

THE LIFE CYCLE OF THE LAYOUTS OF FLEXIBLE AND RECONFIGURABLE MANUFACTURING AREAS AND LINES

ZSOLT MOLNÁR¹–PÉTER TAMÁS²–BÉLA ILLÉS³

Abstract: Nowadays, the life cycle of products has been significantly shortened. This trend is particularly noticeable in the electronics, automotive and food/beverage industries, where new product launches can occur monthly. The introduction of new products is often accompanied by changes in production processes, which also has a direct impact on the production layout. The life cycle of a production line and thus of a production arrangement can be much longer, than the life cycle of the product, for which the production line was originally designed. The field of research on layout redesign demands posed by flexible manufacturing systems is novel and currently has very little literature.

Keywords: layout life cycle, flexible manufacturing, layout planning

1. INTRODUCTION

Customer needs have changed a lot in recent decades. It is already natural that when ordering a car, almost all its parameters can be configured separately. DELL was the first computer manufacturer to allow customers to configure computers when placing an order. NIKE went even further when it started selling fully configurable shoes in colour, pattern, and lace-up features. Apparently, these business models have been successful, as everyone loves to be unique and express their personality through uniqueness. While customers are happy with these new flexible purchasing options, in the meantime, they make for a big challenge for the manufacturing companies who must meet these unique needs in serial production.

The main trends in manufacturing can be summarized in the following three points:

- Increasing product complexity
- Increasing cost pressure
- Reduce time to market and shorter product life cycles

The increase in demand for flexibility can only be met by service and delivery flexibility, which entails the need for production flexibility.

Because of all this, it is becoming increasingly important for production lines to be as flexible as possible. The main aspect of flexibility is to be able to introduce a new product to a given production line in the shortest possible time and at the lowest possible cost. Several technologies have emerged in recent years that greatly support the flexibility of production lines [6, 7, 11, 12].

¹PhD student, University of Miskolc, Institute of Logistics, Hungary
zsolt.molnar.zsolt@outlook.com

²PhD, University of Miskolc, Institute of Logistics, Hungary
alltpeti@uni-miskolc.hu

³university professor, University of Miskolc, Institute of Logistics, Hungary
altilles@uni-miskolc.hu

These include:

- the increasing level of automation, especially in the field of assembly,
- the advancement of additive technologies that not only simplify processes but also increase their stability,
- the emergence of smart devices in manufacturing.

It is important to note that flexible manufacturing systems are much more characteristic of discrete manufacturing, than process or flow manufacturing due to the variety and short life cycle of products. In this article, we mainly focus on discrete manufacturing.

2. LIFE CYCLE OF THE PRODUCT AND THE PRODUCTION AREA

When it comes to layout design, it is very important in today's changing world to deal not only with one-time design, but with the entire life cycle of a production line. Normally, the life cycle of a production line follows the life cycle of the product manufactured on it.

Figure 1 shows the usual life cycle of a product and Figure 2 shows the related manufacturing place (line, factory) life cycle. The first phase of the product life cycle is the product development. The manufacturing planning should start at almost the same time as the product development itself. The two key methods which support it are collaborative engineering and the design for manufacturing. Collaborative engineering means that product development and manufacturing development take place in parallel. Design for manufacturing means that technological possibilities and capabilities are considered in the design through continuous interaction [1, 2]. From the product design side, the following information may be important for production planning and layout planning:

- product size and weight,
- the main components of the product,
- which of the product components are manufactured in-house and which are procured,
- how complex technologies are required for production,
- how much should be produced per period,
- other technological constraints, parameters (unique technology, hazardous technology, etc.).

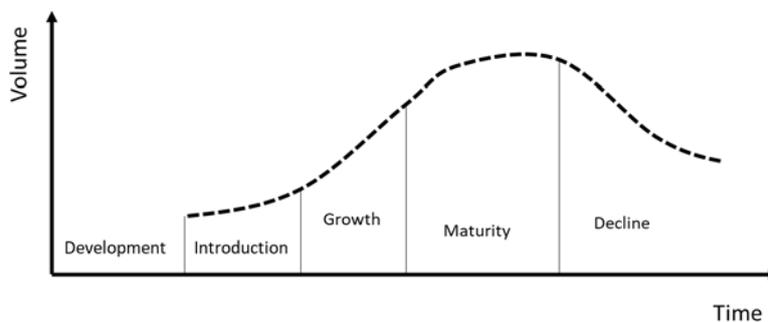


Figure 1. Life cycle of a product

Once a product has been developed, then begins the introduction stage of the product life cycle. This is the phase of the layout design when the initial layout of the production area is created, and the production line is installed. In this stage the product is released for manufacturing for the first time.

If there is market interest, the demand for the product starts to grow. In the life cycle of the production area, this phase is the period of continuous improvement. In this phase, the manufacturing process is typically optimized using lean methods. In this case, minor changes can also take place in the production layout (e.g. changes in the size of storage spaces, splitting of process steps, better line alignment).

The maturity period for a product is when its sales tend to slow. At this stage, the main goal for the production line is to ensure continuous, stable production. They try to keep the cost of line maintenance to a minimum. At most, there are investments in the line that have a very short return on investment, such as replacing employee activity with a collaborative robot. In this phase, companies often begin innovating by changing, or developing their product to maintain their performance.

In the case of the final decline phase, the number of pieces decreases, and in the case of the production line, only maintenance is performed.

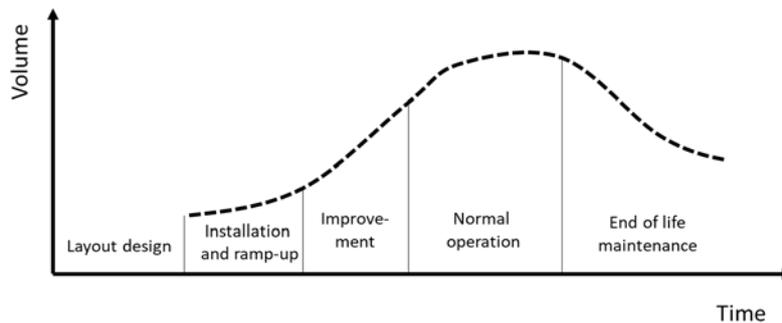


Figure 2. Life cycle of the production area (line, factory)

The above description is a good illustration of the life cycle of a product and its associated production line for a single product [8]. However, in the case where several products are produced on a production line, each product has its own separate cycle, which also means that the life cycle of a production line will be much longer than the life cycle of a single product. Obviously, this also means that layout changes can occur several times over the life cycle of the production line, either to a lesser or greater extent.

Figure 3 shows how the life cycle of a flexible production line develops. The line typically starts with 1 or 2 product types, and over time the number of products to be manufactured expands. As new products are added to the production line, other products reach the end of their life cycle and their production finishes. These changes should be followed and maintained by the production line layout.

We can conclude that new product introductions (NPIs) can extend the life cycle of a production line. In the case of new product launches, two main types can be distinguished:

- Product configurations of the same product: in this case the parameter of an existing product changes. In many cases, for example, this only means the replacement of

some parts (e.g. different coloured covers). Routing is the same or minimally different for each product configuration.

- Different products: in this case there are several products that are significantly different from each other. Routing may be different, but there is significant overlap between the technologies used. It usually requires a more logistically complex service.

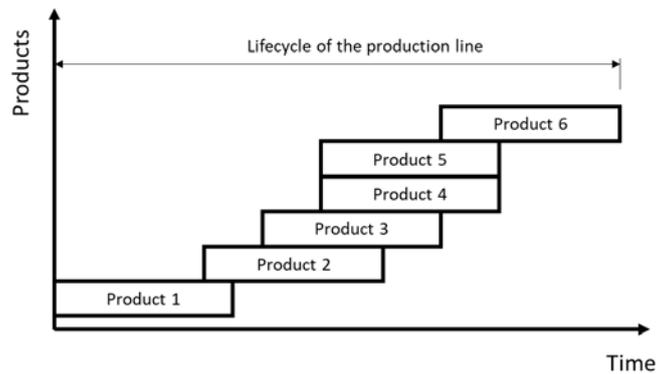


Figure 3. The lifecycle of a flexible manufacturing line

3. THE COST OF THE LIFE CYCLE

Although layout design seems like an engineering problem at first glance, it is inseparable from financial / return decisions. The goal of a production line is to make a return as soon as possible at the beginning of its life and to make a profit for a significant part of its life cycle.

In the case of a traditional production line, the cost of the production line during its life cycle consists of two main items, the initial cost, and the subsequent operating cost. In the case of flexible production systems, by extending and extending the life of the production line, this period of profit can increase significantly (Figure 4).

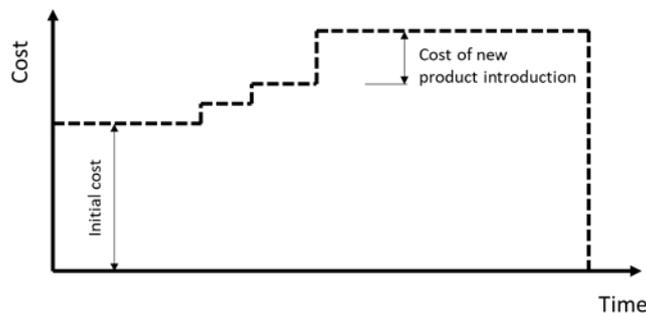


Figure 4. The effect of the NPIs on the life cycle cost of the manufacturing area

The basic cost calculation during the life cycle (1):

$$LCC = IC + DC + EC + OC + MC + DC + RC + \sum_{i=1}^n NC \quad (1)$$

where:

- LCC – Life cycle Cost,
- IC – Initial Cost,
- DC – Delivery and Installation Cost,
- EC – Energy Cost,
- OC – Operational Cost,
- MC – Maintenance Cost,
- DC – Downtime Cost,
- RC – Disposal and Decommissioning Cost,
- NC – New Product Introduction Cost,
- n – Number of new product introductions (NPI) during the life cycle of the line.

In the case of investments in flexible production systems, several aspects do not arise in the case of a production line dedicated to a specific product. These considerations can mainly be decisions related to extending the life of a production line. In fact, the future viability of the production line is ensured by these decisions. Examples include:

- It is much better to buy more expensive, versatile equipment at the start of the line if you are expecting to need it with the arrival of new products
- It may be worth ordering a spare of the more special devices so that they can be used for a significant part of the life cycle
- Investing in a newer technology can return that investment through productivity during the life cycle

4. THE BUSINESS CASE BEHIND

From a business point of view, the production volume of the products included can be clearly equated with the sales volume (Figure 5). Profit is adequate in the Growth and Maturity phases of a product, however, as sales of a given product begin to decline, profits also begin to decline rapidly. When calculating the profit, both fixed and variable costs must be considered. Fixed costs related to the production layout can be, for example, equipment, machinery, installation costs. Variable costs associated with manufacturing layout decisions include maintenance costs, material handling costs, and so on.

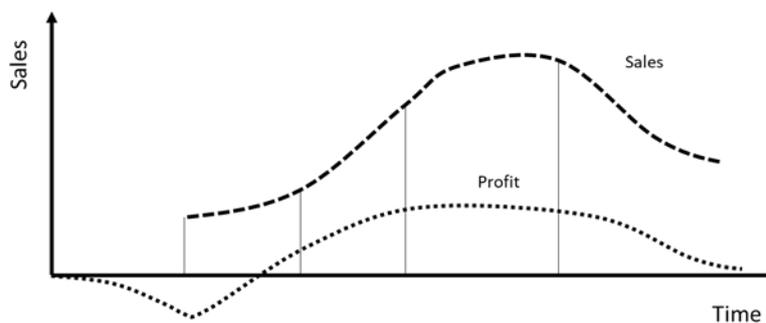


Figure 5. The sales and profit curve during the product life cycle

In the case of a traditional production line, the decrease in profit also means the end of the production line life cycle. In the case of flexible and configurable production lines, however, the solution in such cases is to introduce a new product to the production line, which can be used to restore the production volume and thus profitability. Properly designed new product launches can ensure a continuous adequate level of profit for the line or production area (Figure 6).

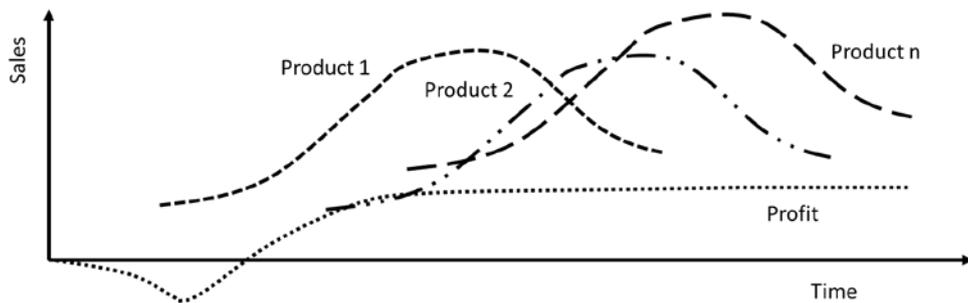


Figure 6. The effect of the new product introductions on the profit curve of the product

Figure 7 below shows the phases of line (factory) design [3]. The first step is to choose the place or location, which is usually a financial decision based on the previous development / support parameters. Closely related to this phase is the determination of the size of facilities and buildings based on the expected production capacity requirements. These dimensions also delimit the production area and the logistics and warehousing area [9].

We tend to distinguish two versions of manufacturing layout design; these are greenfield design and re-layout. Greenfield design means the design of completely new factories and production areas, while re-layout means the redesign of existing production areas. As product life cycles shorten and flexible manufacturing grows, there is less and less greenfield design, but the role of re-layout increases significantly.

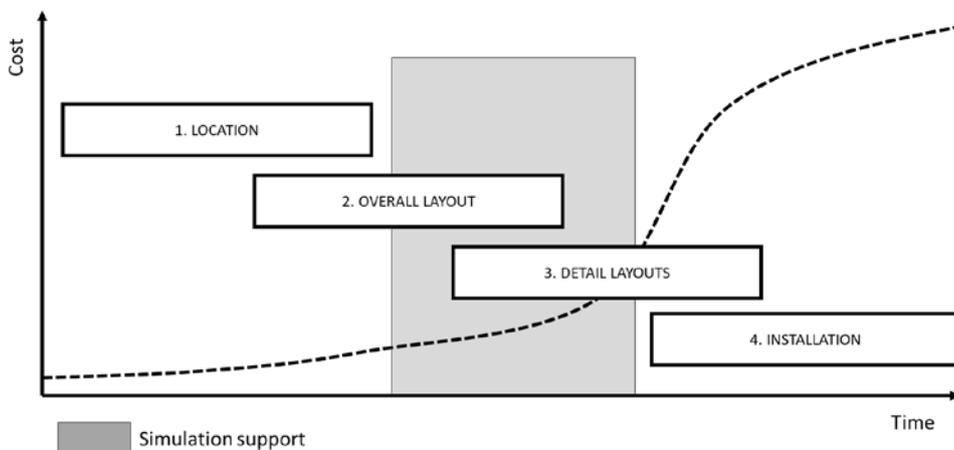


Figure 7. The main phases of layout design and the period that can be supported by simulation

During the Overall layout phase, the following plans should be created:

- Site layout master plan
- Work area design

The Detail layout phase creates the working layout during these plans:

- Workplace design
- Workplace ergonomics

5. SIMULATION DURING THE LAYOUT LIFE CYCLE

One of the most common and accepted methods in the design, validation and development of production lines is simulation, including discrete event-driven simulation [4] [5]. Figure 8 shows the part of the production line lifecycle where simulation can support the decisions and can give valuable results for planning and improvement.

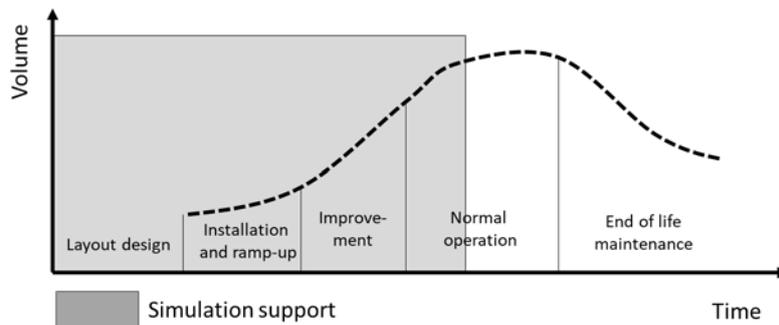


Figure 8. The production line life cycle and the parts of it that can be supported by simulation.

Advantages of simulation in layout design:

- It supports top-down design mode, i.e. it allows you to create a rough layout and model first, and then detail it. Layout design is usually a longer process, with gradually more and more data available to develop the model in more detail. In most places this is called a block layout and then a detailed layout. The block layout includes the number of departments, area, shape of departments, base material handling configuration. The detailed layout can contain the number of machines, machine placement and orientation, material handling points.
- It can support almost the entire life cycle of a layout. Support for the development of the initial layout is clear, as a well-constructed simulation model is practically a digital twin of the production line. The simulation model includes and manages, among other things, the following parameters of production and the production line:
 - o dimensions, layout,
 - o process steps and process parameters (times, ordering times, failures),
 - o maintenance and migration data,
 - o shift pattern,
 - o material supply and other logistics rules,
 - o quantities to be produced or customer requirements.

- Supports the creation and evaluation of different layout variations at each level. For different layout variants, the simulation can provide the ability to use and compare many KPIs.
- In the installation and ramp-up phase, it may be possible to test the functionality and control of the production line before installation with the help of virtual commissioning on the existing simulation model. One of the common ways to do this is to connect the line controller to the simulation model and thus test the operation and logic of the control unit.
- An arbitrarily long period can be run in the simulation, so the planned entire life cycle of the line can be simulated and examined.
- In the improvement phase, the simulation model provides tools for analysing and solving problems in production. For example, optimizing transitions or queuing.
- During normal operation, the simulation model is usually already prepared for how the next product can be integrated into the line, what changes are needed in the line layout and control for the new product to be manufactured and efficiently manufactured on the line.

6. THE LIFE CYCLE OF A TURBOCHARGER LINE

Figure 9 shows a turbocharger production line example from the Siemens Plant Simulation discrete event-based simulation system. The production line mainly includes assembly operations through 8 stations. The in-line material supply is done as a milk-run circuit with a forklift.

If we look at the life cycle of a line layout for such a production, assuming the factory already existed, site selection was not part of the line design. Usually in the automotive industry, such production lines are tied to the customer, so only the product of the given customer can be produced on it.



Figure 9. Turbo charger factory simulation model (source: Siemens sample model)

The line starts with one product, but there is usually information already in the planning phase about what additional products are expected on the line. These determine the required raw material storage space, and the length of the conveyors used as buffers.

When multiple types are produced on a line, the operating times for different stations for different product types / variations may differ. It is possible that at a screwing station, the operating time of the type A product is 1 minute, while that of the type B product is 1.5 minutes as the type B product has several screws.

Because of the type-specific operation times, it is important to put buffers in the line to avoid blocking and waiting. Another effect of type-dependent operating times is that line performance may vary depending on the product mix, so there may be a significant difference in the number of units produced for A: B = 30:70 and A: B = 40:60.

An important element of the line design is the supply of raw materials, which largely depends on the parts list of the products. In a line, it is worthwhile to produce products whereas many elements of the parts list as possible are the same, thus reducing the space requirement of the material supplied and the complexity of the material supply process [10].

After the first layout is completed and the line has been in operation for a few years, it may be necessary to integrate other similar types into the line. It requires a major change if the product changes significantly, for example, in addition to plain turbochargers, biturbo versions will also appear. This can mean new operation steps that even require the creation of new stations. At this stage, it is no longer certain that every product will go through every process step. Because of the number of jobs, workers often must perform more activities as well. In such cases, it is increasingly important that the line and the work activity are also balanced.

The next phase in the life of the layout may be when, with the advancement of electric cars, customer demand decreases, and the number of units produced falls. By then, the line is already “on its way” to the manufacturing area. In many cases, such lines are relocated to a less frequented area of the factory and tend to incur slightly higher internal material handling costs, but in the most central area, the lines of the most important, highest-volume products remain. During relocation, it is not uncommon for the line size to also decrease because smaller buffers and material supply areas are required for a smaller number of pieces. In many cases, certain sub-activities can be transferred from the line to the supplier.

The last phase of the layout is when warranty pieces no longer need to be manufactured. This puts an end to the life cycle of the line, with the last question being which elements can be used elsewhere and how to end production in an environmentally conscious way. Another important task of closing a production line is to retrain those who work there.

7. CONCLUSIONS

The design of flexible manufacturing systems is an important and forward-looking area of research that has many parts for which there is still no best practice today. This article is part of a more comprehensive research, which aimed to further develop the design methodology of flexible and configurable production lines and production systems with simulation methods. In this article, we reviewed the main phases of designing a layout and how the introduction of new products affects the life cycle of a line layout. In the second half of the article, we looked at an automotive example through the life cycle of a production line. It is also clear from the example that the production lines will face serious flexibility challenges in the coming years and decades, which means that the layouts of the production lines will be under constant change.

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