ISSN 2683-345X
journal homepage: http://ijiemjournal.uns.ac.rs/

International Journal of Industrial Engineering and Management

Volume 17 / No 4 / December 2026 / 473 - 483

Original research article

Application of cost-time profile as a criterion for optimizing an investment project

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ABSTRACT

Increasing demands for efficient resource allocation and project performance are closely related to balancing economic efficiency and implementation duration. The problem of cost-time optimization is a key aspect of investment project planning from the perspective of lean production. Investors and project planners must select appropriate resources, including contractors, equipment, processes, and technology, to ensure efficient project implementation. They are always faced with the need to find a compromise between cost, quality, and time to complete the required activities. The paper analyses a project for building a 50 kW heat and electricity cogeneration plant. Various measures for cost-time optimization of the project are simulated, and their results (project costs, duration, cost-time investment) and consequences are evaluated. The findings show that faster projects offer significant advantages. The article provides important support for decision-making in projects.

ARTICLE INFO

Article history:
Received March 24, 2026
Revised June 24, 2026
Accepted July 28, 2026
Published online October 14, 2026

Keywords:
Investment project;
Value stream analysis;
Cost-time profile;
Cost-time investment;
Optimization

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1. Introduction

In the field of engineering, there has been significant development of methods, tools, and techniques that are successfully used to solve various optimization problems [1]. Modern production demands, above all, shorter lead times and production cycles, reduced inventories, greater adaptability to customer requirements, lower costs, increased efficiency, high profitability, increased market share, and defect-free quality products [2]. These topics are discussed daily in academic circles across various fields (engineering, management, economics, law) and within the economy across different industries [3]. Intense competition in the markets requires providers to meet customer requirements at a high level and, crucially, to outperform competing providers [4].

The aim of the research is to analyze and optimize a planned investment project in the field of electricity and heat production. The main focus will be on the structure of the necessary activities, time and costs, procurement of materials, and the scheduling of activities. The research objectives address areas where professional literature does not provide clear answers for industrial practice, as each project presents specif-

Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.
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https://doi.org/10.24867/IJIEM-429

ic requirements, feasibility conditions, and a comprehensive implementation framework, which forms the basis for creating rational organizational solutions.

Lean manufacturing means that a company uses less labor, less space, less investment, less time, and fewer resources for process activities [4], [5]. Therefore, this article will compare different variants of implementing an investment project in terms of savings in materials, labor, and faster implementation (reduced waiting time).

To optimize the investment project for the construction of a micro-cogeneration plant (50 kW) generating electricity from natural gas, an extended value stream model will be used, which includes a Cost-Time Profile (CTP) and determination of the necessary Cost-Time Investment (CTI). An analysis of the required activities, planning of implementation costs, value stream analysis, and optimization of the cost-time investment will be carried out based on the developed variants of the project's cost-time profile, with the aim of achieving "leanness" in project implementation.

The remainder of the paper is organized as follows. Section 2 provides literature review. Section 3 introduces the applied heat and electricity cogeneration project with the initial and optimized states. Section 4 summarizes the research conclusions, emphasizes novelty, analyses challenges, and discusses future research directions.

2. Literature review

2.1 Cost-time profile

Accounting addresses costs without considering their relationship to time, whereas the value stream presentation places the greatest emphasis on the flow of time and does not include information on how costs were incurred or how the accumulation of costs over time affects the operations and parameters of the production system [6].

One possible solution to the previously mentioned shortcomings of existing approaches is the cost-time profile. This concept was first introduced by Fooks [1] at Westinghouse Electric Corporation. The developed technique answered the question of how to measure system progress or how to make appropriate decisions regarding process improvement measures. Fooks defined the cost-time profile as a diagram showing the accumulation of costs over time throughout the entire business cycle (from negotiating with the customer and receiving the order to delivering the product and receiving payment). It is therefore a money-oriented diagram, as investment must be understood as a dynamic rather than a static category. Money represents value, and this value is linked to time dynamics.

The cost-time profile is based on the idea that every business activity can be seen as an accumulation of costs over time. This tool is fully compatible with value stream mapping and provides a more comprehensive view of processes, as it enables monitoring the relationship between time and money [2].

The cost-time profile is a graphical representation of the accumulation of direct costs, tracking the movement of a product through the process and showing how much money is spent on production and how much time will elapse until the money is returned through the sale of the product [3]. The cost-time profile deserves full attention, as it reveals opportunities for improvement and assists in selecting measures to achieve improvement. It also allows the quantification of savings after implementing measures to improve operations.

To draw a cost-time profile (an illustrative example is shown in Figure 1), data on processes, costs, and activities are required, regardless of the type or complexity of the production process: 1) material (including for services and information provision), 2) labor (workforce), 3) waiting [1], [3].

The component relating to the workforce can also be referred to as an activity, as it concerns the performance of an activity.

Material costs are shown on the diagram with a vertical line, as they are incurred immediately at the start of an activity. The material may enter the process at the outset, or a Just-In-Time materials procurement system may be used, where the material enters precisely when required for a specific activity.

Since only identified direct costs are considered when creating a cost-time profile, waiting is shown as a horizontal line in this context, although it does affect indirect costs to some extent. However, this line is not perfectly horizontal, as it has a slight slope because waiting always incurs certain costs, such as cost of tied-up assets, inventory costs, and similar expenses [4]. Waiting definitely affects the cost-time investment, as it increases the time needed to recover the investment and also extends the time to deliver the product to the market.

Activities are represented on the diagram by an inclined line. This essentially reflects the work performed, shown as the amount of money per unit of time added to the total investment over time. For each activity, data must be collected on the start and

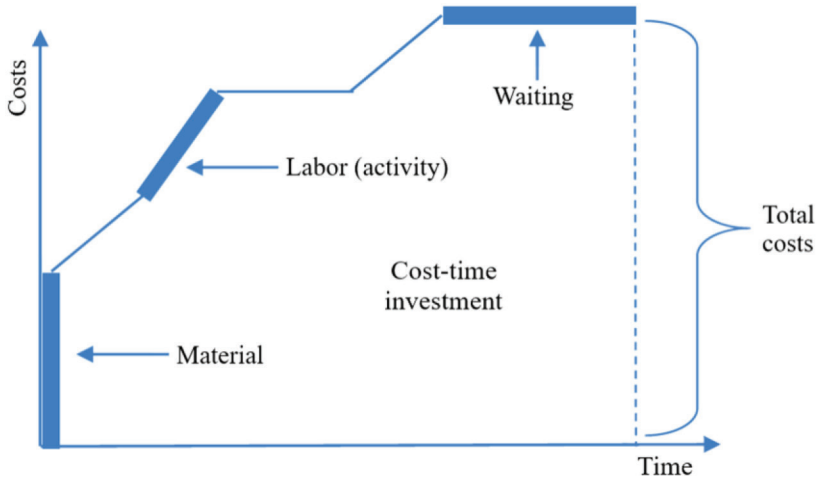


Figure 1. Cost-time profile description [1].

end of execution (duration), the labor costs associated with the activity, the costs of working resources, and other direct costs incurred by the activity. With the collected data, we can see when each component is performed and how much it costs. By combining these two sets of data, we can determine the cost of each time unit in the process [2]. The area under the accumulated cost curve also represents the inventories in the system, including inventories of materials, work in progress, and finished goods.

Total costs represent the sum of all direct costs; in the diagram, this is the highest point on the right. However, total costs alone do not provide information about the impact of time on investment. The cost-time profile adds the time dimension to cost accumulation, while the cost-time investment, or the area under the curve, measures the resources invested in the process of creating a product and its value [2]. Only the cost-time investment shows the relationship between time and costs, and the aim is to reduce this area under the curve by any economical means. A decrease in the height of the area indicates lower direct costs, while a decrease in its length indicates a shorter production cycle, leading to higher quality of service for the customer.

The total cost doesn't reflect the effect of time on the investment. Cost-time investment consists of cost and time dimensions; it is closely related to the Theory of Constraints. Its cost value can be obtained by multiplying it by the appropriate interest rate. The direct cost is obtained as follows [5]:

$$\text{Direct cost} = \text{Total cost} + (\text{Cost-Time Investment} \times \text{Cost-of-money Rate}) \quad (1)$$

The most important goal of value stream optimization is therefore to find the best way to reduce the area under the curve. The cost-time profile is extremely useful because it links financial analysis with competitive analysis and expands opportunities for improvement. It helps us to better understand the processes from a value perspective. It provides more accurate estimates of the costs associated with the processes and enables improved idea generation and evaluation.

2.2 Brief overview of recent publications

Rivera and Chen [3] laid the foundations of the cost-time profile as a tool that tracks the accumulation of cost in the manufacturing of a product over time, and the cost-time investment, which indicates the use of resources in manufacturing through quantities and timing. Gracanin et al. [4] introduced a framework for value stream optimization by combining value stream costing and the cost-time profile, which is also a powerful tool for visualizing cost accumulation over time across the entire production flow.

Hybrid modelling to optimize the number of workers with minimal asynchronous waiting time and activity costs, based on waste management collaboration processes, was presented by Sungkono et al. [6]. Ojstersek and Buchmeister [7] presented the impact of manufacturing flexibility on cost-time investment as a function of sustainable production. A new method for evaluating optimization parameters with respect to the impacts of manufacturing flexibility on cost-time investment is provided.

Keykavoussi and Ebrahimi [8] emphasized the effective use of value stream mapping, and for each future state map, the new fuzzy approach to the cost-time profile has been considered and compared. Khakpour et al. [9] examined the effect of the time

value of money on sustainability by using the cost-time profile as a sustainability criterion. This broader perspective on sustainability criteria enables practitioners to assess and enhance sustainability in their operations more holistically.

Seyedhosseini and Ebrahimi-Taleghani [10] incorporated the cost-time profile into the future state map selection process and analyzed cost-time investment in relation to total production lead time and the direct cost of the product. Ojstersek et al. [11] investigated the interactivity between mathematical and simulation models for production system scheduling. The interactive method presented can be applied in various production and service companies to ensure an optimized and sustainable cost-time profile.

Marc et al. [12] developed a decision-making model to analyze the average cost of the product and highlighted the importance of the cost-time profile. This model allows simulation of optimal actions in response to changing market conditions. Gracanin et al. [13] simulated the impact of different schedules on total production cost and cost-time investment (representing the time value of money), which they propose as a new scheduling objective function. Kremljak et al. [14] simulated cases with varied execution periods of non-critical project activities within the slack and measured cost-time investment. The results indicate that the differences are significant, offering potential for project optimization.

Rieger and Sebastián [15] developed the PECOTA method, a graphical approach for analyzing the value stream map and the cost-time profile. It enables initial analysis and evaluation of changes in a manufacturing process. It can be concluded that relatively few articles address the use of cost-time profiles.

From all of the above, it is clear that there is a research gap regarding the use of the cost-time profile in larger investment projects and in the selection, evaluation and inclusion of appropriate optimization measures.

3. Heat and electricity cogeneration project

The main objective of the project was to install a 50 kW micro-cogeneration plant using natural gas for the purpose of heating an industrial facility, including the construction of the plant and connection to the network (to the distribution electricity network, to the natural gas network and to the facility's hot water network). With cogeneration using natural gas, we can save up to 40 % on primary energy consumption, and at the same time we can reduce the costs of energy supply. The project has been implemented at ECOS CENTER d.o.o., Murska Sobota. The project's sources of financing were company's own funds and government support (incentive) was in the form of a feed in tariff for electricity in the amount of 0.24 €/kWh for a period of 10 years. Some basic data:

- micro-cogeneration unit with installed electric power of 50 kW,
- electricity production: 200 MWh/year,
- natural gas consumption: 57,143 Nm^3/year,
- operation hours: 4,000 h/year.

The list of necessary, appropriately grouped project activities for the construction of a cogeneration device is provided in Table 1. Basic data on project activities, including their duration, interdependence or sequence, costs of materials, labor, external services, and costs arising from legal obligations, are presented in Table 2. All time data refer to the standard calendar (1 week equals 7 days), not just working days.

Analysis using a network diagram indicates that the expected duration of the project is 177 days (approximately 25 weeks, or just under half a year). Critical path:

A – B – C – D – E – G – H (I) – J – K.

3.1 Cost-Time Profiler software

Cost-Time Profiler is dedicated software developed to facilitate data collection, perform calculations, and plot cost-time profiles [3]. The software was developed at the University of Virginia (USA) – Virginia Tech, in the Center for High Performance Manufacturing.

The cost data entry fields are tailored to the requirements of value stream-based cost accounting, meaning that only direct costs are considered. First, we define the project name, add a short description, then we enter the number of working days per year and the time unit for all time-related entries. In the settings, we define the appearance of the cost-time profile diagrams. Next, we enter data about the company (the investor), data about the contractors of individual activities and their labor costs, data about the equipment, its purchase value, maintenance costs and life cycle, with the aim of calculating all direct costs related to the equipment. Finally, we enter data about the activities, the start and finish times of operations, the cost of the material for a specific activity, the

Table 1. List of project activities.

Activity code	Activity
A	Conceptual design
B	Obtaining project conditions and obtaining consent for connection to the grid
C	Project for the implementation of works
D	Tender documentation and contractor selection
E	Construction of a cogeneration facility
F	Signing the network connection contract Construction of electrical connection Signing an electricity sales contract
G	Project of the executed works and operating instructions
H	Signing a network access contract
I	Review of compliance with connection conditions
J	Technical inspection Connecting the cogeneration device
K	Obtaining a declaration for a cogeneration facility Obtaining a decision on granting support Signing of the support contract Operation in the support scheme (= project objective achieved)

Table 2. Basic data on cogeneration project activities.

Activity code	Duration (days)	Immediate predecessors	Costs
A	30	/	Labor: 3,000 €
B	30	A	/
C	10	B	Labor: 2,000 €
D	7	C	Labor: 1,000 €
E	45	D	Material: 50,000 €. Labor: 23,000 €
F	7	B	Service: 2,000 €
G	7	E, F	Service: 1,000 €
H	2	G	/
I	2	G	Labor: 500 €
J	1	H, I	Service: 2,500 €
K	45	J	/

equipment used and the contractors. We also specify the predecessor for each activity. After entering the necessary data, the software generates a cost-time profile and calculates the total project costs and cost-time investment. The software also calculates the costs for each activity separately and displays the occupancy of contractors and equipment for the project.

3.2 Project cost-time profile (baseline calculation)

Additional project information, simplifications, limitations, constraints or assumptions are as follows:

- The number of working days per year is 255.
- The time unit used is the day.
- The project is guaranteed to start at the scheduled time.
- The project plan is not changed during implementation; the case study is deterministic.
- The annual cost of capital rate is 10 %.
- The profit and overhead rate are set at 0 %, as this is not the subject of the research.
- Necessary materials are purchased according to the JIT principle (at the start of the activities that require them).
- The labor costs of the group of contractors by activity (in € per day) are: A: 100, C: 200, D: 143, E: 511, F: 286, G: 143, I: 250, J: 2,500
- The potential use of new technology does not cause any project delays (e.g. due to lack of

knowledge, training needs, etc.). Workers' motivation and quality of work remain the same.
- For better transparency in graphic presentations, all costs are given with a ratio of 100, i.e. they are entered in 100 € units (e.g. for 2,500 € we enter 25, etc.); on the plots of the cost-time profile, days are always on the x-axis and costs in 100 € units are on the y-axis.
- All activities are completed exactly by the planned deadline, and the quality of implementation is always adequate. There are no additional costs for overtime work.
- Activity F is not critical; in the basic variant, it is carried out as soon as possible, and in the optimized variants, as late as possible.
- All necessary resources (contractors, financial resources, equipment, data, etc.) are available during the specified period, regardless of business opportunities or other conditions.

By selecting the "Project / Perform Calculations" command, the software calculates the cost-time profile and displays it graphically (CTP diagram, Figure 2).

The results show that the total project costs are 84,999 €, and the direct costs, which include the interest rate on the invested funds, are 85,374 €. The cost-time investment is 8,029,244 €×days. This means that over the 177-day project period, an average of 45,363 € is invested (tied up).

3.3 Project cost-time profiles (optimized states)

For optimization, we consider five variants, each offering a specific opportunity to optimize the implementation of the cogeneration of heat and electricity project:

- faster completion of certain activities at the same cost (a),
- cheaper completion of certain activities with the same duration (b),
- implementation of non-critical activity F at the latest possible deadline (c),
- use of cheaper materials for the project (d),
- a combination of all four previous optimization options (e).

(a) After assessing possible time savings in activity duration (with unchanged implementation costs), we calculate the cost-time profile with the following data:

- activity A is completed in 15 days (previously 30 days),
- activity B is completed in 15 days (previously 30 days),

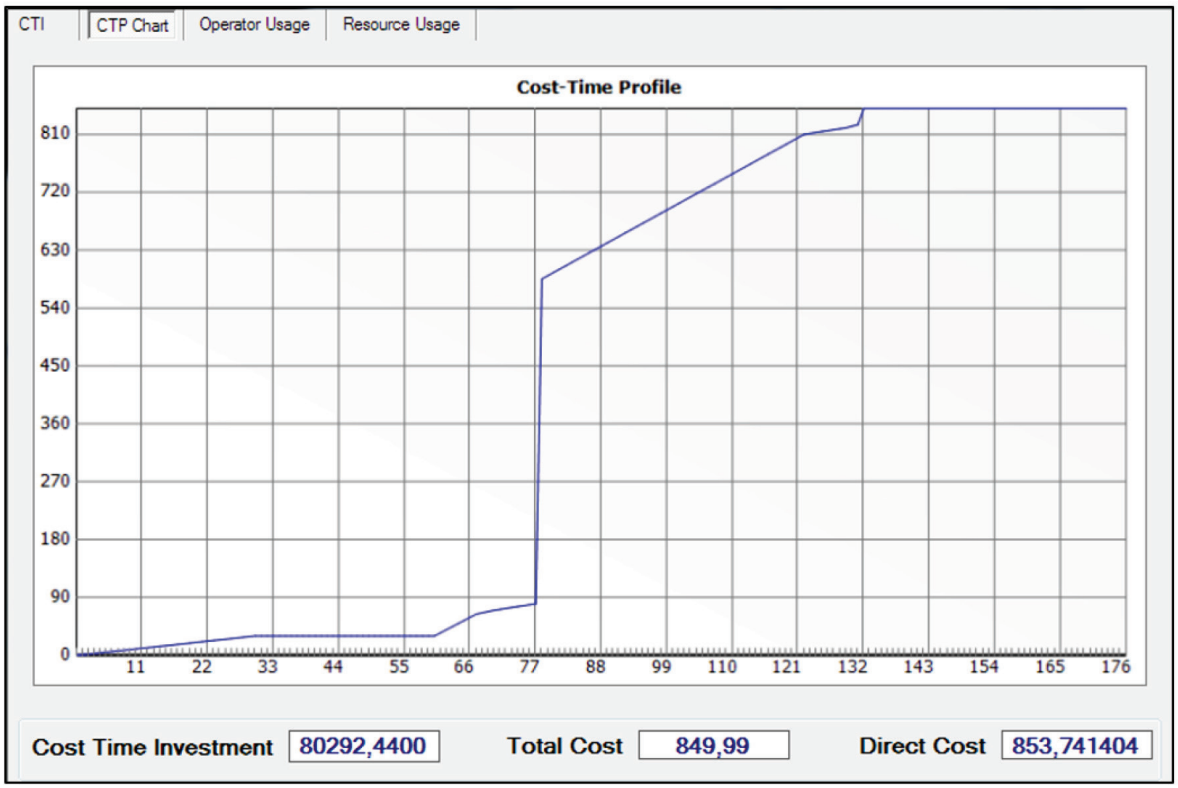


Figure 2. Project cost-time profile for the baseline. *Authors own work*

- activity C is completed in 5 days (previously 10 days),
- activity E is completed in 30 days (previously 45 days),
- activity K is completed in 30 days (previously 45 days).

Such reductions can be achieved primarily by engaging a larger number of workers (with the same motivation). This is the most optimistic implementation in terms of time. The total expected duration of the project is now only 112 days (16 weeks or less than 4 months). Thus, we achieve a reduction in total time of 65 days, corresponding to the amount by which we have shortened the duration of the selected critical activities (Figure 3). The critical path remains unchanged. The cost-time investment is 5,615,074 €×days, representing a 30 % reduction. During the 112-day project duration, we have an average of 50,135 € invested (tied up).

(b) After assessing possible cost savings achieved through negotiations with contractors or through work rationalization (with the implementation duration and quality of work remaining unchanged), we calculate the cost-time profile with the following data:

- labor costs for activity A are 2,400 € (previously 3,000 €).
- labor costs for activity E are 21,000 € (previously 23,000 €).

The results show that the total project costs are 82,419 € (a 3 % reduction compared to the baseline), and the direct costs are 82,782 € (Figure 4). The cost-time investment is 7,777,304 €×days, which also represents only a 3 % reduction. During the 177-day project duration, we have an average of 43,940 € invested (tied up).

A comparison of the first two optimization measures shows that it is much more important to implement the project as quickly as possible (without special cost-cutting) than to invest additional effort and time in finding cheaper contractors, with the associated risk of poorer quality work.

(c) Activity F is not critical and is performed at the latest possible deadline (activity duration and implementation costs remain the same as in the baseline). Activity F starts on day 116, i.e., 55 days later.

The cost-time investment is 7,919,134 €×days, which represents only a minimal 1 % reduction (Figure 5). Over the 177-day project period, the average amount invested (tied up) is 44,741 €.

In this case as well, it is evident that time optimization of activities with a minimal share in project costs (activity F accounts for around 2 % of total costs) does not yield significant savings.

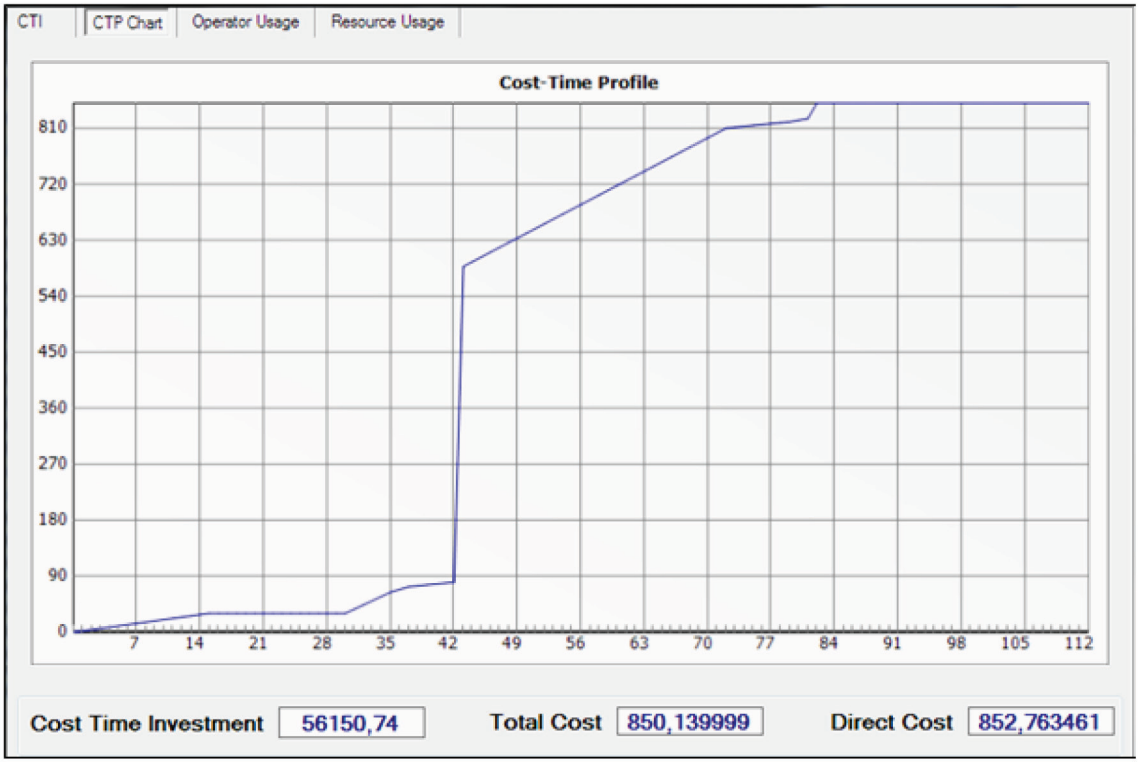


Figure 3. Project cost-time profile for the reduced activity durations option. *Authors own work*

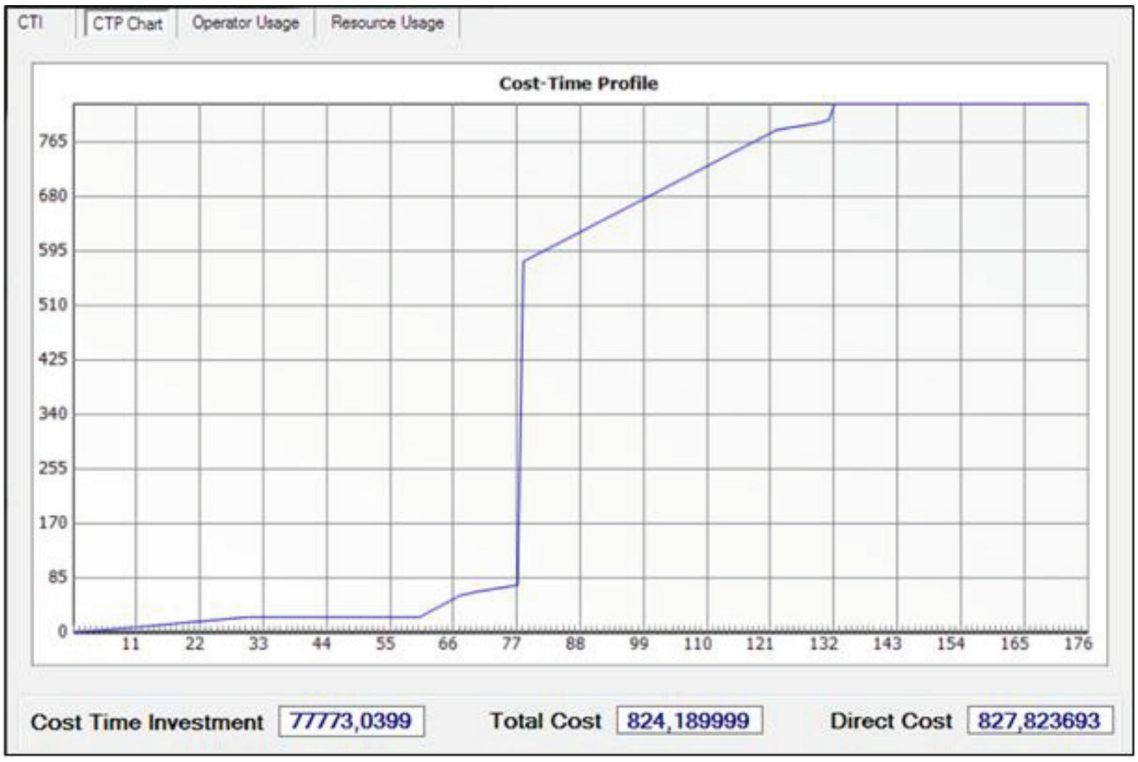


Figure 4. Project cost-time profile for the reduced labor costs option. *Authors own work*

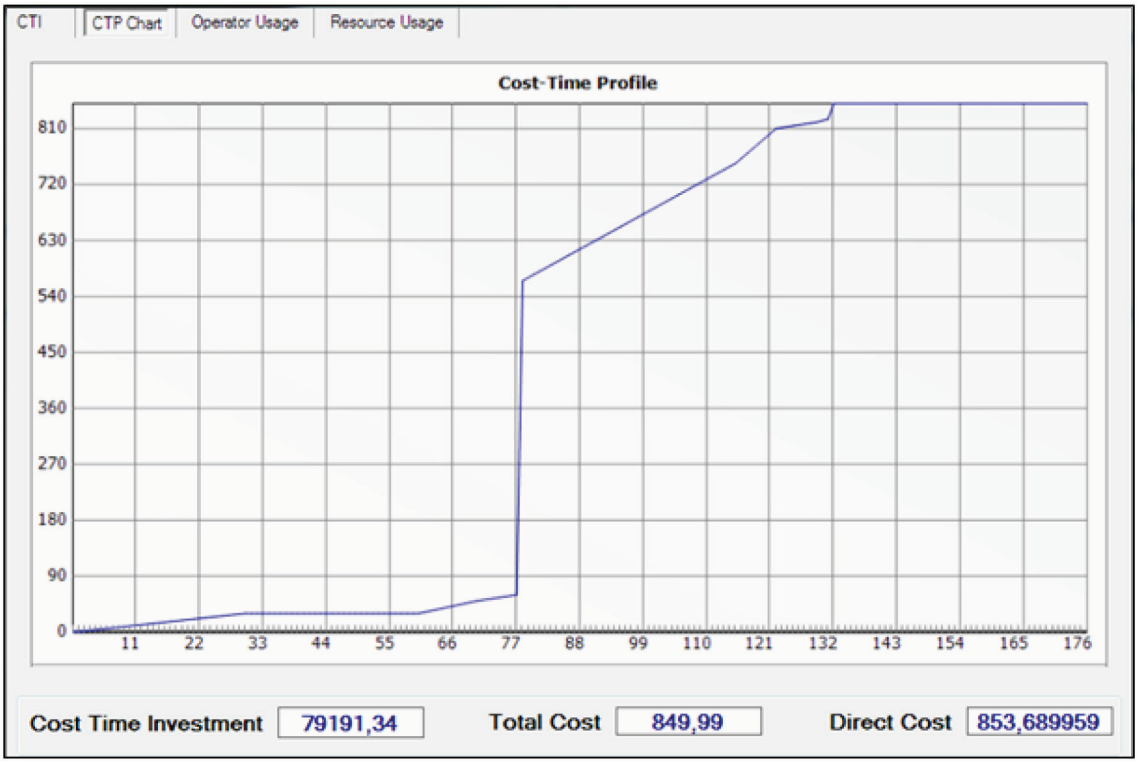


Figure 5. Project cost-time profile for the latest possible performance of activity F option. *Authors own work*

(d) The project has the option of purchasing cheaper equipment; instead of proven Western technology, a cogeneration device can be bought, for example, from a Chinese provider (the project assumes unchanged implementation duration and equal labor and service costs). In the initial variant, materials account for 59 % of total costs, while in the optimized variant, they account for 46 %.

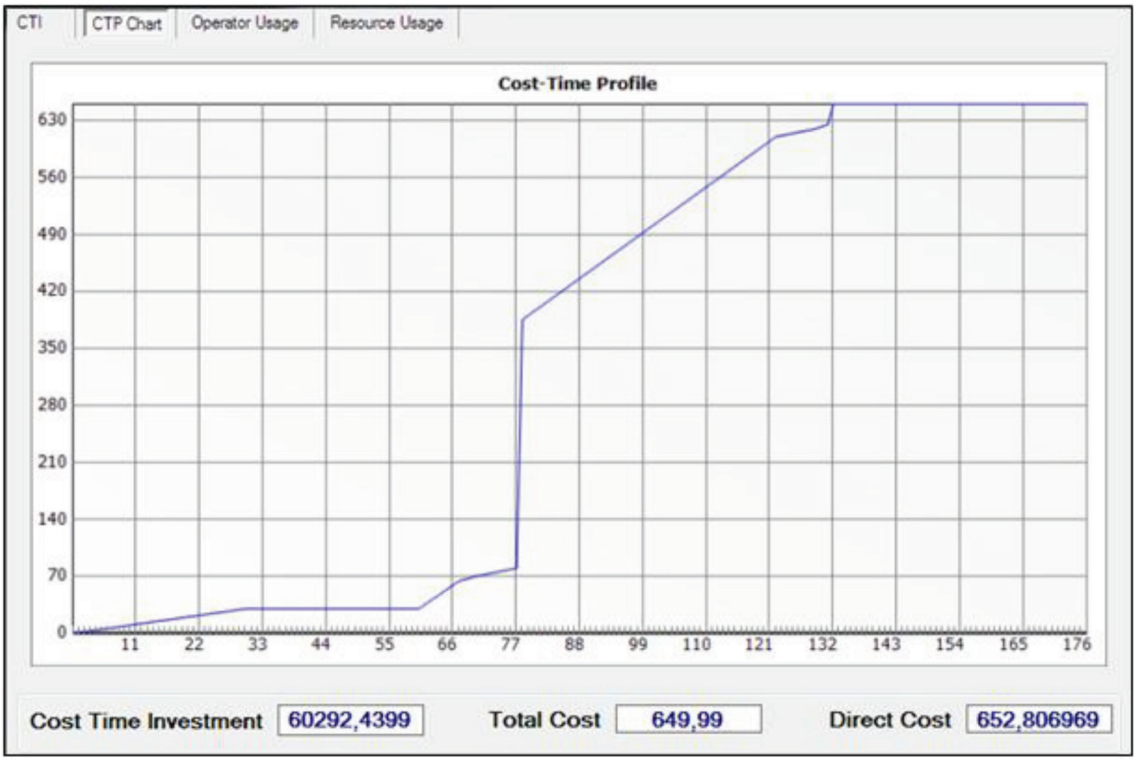


Figure 6. Project cost-time profile for cheaper equipment option. *Authors own work*

When calculating the cost-time profile, the lower material price of 30,000 € (previously 50,000 €) is considered (Figure 6).

The results show that total project costs are 64,999 € (a 24 % reduction compared to the baseline), and direct costs are 65,281 €. The cost savings are solely due to the purchase of a cogeneration device that is 20,000 € cheaper. The cost-time investment is 6,029,244 €×days, representing a reduction of around 25 %. During the 177-day project duration, the average amount invested (tied up) is 34,064 €.

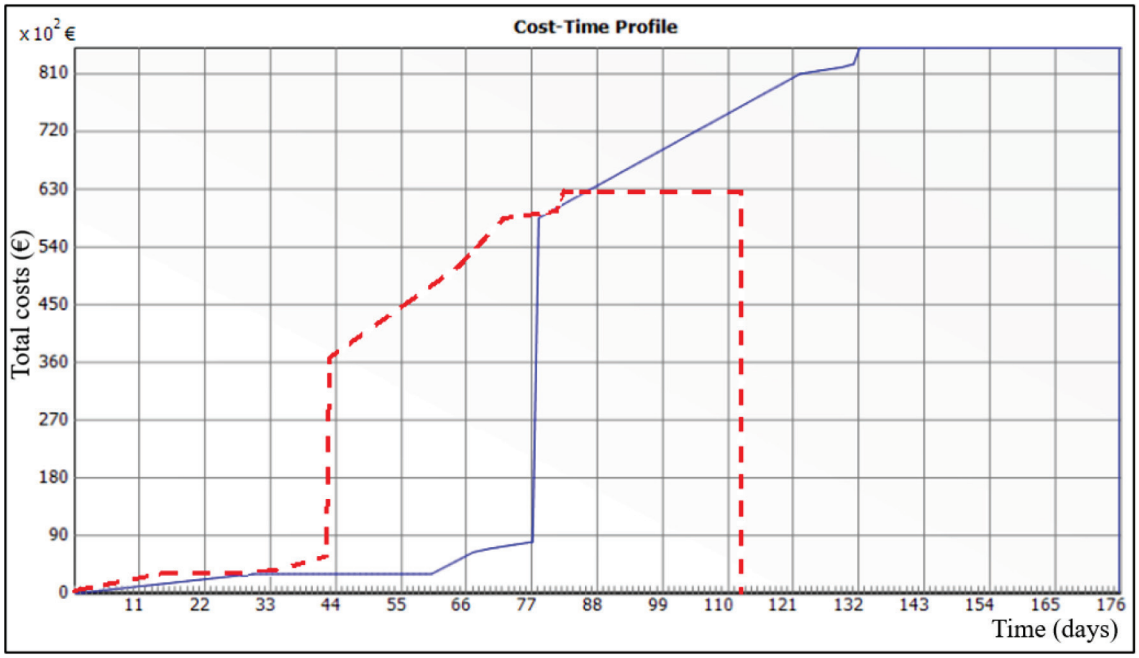
When purchasing cheaper equipment, we must recognize that this will result in lower costs and reduced financial requirements during project implementation, and lower project reliability. However, over the entire lifespan of the production facility, there will be a significantly higher risk of failures due to the potentially lower quality of equipment from a less established supplier. We must also consider the implications for maintenance, procurement of spare parts, and the operational efficiency achieved by the facility.

(e) The cost-time profile is calculated by considering all the changes described in the previous optimization measures (a), (b), (c), and (d). The results show that total project costs are 62,404 €, representing a 27 % reduction compared to the baseline (and the total possible savings from implementing the investment). Direct costs are 62,590 €. It is evident that the total cost of tied-up assets, inventory costs, and similar items in the project does not exceed 186 €, which represents only 3 ‰ of the investment. The cost-time investment is 3,970,449 €×days, which is more than a 50 % reduction compared to the baseline. During the 112-day project duration, an average of 35,450 € is invested (tied up).

A graphical representation of the savings in project costs and cost-time investment is shown in Figure 7, which combines the latest (e) and baseline data. The savings are significant, but it is important to be aware of all the associated risks and uncertainties that the new situation entails.

4. Conclusion

Project management is a very important research area, as it connects activities and ensures the economical use of resources. Project implementation is linked to time, available funds (budget), quality, customer satisfaction, and other factors. Project-oriented companies very rarely use the cost-time profile as part of project evaluation activities. Therefore, this research used an analysis based on the project's cost-time profile, comparing six project implementation variants and highlighting the advantages and disadvantages of



Note: Solid (blue) line – baseline, dashed (red) line – optimized state (e)

Figure 7. Comparison of the project cost-time profile in the case of a combination of all optimization options and the baseline. *Authors own work*

each. The findings show that faster projects offer significant benefits, but it is important not to overlook the potential for cheaper labor and materials, provided that appropriate quality and subsequent operational efficiency of the devices are maintained. In capital-intensive projects time compression is essential.

The original scientific contribution of this research lies in the application of the cost-time profile as a decision-support criterion for investment project optimization. Through a detailed case study of a co-generation plant project, the research quantitatively evaluates alternative implementation scenarios and demonstrates how project duration influences both total costs and cost-time investment. The study integrates lean production principles with project scheduling and investment evaluation, providing a practical framework for identifying economically optimal project execution strategies. With some details emphasized:

- Integration of lean production principles with project optimization (the study integrates lean production principles with project scheduling and investment evaluation through the cost-time profile approach, providing a framework for simultaneously assessing project duration and capital commitment).
- Novel application of the cost-time profile method (application of the cost-time profile concept to demonstrate its usefulness as a practical decision-support criterion in real investment environments).
- Multi-scenario quantitative evaluation (the novelty is the systematic comparison rather than merely calculating a schedule; the paper develops and compares multiple project execution scenarios and quantitatively evaluates their effects on project duration, total cost, and cost-time investment, providing evidence-based guidance for selecting an optimal implementation strategy).
- Demonstration that minimum cost is not necessarily optimal (the research demonstrates that project optimization based solely on direct costs may lead to suboptimal decisions, while the cost-time profile reveals economically superior solutions that balance expenditure and implementation speed).
- Introduction of cost-time investment as a decision criterion (the study proposes the use of cost-time investment as an additional project evaluation criterion, enabling decision-makers to capture the economic consequences of project duration that are overlooked by conventional cost-based analyses).

Additional optimization options include the following: rescheduling high-cost activities to later time windows (by splitting some critical activities, which also reduces cost peaks), resource smoothing to avoid

cost spikes, converting upfront costs into milestone-based payments (shifting cost accumulation to later stages), and re-evaluating the critical path under CTP logic (cost-critical path – activities that contribute most to CTI). Including an uncertainty analysis by incorporating risk (resource availability, schedules, material arrivals, durations, quality outcomes, costs etc.) would also be useful to make the results more realistic.

Another advantage of using the cost-time profile in project management is its ability to reveal hidden inefficiencies that traditional project metrics often overlook. By visualizing how costs accumulate throughout the project lifecycle, managers gain a clearer understanding of capital exposure, enabling more informed decisions about scheduling, procurement, and resource allocation. The method also supports proactive risk management, as shifts in the cost-time curve can indicate emerging delays or budget pressures earlier than conventional monitoring tools. Furthermore, the cost-time profile encourages a more holistic view of project performance by integrating financial and temporal dimensions into a single analytical framework. This makes it a valuable complement to established project management techniques and a practical tool for continuous improvement in project-oriented organizations.

This article presents guidelines for project-oriented companies on how to analyze and improve operations using the cost-time profile, as it is a viable tool within the value stream improvement methodology. Future research will focus on other potential areas of application for the cost-time profile, like batch production.

Funding

This work was supported by the Slovenian Research and Innovation Agency [grant agreement number P2-0190].

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