APPLICATION OF PERT AND CPM IN PRODUCTION PLANNING

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ABSTRACT

Lappeenranta–Lahti University of Technology LUT
LUT School of Engineering Science
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Application of PERT and CPM in production planning

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Production planning is crucial for the smooth production of products. It helps in proper resource planning and reduces waste and variability in the production process. It allows companies to improve quality and greater competitiveness. This thesis aims to apply the technique of project evaluation and review (PERT) and the critical path method (CPM) in the process of surface protection of metal surfaces - galvanizing process.

The existing planning of the production of a certain product in the company is described. One order from receipt of goods to the final galvanized product was observed and all activities in the process of product production were identified. Both predecessors and successors of each activity were identified, and a three-time estimate was performed by the measuring time for completion of each identified activity. The early start, early finish, late start, and late finish of each activity are determined as well as the slack of the activity. A Gantt chart, as well as a network diagram, was developed. Also, the critical path was identified and the time of completion of the activity on the critical path was calculated, including the estimated time. With the help of all the mentioned things, the probability that the galvanizing of the goods will be

completed in a certain period for the ideal case when there is no waiting in the production process as well as for the case when certain waiting is present is calculated.

When the obtained results were considered, it was very useful to notice which activities take the most time in the process. In this case, it was about the control of finished products, but as it is a smaller company that cannot invest in the control systems, the reorganization of the workforce was proposed as an option that can significantly reduce the duration of the process.

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1. Introduction

Planning is imposed as the foundation of every successful business of a company. Whether it is the planning of human resources, materials, or time, these are all domains in which companies acquire their objectives. In the multitude of similar companies and products today, developments and changes in the market come expeditiously leaving behind earlier dominant things. Market growth is the key driver that motivates companies to have a competitive advantage, offer better quality to customers, reduce waste, and have smooth production of products. This is also the case with companies in Bosnia and Herzegovina. The metal industry maintains a key place in the structure of Bosnia and Herzegovina's industry and economy, and the metal sector in this country has competitive advantages due to already existing raw material resources, as well as price-competitive and skilled labour. However, the modern metal industry is exposed to many demands of a dynamic market that requires the development of projects with new technologies, waste reduction, more affordable prices, and projects aimed at more durable and reliable products.

Defined, the project is a unique venture created of a group of interdependent activities, with a beginning and end and carried out to reach the aims in terms of price, schedule, and quality (Pinto, 2016). However, completing a particular project successfully and on time is not easy. Coordinating optimal cost-time criteria is more complex than it seems and it requires dealing with many factors that influence these activities like contractor delays, material and client delays, etc. The effect of these factors will later contribute to exceeding the duration of the entire project, getting out of the planned budget, higher costs, and several other problems that follow each other in the entire chain of activities. The most implemented and closely related techniques utilized for project planning and coordination are PERT (program evaluation and review technique) and CPM (critical path method). Since in companies every order is treated as a project concerning its beginning and end, this thesis aims to apply the mentioned techniques to multiple processes of metal surface protection of products in the company “Eurosjaj d.o.o.” in Bosnia and Herzegovina. This company was founded in 1996 as a partner company of “SurTec International” from Germany as a joint venture. Later, in 2010, it became a fully Bosnian company. Today, it has about 300 workers and with its work contributes a lot to the whole economy of Bosnia and Herzegovina. “Eurosjaj d.o.o.” in its production facilities provides surface protection services, as well as the production and sale of electroplating chemicals and industrial degreasers. Whether you need to protect parts from the automotive, metal, electrical, construction, or furniture sectors, this company provides a range of features and techniques to offer its customers top quality and impeccable service. There are installed lines for galvanizing, nickel plating, chromium plating (decorative and hard), tinning, copper plating, brass, silvering, phosphating, electrostatic and cataphoretic varnishing, and the latest trivalent chromium plating technology produced according to the latest environmental requirements. This thesis will focus on the coating of metals with zinc. Production processes in this company will be observed from the beginning of the order until the delivery of the product. Firstly, the already existing production planning of product in the company will be described, including identifying all activities in a given production process. The and successors of each activity will be determined and therefore the relationship of priorities will be defined. Sometimes companies waste a lot of time on activities that can be executed in parallel, so recognizing these activities is also significant. The completion of each activity will be measured and thus a three-time estimate will be performed. To apply the named methods, it will be essential to determine the early start and early finish, as well as late start, late finish, and slack. To plan the use of resources, the allocation of human resources, equipment, and all other resources needed to complete a certain activity will also be defined. After the obtained measurements, a Gantt chart will be developed as well as a precedence network diagram. There are critical activities in projects whose start delay will delay the total project completion time. Accordingly, it is necessary to identify the critical path and calculate the completion time of the activity on that path including the probabilistic time estimate. The probability that the production will be finished within a certain time will be calculated. Looking at the results of the PERT and CPM methods, it will be determined whether there is an opportunity for improvements in the company. The possibility of reducing costs, reorganizing the workforce, or activities that can improve the business of this company will be proposed.

2. Literature review

That the application of the PERT and CPM methods is widespread in various fields can be concluded from the examples that will be given in this chapter. They have been developed and applied throughout history to various projects in various branches. Program evaluation and review techniques, as well as critical path methods, were developed in the 1950s. The purpose of their development was to assist managers to control complex projects more easily. These methods are quite similar, however, they have been developed to be used in very different business areas. The CPM method was introduced in 1957. and intended for construction and maintenance because the durations and processes were known, while the PERT was focused on military research where it was difficult to estimate the duration of activities. The idea of developing the PERT method occurs in 1958. with the aim to help the US Navy (Heizer, Render and Munson, 2017). First, the PERT-TIME method was developed for planning and controlling the time of project work, and then PERT-COST, which is used for planning, monitoring, and controlling project costs. Initially, the PERT and CPM methods differed significantly, but they also had a lot in common. However, over the years, these methods have gradually merged and now are usually used interchangeably and their application is combined using the name PERT/CPM (Hillier and Lieberman, 2001).

According to Schoderbek (1965), ten years after the development of these methods, only 44% of the 186 surveyed companies in the United States used PERT/CPM. The other 56% cite inability and unfamiliarity with their use as the reason for not using the method. In this research, most respondents mentioned the complexity and size of the project as criteria for using these methods, while a much smaller percentage of responses were credited to time and cost criteria. That project control was the top priority for respondents at the time is proven by this research in which 66,6% of them pointed out better control as the biggest advantage of PERT/CPM. Even then, there was a surprisingly wide range of applications for these methods. Of the 81 respondents who confirmed their use, as many as 59,3% belonged to constructions. In second place were research and development, while in third place with 37% was product planning. Other areas of application where these methods have also found their place are maintenance, marketing, and computer installations.

Hillier and Lieberman (2001) in their book list the range of projects in which these techniques find their application. Some of them are the construction of a new plant, movie productions, research and development of a new product, NASA space exploration projects, maintenance of a nuclear reactor, building a ship, government-sponsored projects for developing a new weapons system, etc. There are thousands of research papers in which different applications of the PERT and CPM methods can be observed, although very few of them refer to the field of the metal industry.

Lermen et al. (2016) applied the PERT/ CPM technique in the production project of a horizontal laminator used in the mattress industry, intending to optimize time and cost. They came to the data that if all activities that are on the critical path are accelerated, the project can be completed in 186,7 hours less, which on the contrary increased the total cost of the project. However, the analysis of slack activity achieved a reduction in costs which ultimately resulted in a reduction in the total cost of the project by 12,56%.

An unusual case of the application of the mentioned methods is also in the field of operational research. A study by Sengamalaselvi, Keerthi, and Kiran (2017) use these tools to find a solution to minimize transportation costs between two nodes in a network topology. In this paper, the PERT and CPM methods have found their use in identifying delays as well as identifying critical paths, intending to achieve more efficient use of resources, improved project coordination, and cost determination.

Another application of the CPM method that has not been seen before is described in the paper by Karaca and Onargan (2007). They are researching marble production as an important factor in the development of countries such as Turkey, China, and Brazil. The marble industry was described in the study as an open field that was explored by many engineers in those years. In this case, their object was to use the CPM method to select the suitable production process and of course, as in all the aforementioned research, to optimize costs and use time efficiently. They focused their work on reviewing workflow schemes for three marble processing plants. They presented the production lines and considering their characteristics as well as the characteristics of the machines, they proposed a new scheme of work which they applied to the two plants. A new production plan was proposed, and by it, an appropriate marble processing plant was put into work. The results showed that the new plant had a higher production rate compared to the three plants that were considered in the work.

Badruzzaman et al. (2020) in their work as a model of production scheduling problems considered child veil production. They determined the basic activities in this process: design planning, preparation of raw materials, measurements, pattern making, cutting materials, sewing, grinding, neci, accessories preparation, installation of accessories, colour and size separation, grouping, calculation of the number of orders, and packing. The elaboration of CPM and PERT analysis concluded that the measurement activity can be performed simultaneously as the material preparation activity, and the equipment preparation activity with the neci activity. A time difference of 0,458 hours compared to the existing condition was also achieved.

Demand for nuclear energy as an alternative in Malaysia is growing because, in terms of environmental pollution, it can be considered green. In a paper written by Abdul Rahman et al (2010), these techniques have helped facilitate project management for the construction of nuclear power plants in Malaysia. The nuclear industry is developing rapidly from year to year and, accordingly, encourages the construction of new generations of reactors to answer the demand. This work aims to ensure that the construction of this reactor is finalized by the scheduled time so that it does not exceed the estimated costs. For the listed activities in this project, a Gantt chart was also used to ensure that the project developed smoothly.

Probably most of the research papers in which planning techniques have found their utilization are related to construction projects. In the area of construction, it is very important to set time limits and form a sequence of activities. Kholil, Alfa, and Hariadi (2018) also used them to find the optimal time to complete a house construction project. Before the use of the method, the duration of the project was 173 days. First, the critical path method was applied, which was much more effective and resulted in a completion of 131 days, while the application of the PERT method resulted in a completion of 136 days. There is a fairly high probability that the project will be completed on time. Thus, using the CPM method would save time in 42 days, but both methods showed a significant impact on project completion.

The problem of delays in the construction industry is also discussed by Cynthia (2020). In projects of this type, there are a lot of activities that have complex dependencies, and project management here is a very challenging job for all managers. In this case, both CPM and PERT analysis showed almost the same results, and the project completion time using both methods differed in only one day. The PERT analysis proved to be more effective with a calculated project completion probability of 99,8%. This paper also proved that the methods are effective and efficiently applied in this field.

An example of the application of the CPM method is also explained in the paper by Razdan et al. (2017) in which it is used to optimize the ATV (all-terrain vehicle) manufacturing process by considering the time constraint and available resources. It has been shown that this method can be used efficiently in the production of this vehicle.

The following example to be described was done in India. Rautela et al. (2015) in their work describe India as a leading exporter of shoes to the international market. Deliveries from India most often go to European countries and the American market. However, smaller sector companies often receive penalties for delivery delays, and the inability to meet the promised delivery time is a significant problem for them. The research was done on the example of an order from a European customer whose order requires 1500 pairs of shoes. The manufacturer in India is limited in time and the order should arrive in Europe after 120 days of receipt, taking into account a holiday in Europe that lasts 10 days. Of course, based on pessimistic, optimistic, and most likely times, a critical path was identified and it was found that this method can be applied to both smaller projects and large-scale projects.

Göks and Ćatović (2012) explained in their work that the mentioned methods are very applicable in the furniture industry as well. Their work aimed to identify all activities, recognize all the benefits and disadvantages that methods could create in the organization, and describe how these methods affect the very competitiveness of the furniture industry in the market. Factors that offer competitiveness to companies in this industry are innovation, design, quality, and access to exports to third countries, etc. All activities in the process have been established, starting with the selection of design, cutting of wooden blocks and their shaping, carving, assembly to obtain the finished product, grinding, and application of smooth material. After that finishing and upholstery are done. As expected, these planning methods significantly reduced project completion time. The analysis was performed on six selected products from the Dallas factory, and compared to the previous data, using the PERT/CPM method, the efficiency, and efficiency of the organization in this company was achieved.

That the project does not necessarily have to be completed successfully is the construction of the Alkut Olympic Stadium in Iraq, which was supposed to have a capacity of about 20,000 people, with an area of 73,000 m^2. In this project, 250 activities have been identified that should be completed in 750 working days. Construction of this stadium began on February 12, 2011, and the scheduled completion was scheduled for November 22, 2013. Unfortunately, only 63.5% of this project was completed by March 15, 2015. The reasons for this failure were different, starting from the wrong assessment of the depth of the foundation of the stadium, wrong construction following legal regulations, and the impossibility of implementing the roof (Salgude and Multashi, 2013).

Also, Denver Airport had a project to build a new airport in 1989, intending to introduce an automated baggage management system. The airport was supposed to be 140 km^2, and this whole project was supposed to save boarding time and the time of disembarking. However, the impossibility of implementing an automated system leads this project to collapse. Airport maintenance costs of 1,1 million per day were achieved, and the opening of the airport was prolonged for a full six months (Calleam Consulting, 2008).

Construction of the Berlin-Brandenburg airport began in 2006, and the official opening was planned for 2010 and was extended 4 times. In this case, also, there was a change in the planned plans, which resulted in problems and delays in construction. A lot of valuable time was also spent on the idea of building a special runway for the Airbus A380, which was eventually abandoned (Anzinger and Kostka, 2016).

From these examples, it can be concluded how important it is to plan projects accurately and precisely. Proper estimation of resources, time, and budget is the key to a prosperous project. Today, there are many methods by which this can be achieved. As can be concluded from the previously described researches, PERT and CPM methods are effective, especially if they are one-time processes. It can be concluded that the range of applications of these methods has always been wide and that they can be successfully used whether it is planning development projects, facility design, development of new products on the market, construction works, and organizational processes and conferences. In the following chapters these methods will be applied to the process of metal galvanization, an application which has rarely been found in the literature to date.

3. Project planning methods

There are many different types of project planning methods that can be found in the literature. They can generally be divided into:

- Gantt diagram, and
- network planning methods, which include the PERT network diagram, the critical path method, constant time network diagram and diagram priority method.

Gantt chart, PERT, and CPM methods are three popular techniques that allow managers to properly plan, schedule, and control their projects (Heizer, Render and Munson, 2017). While a Gantt chart is a diagram with lines or lengths showing the duration of individual project activities, network planning methods use networks or graphs to show priority activities. Each of the methods has certain advantages and disadvantages and they will be written below.

3.1. Gantt charts

The Gantt chart was developed by Harvey Gant in 1917 and is used to plan and visually track individual activities (Pinto, 2016). Gantt chart looks like a table showing activities in time-dependent horizontal rows whose length represents the duration of the activity itself. This kind of chart is a common one in practice for displaying a project schedule because the bars nicely present the scheduled start and finish times for the particular activities.

First of all, it is necessary to identify the main activities of the project, and then evaluate the duration of each of them, as well as determine their sequence. By combining this information, a graph which is shown in Figure 1, for instance, is formed, and it will show the manager which activities should take place, how long they are planned to last and when they will take place.

Using the Gantt chart formed in this way, the manager can monitor the process over time by relating the planned process with the exact one. He can recognize which activities are going according to schedule, as well as spot those that are late. This is the simplest way to display project information. On the Gantt chart it can be easily seen what the start date of the project is, what are the project activities, who works on each activity, overview of each activity, duration and sequence of all activities, when the tasks are started and when they are completed, how long each activity on the project lasts, how the project activities overlap and connect with each other, and the project completion date. The Gantt chart in this thesis will later be a good indicator of which galvanizing cycles and activities take place in parallel, and it will be possible to see visually which are the activities that take the most time in the galvanizing process.

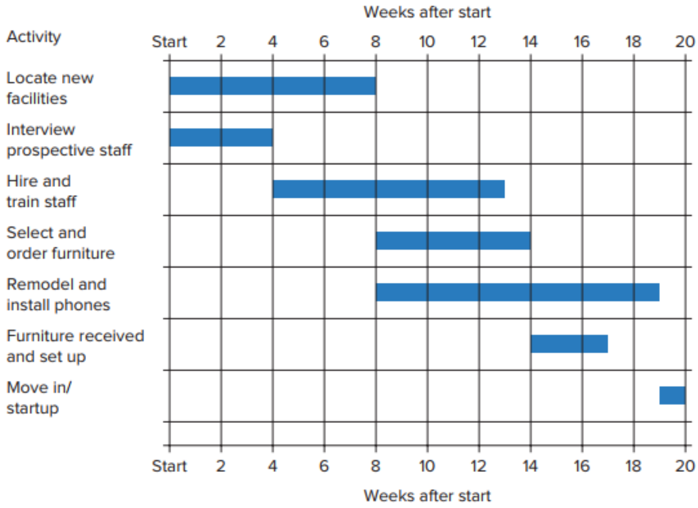


Figure 1: Gantt chart for bank example (Stevenson,2018)

However, the content of the Gantt chart is relatively limited. The disadvantage of Gantt charts is that they do not reveal links between activities, so if there is a delay of a particular activity, the manager should have information on which activities this delay will affect and lead to their delay as well. It is also known that there are activities that can be postponed without affecting the overall duration of the project. Information on these activities is also not available in the Gantt chart and this is another reason why this planning method is usually used in combination with network diagrams, which is extremely pronounced when it comes to complex projects (Stevenson, 2018).

3.2. Network planning methods – CPM and PERT

The network planning methods were created for the requirements of planning and control of long-term and complex, primarily military projects. This method can include the huge complexity of the project and a large number of participants in the implementation of the project. Network planning methods enable the graphical presentation of individual activities and their interdependence through a network diagram, which provides a logical structure for the implementation of a particular project and allows a detailed analysis of the time of implementation of individual activities and the project as a whole. These methods include CPM and PERT techniques, which have become widely used over time and now are an indispensable tool for planning, monitoring, and control, more precisely for efficient management of complex, long-term, and expensive development and investment projects. The process of making a network diagram includes two basic phases: *structure analysis and time analysis.* The analysis of the structure implies the establishment of logical order and interdependence of activities, and the analysis of time means the calculation of the beginnings and endings of activities and time reserves. PERT and CPM methods differ in the way of determining the duration of individual activities, as well as time analysis, while the rules for forming a network diagram and structure analysis remain the same. In addition to structure and time analysis, there is also a *cost analysis*. This analysis includes determining the costs of individual activities and the entire project and finding the most beneficial relationship between time and cost of implementation of individual activities in the project. The framework for constructing a network planning diagram consists of 6 steps that apply to both the PERT and the CPM method. These steps are described in the book by Heizer, Render and Munson (2017) as follows:

1. determine the project and prepare the activities,
2. develop the relationships among the activities and determine the predecessors and followers of each activity,
3. draw the network which connects all the activities,
4. assign time and/or cost estimates to each activity,
5. determine the critical path- the path that has the longest duration, and
6. use this network to help plan, schedule, monitor, and control the project.

3.2.1. Structure analysis

Once the project has been determined, it is necessary to work on its activities. When a list of activities is formed, it is necessary to arrange them in the order in which they occur and then establish their interdependence. It is necessary to determine on which activities an activity depends in order to determine the predecessor and successor of each.

The next step is the construction of a network diagram. A network diagram can be event or activity-oriented. *Activities* are individual tasks whose logical connection forms the whole of the project, and whose execution requires certain resources and a certain amount of time. An *event* in the network planning technique represents a certain state, which indicates the beginning or end of an activity and has no time dimension. The initial event shows the start of the activity, and the final event the end of the activity, ie the beginning of the next activity (Pinto, 2016).

The network diagram consists of arrows and nodes. Activities are graphically represented by an oriented arrow, and events by a circle in which the necessary data is entered. Therefore, two approaches to drawing these networks can be named:

- AON - activity-on-node, and
- AOA - activity-on-arrow.

In the case of the AON convention, the activities are represented by nodes, and the arrows connecting the circles indicate the order of the activities. When it comes to the AOA convention, arrows represent activities, where the beginning of the arrow indicates the start of the activity and the top of the arrow the end of an activity. These activities are connected by nodes which are also called events. Consequently, an event is the end of the activity that enters the node and at the same time the beginning of the activity that comes out of the node, which can be seen in Figure 3. Considering the activities consume both resources and time, it can be concluded that nodes in the AOA approach do not consume time nor resources (Heizer, Render and Munson, 2017).

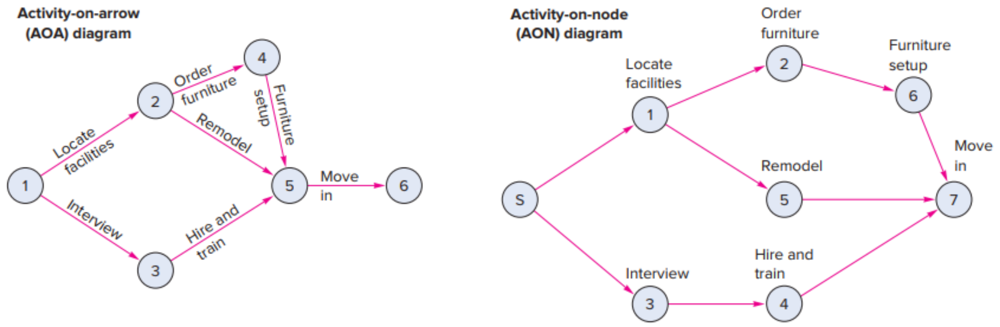


Figure 2: Example of AOA and AON diagrams (Stevenson, 2018)

In his book, Pinto (2016) explains that these two approaches, despite having the same goal - to create a sequential logic for activities, connect them, determine the total project duration, critical path, and slack activities, have both individual advantages and disadvantages. He explains AON networks as much easier to understand and read due to fact that their structure is simplified since the activity is located only in the node. However, when it comes to more complex projects, understanding this network is much more difficult because of the large number of arrows and node connections. The AOA approach is much easier to use when it comes to complex projects since the nodes and activities of this network are certainly easier to identify. Also, there may be *dummy activities* in the network diagram. They can only occur in AOA networks and the duration of this activity is zero. It represents a precursor for two activities with the same start and end node. Thus, they are used to describe the logical dependence between activities that one activity cannot begin until another is completed taking into account that these activities do not lie on the same path. In a network diagram, dummy activities are most often marked by a dashed line (Pinto, 2016).

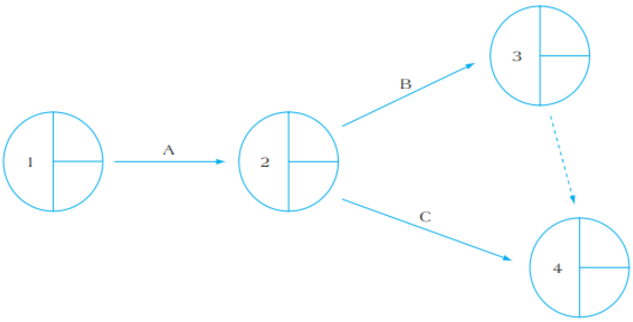


Figure 3: Example of a dummy activity (Pinto, 2016)

In the technique of network planning, there are certain basic rules for constructing network diagrams that should be followed in order to properly construct a network diagram. These rules are clearly presented in the following figure by Stevenson (2018).

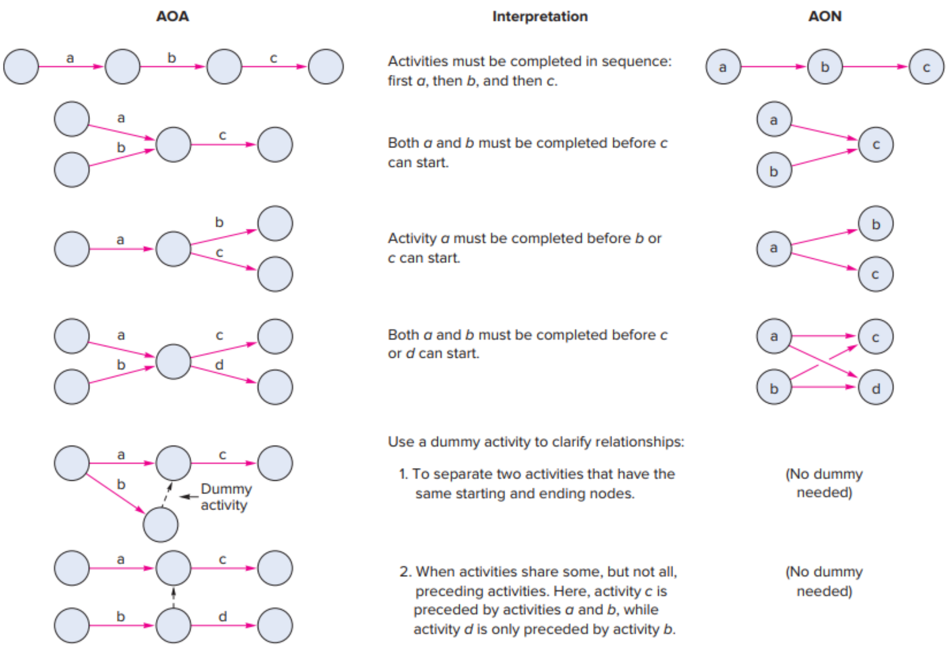


Figure 4: Network conventions (Stevenson, 2018)

3.2.2. Time analysis

The time analysis of a project is approached after shaping the process of the project and depends on the structure analysis, so it is impossible to do it until the structural analysis is performed. The introduction of the time dimension includes the estimation and determination of the time required for the execution of individual activities and the realization of the project as a whole. By performing a time analysis, it is possible to get answers to the following questions: how long does the project last, beginnings and endings of activities, is there a possibility of being late with any activity, how to determine which activities should not be delayed, and what is a critical path? The essence is to precisely determine the required duration of the project and the duration of all phases or activities that it contains. As already mentioned, the structure analysis for all network planning methods is the same but when it comes to time analysis then it differs significantly and will therefore be explained separately.

To determine the duration of the project, the slack time as well as the critical path of the project, it is first necessary to determine the following times (Stevenson, 2018):

- ES - the earliest time activity can start,
- EF - the earliest time the activity can finish,
- LS - the latest time the activity can start and not delay the project,
- LF - the latest time the activity can finish and not delay the project.

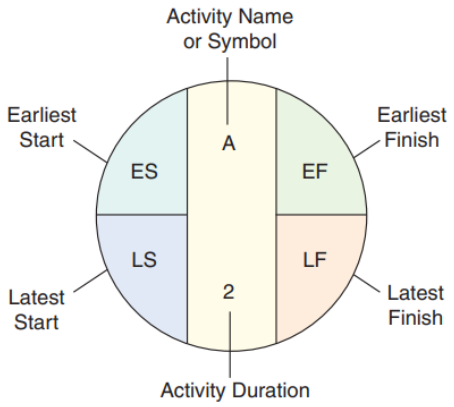


Figure 5: Notation used in nodes (Heizer, Render, and Munson, 2017)

According to Heizer, Render, and Munson (2017) *forward pass* is used to determine the earliest start and earliest finish of activity. It is important to remember that before an activity can begin, all of its immediate predecessors must be completed. There are two rules for determining the earliest start:

1. If an activity has only one predecessor, then its ES is equal to the EF of the predecessor.

2. If an activity has multiple predecessors, then its ES corresponds to the maximum of all EF values of its predecessors.

$$\textbf{ES = max. (EF of all immediate predecessors)} \qquad \textbf{(1)}$$

The earliest finish time (EF) of an activity is the sum of its earliest start time (ES) and its activity time.

$$\textbf{EF = ES +Activity time} \qquad \textbf{(2)}$$

A *backward pass* is used to determine the latest start and the latest finish and this procedure starts from the last activity in the project, determining first the LF and then the LS value. When determining the LF value, it must be remembered that before the activity can begin, all its immediate predecessors must be completed and the following rules must be followed:

1. If a particular activity is a predecessor to only one activity, its LF is equal to the LS of the activity immediately following it.
2. If an activity is a predecessor to several activities, its LF represents the minimum of all LS values of all activities that immediately follow it.

$$\textbf{LF = min. (LS of all immediate follow-up activities)} \qquad \textbf{(3)}$$

The latest start time (LS) of an activity is the difference between its latest finish time (LF) and the activity time.

$$\textbf{LS = LF – Activity time} \qquad \textbf{(4)}$$

After calculating these times, the next step is to calculate the slack time. Slack is a period of time in which an activity can be delayed without delaying the entire project. This time can be calculated as follows (Heizer, Render, and Munson, 2017):

$$\textbf{Slack = LS – ES or Slack = LF - EF} \qquad \textbf{(5)}$$

Determining slack time is extremely important for managers. Based on this time, they have the opportunity to get information about which activities need special attention and which are the activities that can most contribute to the postponement of a project (Stevenson, 2018).

Pinto (2016) in his book defines the *path* as a sequence of activities determined by the project network logic. The length of the path is determined by summing the (estimated) duration of the activity on that path, and the duration of the project corresponds to the length of the longest path through the project network (Hillier and Lieberman, 2001). The longest path through the network is called the *critical path.* The critical path is critical because any extension of the duration of the activity due to the delay will necessarily prolong the critical path and therefore delay the completion of the project. A project can have more than one critical path, i.e., several paths may go competitively. Indeed, if each route through the network is of the same duration, it can be argued that the project is optimized (Clayton, 2018). Those activities whose slack time is zero are on a critical path and are named *critical activities*. The total slack time shows how long the start of the activity can be postponed or the duration of a certain activity can be extended without extending the duration of the entire project (Stevenson, 2018).

The purpose of CPM is to identify the critical path - the longest path in the project network, because that path conveys information to the project manager about how long it takes for the project to be completed (Monhor, 2011). Therefore, from the previously described order of calculations, it can be concluded that the critical path method evaluates ES, EF, LS and LF when there is a specific estimated time to complete each activity. This method assumes that the duration of the activity is fixed and clearly determined. The CPM method distinguishes between critical and non-critical activities, and their identification is crucial to reduce time and to avoid delaying any activities that later lead to an extension of the overall project duration.

Unlike the CPM method, the PERT method also takes into account uncertainties when it comes to estimating the duration of activities. This technique is used when the estimated end times of the activity are not given, but some data are known that describe the probability distribution for the range of possible end times of the activity. The activities and their interdependence remain clearly defined, but a dose of uncertainty is still allowed for the duration of the activities (Jamie, 2004). This uncertainty is represented by three-time estimates, which need to be considered for each activity (Heizer, Render, and Munson, 2017):

- *Optimistic time (a)* = time an activity will take if everything goes as planned - the probability that this time can be achieved is usually less than 1 percent
- *Pessimistic time (b)* = time an activity will take assuming very unfavourable conditions - the probability that this time can be achieved is usually less than 1 percent
- *Most likely time (m)* = most realistic estimate of the time required to complete an activity

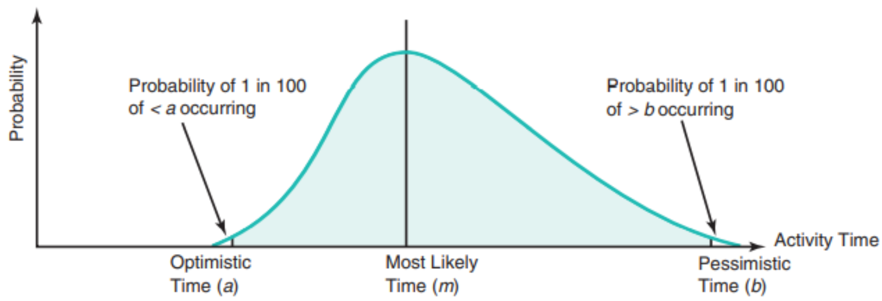


Figure 6: Beta probability distribution with three-time estimates (Heizer, Render, and Munson, 2017)

Information about these times is most often collected from people from the project team, managers, those who will perform project activities or know about them. A normal probability distribution that is symmetric, or a beta distribution that is asymmetric, can be used for time estimates. In real situations, it is very rare to find cases in which optimistic and pessimistic times are symmetrical to each other relative to the mean. In practice, projects where beta distribution is present, are most often encountered (Pinto, 2016). *The beta distribution* is a powerful tool utilized to describe the inherent variability in time estimates (Stevenson, 2018). If three-time estimation tools are compound with statistical parameters like mean, standard deviation, or Z-values, it is possible to better project management by optimizing time, cost as well as effort. To reach variance (σ2) and mean (E(t)) values, the following equations are used. Equation 6 represents the estimated time for activity and it is based on the beta distribution and weighs the most probable time four times more than the optimistic or pessimistic time (Sherman, 2011):

$$\mathbf{E(t)} = \frac{\boldsymbol{a + 4m + b}}{\mathbf{6}} \qquad \mathbf{(6)}$$

E(t) is therefore the expected time to complete the activity and the PERT method uses this time as the given time for each activity and then uses the CPM method to further obtain the ES, EF, LS and LF times. From the following equation 7, a variance can be found by squaring the standard deviation, and can be obtained as the square of the sixth difference between the optimistic and pessimistic estimate of time. The greater this difference between the extremes, the greater the variance (Sherman, 2011).

$$\sigma^2 = \left(\frac{\boldsymbol{b - a}}{\mathbf{6}}\right)^{\mathbf{2}} \qquad \mathbf{(7)}$$

Variance indicates uncertainty throughout the time of an activity, and the higher it is, the greater the uncertainty. To calculate the variance of a path, it is necessary to sum the variances of the activity on that path, using the following formula (Stevenson, 2018):

$$\sigma^{\mathbf{2}}_{\boldsymbol{path}} = \sum \boldsymbol{Variances\ of\ activities\ on\ path} \qquad \mathbf{(8)}$$

Variations that are on a critical path can significantly lead to the possibility of delaying project completion. Thus, the PERT method uses the variance of the critical path activity, to arrive at the value of the variance of the overall project. Therefore, following the example of the previously mentioned equation, the project variance can be calculated by summing the variances of critical activities, i.e., using the following equation (Heizer, Render, and Munson, 2017):

$$\sigma_p^2 = \boldsymbol{Project\ variance} = \\ = \sum \boldsymbol{Variances\ of\ activities\ on\ critical\ path} \tag{9}$$

Also, a very important section is the calculation of the probability that a certain path will be completed in a certain period. According to Stevenson (2018) it is calculated using Equation 10, and the z-value shows how many standard deviations the target completion time is away from the arithmetic mean.

$$\mathbf{z} = \frac{\boldsymbol{Target - Path\ mean}}{\boldsymbol{Path\ standard\ deviation}} \tag{10}$$

If this z-value is negative, it means that the stated time is earlier than the expected duration of the path, and the more positive the z-value, the better. When the value of z is found, it is possible to read the probability that the path will be completed by the specified time using a table from Appendix 1. This can be modelled by a normal distribution curve. By Stevenson's (2018) definition, the path probability corresponds to the area below the normal curve to the left of a standardized value z. Also, the probability can be calculated using certain Excel function, whose use will be shown later in the experimental part of the paper.

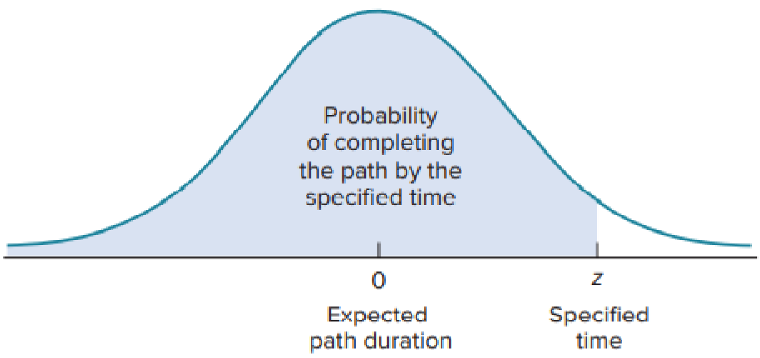


Figure 7: The path probability graph (Stevenson, 2018)

4. Metal surface protection

In order to protect some metals such as steel, copper, aluminium, brass, bronze, etc. from oxidation or corrosion on the outside, it is possible to electrically coat (galvanize) their surfaces with a layer of another metal such as nickel, copper, etc. In addition to protection against oxidation or corrosion, metals are also surface protected to give them additional properties such as hardness, wear resistance and decorativeness (Ničota, 1958). Examples of galvanized objects can be seen all around us and one such example can be seen in Figure 8. Whether it is car parts, traffic signs, containers, pipes, or highway barriers, the range of applications of this technology is huge. Therefore, galvanization is the application of a thin layer, in this case, zinc to the base metal. If the metal does not have a protective layer of zinc, then it is exposed to reactions with other elements, and these reactions can cause oxidation or corrosion (Metal Supermarkets, 2016). Corrosion is an electrochemical process that occurs due to differences in electrical potential between metals in contact in the presence of electrolytes. Due to electrochemical reactions in that contact or chemical reactions of metals with the environment, metal loss occurs and this phenomenon is recognized as corrosion (Ozturk, Evis, Kilic, 2017). Therefore, galvanizing is a very good and cost-effective way to protect the base metal from the environment by providing it with anti-corrosion properties. Also, a very important aspect is that this zinc coating protects the base metal from moisture and water. If two metals of different electrochemical compositions are put in contact, in the presence of electrolytes, one metal always acts as an anode and the other as a cathode. This leads to the conclusion of why choose zinc as an option for metal protection. It is known that the anode generally corrodes faster, while the cathode corrodes much more

Figure 8: Zinc coated parts (Eurosjaj, 2021)

Magnesium	Active (anode)
Zinc	
Aluminum	
Cadmium	
Steel/iron	
Lead	
Tin	
Nickel	
Brass	
Bronze	
Copper	
Stainless steel	
Silver	
Graphite	
Titanium	
Gold	
Platinum	Noble (cathode)

Figure 9: Electrical activity of metals/alloys in seawater (Sahoo, Das and Davim, 2017)

slowly than it would corrode by itself. Zinc always tends to be an anode in contact with another metal, which consequently causes corrosion only in zinc and prevents or slows down the corrosion of the metal which in this case is the cathode (Metal Supermarkets, 2016). In their chapter, Sahoo, Das, and Davim (2017) presented a Figure 9 where a number of metals and alloys can be seen that in descending order represent electrical activities in seawater. Based on this, it can be concluded which of these metals will be in contact with the other anode and which a cathode. The metals that are higher will be anode to those that are lower, which confirms the aforementioned claim about the behaviour of zinc. Low melting point and rather poor mechanical properties of zinc limit the application of zinc as a construction material. Therefore, zinc is mainly used for galvanizing iron and steel products, to protect against corrosion, to form alloys. Zinc is an electronegative metal, so corrosion can be accelerated by any contact with a metal other than magnesium. Under certain conditions, a protective film is formed on its surface, so it is resistant in a humid atmosphere.

„Eurosjaj d.o.o.“ operates with four galvanic lines with hangers and two galvanic lines with drums. Larger goods are galvanized in line with hangers while small items are galvanized in line with drums. If it is a process that uses hangers, there is a stand that contains hooks on it and this means that each part should be individually attached to them. During the process, the whole assembly is immersed in a tub of chemicals. Figure 10 shows the galvanic line with hangers in the company „Eurosjaj d.o.o. “, while in Figure 11 it is possible to see the galvanized parts attached to the hangers.

Figure 10: Galvanic line with hangers (Eurosjaj, 2021)

Figure 11: Galvanizing of parts hung on hangers (Eurosjaj, 2021)

On the other hand, the drum can be mounted instead of hooks where a certain number of parts are inserted into the drum which rotates during immersion, thus enabling each part in it to be galvanized.

All these lines are very similar, however, there are also certain differences when one of them is used. For example, line no. 1 is an alkaline galvanizing on ZAMAC materials (zinc alloy with aluminium, magnesium and copper) and is most commonly used to work on car parts that represent safety factors in most vehicles and therefore this line requires work perfection, dedication, and involvement of a lot of workers as the auto industry is detail-oriented and high precision. The maximum dimensions of the galvanizing positions on this line are 1800x800 mm. Galvanizing on this line can be done on hangers as well as on drums. Otherwise, hanging parts on hangers is a longer process. When it is necessary to galvanize a large number of small parts, drums are usually used because they are much more practical for such situations. How the drum actually looks in this company can be seen in the Figure 12 below. Line no. 2 is alkaline galvanizing on steel materials and also requires perfection because it deals with special customer requirements that other galvanic lines cannot achieve.

Figure 12: Drum for galvanizing goods

These special requirements apply to large layers of zinc coatings or maximum commitment to visual appearance. Line no. 3 is a line used for the serial production of goods of different dimensions whose basic material is also steel. This line works with increased intensity and can galvanize over 400 tons of goods per month.

There are three types of galvanizing. The first type is *hot-dip galvanizing* and it involves immersing the base metal in a pool in which zinc is molten, and this type was used in the case of the order processed in this paper. The first step that is necessary in the galvanizing process is the preparation of the surface, which involves cleaning the base material. This is done to make the connection between the base metal and zinc as good as possible because zinc will not react with impure metal and it is necessary to perform both mechanical and chemical cleaning. So, the first two steps are degreasing and pickling. Degreasing removes various paints, greases and oils from the surface, followed by rinsing with hot water in order to neutralize the surface from its alkaline nature. Pickling is a process where the surface is immersed in acid to remove scale, rust and the like. Flux or centrifuge can be dry and wet. Dry fluxing means immersing a part in a heated solution of zinc ammonium chloride. The final stage is to immerse the part in a bath of molten zinc. Air cooling is then performed to remove further reaction of the base material and zinc (Workshop Insider, 2021). The phases of this type of galvanizing are also shown in the Figure 13.

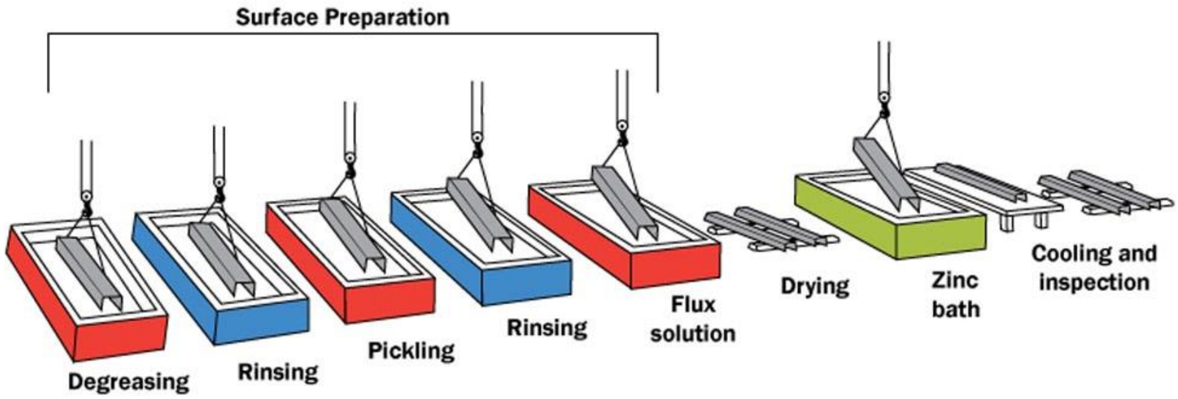


Figure 13: Hot-dip galvanizing process (Workshop Insider, 2021)

Pre-galvanizing is another type that is mainly used if it is about materials that already have a specific shape and is done in steel mills. Cleaning is performed as in hot-dip galvanizing, after which the metal is passed through a pool of hot and liquid zinc and then recoiled. And the third type is *electro galvanizing*. To transfer zinc ions to the base metal, an electric current in the electrolyte solution is used. There is an electrical reduction of positively charged zinc ions to zinc metal which are then placed on the positively charged material. This technique gives a coating that is thinner than that achieved by hot-dip galvanizing, which means that it can affect less corrosion protection (Metal Supermarkets, 2016).

5. Application of PERT and CPM methods to experimental data

Since there is a whole range of techniques and customer requirements, this paper will focus specifically on a single order where the metal has to be protected by applying a coating of zinc, and where the base material is ZAMAC, therefore, galvanization will be done on the Line 1. The customer's request was to apply a protective layer of zinc 8 µm thick to 240kg positions for the automotive industry, and that the base material be further protected by thick-layer passivation and ensiling. This paper aims to apply the PERT and CPM method to determine whether the aforementioned order from one pallet of positions can be galvanized in 12h.

Since line 1 is automated, the following Table 1 presents the steps of this procedure. This table is taken from the company and presents the sequence of steps in the galvanizing process as well as the parameters that need to be established and adjusted as required by the base material. As can be seen, these steps correspond to those previously described in Figure 11, but in the case of this order, the customer had additional requirements regarding ensiling and thick-layer passivation, so this table has some additional steps to meet the customer's request. In order to improve the service, another additional treatment of white (blue), yellow and thick-layer passivation is performed, which gives the treated surfaces a different colour, i.e., visual appearance and different corrosion resistance. The table also lists the chemicals required for each activity, where **C** is concentration, **T**- temperature, **pH** - acidity, **I** - current, **t-** time, **d -** layer thickness, and **m** - mass of the goods in the drum. As can be seen from Table 1, the galvanization on this line is automated and the times of each activity are fixed or have a precisely defined range in which they must be performed. The activities that have a time range in this table also need to be adjusted to the required conditions. Specifically in the case of this order, 6 minutes are taken for the necessary drying and dripping, which can be seen also in the Table 1. Usually, the galvanizing process is completed in close to 2 hours, or more precisely in 108,10 minutes. Depending on the base material, the parameters can change not so drastically, so the galvanizing process can be completed in 106,10 minutes at best, while in the worst case this process takes 118,10 minutes. The only steps that have a human share in this process is short control which is performed before the finished positions go to the output control.

Table 1: Galvanization process

No. of the operation	Name of the operation	Medium	Operating parameters
1.	Chemical degreasing	Presol 1076 IG C=50-80 g/l	T= 40 -70 °C t= 10 min
2.	Rinsing (economical)	Water	t= 15 sec
3.	Rinsing (flow)	Water	t= 20 sec
4.	Pickling (activation)	Picklane Dryac C= 15-30 g/l	t= 30 sec
5.	Rinsing (flow)	Water	t= 20 sec
6.	Galvanizing	Primion 240 Zn=7-14 g/l NaOH =110-150 g/l	d= 8µm T= 20-35°C I=515±50A t= 70 min
7.	Rinsing (economical)	Water	t= 15 sec
8.	Rinsing (flow)	Water	t= 30 sec
9.	Rinsing (flow)	Water	t= 50 sec
10.	Illumination	HNO_3 C= 0,5% vol	t= 30 sec pH=1,0 – 1,8
11.	Thick-layer passivation	Lanthane 317 C=80-120 ml/l	T=20-30°C t=45sec pH=1,6 – 2,2
12.	Rinsing (flow)	Water	t= 50 sec
13.	Dripping Centrifuge	Air	T= room temperature t= 5-10 min (6 min)
14.	Ensiling Tilting centrifuge	Finigard 401 C=30-40% vol	T= room temperature t= 60 sec pH= 8,5-9,2 n = 30-50 rpm
15.	Dripping Centrifuge	Air	T= room temperature t= 5-10 min (6 min)
16.	Drying Centrifuge	Warm air	T=60-100°C t=5-10 min (6 min) n=200-250 rpm
17.	Control	-	t= 5-8 min

5.1. Ideal case - a process without waiting

The company has received an order from a customer and has a request to galvanize one pallet (240 kg) of positions for the automotive industry within 12 hours. Receipt of these goods is done in the entrance warehouse where mainly two workers are in charge of unloading it. The truck stops in front of the warehouse so the goods don’t need to be transported anywhere far away. The raw goods arrive in the form as shown in Figure 15 below, with the accompanying papers stating the customer’s requirements. When the goods are unloaded, first of all, it is necessary to weigh them on a scale located in the entrance warehouse to know how many kilograms of the order it is. Once the weight of the position has been established, it is necessary to fill in the order card which contains all the necessary information about the order. The card states which customer it is, how much the order weighs, what the customer's requirements are, and what the completion deadline is that the customer requires. All these things are stated so that the people in the production know what their obligations are and the card is hung on the boxes with the weighed goods.

Figure 15: Raw goods arriving at the company

Figure 14: Finished goods packed after the control

After it is determined that the goods will be processed on line no. 1, it is necessary to divide them into quantities Q. One line has three drums, the maximum capacity, i.e., the mass that one drum can receive is 50 kg. Therefore, since there are three drums that receive 50 kg each, if the order weighs over 150 kg, galvanizing must be performed in several cycles. Specifically, in the case of these orders, taking into account that each drum can galvanize only 50 kg of goods, it was concluded that galvanizing will be done in five parts, i.e., the goods will be divided into five quantities: **Q1 = 50 kg, Q2 = 50 kg, Q3 = 50 kg, Q4 = 50 kg, and Q5 = 40 kg**. Since Line 1 has only three drums, then drum 1 and drum 2 will have to work two cycles in order for this order to be fulfilled. Divided quantities of goods are placed in 50 kg buckets.

At the same time, in addition to this, two other activities can be performed, namely checking the parameters on the galvanic line and providing equipment for work. Depending on the surface condition of the base material, the parameters within the limits listed in Table 1, such as temperature and pH value, are adjusted. It is also necessary to provide equipment, such as gloves, as well as the necessary chemical for the procedure.

The workers transfer the goods in the buckets on carts to the galvanic line and immediately fill the first drum if everything is ready for the process. The way the worker fills the drum can be seen in Figure 16.

Figure 16: Drum filling

The goods are inserted in such a way that first one drum is filled which then goes for galvanizing, and after that another drum is automatically prepared which immediately follows. So, in the case of this order, all three drums were filled and 150 kg of goods immediately started the galvanizing process. It has already been said that this procedure is automated, so its steps and duration are adopted as such. Figure 17 shows the galvanic line 1. It shows the tubs arranged side by side in the order in which the process phases take place. Each tub represents one phase of the process - so in one tub degreasing is performed, in the other drip, centrifuge and the like. Figure 18 shows the centrifuge step for ensiling and drying. As soon as the first drum is emptied, it is refilled to galvanize the quantity of goods Q4. In the same way, when drum 2 is emptied it will be refilled with Q5.

The first control is performed on drying in the process of galvanization. It is a short control in which it is only visually checked whether the colour has been achieved and whether the

Figure 17: Galvanic Line 1

Figure 18: Centrifuge for ensiling and drying

procedure has been completed successfully. After the goods in the drum have completed the galvanizing process, the drum is opened and turned, and in this way the galvanized positions are ejected into the baskets below the drum through the cavity which can also be seen in Figure 13 positioned below the drum. Workers put these baskets on carts and drive them to the exit control procedure. Exit control is done manually, meaning one person borrows one basket and visually inspects each part individually to ensure that the coating is evenly distributed throughout the position. This company has a lot of workers at its disposal, so that several drums can be inspected at the same time, but there is usually always one worker in charge of one basket, i.e., 50 kg of positions. It is a time-consuming process, especially since these are pretty small parts. When checking the quality of galvanizing, attention is paid to the appearance of the surface of the zinc coating and the thickness of the zinc coating. A very important aspect of

galvanizing is actually the thickness of the zinc layer. There are digital devices that can very easily check the thickness of the layer by pressing the device on a galvanized surface. Th
e procedure for checking the thickness of zinc on galvanized containers is shown in the Figure 19.

Figure 19: Checking the zinc thickness with a digital device on galvanized containers (Eurosjaj, 2021)

When the worker inspects the position, if it is successfully galvanized, he puts it in the box, and if it is not, he separates it from the side so that it can be repaired or scrapped. When the control is completed, the person packs the galvanized items in boxes and they are further stored in the warehouse and then transported to the customer. Packaged finished goods can be seen in Figure 14. Based on this sequence of activities, a list of activities of this process and their interdependence can be formed, presented in Table 2.

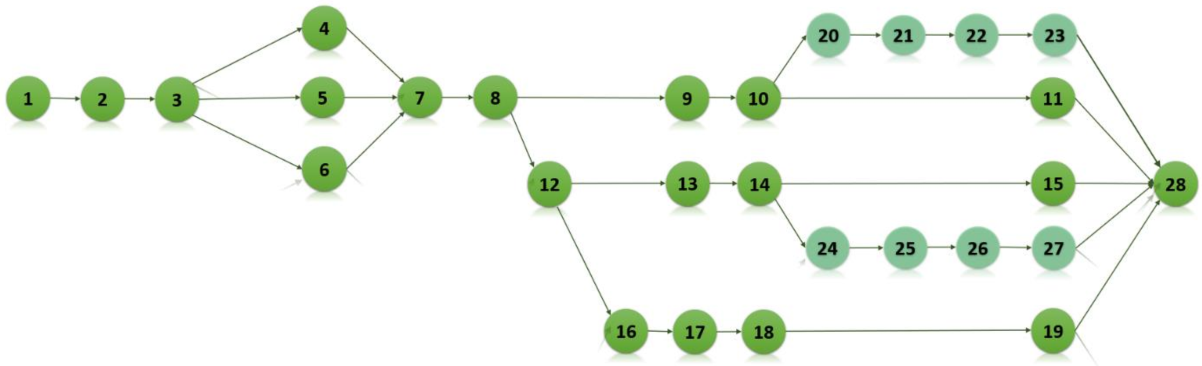
Table 2: List of activities, their order and dependence

Number of the activity	Name of the activity	Predecessor of the activity
1.	Discharging goods from the truck	-
2.	Weighing	1
3.	Filling in the card	2
4.	Division of goods into quantities Q	3
5.	Checking parameters on the galvanic line	3
6.	Providing work equipment	3
7.	Trasfer of goods to the galvanic line	4,5,6
8.	Filling drum 1 with Q1	7
9.	Galvanizing of Q1 in drum 1	8

10.	Discharging from drum 1 and transport to the controller	9
11.	Control and packing of Q1	10
12.	Filling drum 2 with Q2	8
13.	Galvanizing of Q2 in drum 2	12
14.	Discharging from drum 2 and transport to the controller	13
15.	Control and packing of Q2	14
16.	Filling drum 3 with Q3	12
17.	Galvanizing of Q3 in drum 3	16
18.	Discharging from drum 3 and transport to the controller	17
19.	Control and packing of Q3	18
20.	Filling drum 1 with Q4	10
21.	Galvanizing of Q4 in drum 1	20
22.	Discharging from drum 1 and transport to the controller	21
23.	Control and packing of Q4	22
24.	Filling drum 2 with Q5	14
25.	Galvanizing of Q5 in drum 2	24
26.	Discharging from drum 2 and transport to the controller	25
27.	Control and packing of Q5	26
28.	Storage	11,15,19,23,27

The next step after determining the order and dependence between the activities is forming a network diagram. Compared to large projects and processes that have dozens or hundreds of more activities that make them up, the diagram of this galvanizing process is not that complicated. It gives a clear picture of 28 activities and the dependencies between them, as well as a clear overview of the parallel activities. The activities that make up the second cycle of the process are marked in light green so that they can be more easily identified.

Diagram 1: Network diagram of the galvanizing process



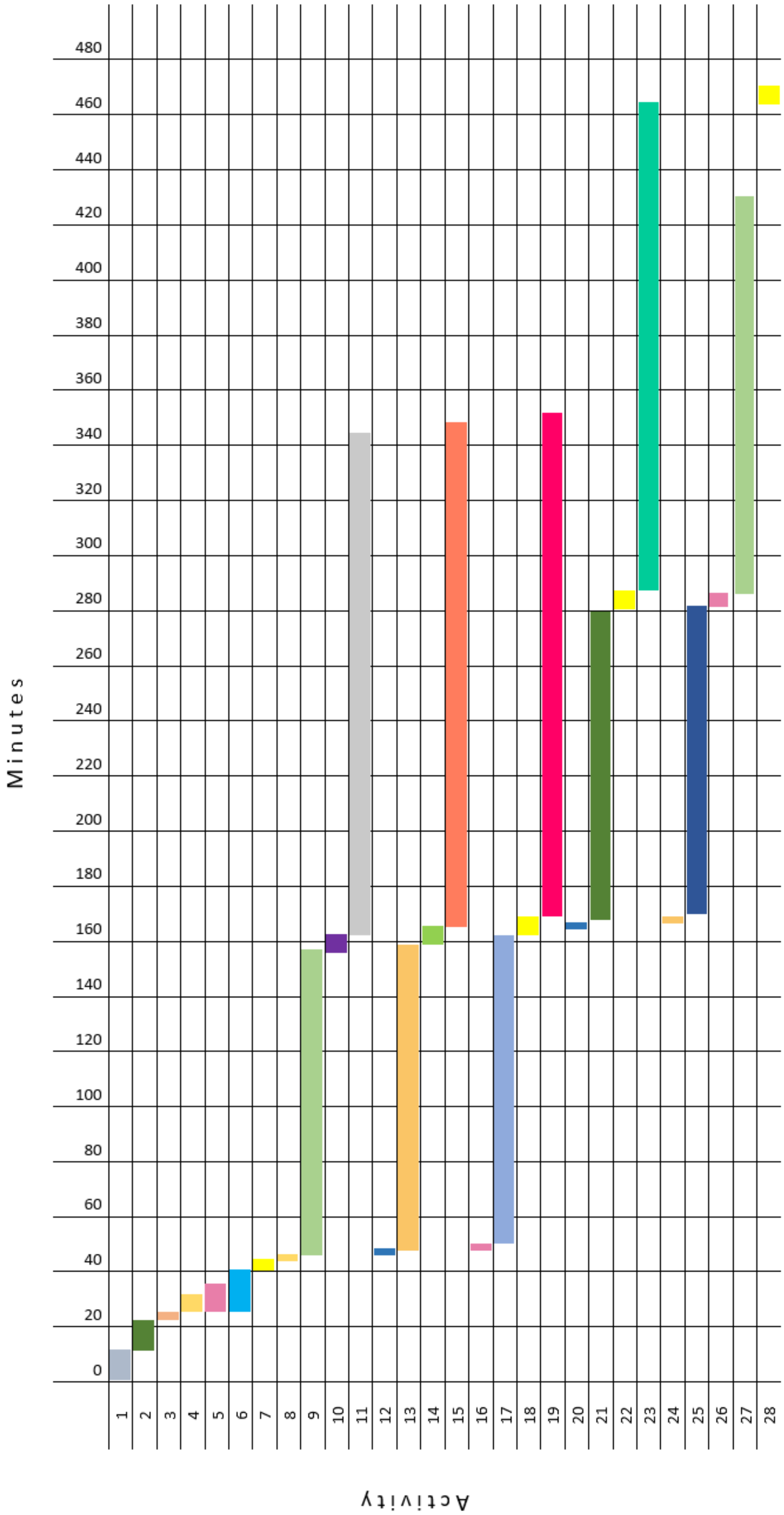
The order that arrived at the company “Eurosjaj d.o.o.” was monitored from the receipt until delivery to the customer, and thus the duration of each listed activity was determined. The expected completion time of the activity was obtained by making a three-time estimate for each activity. It was previously explained that this involves measuring three key times, which are optimistic, pessimistic and most likely time, and they are described in the following Table 3. A document with these three measured times for all 28 activities was obtained from the company where the duration of each listed activity was measured using stopwatch. Measurements were performed in such a way that, according to the need for data for this thesis, one worker followed the order from beginning to end and tracking the goods through each activity records how much it really takes workers to perform the activities for which they are in charge. As already mentioned, times are measured on exactly one order and they are, like waiting in the process that will be listed later, exactly as they were found and measured specifically on this order. Optimistic, pessimistic and more likely times were measured once for each activity. Taking the finished data from the company, all further calculations and analyses were performed.

Using equation 6, the expected time for each activity was calculated, and using Equations 1,2,3 and 4, the earliest and latest beginnings and endings of each activity were calculated. Based on the forward pass rule, ES and EF were calculated, and by using the backward pass rule, it was possible to obtain LS and LF numbers. Also, the slack is calculated using Equation 5. When the E(t) time is determined, a Gantt chart is formed based on those times. The Gantt chart is presented in Diagram 2, and from this diagram it is possible to clearly see the whole process, to see which activities take place in parallel. It gives a much better overview of how much galvanizing of individual quantities is actually behind this before and when the next drum is being filled.

Table 3: Calculation of E(t), ES, EF, LS, LF and Slack values based on measured a, m and b values

No. of the activity	Name of the activity	Predecessor of the activity	a (min)	m (min)	b (min)	E(t) (min)	ES (min)	EF (min)	LS (min)	LF (min)	Slack (min)
1.	Discharging goods from the truck	-	10,00	13,00	15,00	12,83	0,00	12,83	0,00	12,83	0,00
2.	Weighing	1	8,00	9,00	10,00	9,00	12,83	21,83	12,83	21,83	0,00
3.	Filling in the card	2	2,00	2,50	3,00	2,50	21,83	24,33	21,83	24,33	0,00
4.	Division of goods into quantities Q	3	5,00	6,50	10,00	6,83	24,33	31,17	33,33	40,17	9,00
5.	Checking parameters on the galvanic line	3	5,00	10,00	15,00	10,00	24,33	34,33	30,17	40,17	5,83
6.	Providing work equipment	3	10,00	15,00	25,00	15,83	24,33	40,17	24,33	40,17	0,00
7.	Transfer of goods to the galvanic line	4,5,6	3,00	4,00	5,00	4,00	40,17	44,17	40,17	44,17	0,00
8.	Filling drum 1 with Q1	7	2,00	2,50	3,00	2,50	44,17	46,67	44,17	46,67	0,00
9.	Galvanizing of Q1 in drum 1	8	106,10	108,10	118,10	109,43	46,67	156,10	46,67	156,10	0,00
10.	Discharging from drum 1 and transport to the controller	9	4,00	6,50	8,00	6,33	156,10	162,43	156,10	162,43	0,00
11.	Control and packing of Q1	10	141,00	186,00	210,00	182,50	162,43	344,93	280,70	463,20	118,27
12.	Filling drum 2 with Q2	8	2,00	2,50	3,00	2,50	46,67	49,17	84,87	87,37	38,20
13.	Galvanizing of Q2 in drum 2	12	106,10	108,10	118,10	109,43	49,17	158,60	87,37	196,80	38,20
14.	Discharging from drum 2 and transport to the controller	13	4,00	6,50	8,00	6,33	158,60	164,93	196,80	203,13	38,20
15.	Control and packing of Q2	14	141,00	186,00	210,00	182,50	164,93	347,43	280,70	463,20	115,77
16.	Filling drum 3 with Q3	12	2,00	2,50	3,00	2,50	49,17	51,67	162,43	164,93	113,27
17.	Galvanizing of Q3 in drum 3	16	106,10	108,10	118,10	109,43	51,67	161,10	164,93	274,37	113,27
18.	Discharging from drum 3 and transport to the controller	17	4,00	6,50	8,00	6,33	161,10	167,43	274,37	280,70	113,27
19.	Control and packing of Q3	18	141,00	186,00	210,00	182,50	167,43	349,93	280,70	463,20	113,27
20.	Filling drum 1 with Q4	10	2,00	2,50	3,00	2,50	162,43	164,93	162,43	164,93	0,00
21.	Galvanizing of Q4 in drum 1	20	106,10	108,10	118,10	109,43	164,93	274,37	164,93	274,37	0,00
22.	Discharging from drum 1 and transport to the controller	21	4,00	6,50	8,00	6,33	274,37	280,70	274,37	280,70	0,00
23.	Control and packing of Q4	22	141,00	186,00	210,00	182,50	280,70	463,20	280,70	463,20	0,00
24.	Filling drum 2 with Q5	14	1,50	2,00	2,50	2,00	164,93	166,93	203,13	205,13	38,20
25.	Galvanizing of Q5 in drum 2	24	106,10	108,10	118,10	109,43	166,93	276,37	205,13	314,57	38,20
26.	Discharging from drum 2 and transport to the controller	25	3,50	6,00	7,50	5,83	276,37	282,20	314,57	320,40	38,20
27.	Control and packing of Q5	26	112,80	144,00	168,00	142,80	282,20	425,00	320,40	463,20	38,20
28.	Storage	11,15,19,23,27	4,00	6,00	10,00	6,33	463,20	469,53	463,20	469,53	0,00

Diagram 2: Gantt chart according to E(t) duration of activity



Once the duration of each activity E(t) has been determined, a critical path can be detected. Table 4 shows all the paths that are possible in this process and there are 15 of them. As explained earlier, the duration of each path can be determined by summing the duration of each activity located on that path. Therefore, the duration of each path is determined to find the critical path.

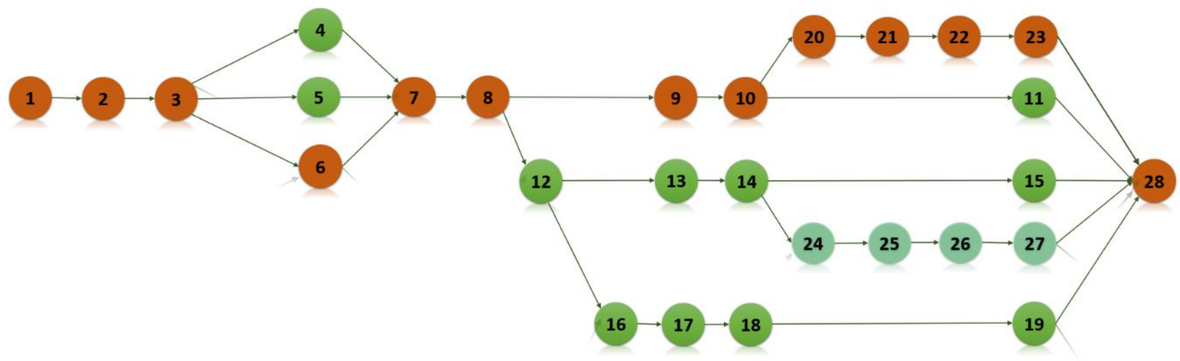
Table 4: Process paths and their durations

	Path	Duration (min)
1	1-2-3-4-7-8-9-10-20-21-22-23-28	460,53
2	1-2-3-4-7-8-9-10-11-28	342,27
3	1-2-3-4-7-8-12-13-14-15-28	344,77
4	1-2-3-4-7-8-12-13-14-24-25-26-27-28	422,33
5	1-2-3-4-7-8-12-16-17-18-19-28	347,27
6	1-2-3-5-7-8-9-10-20-21-22-23-28	463,70
7	1-2-3-5-7-8-9-10-11-28	345,43
8	1-2-3-5-7-8-12-13-14-15-28	347,93
9	1-2-3-5-7-8-12-13-14-24-25-26-27-28	425,50
10	1-2-3-5-7-8-12-16-17-18-19-28	350,43
11	1-2-3-6-7-8-9-10-20-21-22-23-28	469,53
12	1-2-3-6-7-8-9-10-11-28	351,27
13	1-2-3-6-7-8-12-13-14-15-28	353,77
14	1-2-3-6-7-8-12-13-14-24-25-26-27-28	431,33
15	1-2-3-6-7-8-12-16-17-18-19-28	356,27

As can be seen, as roughly as expected, the longest duration has path number 11 (1-2-3-6-7-8-9-10-20-21-22-23-28) which includes a new galvanization cycle again in drum 1. This is the critical path of this process. It can also be seen from Table 4 that all activities located on this critical path have a slack equal to zero. This means that any delay in any activity that is on a critical path will significantly affect and prolong the completion of the project.

$$E(t)_{CP} = E(t)_1 + E(t)_2 + E(t)_3 + E(t)_6 + E(t)_7 + E(t)_8 + E(t)_9 + E(t)_{10} + E(t)_{20} + E(t)_{21} + E(t)_{22} + E(t)_{23} + E(t)_{28}$$
$$= 12{,}83 + 9{,}00 + 2{,}50 + 15{,}83 + 4{,}00 + 2{,}50 + 109{,}43 + 6{,}33 + 2{,}50 + 109{,}43 + 6{,}33 + 182{,}50 + 6{,}33 = \mathbf{469{,}53\ min.}$$

Diagram 3: Critical path



Further, in order to obtain final information on whether the project will be completed in 12 hours, it is necessary to determine the variance of the critical path. It is calculated according to Equations 7 and 8, and the obtained results can be seen in the following Table 5.

Table 5: Calculation of critical path variance

Activity	**a** (min)	**m** (min)	**b** (min)	**E(t)** (min)	**σ^2** (min)
1	10,00	13,00	15,00	12,83	0,69
2	8,00	9,00	10,00	9,00	0,11
3	2,00	2,50	3,00	2,50	0,03
6	10,00	15,00	25,00	15,83	6,25
7	3,00	4,00	5,00	4,00	0,11
8	2,00	2,50	3,00	2,50	0,03
9	106,10	108,10	118,10	109,43	4,00
10	4,00	6,50	8,00	6,33	0,44
20	2,00	2,50	3,00	2,50	0,03
21	106,10	108,10	118,10	109,43	4,00
22	4,00	6,50	8,00	6,33	0,44
23	141,00	186,00	210,00	182,50	132,25
28	4,00	6,00	10,00	6,33	1,00
			Σ	**469,53**	**149,39**
			in hours:	**7,83**	**2,49**

As can be seen, the entire process can be completed in 7,83 h. According to Equation 10 and the target completion time of 12 hours, there is the following:

$$z = \frac{Target - Path\ mean}{Path\ standard\ deviation} = \frac{12 - 7{,}83}{\sqrt{2{,}49}} = 2{,}64$$

The next step is to read the probabilities from the aforementioned normal distribution table in Appendix 1. The probability is read by taking the value of z, having in mind that the values on the left represent the tenth, and those at the top represent the values on the nearest hundred. From Figure 20 it can be read that the probability for z = 2,64 is 0,9959. Therefore, the probability that the project can be completed in 12 hours or less is 99,59%.

z	.00	.01	.02	.03	.04	.05
2.4	.9918	.9920	.9922	.9925	.9927	.9929
2.5	.9938	.9940	.9941	.9943	.9945	.9946
2.6	.9953	.9955	.9956	.9957	.9959	.9960
2.7	.9965	.9966	.9967	.9968	.9969	.9970
2.8	.9974	.9975	.9976	.9977	.9977	.9978
2.9	.9981	.9982	.9982	.9983	.9984	.9984
3.0	.9987	.9987	.9987	.9988	.9988	.9989
3.1	.9990	.9991	.9991	.9991	.9992	.9992

Figure 20: Finding the probability using a table from Appendix 1 given by Stevenson

$$Probability\ that\ the\ project$$
$$can\ be\ completed\ in\ 12\ hours\ or\ less = 99{,}59\%$$

Also, based on the target value, mean and standard deviation, this probability can be calculated using Excel. The formula used for the calculation is as follows:

=NORMDIST(target; mean; stdev; cumulative) (11)

In this case, there will be:

=NORMDIST(12;7,83;1,58;1) = 0,9958454 = **99,59%**

As can be seen from the previous calculation, the order can be fulfilled within the given deadline. Further delivery to the customer will depend on the possibility and organization of transport to the destination. Considering that one work shift lasts 8 hours, it is of great importance to calculate the probability that the process can be completed during its duration. In the same way as in the previous case, the probability that the process would be completed in

11, 10, 9 or 8 hours or less was calculated. Table 6 contains the probability values for these target values where it can be concluded that reducing the target completion time also leads to a decrease in the probability values.

Table 6: Probability for different target values for ideal case

Target	Probability	
12 h	0,9959	99,59 %
11 h	0,9779	97,79 %
10 h	0,9159	91,59 %
9 h	0,7717	77,17 %
8 h	0,5440	54,40 %

The analysis of this process was performed in such a way that all activities take place continuously, so as soon as one activity is completed, another begins. Does the process really work this way in practice? So, the process will be completed in 7,83 h if there are absolutely no waits, and human resources are available for each activity immediately.

5.1.1. Reducing process duration by reorganizing the workforce

From the Gantt chart it can be clearly seen which are the most time-consuming activities. Since galvanization is an automated process, its duration cannot be influenced, and there is no opportunity for any optimization in this activity. However, what convincingly takes the most time is the control of finished products. The principle of control has already been explained. Each worker is in charge of one bucket of positions and this is an outdated way which is first and foremost very exhausting for the workers and is certainly a form of cost to the company as there are orders pending until control of these products is complete. Inspecting the finished galvanized parts implies knowing the specific specifications and it is a fairly simple process. It is very easy for the controller to notice the individual part that has remained uncoated.

When it comes to automatic control of galvanized products, it is possible to find in the literature various mathematical and software models that are developed to design a system that can automatically monitor and control the process, but it is not possible to find an example of only one machine that works on the principle of classification of accurate and wrong products. It would probably be possible to design a machine that would work on the principle of measuring the thickness of the zinc layer and that could visually inspect and spot the wrong piece, but that is not what the goal of this company is. The fact is that "Eurosjaj d.o.o." is a smaller company and since they are engaged in galvanizing pieces of various sizes - from huge containers and fences to small positions such as the one described in the thesis, investing in control systems is not a suitable option for them. Even if they decided on something like that, it is very difficult to design one that could be suitable for all types and sizes of orders. Therefore, human resources are the most acceptable option for them.

So, according to the previous calculation, five workers are needed to control the finished products, and each of them controls 50 kg of goods. Since the control of the quantity Q4 is on a critical path, the impact on the results will be considered if the control of only that quantity is performed by two workers instead of one. In this case, control Q4, i.e., activity number 23 will last half the time shorter than it was the case with one controller. Then the whole procedure and calculation is repeated again. In that case path 11 would no longer be critical, and the longest path would then be path 14, with a duration of 431,33 min. In this way, the total duration of the project would be reduced to 7,13 hours. If the control of the Q5 quantity is performed by two controllers as well, i.e., if the entire control of the second galvanizing cycle is intensified by manpower, then the critical path will remain path 11, but the duration of this path will be reduced to 378,28 min, which is 6,30 h.

If the workers did not wait to strictly control their 50 kg but deployed in such a way that each controller participated in the control of two quantities of goods, as shown in the Table 7 below, the results would remain the same as in the previous case. The process will last 6,30 hours, but in this way each worker is given a break from work after inspecting 25 kg of positions.

Table 7: Reorganization of process controllers

	Controller 1	Controller 2	Controller 3	Controller 4	Controller 5
Control and packing of Q1	X			X	
Control and packing of Q2		X			X
Control and packing of Q3	X		X		
Control and packing of Q4		X		X	
Control and packing of Q5			X		X

From this it can be concluded that in this process it is possible to shorten the duration of the project by redistributing the workforce - workers will control the same number of positions in a much easier way and thus significantly shorten the duration of the process and allow the company to have more space and time for other orders. with a slightly better distribution of labor, it would be possible to complete the process during one shift, thus giving space to unplanned waits that affect the overtime of one shift, which are discussed in the next chapter.

5.2. Case with included waits between individual process activities

In practice, there are certain waits that also need to be taken into account. In particular, in the case of this order, there were, at first glance, short and insignificant waits. However, how much impact do they have on the completion of the process and are they really insignificant? The durations of these waits are presented in Table 8, and they are graphically presented in Diagram 8. As can be deduced from this, these waits are located between such activities that they do not affect the change of the critical path, because each of the above paths will include this waiting.

Table 8: Waiting time in process

	a (min)	m (min)	b (min)	E(t) (min)
Waiting 1	5,00	5,50	6,00	5,50
Waiting 2	3,00	4,50	5,00	4,33
Waiting 3	3,00	3,50	4,50	3,58

In consultation with the workers of Eurosjaj d.o.o. it was found that these wait of a few minutes in the case of a tracked order did not have any qualitative reasons. Simply, when the goods were unloaded, it took about 5,50 minutes for one of the workers in charge of weighing to come and start the task. It also took a few minutes for one of the workers to arrive to transport the goods to the galvanic line. The same case was after the end of the last control where there was a wait of about 3,50 minutes. Quite simply, the workers did not stand in such positions that they could start activities immediately. So, the critical path is path number 11, it still has the longest duration. However, the duration of this path has now been extended from 7,83h to 8,05h. In the same way as in the previous ideal case, the probabilities of completion of this process were calculated and they are presented in the following table. The process is again possible to finish in 12 hours and the customer will receive his goods in the required time, but it is known that one shift lasts 8 hours, so the goal is to focus on this time because if the process lasts longer than that, it would cause complications for the second shift. Now that there have been certain waits, it can be seen that the duration of the process went beyond the duration of one shift for 3 minutes. It doesn’t take much time for the second shift to take over the rest of the work, and it certainly involves some form of overtime work of the first shift. In the case of this order it was not much time however it should be borne in mind that even the slightest wait has an impact on the completion of the process.

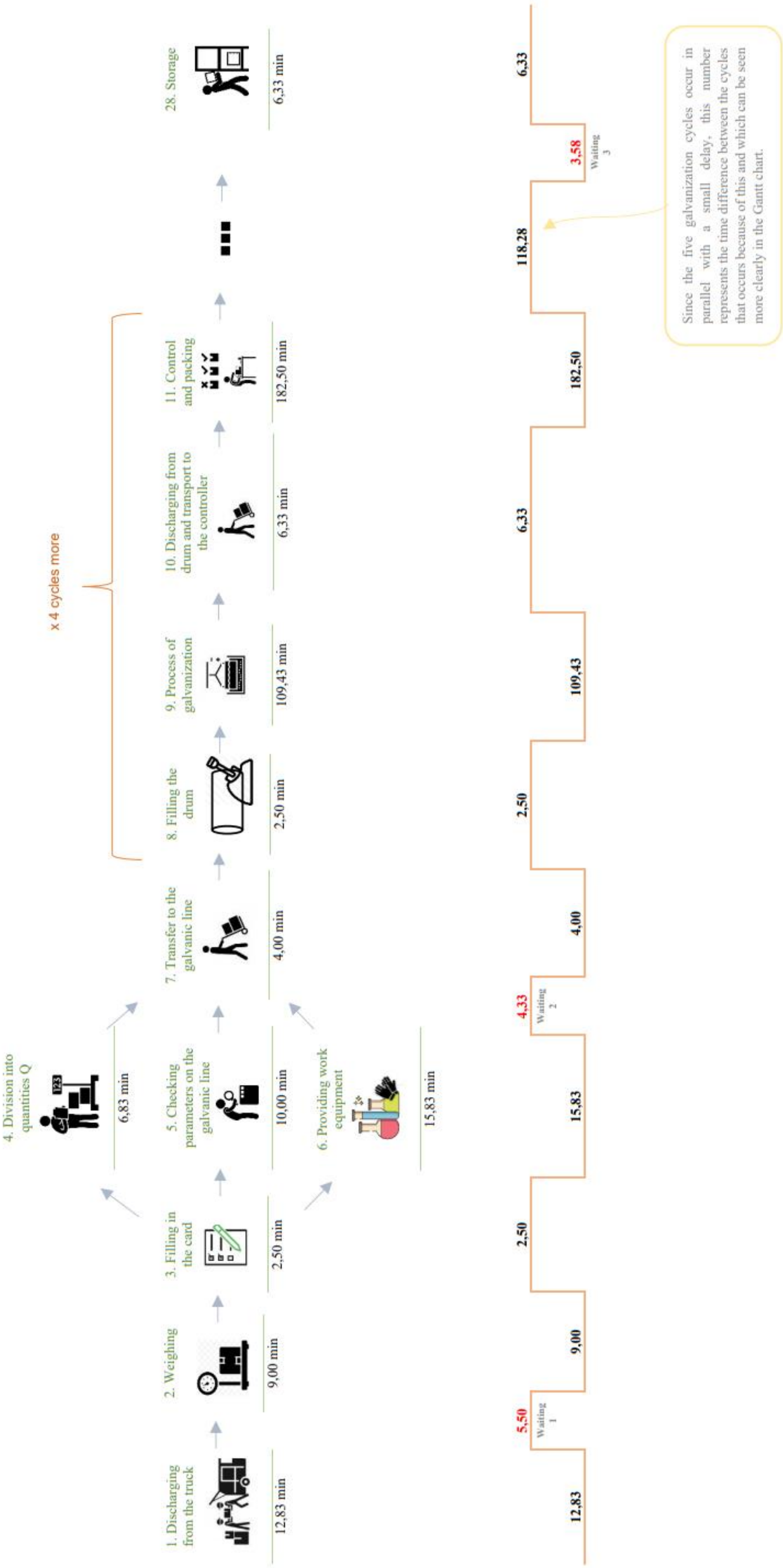
Table 9: Probability for different target values for non-ideal case

Target	Probability	
12 h	0,9938	99,38 %
11 h	0,9692	96,92 %
10 h	0,8917	89,17 %
9 h	0,7265	72,65 %
8 h	0,4876	48,76 %

It can be seen from Tables 6 and 9 that waiting in this process reduced the probability that the process would be completed in 8h by as much as 5,64%. The fact is that this is not the only order made in one shift and that workers must be coordinated and follow all lines in the company, however as it can be concluded the duration of this process even ideally corresponds to the duration of one shift, so it is necessary to work on individual activities and try to reduce the duration of the individual as much as possible, because in the process it will hardly ever fully satisfy the ideal case. There will always be little things that will take up precious time.

In the last chapter, the workers were reorganized in the phase of control of goods, ideally. If the same procedure is applied to this case with the waiting involved, there will again be very large and significant changes. By reorganizing as shown in Table 7, it is found that with the introduction of two workers to control each Q quantity, the process length of 8,05 h can be reduced to 6,53 h. These are enormous differences that require only a little more organization in the company, and which contribute to the fact that the whole process can certainly be completed within the time frame of one shift. The probability that the process will end during one shift will be 82.43% even with waiting in the process.

Diagram 4: A galvanizing process that includes waiting between individual activities



6. Conclusion

The goal of every company is a high level of production organization and continuous work to meet the needs and requirements of their customers. Speed at which something will be produced, quality of service, delivery time, flexibility and new technologies are all areas where companies gain a competitive advantage in a huge market. How much the company will respect all these fields depends exclusively on their organization and planning. Wrong planning could lead projects to ruin. When working on the implementation of large projects, it happened that mistakes in the organization and planning, whether it is time, money or human resources planning, lead to the collapse of a project, its prolongation for several years longer than originally planned and to huge costs and deviations from the planned budget. To avoid these situations, PERT and CPM methods, which have historically merged into one method over time, are tools that are used intensively in production planning. The scope of these methods is far from limited. They can be applied to various types of projects, from construction, maintenance, development of new technologies, all the way to the galvanizing process in which these methods are applied in this thesis.

This work aimed to use the PERT and CPM method to determine whether it is possible to galvanize an order of 240 kg of positions for the automotive industry in 12 hours. Data for these analyzes were collected in the company „Eurosjaj d.o.o.“ and since one shift lasts 8 hours, then this thesis is focused on whether this order can be fulfilled during the duration of one shift. The process in this company was followed from the order to the finished galvanized products. Firstly, it was needed to collect a list of all activities that are part of this process. It was found that there are 28 activities and the order of their development as well as their interdependence was established. Based on these data, it was possible to form a network diagram. Data on the duration of each activity were obtained from the company, where each of them was measured optimistic, pessimistic and more likely time. Based on these times, the expected time E (t), LS, LF, ES and EF were calculated, as well as the slack for each activity. a Gantt chart was also formed and it was a extremely helpful graphical representation of this process. The activities that take place in parallel and those that are most time consuming could be seen. Calculating the duration of each possible path in this process, the one with the longest duration was found and it represents the critical path of this process with a duration of 7,83 h in the ideal case. For this duration of the process, the probability that it will be possible to complete it in 12 hours was 99,59%, and in 8 hours it was 54,40%. Since controlling galvanized goods would require more expensive and highly advanced systems and machines, the most acceptable option for this company to reduce control time is by reorganizing the workforce. By introducing two workers to control each quantity, the duration of the process was reduced by 1,53 hours. This option is even more desirable for this company, because not only will the process be completed faster but workers will have breaks in this way and will be more relieved since the visual inspection of each part requires concentration, and the situation found in the company where one worker controlling all 50 kg without a break is exhausting.

Since it is almost impossible to achieve an ideal case in the process, the analysis of the duration of the process with certain waiting included is considered. These waits in the process of a few minutes did not have any justified reasons - they simply happened due to probably a certain dose of leisure in the work, and they unquestionably extended the duration of the process to 8,05 hours. The probability that the process with this duration will be completed during one shift was now 48,76%, and when the mentioned reorganization of workers was applied, the process would be possible to finish in 6,53 hours. Waiting is something that happens spontaneously and unplanned. They can sometimes extend the process by a minute, and sometimes it can be an hour. Therefore, it is crucial to create a process that can afford certain waits and organize it so that the customer must not suffer because of the situations that take place in the process. As can be concluded from the processed order, the duration was very close to the duration of one shift, and exceeding it does not benefit the company. Transferring work to the next shift and investing more labor from the second shift in this order or even working overtime is not an acceptable option, so it is necessary with only a small reorganization to try to make a stable, shorter, and more productive process.

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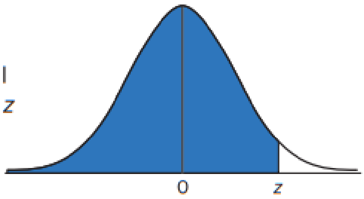
Appendix 1: Table of areas under the standardized normal curve, Stevenson (2018)

Table B.2
Areas under the standardized normal curve, from $-\infty$ to $+z$



z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7703	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998