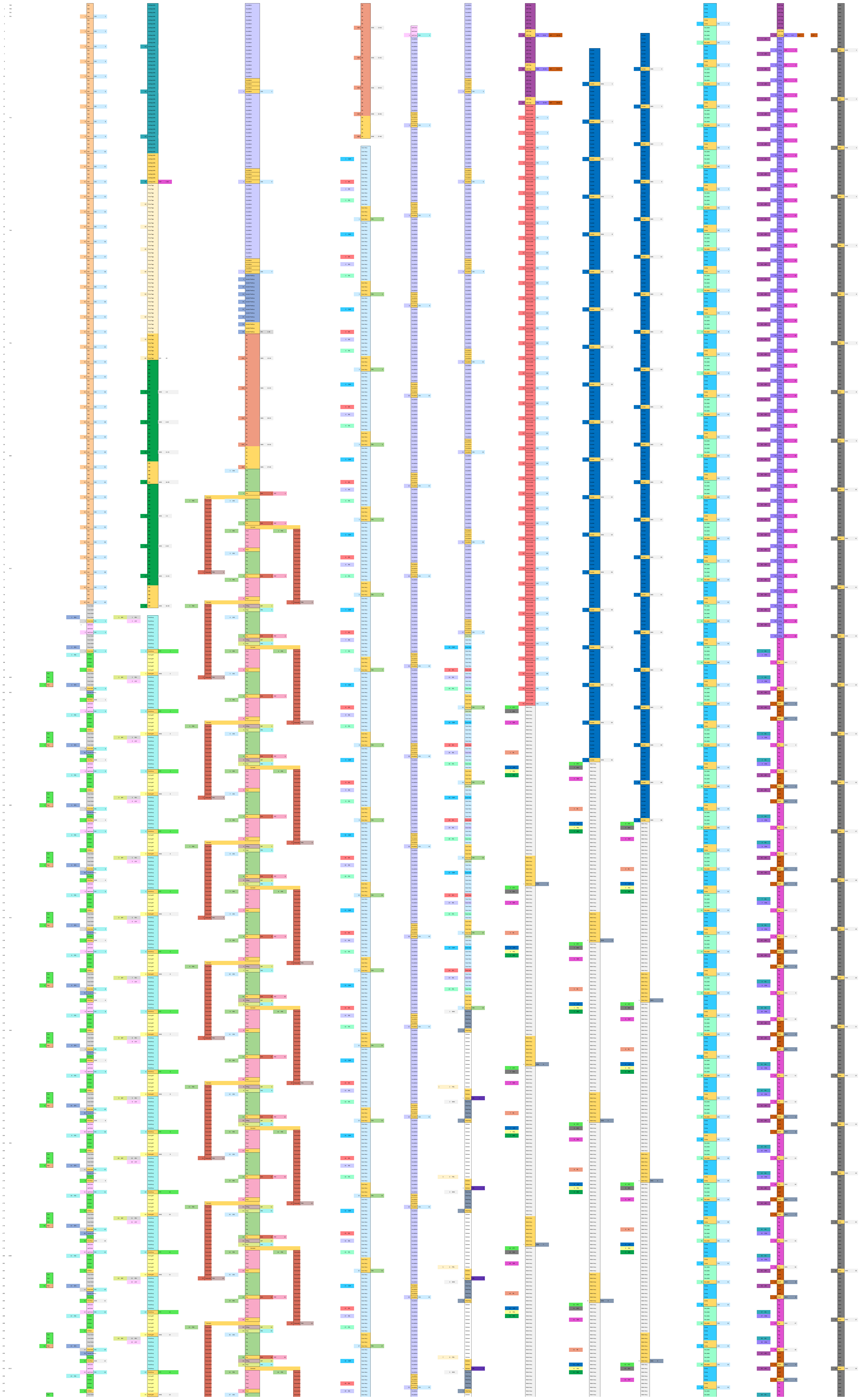
DAY X

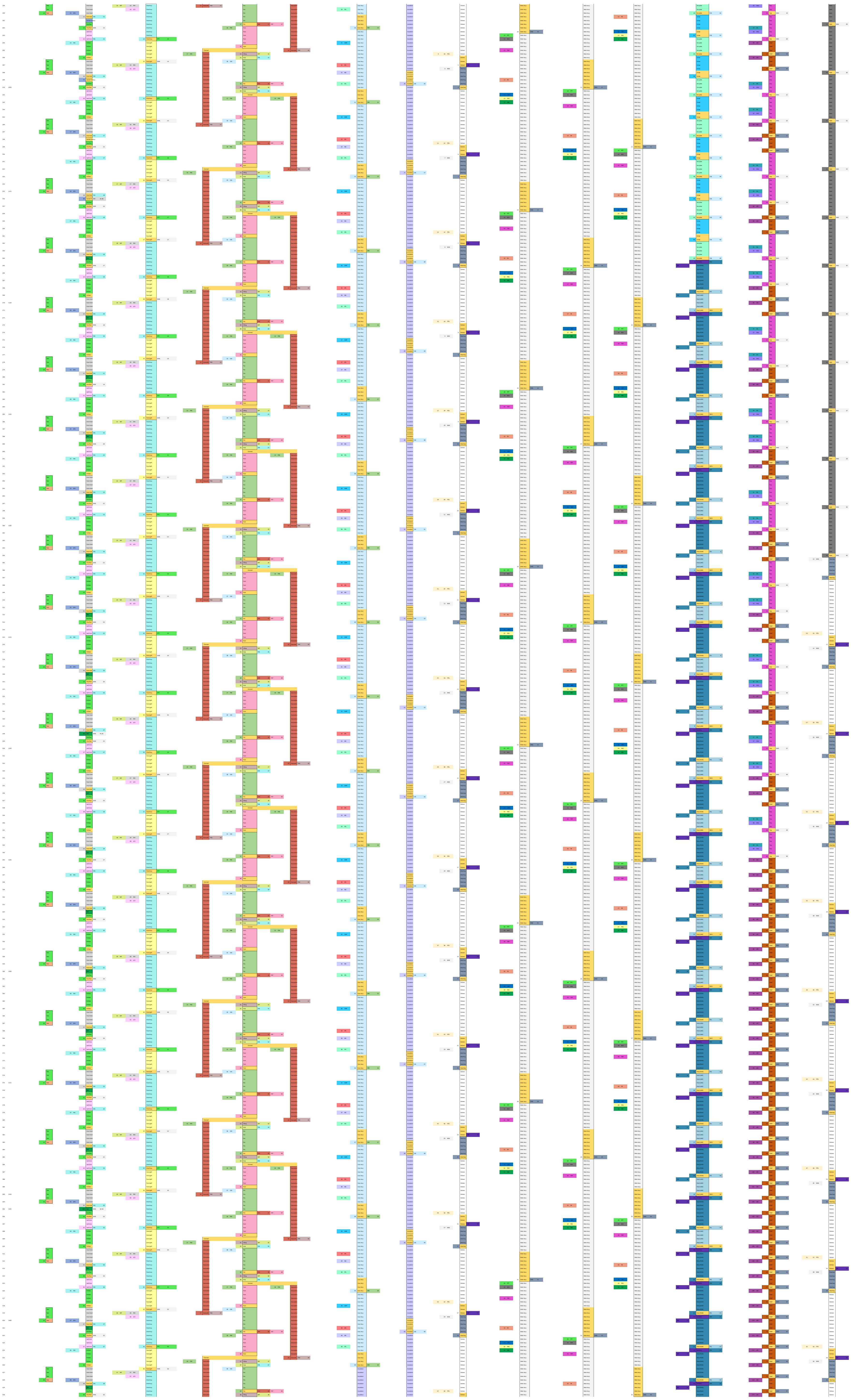


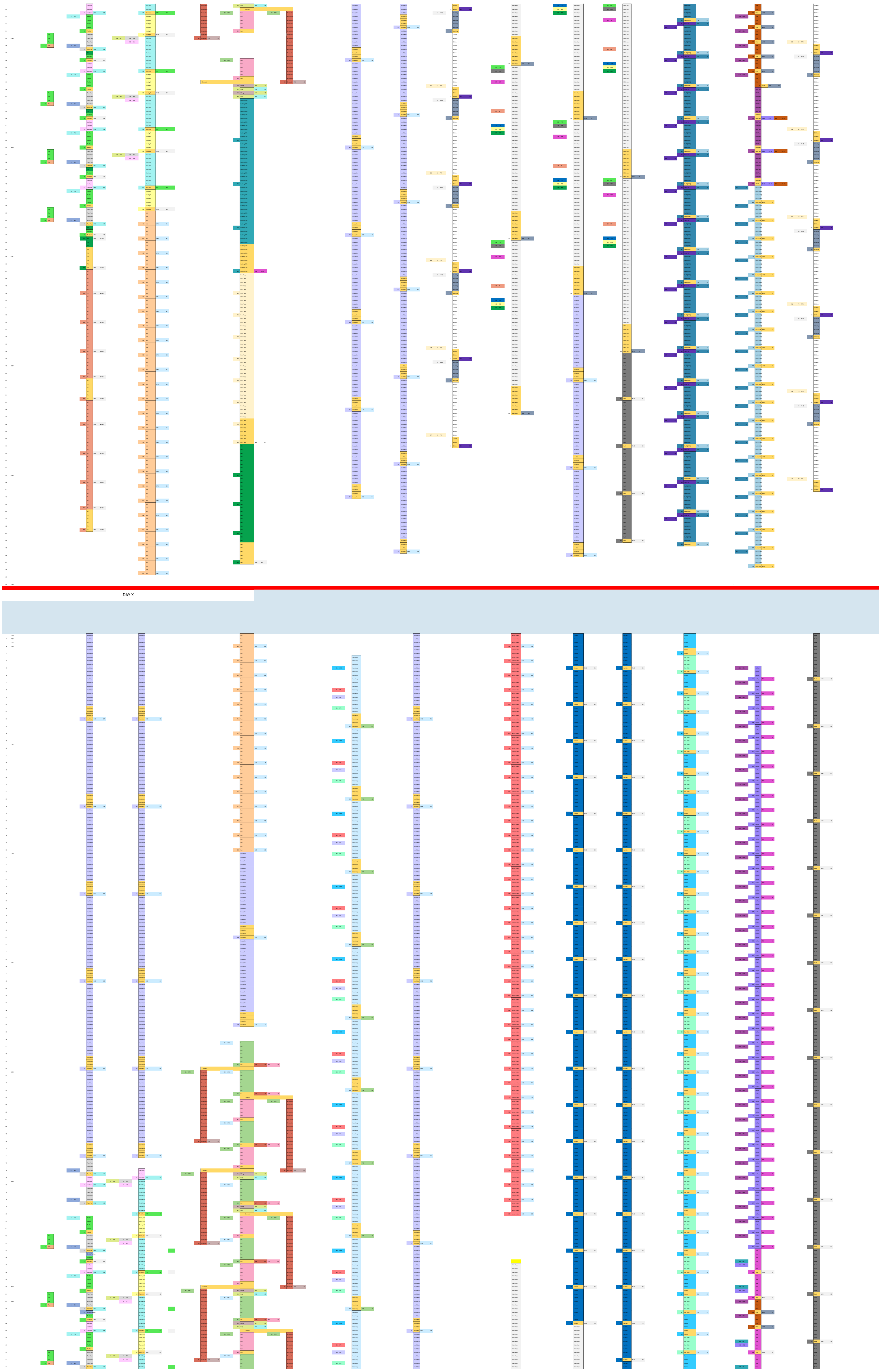


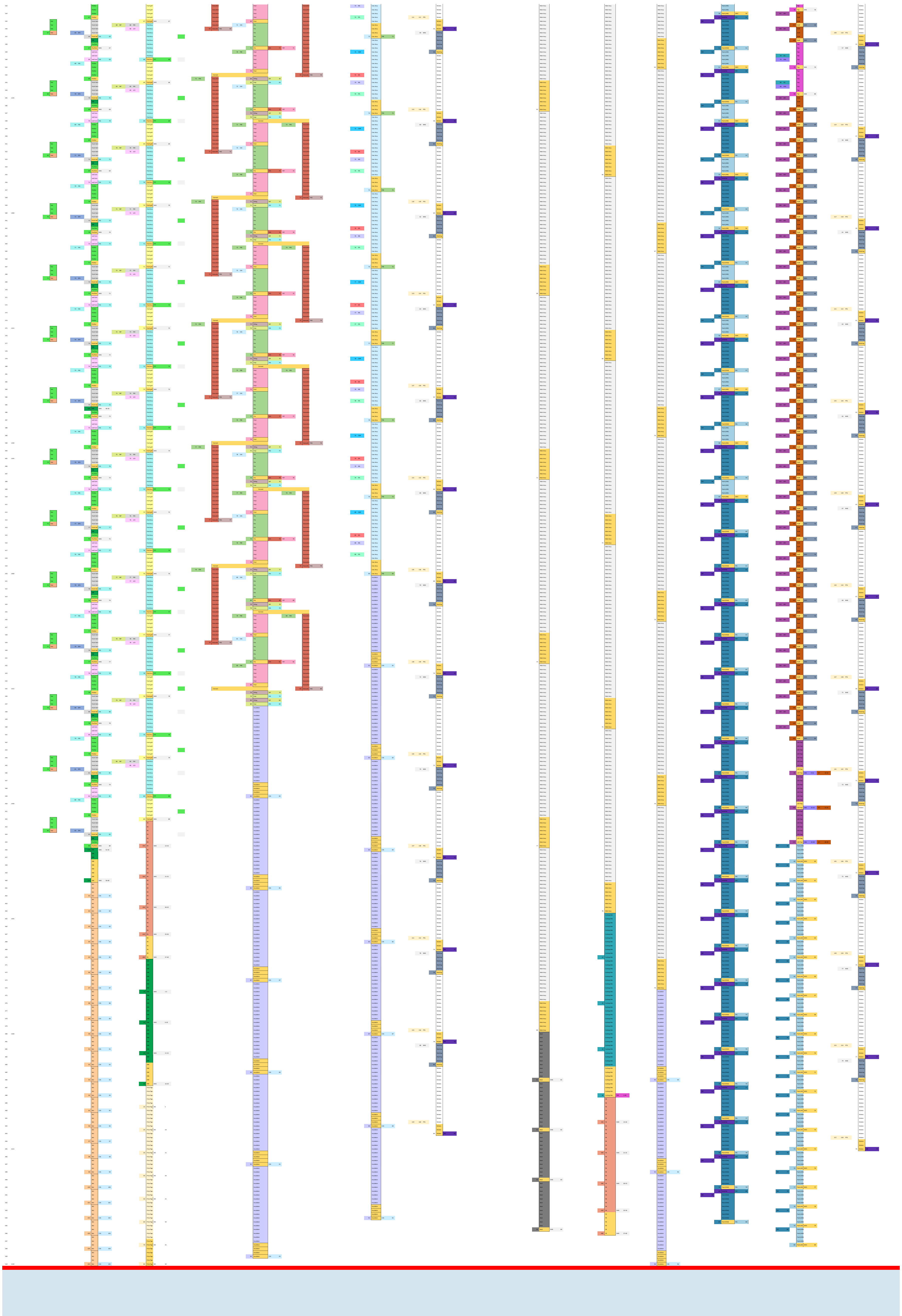


DAY 0 40 Units/day

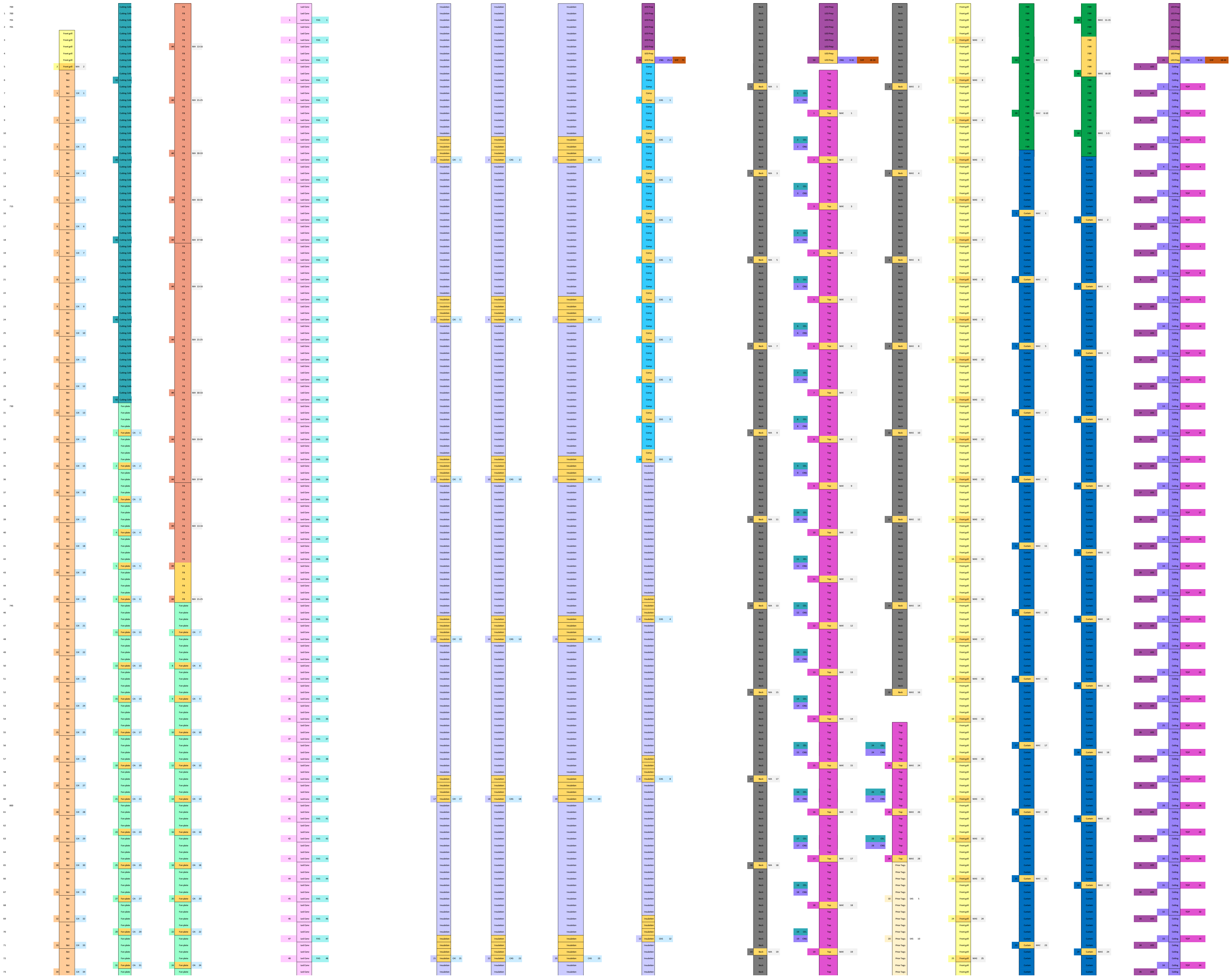


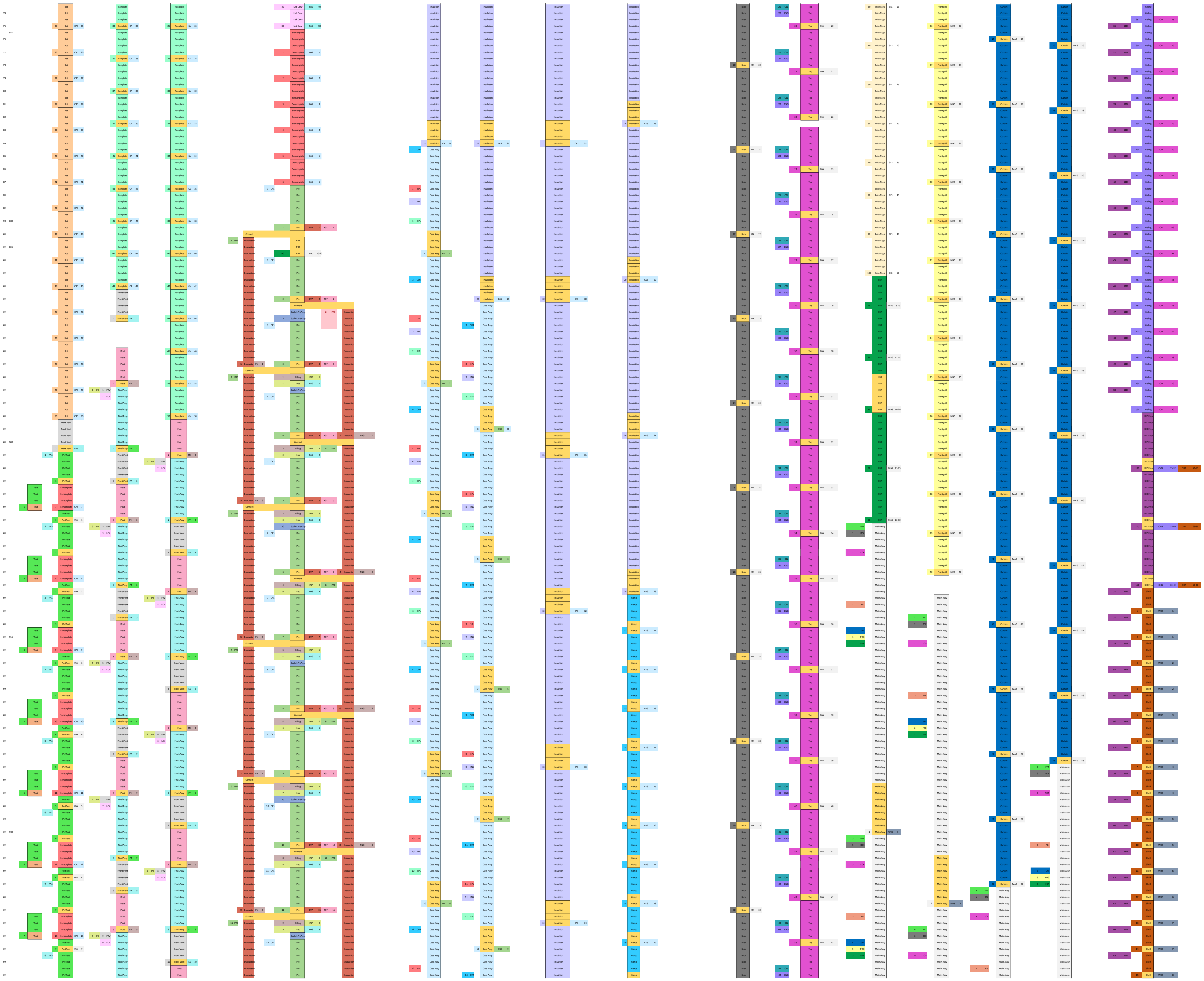


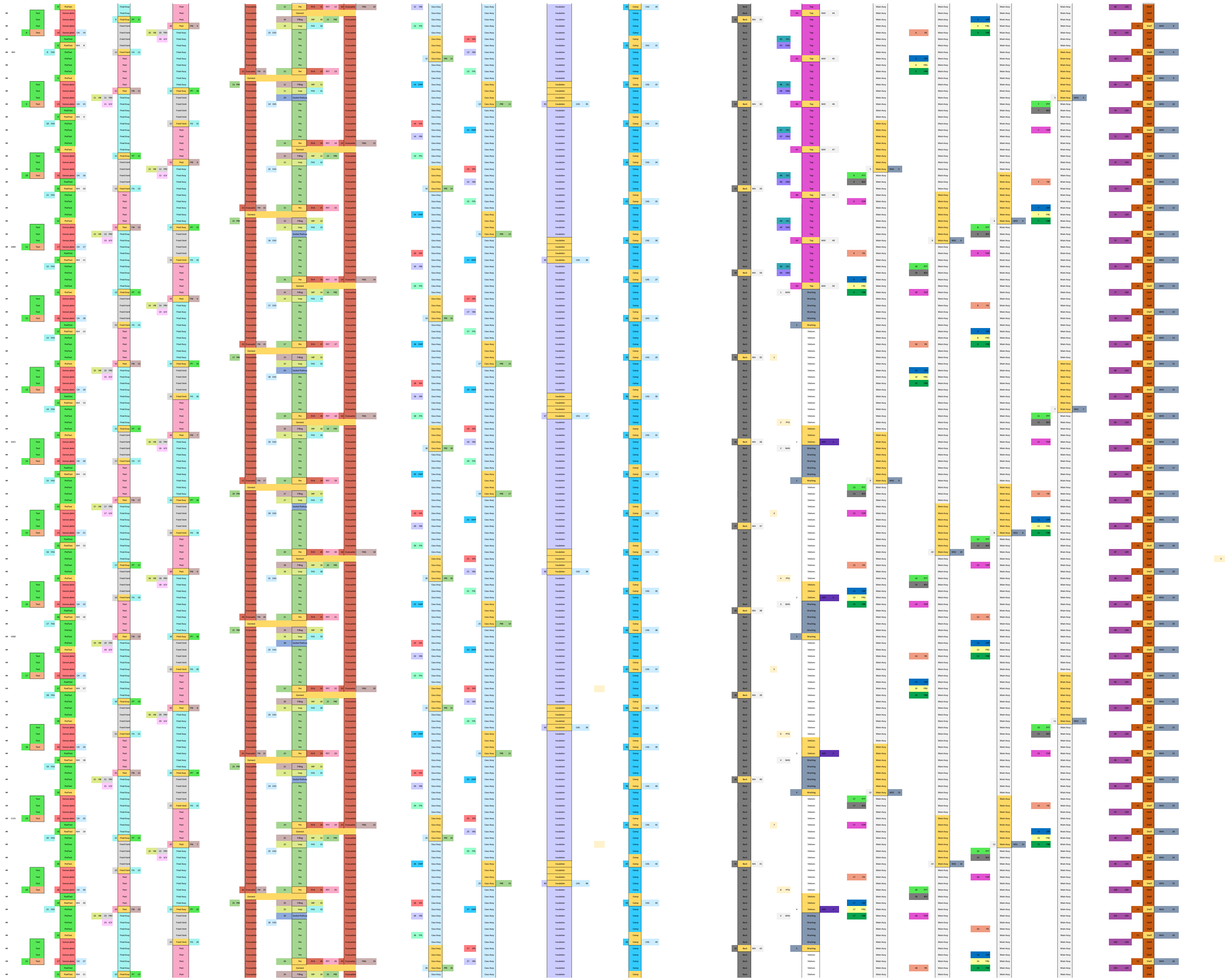

DAY X

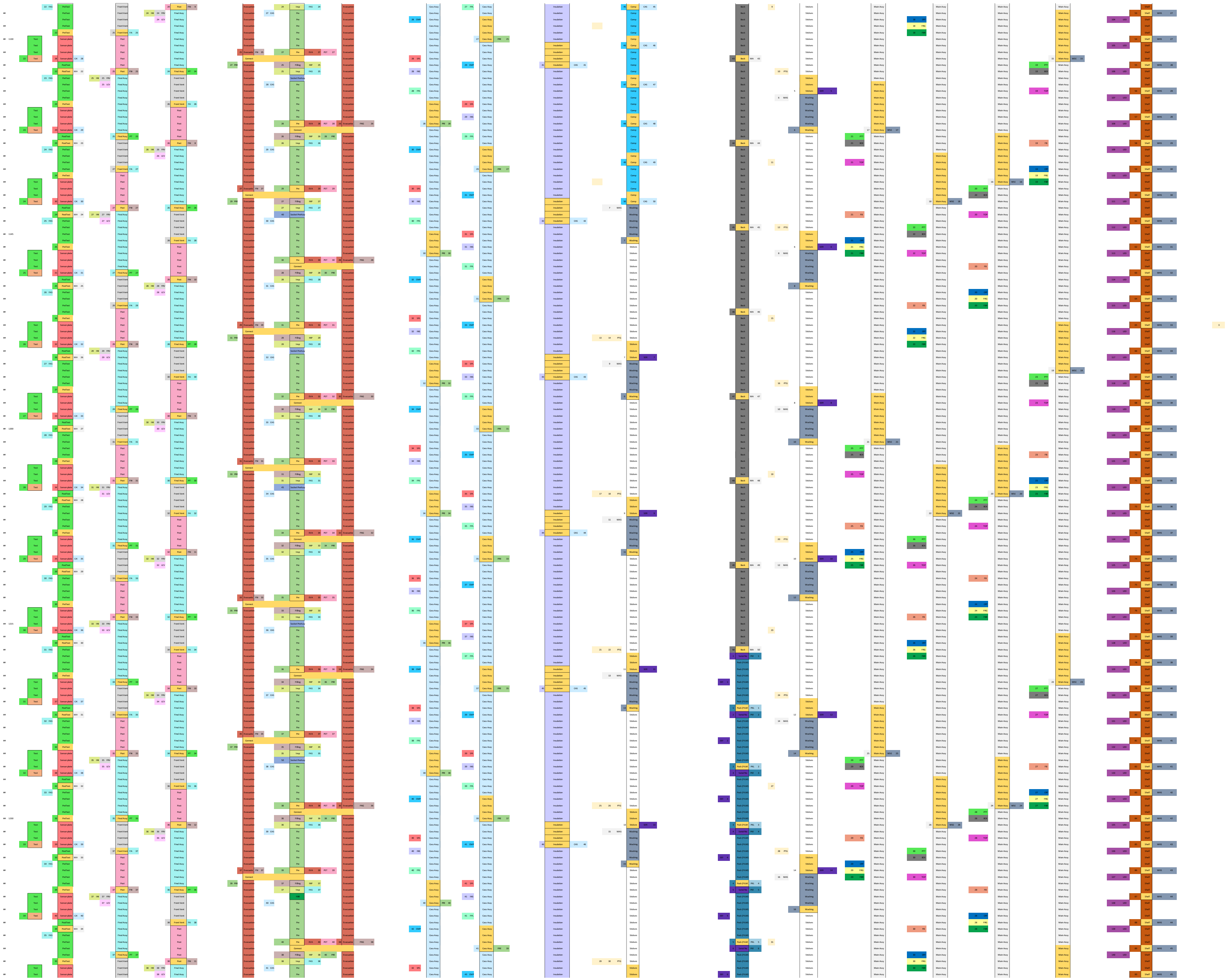


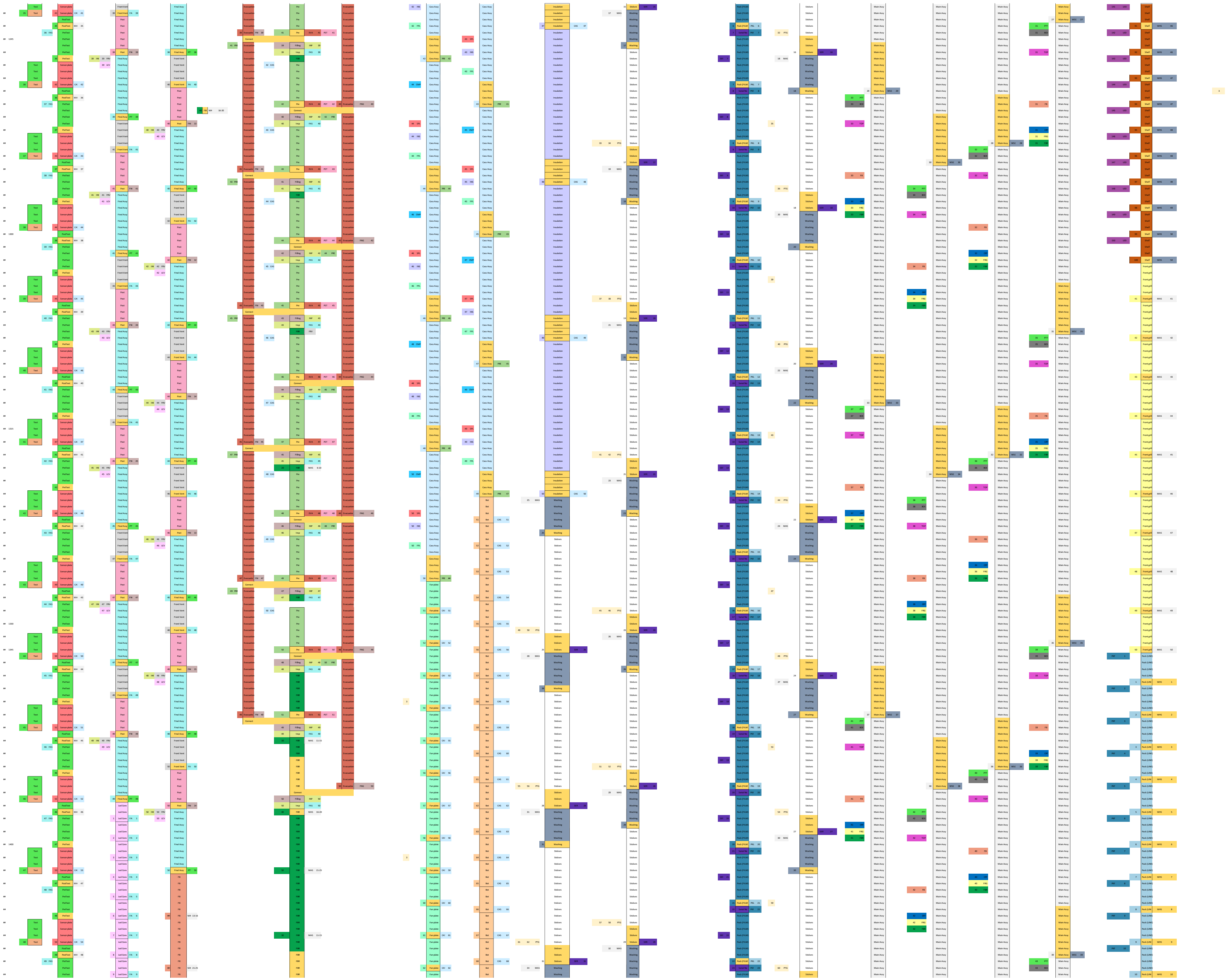
DAY 0. 50 Units/day

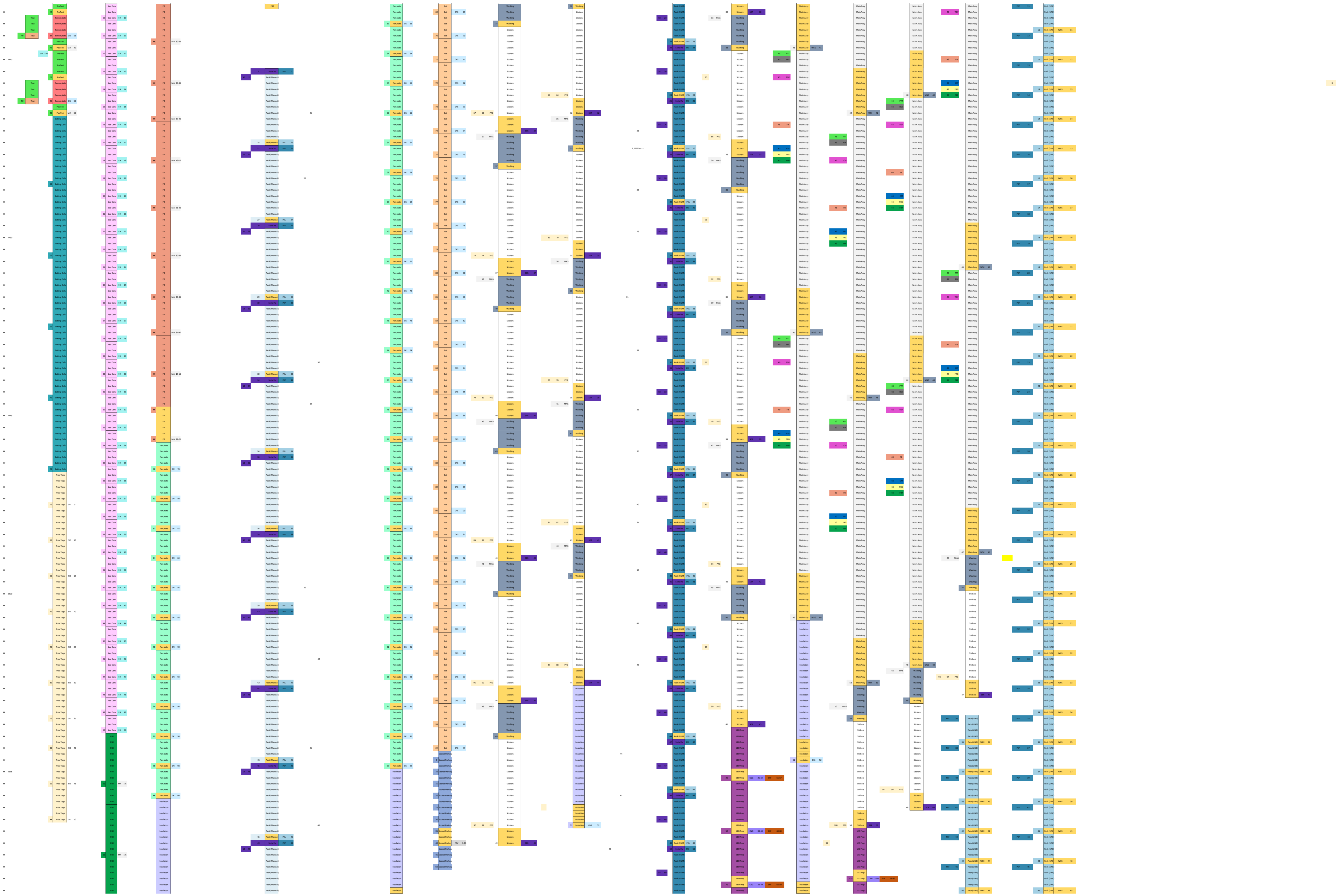


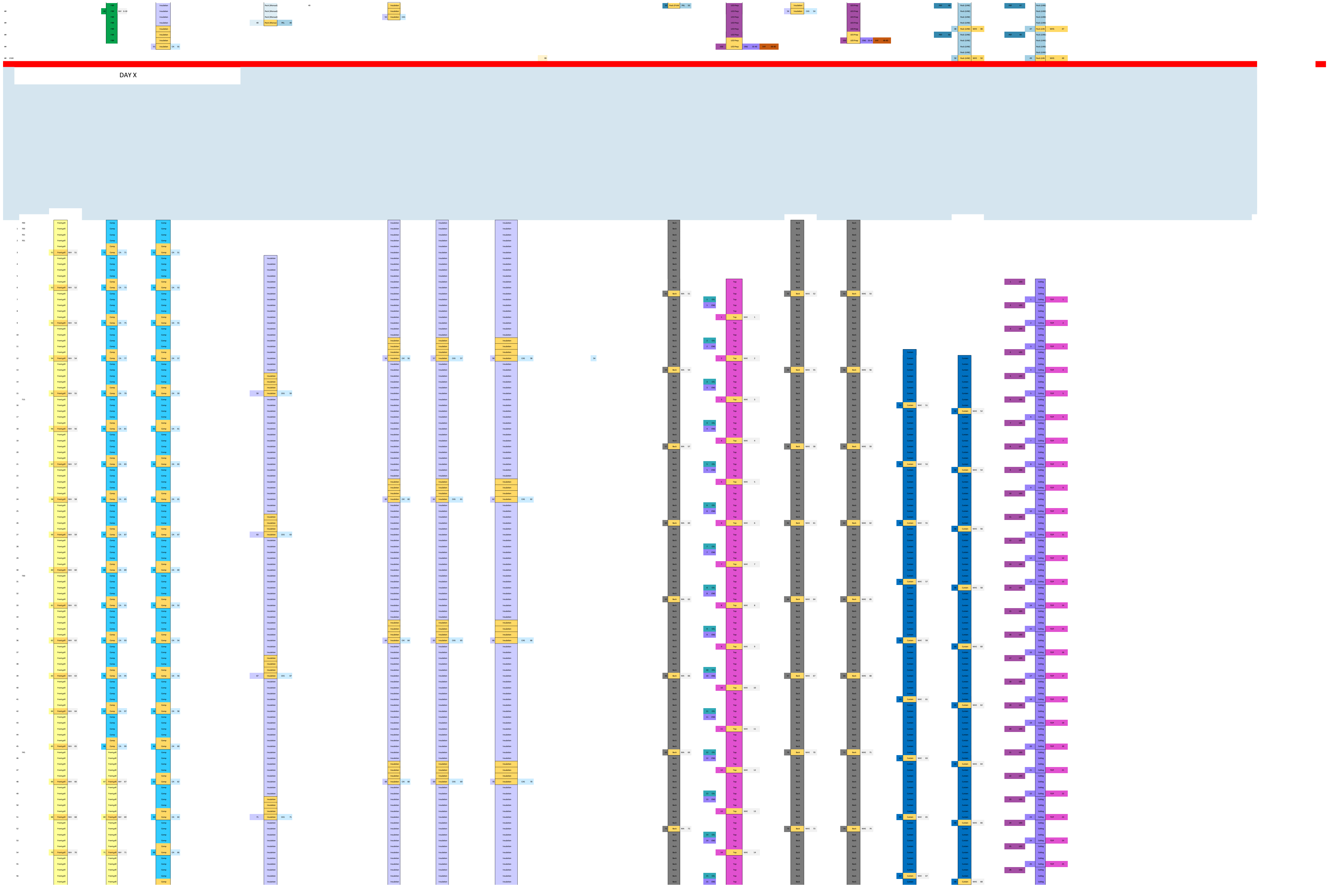


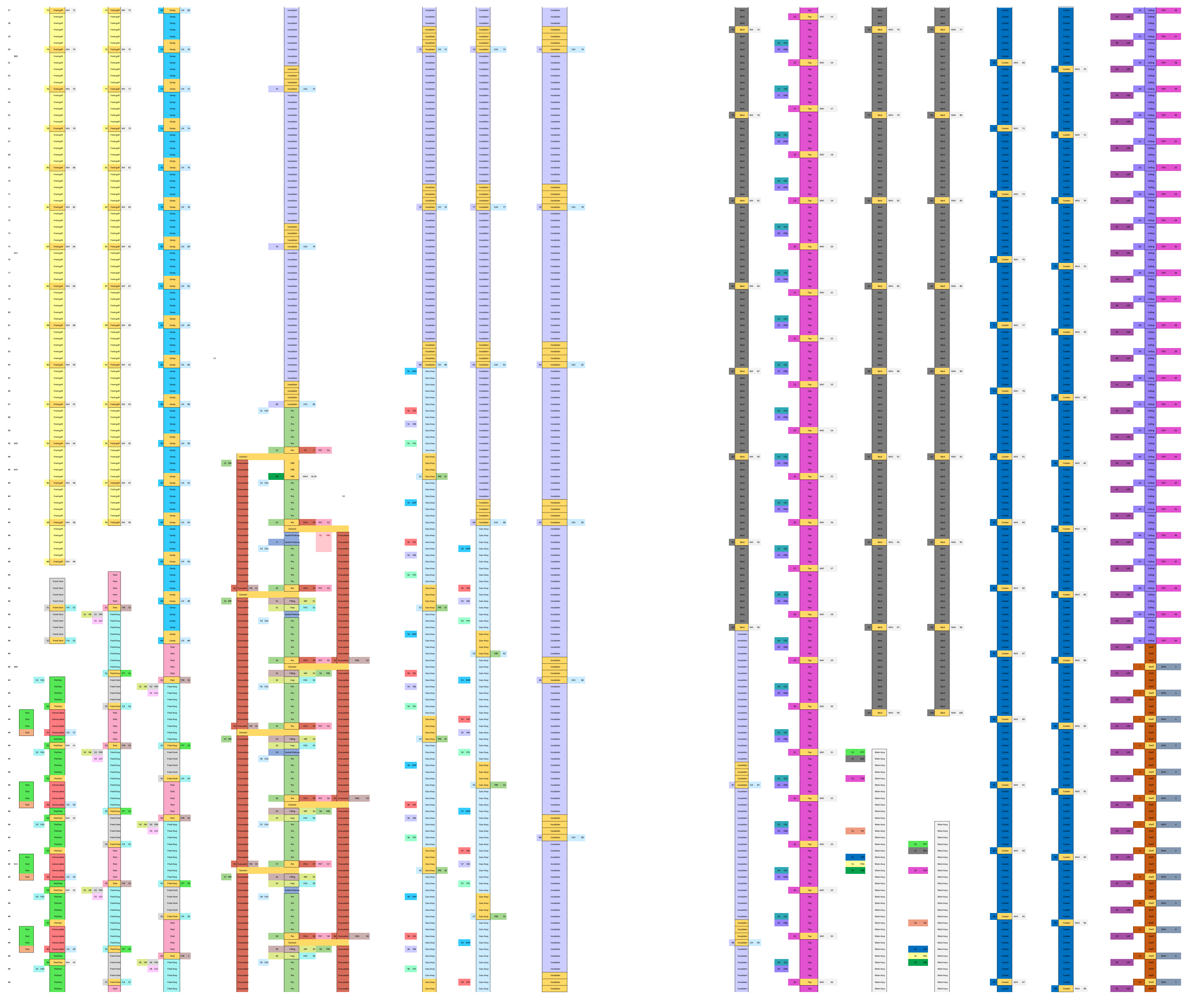


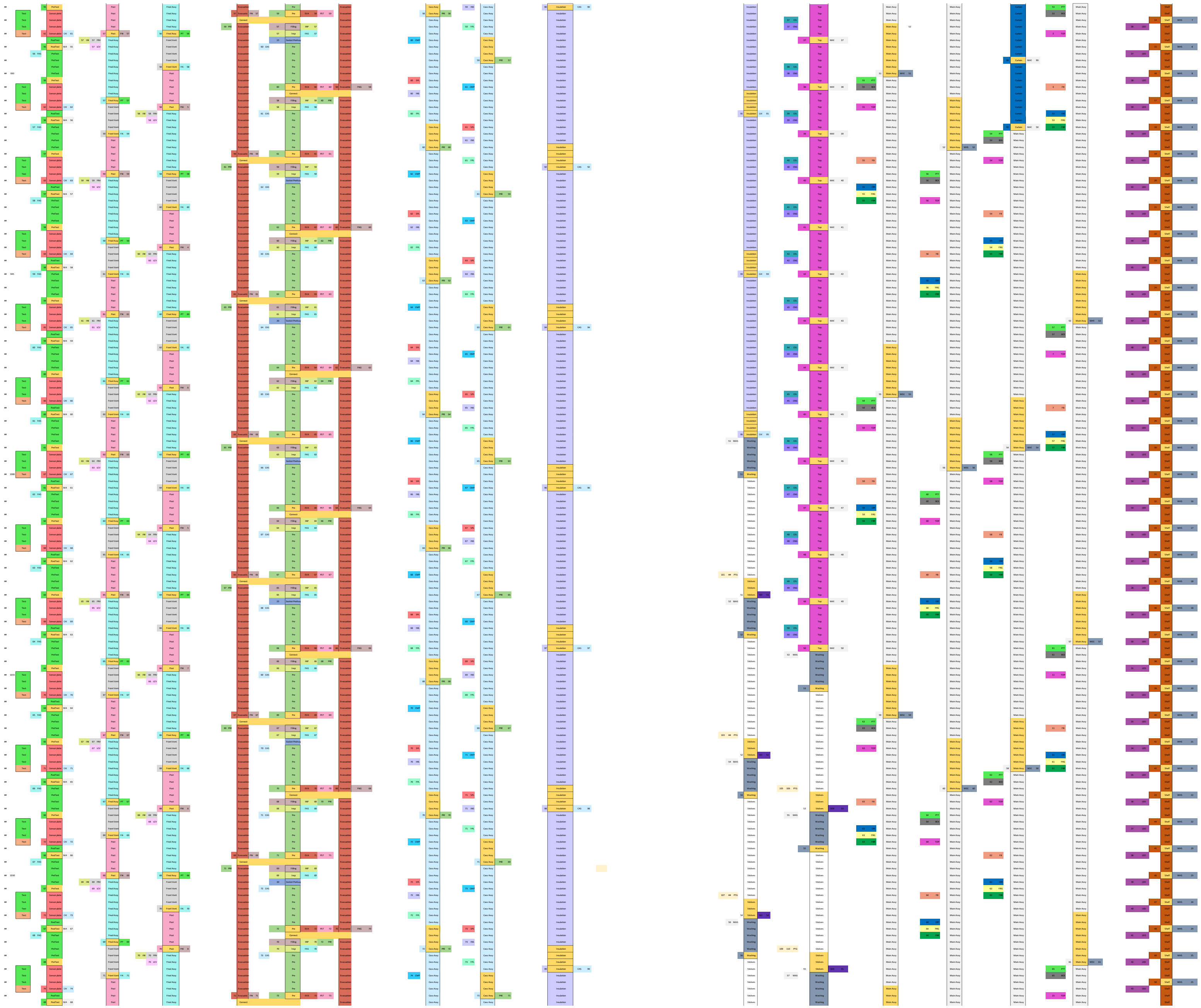


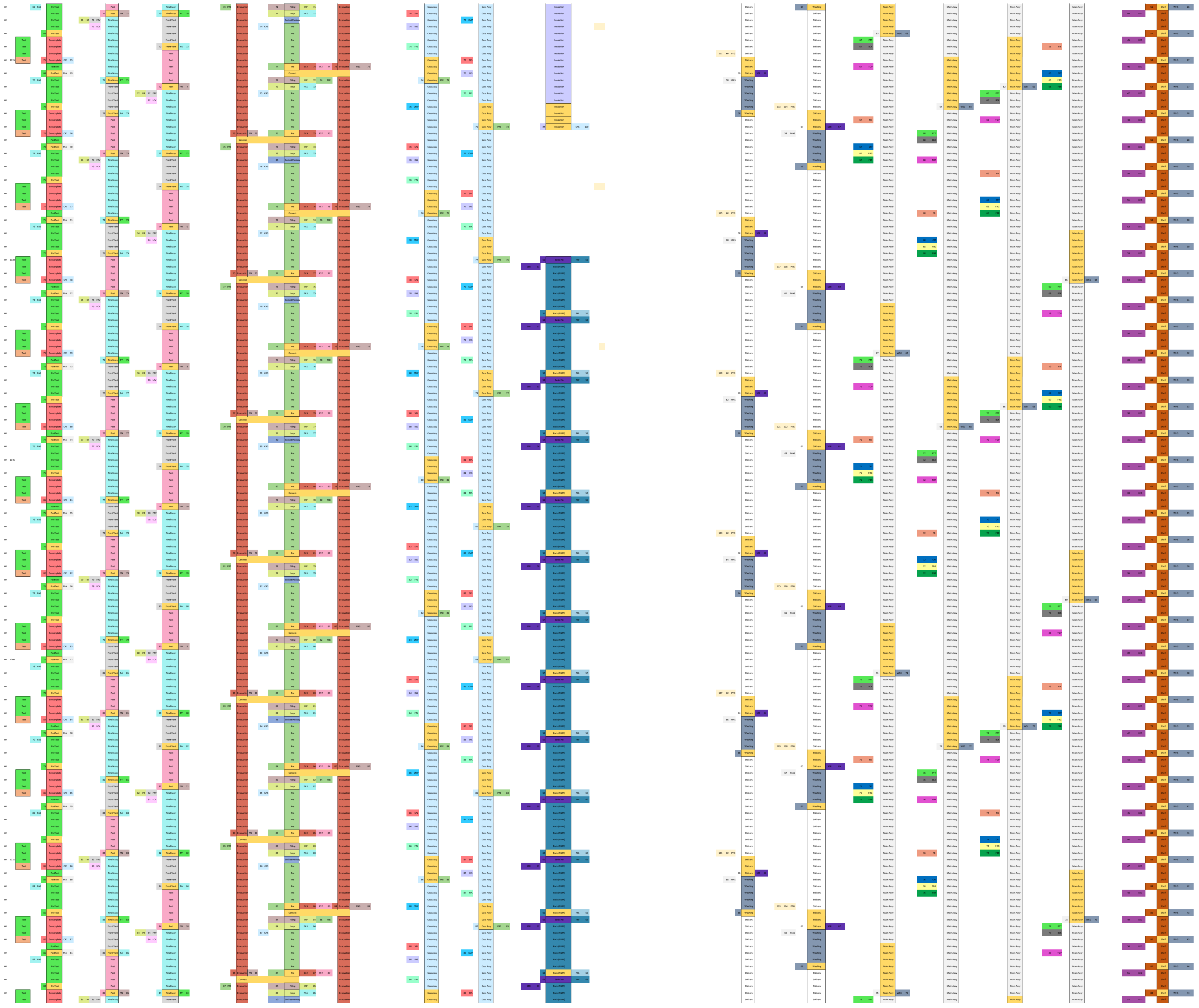


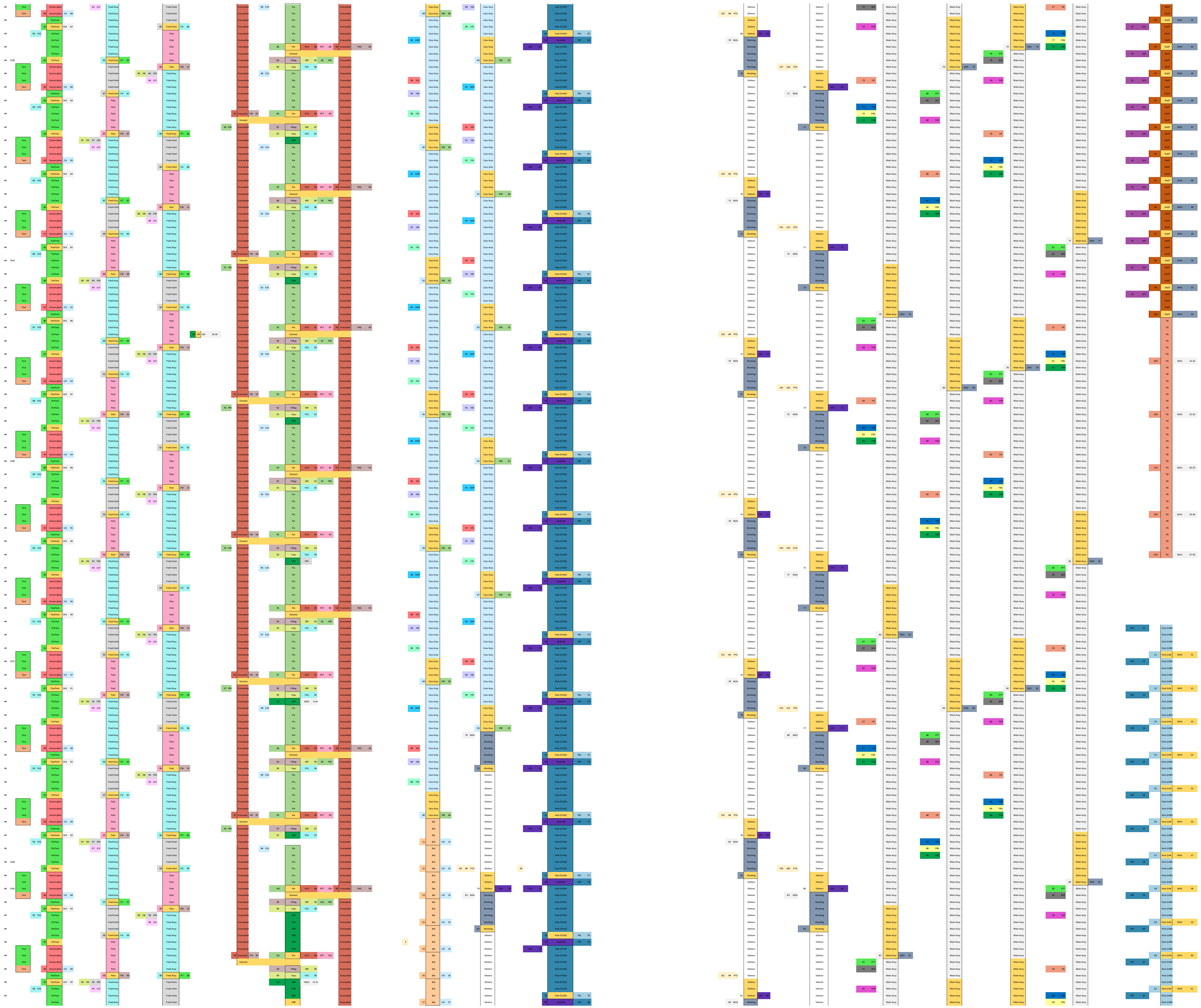


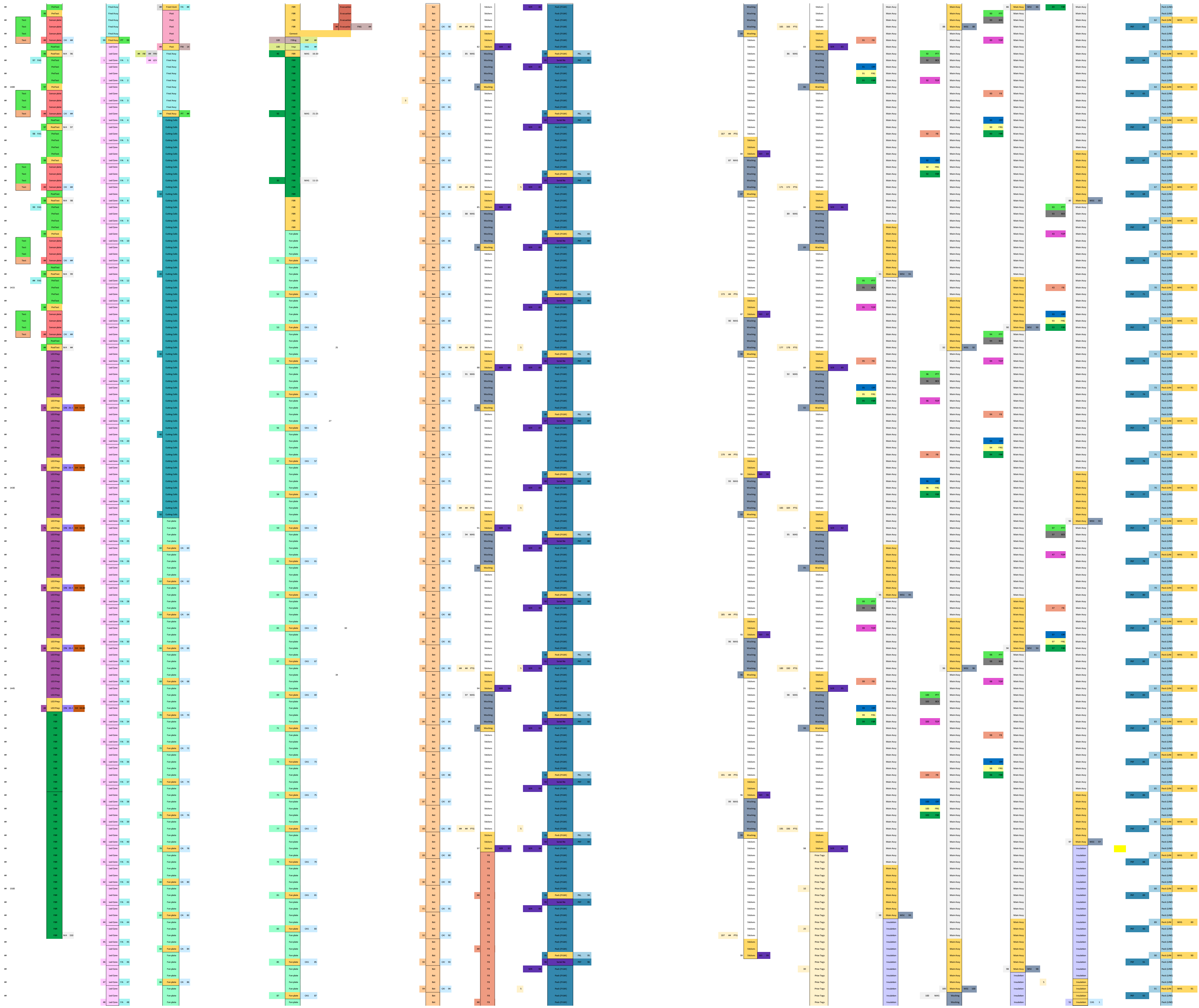

DAY X

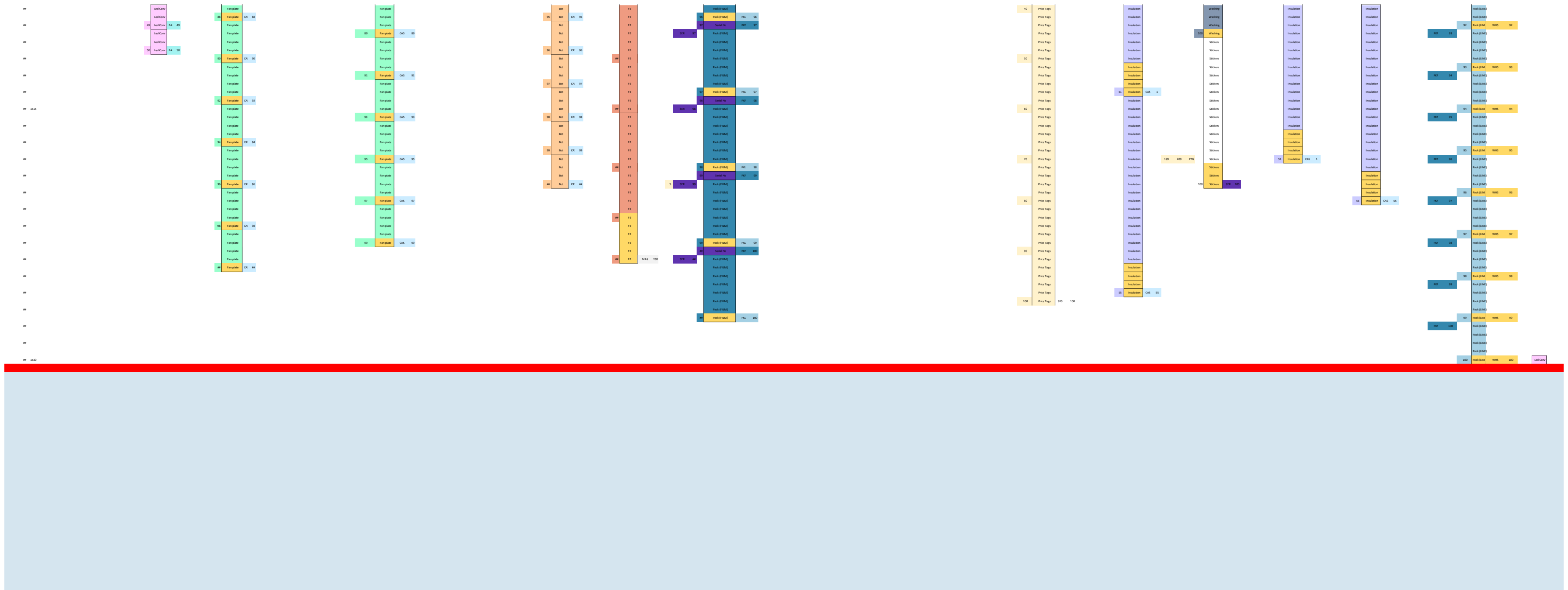




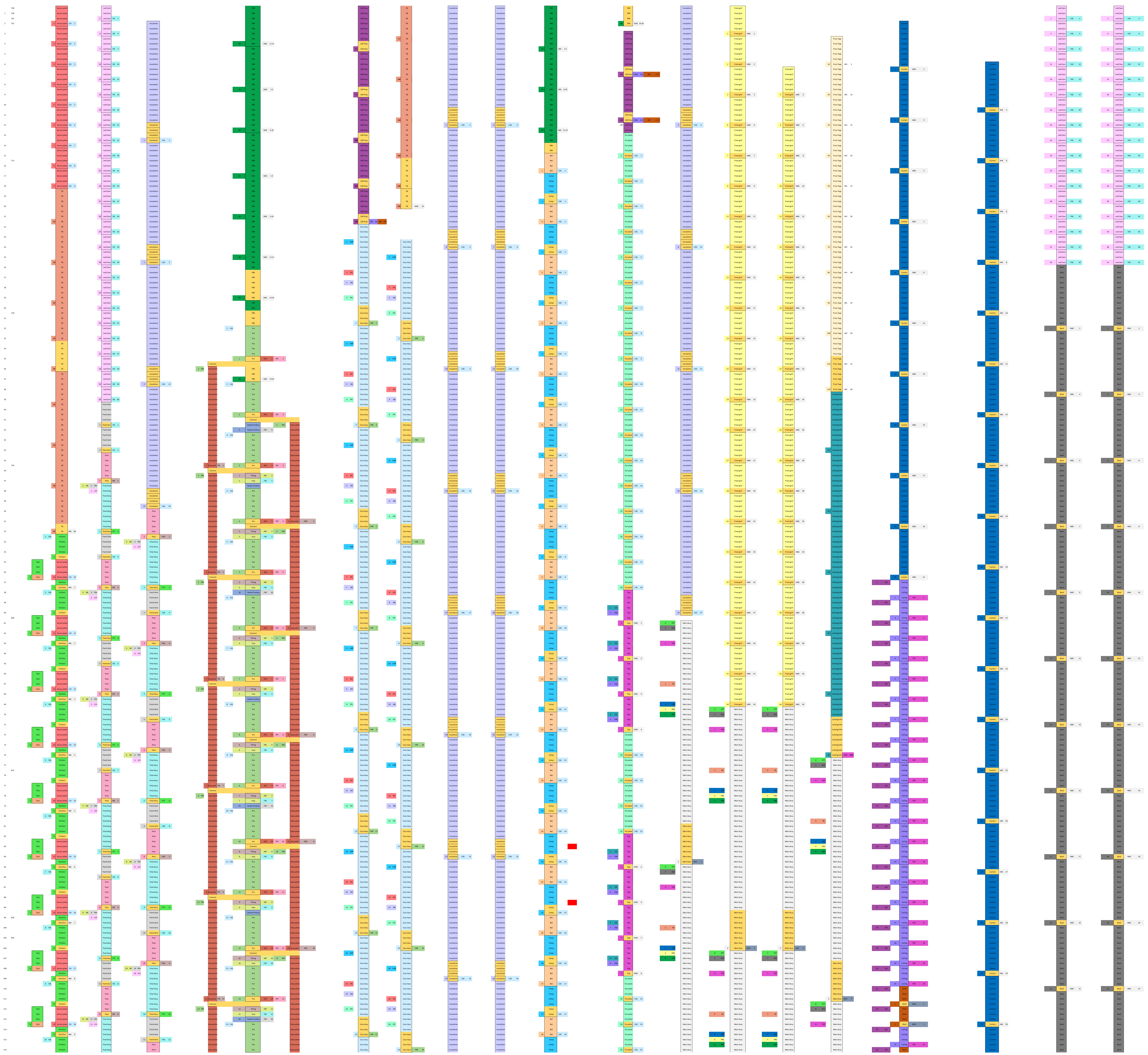


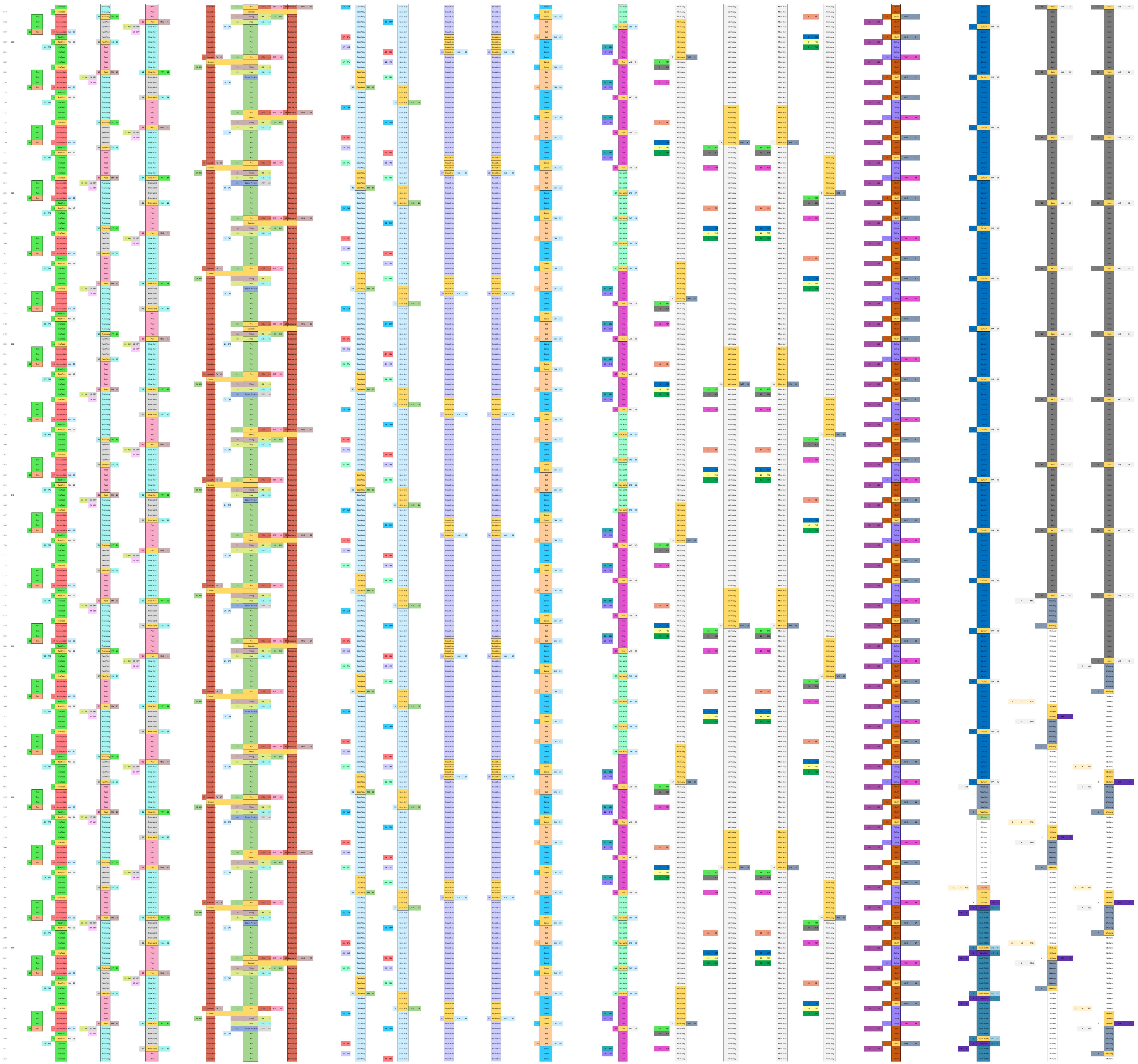


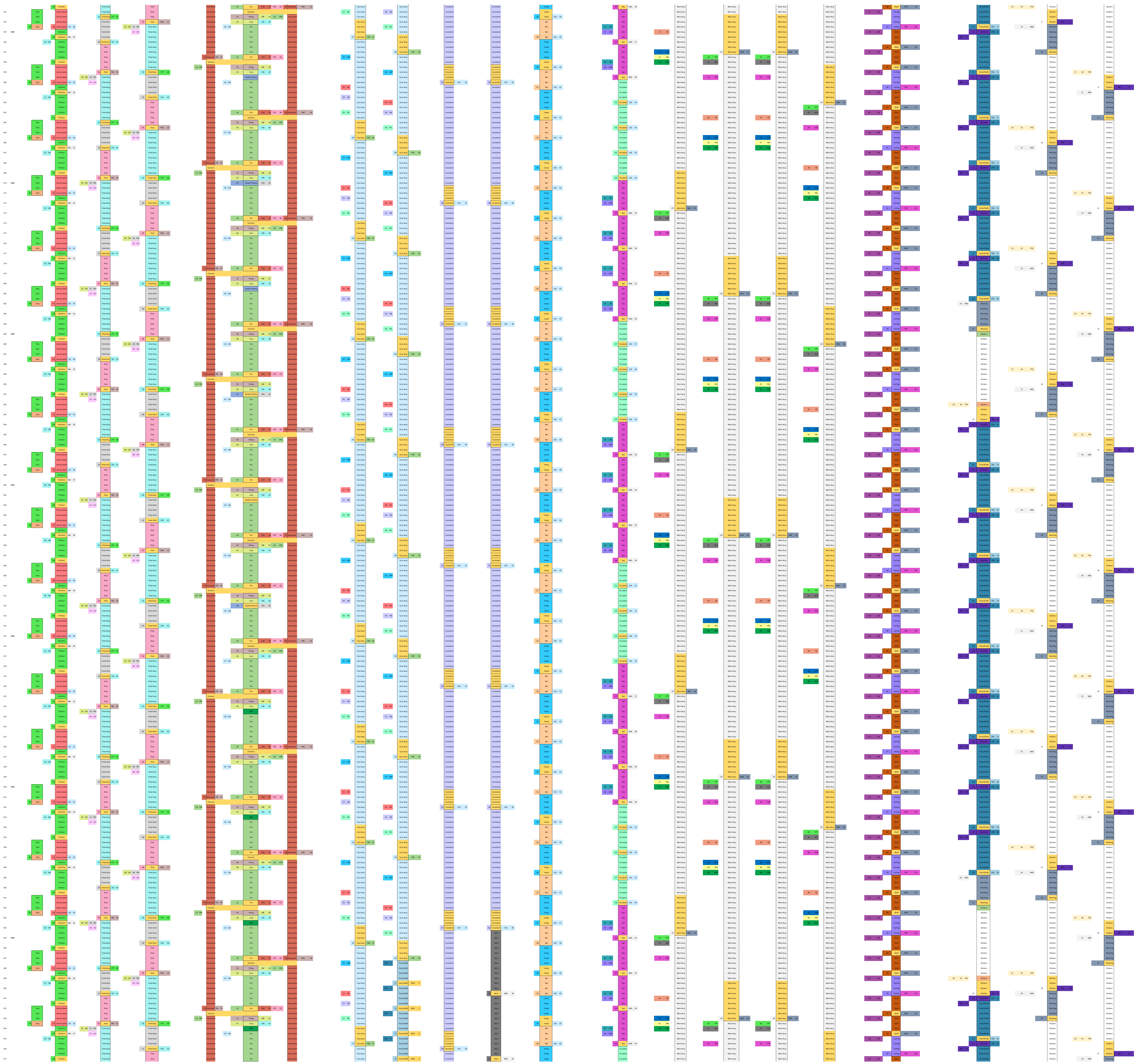


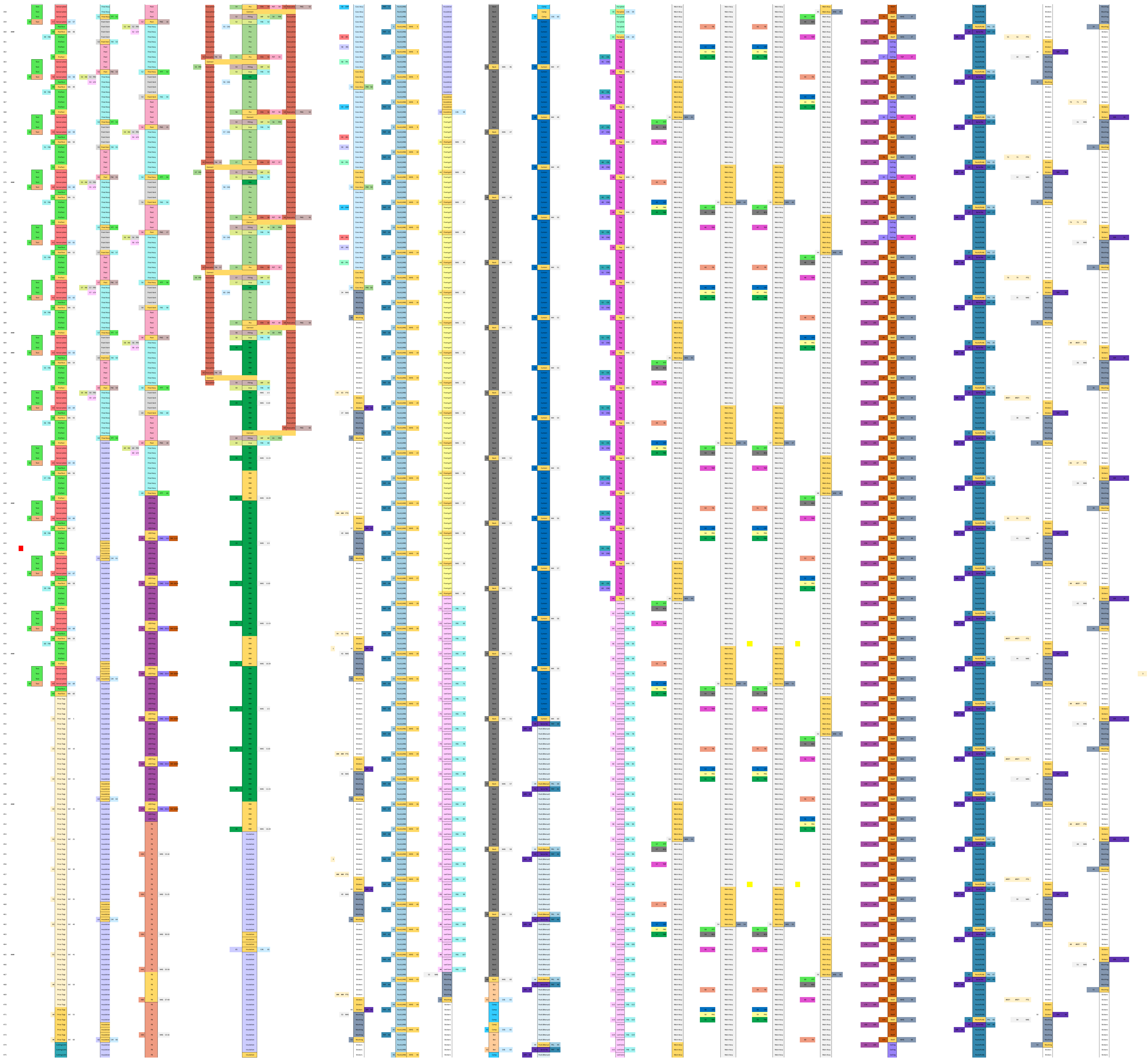


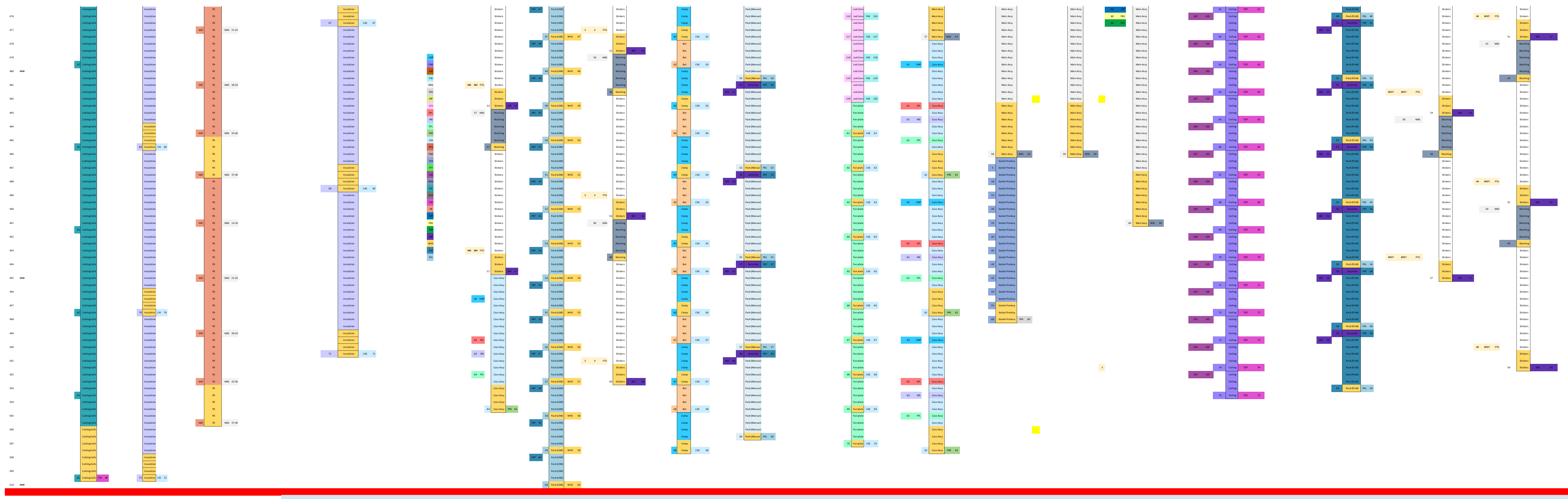
DAY 0 60 Units/day











DAY X