PAYBACK CALCULATION REFINEMENT OF INDUSTRIAL ROBOT APPLICATIONS

DAVID ZENISEK[1], TOMAS BROUM[1], MICHAL SIMON[1]

[1]Department of Industrial Engineering and Management, Faculty of Mechanical Engineering, University of West Bohemia, Pilsen, Czech Republic

DOI: 10.17973/MMSJ.2023_10_2023077

broum@fst.zcu.cz

The paper focuses on describing and applying a refined method of investment payback calculation related to industrial robot applications. Industrial robots play an important role in modern manufacturing companies, therefore it is important to precisely determine the investment payback of robot applications. In the first part of the paper, we introduce payback calculation theory in general and the current approaches to payback calculation of robot applications in practice. Subsequently, we point out that current approaches seem insufficient due to tracking only a limited number of costs and savings. Subsequently, we attempt to identify all identifiable costs and savings related to robotic applications, then we present a refined method to determine the payback of robot applications more precisely. The method is then applied in a case study performed in an industrial enterprise. Finally, we evaluate how significantly this refined method differs from the calculation used in practice and these findings are summarised.

KEYWORDS

Payback, Industrial Robot, Costs, Savings, Investment

1 INTRODUCTION

Modern technology is fundamentally influencing manufacturing worldwide. Each industrial revolution has brought significant changes and within a few decades has fundamentally changed industry. Nowadays, there is a fourth industrial revolution (also called Industry 4.0), which encompasses technologies that have profound effects on worker performance, or more accurately, on the workplace performance. One of these technologies is automation by industrial robots, where humans and robots not only coexist but also cooperate (collaborate). [Geissbauer 2015], [Liao 2017], [Malaga 2020], [Narodni iniciativa Prumysl 4.0 2015], [Pollak 2022], [Rüßmann 2015], [Sniderman 2016]

The International Federation of Robotics (IFR) annual report shows the increasing global sales of industrial robots over the last 10 years, with annual growth of around 11% over the last five years, with over half a million robots installed by 2021, see Fig. 1. [IFR 2022]

According to market research reports [MRR 2019], the global industrial robotics market is expected to reach 42.29 billion USD by 2026 in terms of robotic machines, and 138.03 billion USD in terms of robotic systems. According to IFR [IFR 2017], the average price of an industrial robot has fallen by 60% since 2005 to $27,074 in 2017 and further decline is expected. Robots are being used across industries and their applicability continues to grow due to developments and new technologies [Lee 2015], [McKinsey & Company 2019], [Murphy 2017], [Pollak 2022]. A 2018 McKinsey survey [McKinsey & Company 2019] shows that the main reasons for investing in robotics and automation is to reduce costs. The costs are therefore crucial and precise payback calculation linked to the costs is very important. In this paper we point out that current approaches seem insufficient due to tracking only a limited number of costs and savings related to robotics. So we concentrate on the detailed specification of costs together with potential savings in relation to the application of industrial robots and on the basis of this we propose a refined and relevant payback method. This can potentially help industrial companies to make better decisions related to industrial robot applications.

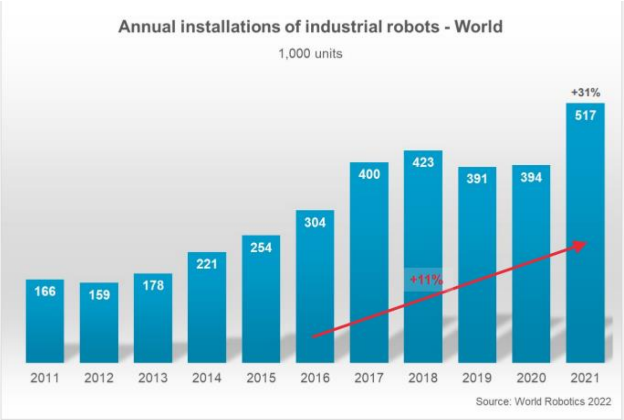

Figure 1. Annual installations of industrial robots – World [IFR 2022]

2 LITERATURE REVIEW

Cost reduction is one of the main factors in the acquisition decision. The payback calculation is directly linked to cost reduction and supports the important decision of many companies of whether or not to use industrial robots. [Grznar 2020], [Horejsi 2020], [Rudy 2022] First, we look at the approaches to payback given in the literature, and compare them with how businesses look at payback.

In the literature, there are a number of views on payback and its definition. Pearce [Pearce 2016] argues that the purpose of calculating payback is to measure over a period of time the rate of return on money invested in order to decide whether it is worthwhile making an investment. Botchkarev and Andru [Botchkarev 2011] write that payback can be understood as any kind of (financial and non-financial) benefit/effect/outcome or impact/value to the company. In this text, we will stick to the first definition and we will evaluate robot application economically. Technical evaluation is not intended to be a significant part of the paper, but the technical values will be important inputs to the presented refined method.

The literature offers many approaches to evaluating investment and its payback. From an economic point of view, the investment evaluation methods can be divided into static and dynamic methods, depending on whether or not they take time as a factor. [Synek 2011]

Static methods include TCO (Total Cost of Ownership), ROI (Return on Investment), Break-even point methods and the payback period. TCO is used to express the complete cost of an investment and its operation, taking into account not only the purchase price but also the expenses related to owning the investment and operating it [De Clerck 2016]. According to Kleinova [Kleinova 2005] and Kislingerova [Kislingerova 2007], ROI (sometimes referred to as ROI index) refers to the ratio of money earned to money invested and is the ultimate indicator of the comprehensive efficiency of a business. [Zamfir 2016] Break-even point is used to determine the amount of production or time at which a company incurs no profit or loss related to the specific product and its investment. It is the point at which the business pays off the investment (returns money) but has not yet generated any profit. [Kalouda 2011] The payback period is the length of time required to gain back the cost of an investment and is related to the Break-even point method. [Kleinova 2005]

Dynamic methods include NPV (Net Present Value) and IRR (Internal Rate on Return). NPV is one of the most commonly used criteria. The method determines the difference between the discounted revenues of an investment and the initial investment cost. IRR gives a result which is a percentage reflecting the value at which the discounted revenues of the investment are equal to the initial cost of the investment. [Kleinova 2005], [Kislingerova 2007], [Kalouda 2011]

Online payback calculators can be found on the internet [RIA 2023], [TIE 2023], [MSI TEC 2021], [Yaskawa 2023]. They say they calculate the return on investment, but actually these online calculators calculate the payback period of an investment using cost savings over a specified time period. In other words, they divide the investment costs to the robotic solution by the result of the difference between current and proposed operating costs.

The factors considered in the calculators are mostly the same. For example, RIA [RIA 2023] and T.I.E. Indusitrial & Robots [TIE 2023] calculators take into account the cost factors, stated limitations and results shown in Tab. 1.

RIA [RIA 2023]	TIE [TIE 2023]
Investment Costs	
Total cost of the robotic solution	Total cost of the robotic solution + accessories
Number of robots	Number of robots
Operating Costs / Savings	
Number of shifts	Number of shifts
Average labour costs per worker, including other related costs	Annual cost per worker (including estimated benefits and bonuses)
Number of replaced workers	Number of replaced workers
% of staff remaining for maintenance of robots	Number of robot operators
% of expected productivity increase	Estimated electricity costs (which consider an electricity cost of $0.5/hour per robot.)
Other expected savings	
Stated limitations	
Assuming 2% annual energy and labour cost / savings inflation	Not taking into account: inflation, maintenance and other
Results	
Break-even point in months	Break-even point in months
Savings on labor costs	Estimated net cost savings in the first year and over five years.
Productivity savings	
ROI table with year-by-year values for: robotic system, maintenance, operating, energy, labour, productivity and other savings, annual and cumulative cash flow.	

Table 1. Calculator comparison

The descriptions of these calculators further state that the typical payback period for any robotic system, new or used, is between 6 and 18 months, depending on the initial investment. It is stated that a robotic system is capable of achieving 95% efficiency, while a manual worker is only capable of achieving 20 to 25% during a shift. This is due to mandatory breaks, holidays, fatigue and other factors. Depending on the job, the robot can handle the work of up to four people per shift, making twelve people in a three-shift operation. The description of T.I.E. Indusitrial & Robots calculator [TIE 2023] further states that the robot should be functional for at least 20 years. Only the Yaskawa partners calculator [Yaskawa 2023] takes savings into account. Its calculation includes savings targets: target payback time in months, target throughput gain - the rate of production or the rate at which something is processed per shift, approximate annual savings for waste and claims, approximate annual savings for materials and other annual savings.

Consultation with professionals from the robotic solutions vendor sector from FANUC and AMTECH revealed that vendors do not normally perform ROI calculations for customers, or they only use a simplified calculator similar to the web-based ones mentioned above. This means they provide no comprehensive tool to help the customer with their decisions. It is therefore up to the customer to determine the payback themselves, and the vendors only provide the necessary information on the costs associated with the robot and its acquisition. From experience, they estimate the payback period to be around 3 years.

We found that direct experience varies from company to company. For example, at Witte Nejdek the payback on robots is usually calculated using labour (wage) savings. Daikin (Daikin Industries Czech Republic) implements robots only in problematic workplaces primarily for quality or safety reasons, but not for performance or cost-saving reasons. The representative from Central Fluidsystems commented that the details of the calculation depend on the size of the investment, which depends on the size and management of the company. In addition, the level of automation already present in the company should be taken into account.

The existing payback calculations linked to robotics investments are therefore rather simplified, with a limited use of the possibilities based on the general payback calculations (e.g. time factor) on the one hand, and on the other hand they do not use detailed quantification of other possible potential savings. On this basis, the following research question can be formulated: **What is the significance of a comprehensive refinement of payback calculation related to robotic application in comparison to the existing standardly used payback method?**

3 METHOD

Our approach to calculating payback is based on more rigorous qualitative and quantitative identification of costs related to the robotic application, which improves the calculation by existing simplified approaches. By applying the proposed method in a case study, we evaluate the significance of its impact and whether it is worthwhile focusing on it in further payback calculations.

The basic motivation for conducting this research is the desire to make more precise decisions about the suitability of implementing robots based on more accurate information.

On the quantitative side, many cost factors are overlooked and not included in the calculation, such as inflation, other energy costs, clothing, cleaning etc.

On the qualitative side of costs, it is worth taking a closer look at how the costs are determined. For example, in relation to the significant electrical energy consumption of robot applications, it is necessary to consider what percent of the time the machine actually works during a shift and what percent of the time it is idle. This significantly affects the amount of electricity consumption.

In this research, we proceed as follows. First, payback of investment is evaluated using the existing simplified method chosen by the evaluated company. Subsequently, our refinement calculation is performed, which includes all other cost factors for which the company has data or for which we can make sufficiently accurate approximations to consider the values as valid. Once the detailed calculation is established and applied, we can compare how significant the individual cost components are and whether the difference between the outputs are significant enough.

We have changed the name of the company to 'DKN', but the presented values are realistic. The existing simplified approach of payback calculation related to robotic application at DKN is based on the following facts:

1. The time factor and related inflation are not included.
2. The cost items include: investment costs, operating costs - simplified calculation of the energy consumption of the robotic workplace, repair and maintenance costs.
3. The savings include: savings on the wages of workers replaced by robots.
4. The payback period method is used.

The proposed refined approach to calculating payback of robotic application at DKN is based on the following facts:

- The time factor and related inflation are included.
- The cost items include: investment costs, operating costs - refined calculation of the energy consumption of the robotic workplace, repair and maintenance costs.
- The savings include: savings on the wages of workers replaced by robots, savings on internal employee spaces (changing rooms, toilets etc.), savings on parking, savings on cleaning, savings on water consumption, savings on employee clothing, savings on robot workplace area.

The limitations of this research are as follows:

- Verification is performed at one company.
- The calculation is based on the situation in the Czech Republic in 2019, with an annual inflation rate of around 2% and stable energy prices. (The current assumption of inflation by the Czech National Bank in the Czech Republic for 2024 is also 2% [CNB 2023b], which is also the ideal long-term state that the Czech National Bank has targeted - that is the reason this value is considered relevant in the paper.)
- We do not evaluate the difficulty of obtaining additional data in terms of time and cost, but focus on the significance of the deviation that the refinement of the calculation will have.
- Neither the company nor us consider opportunity costs, as their determination would be very abstract in this case study.
- Improving the cycle time of the workplace due to robotization has no effect on the production line, as it is not a bottleneck. Therefore, speeding up will not achieve savings that could be included in the calculation.

The proposed approach is applied in the case study below using real data.

4 INDUSTRIAL CASE STUDY

This chapter concentrates on the case study at DKN which produces air conditioning units. This case study corresponds to a real situation. We first describe the industrial process at the company and other conditions linked to its robotic application, along with possible costs. Then we compare the payback calculation used by the company with the refined calculation that takes into account costs in more detail. Subsequently, it is possible to determine whether the company takes into account all significant cost factors.

The subject of the case study is the palletizing process at the end of the production line (workplace F6). This process is currently handled by three employees who are responsible for taking the finished air conditioning unit, scanning it, assembling the box, and then packing the air conditioning unit into the box, labelling the box, taping the box (in some cases from multiple sides), and moving the box to a storage area, from where it is loaded onto pallet that is positioned on an AGV (Automated Guided Vehicle) using a manipulator with vacuum suction cups and taken to the warehouse.

Eight types of air conditioning units with different dimensions (up to 90x90x30cm) and weight (between 17-29 Kg) are produced. The packaging material is a cardboard box, which is assembled by the production line operator. The temperature at the workplace is normal (approx. 20 °C).

The components of the current workplace are:

- semi-automatic taping machine,
- non-powered conveyors,
- conveyor components,
- manipulator with vacuum suction cups,
- AGV.

The workplace is operated by three employees in three shifts.

4.1 Robot deployment scenario

The target of automation is to minimize human actions in the process. Since the nature of the process does not allow for automation of the delivery and packaging of the air conditioning units, it is necessary to focus on the remaining operations of the process, namely labelling, taping, and moving to the AGV cart. The automation can potentially reduce the number of employees from three to two per one shift.

For this application, the FANUC M710iC/45M robot was chosen. Compared to a collaborative robot, it has several advantages, such as higher speed, ability to carry heavier loads, etc. The disadvantages include having to safeguard the robot's workspace for humans. The M710iC/45M allows handling of heavier loads over longer distances. The robot transfers boxes from the conveyor to pallets, which is the palletizing process. The robot's effector with suction cups is used to grip the boxes. The taping machine is automatic in this proposed solution (without rotation). The box is rotated on the following conveyor, which is equipped with a turning mechanism and then transports the package to the labeller, which attaches the appropriate label. The robot's workspace must be designed to prevent collisions during the work cycle. This is solved by additional fences monitored by optical barriers in the pallet exchange area and at the entrance of the boxes travelling on a roller conveyor. The unloading of full pallets and the delivery of empty pallets is done by AGV (which the production line is already equipped with). A detailed evaluation of the technical variants of the workstation process and the selection of the robot with accessories are beyond the scope of this article, so only outputs and the final selected variant are presented.

The company insists on using its own capital for the investment and excludes the option of purchasing on loan or leasing.

When considering payback, DKN considered the following costs:

- Complete investment costs (obtained from the robotic application supplier).
- Operating costs in the form of simple wage savings (savings of 1 employee in each shift).
- Basically determined electrical energy costs by machine energy consumption according to the documentation.
- Maintenance costs identified by the supplier.

4.2 *Investment costs*

Costs associated with the investment, which were identified by the supplier of the robotic solution, are shown in Tab. 2.

Equipment costs	Price without VAT
Fanuc M710iC/45M Robot	1 140 570 CZK
Robot accessories (Ethernet, DCS etc.)	55 193 CZK
Automatic taping machine	524 400 CZK
Label maker	650 000 CZK
Roller conveyor with rotating mechanism	200 000 CZK
Omron PLC workplace control + Omron HMI + light barriers	300 000 CZK
Other components (15% of the material price) - sensors, safety equipment etc.	430 524 CZK
Cost of installation	**Price without VAT**
Engineering	96 000 CZK
Design of electrical installations	128 000 CZK
Mechanical work including on-site assembly	168 000 CZK
Electrical installation	72 000 CZK
Programming of robot and PLC	160 000 CZK

Table 2. Equipment and installation costs

Total investment related to the robot application of the F6 workplace is 3 924 687 CZK.

4.3 *Operating costs – original calculation*

Based on the information provided by experts at FANUC, the maintenance costs for such a machine are estimated at 20 000 CZK per year and 0.75% of the total purchase price related to the workplace for spare parts. Total maintenance costs of the equipment are approximately 50 000 CZK per year.

In addition to the maintenance of the equipment itself, it is necessary to consider the maintenance of the control system of the workstation. If this is to be carried out by an external worker, the cost can be estimated from the hourly rate of a programmer. Due to uninterrupted production and a large number of manufactured units, it is advisable to carry out maintenance at shorter intervals, for example every six months. Software maintenance can be performed while the line is running without causing any production losses. The cost of one software maintenance session (8 hours of work) is 18 000 CZK. If software maintenance is carried out twice a year, the total cost will be 36 000 CZK.

The total maintenance cost is then approximately 86 000 CZK per year.

Prior to automation, the line was operated by three employees, requiring a total number of nine employees to cover three shifts. The average gross salary for an employee in the production line was 23 762 CZK per month, but the employer has to pay 31 841 CZK due to social and health insurance. The annual cost of operating the workplace operated by 9 employees is thus 3 438 836 CZK.

After automation, the workplace is operated by two employees in three shifts. A total number of 6 employees are thus required to operate the line. The annual cost of operating the workstation operated by 6 employees is 2 292 558 CZK, resulting in savings of 1 146 279 CZK.

In its initial scenario, the company estimated electrical energy costs associated with robot operation simply as equipment power consumption (according to the documentation) multiplied by the price per kWh and the number of operating hours per year. These estimated energy costs are 107 386 CZK per year.

These items are normally taken into account by the company when calculating the return on investment.

The payback calculation is the classic division of investment costs by the total variable savings reduced by the total variable costs. The savings are formed by the savings of one employee position in a three-shift organization. Variable costs are given by the increase in electricity energy costs expressed in a less precise way.

Results of the simple payback calculation are shown in Tab. 3.

Investment costs / savings description	Value
Total investment costs	3 924 687 CZK
New annual electrical costs – simply calculated	107 386 CZK
New annual operation and maintenance costs	86 000 CZK
Annual savings on wages for 1 employee per 3 shifts	1 146 279 CZK
Total annual variable costs (electricity + maintenance)	193 386 CZK
Total annual variable savings	1 146 279 CZK
Expected payback period by original calculation	**4 years and 2 months**

Table 3. Original payback calculation values and result

Expected payback period by the original calculation is therefore 4 years and 2 months.

4.4 *Operating costs – refined calculation*

This chapter describes additional and more precisely determined costs / savings together with a more precise payback calculation that leads to the refined payback method. Specific inputs to determine more precise costs / savings:

Real machine electrical energy utilization - when looking at electrical energy consumption, it is necessary to take into account the real operation of the machine, i.e. division of electrical energy consumption during operation and during waiting (idling) of the machine (robot) for the next operation (based on comparing the cycle time of the production line and the cycle time of the machine). Individual machines can stand idle during the work cycle of the workstation (waiting for the next operation), which also leads to energy consumption. According to the experience of the supplier, the consumption is 20% fixed (regardless of activity) and 80% variable depending on activity. The operation of the machines depends directly on the working time of the operator, so the automatic part is inactive during the operator's breaks. In the original simplified approach by the company, costs for electrical energy were estimated as 107 386 CZK. However, taking into account the fact that the machine is active, i.e. used, only 70% of the time (based on similar applications), the calculation needs to be adjusted by multiplying the fixed consumption (0.2) plus variable consumption (0.8) multiplied by the utilization coefficient (0.7). In such a case, we more accurately determine the electrical energy costs as 81 613 CZK per year.

Employee facilities – cost reduction related to reduced size of changing rooms, showers and toilets. Calculation is as follows: size of reduced space related to dressing rooms, showers and toilets in m^2 is quantified using standards, which is then multiplied by the company's cost rate per m^2 of internal/external area. [Reznicek 2013]

Changes of workplace space - cost reduction related to the size of the reduced workplace area (the robot needs less space). Calculation as follows: the size of the reduced workplace area in m^2 multiplied by the company's cost rate per m^2 of production area.

Size of cleaning space – cost reduction related to the reduced size of area that needs to be cleaned regularly every shift. When the area is not used, cleaning should be minimized. Calculation of the cost is: reduced cleaning area in m^2 multiplied by daily company cleaning rate per m^2.

Water consumption - number of employees is directly related to water consumption in showers and toilets, which can also be quantified using standards.

Employee clothing - number of employees is directly related to clothes they standardly need (gloves, t-shirt, safety shoes etc.), that can also be quantified using standards.

Parking - number of employees is directly related to the size of parking space. Related costs can be recalculated by the rate of required space per employee and the associated costs per m^2.

Inflation - an increase in the general price of goods and services in the economy over a certain period of time. The inflation rate affects the operating costs by a few percent each year. For our more precise calculation, an inflation rate of 2% was chosen, which is the target of the Czech National Bank's monetary policy. [CNB 2023]

It is important to mention that different cost / savings items have different influences and immediate impacts on the payback. While items like real machine electrical energy utilization, water consumption and inflation are more precisely calculated future states of the items, other items, such as employee facilities, changes of workplace space, size of cleaning space and parking are directly dependent on potential usage by the company if the company can use them immediately or after favourable accumulation of conditions. For example the company can immediately rent free parking spots to another company, or the company can remove three changing room shelves, but needs to wait for three more to have enough space to make a new archive cabinet out of them. So it is up to the company to put only relevant items into the calculation.

The calculation principle of the payback period according to the refined method is as follows. The size of the investment (fixed, initial costs) is reduced by the total annual savings, which also take into account inflation. The total annual savings represent the total variable component as the difference between the variable annual costs of the original workplace and the variable annual costs of the new robotic workplace, including refined cost data.

The formula for calculating the payback period including the time factor (inflation) used in the refined payback method is as follows.

$$\sum_{t=1}^{T_{sd}} CF_t * (1+r)^{-t} - IN = 0 \quad (1)$$

IN investment
CF annual cost savings
r inflation (discount rate)
Tsd payback period

The values of the more precisely determined costs / savings together with the more precise payback calculation that leads to the refined payback method is shown in Tab. 4. It is applied to the same industrial case study.

Investment costs / savings	Value
Total investment costs	3 924 687 CZK
New annual electrical costs – precisely calculated	81 613 CZK
New operation and maintenance costs	86 000 CZK
Annual savings on wages for 1 employee per 3 shifts	1 146 279 CZK
Annual savings on employee facilities	2 310 CZK
Annual workplace space savings	2 980 CZK
Annual cleaning savings	180 CZK
Annual savings - water consumption	5 085 CZK
Annual savings - employee clothing	10 542 CZK
Annual parking savings	1 050 CZK
Total annual variable costs - more precise values	167 613 CZK
Total annual variable savings – more precise values	1 168 426 CZK
Annual inflation 2% that will increase savings year-on-year by approx.	20 000 CZK
Expected payback period – refined method	**3 years and 10 months**

Table 4. Refined payback calculation values and result

5 RESULTS

The summarised results are shown in Tab. 5, where the calculation according to the original and the refined methods are compared.

	Original method	Refined method
Investment costs	3 924 687 CZK	3 924 687 CZK
Total variable costs	193 386 CZK	167 613 CZK
Total variable savings	1 146 279 CZK	1 168 426 CZK
Annual inflation savings impact	x	20 000 CZK
Expected payback	**4 years and 2 months**	**3 years and 10 months**

Table 5. Results – comparison of values from the two methods

The results containing the absolute and relative differences between the main items of the original and the refined payback method are shown in Tab. 6.

	Difference	Impact on the item
Investment costs	x	x
Total variable costs	25 773 CZK	-13.3%
Total variable savings	22 147 CZK	1.93%
Annual inflation savings impact	Approx. 20 000 CZK	2% (increase savings)
Expected payback	**4 months**	**8.7% difference**

Table 6. Results – comparison of differences between methods

The difference between the methods is 8.7% of the payback period: 50 months calculated by original method versus 46 months calculated by refined method. This can already be considered to be a significant statistical deviation.

The values of the more detailed savings and cost items in absolute terms and relative terms as a part of the total variable cost and savings are shown in Tab. 7. The table is separated into two parts. The upper part concentrates on the variable costs and their detailed items. The lower part of the table contains the variable savings and their specific detailed items.

From Tab. 7 it can be seen that the variable costs (167 613 CZK) are made up of energy, operation and maintenance, the relative difference of which makes only about 3%. In contrast, in the case of the detailed identification of variable savings of 1 168 426 CZK, we identified that 98% of the savings were made up of labour savings and the remaining 2% (22 147 CZK) by newly identified cost factors. Inflation is considered separately in Tab. 5 and Tab. 6.

	Item	Absolute value	Relative value
Variable costs	New energy costs	81 613 CZK	48.69%
	New operation and maintenance costs	86 000 CZK	51.31%
Variable savings	Annual savings on wages	1 146 279 CZK	98.10%
	Savings on indoor space for employees	2 310 CZK	0.20%
	Parking savings (annual)	1 050 CZK	0.09%
	Savings on cleaning	180 CZK	0.02%
	Savings on water consumption	5 085 CZK	0.44%
	Savings on staff clothing	10 542 CZK	0.90%
	Space saving for the robot	2 980 CZK	0.26%

Table 7. Results – detailed savings and cost items

6 DISCUSSION

The results show that our proposed refined method will affect the result of the payback calculation in absolute terms by 4 months, in relative terms by 8.7%. This can make the difference in some cases between deciding to accept the project or not.

The main factors identified are the more accurate determination of electricity consumption and the inclusion of inflation in the calculation. Moreover, these two factors become more important when considering the current global economic fluctuations, for example in Germany, electricity costs have increased by 38 percent over the last 10 years [Appunn 2023]. While inflation in the euro area was only 0.3% in 2020 [ECB 2021], it rose to 2.6% in 2021 [ECB 2022] and rose significantly to 8.4% in 2022 [ECB 2023]. However, it is expected to fall again gradually to 2.3% in 2025 [Eurostat 2022]. Higher employee-related costs are also not negligible.

A limitation of the research is that we find it difficult to determine some of the costs and evaluate their relevance, and they were therefore not included in the method. The ability of a company to determine some costs may be limited, but for many of them coefficients and standardised prices can be used, such as water consumption by employees or cleaning costs. It is also necessary for a company to consider the relevance of the savings involved, whether or not a company will include specific items in the calculation. Overall, we find the research beneficial as the output is closer to reality.

A particular benefit of the refined method in comparison to the online calculators mentioned in the literature review [RIA 2023], [TIE 2023], [MSI TEC 2021], [Yaskawa 2023] is the more precise calculation. How significant the refinement will be depends on the amount of specific costs / savings items included in the payback calculation. For example, RIA's calculator [RIA 2023] will be more precise and the values will be closer to our refined approach than the values from T.I.E. Indusitrial & Robot's [TIE 2023] calculator, which does not consider inflation.

7 CONCLUSION

The paper focuses on the comparison of the original and a new method of calculating the payback of a robotic workplace. The comparison was evaluated using the data from a specific company in a case study. The new method took into account more precise costs, with precisely determined electricity consumption and inflation playing a significant role.

Coming back to the research question: What is the significance of a comprehensive refinement of payback calculation related to robotic application in comparison to the existing standardly used payback method?

It can be said, based on the case study presented in the paper, that the results that emerged from the study showed that the new method had a significant impact on the outcome of the calculation. The payback time decreased by 8.7%, which is a substantial value that can significantly influence the decision to implement robotic application or not.

The limitation is of course that this validation was done on one case study only and the current outcome gives future possibility for further research in the field and validation on more case studies. Another topic for future research is to use and evaluate the remaining static and dynamic investment evaluation methods mentioned in the literature review section of the paper. The research would be extended to the calculation of the remaining methods, for the original state and for the new refined state, and then compared and finally evaluated.

ACKNOWLEDGMENTS

This article was created with the subsidy of the project SGS-2021-028 'Developmental and training tools for the interaction of man and the cyber-physical production system' under the Internal Grant Agency of the University of West Bohemia.

REFERENCES

[Appunn 2023] Appunn, K. et al. Germany's energy consumption and power mix in charts. 2023 [online], [2023-06-29]. Available from: https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts

[Botchkarev 2011] Botchkarev, A. and Andru, P. A Return on Investment as a Metric for Evaluating Information Systems: Taxonomy and Application. Interdisciplinary Journal of Information, Knowledge, and Management, 2011, Issue 6, page 245–269. DOI: 10.28945/1535

[CNB 2023] CNB – Czech National Bank. Inflation target. 2023 [online]. [2023-06-29]. Available from: https://www.cnb.cz/en/monetary-policy/inflation-target/

[CNB 2023b] CNB – Czech National Bank. CNB forecast – Spring 2023. 2023 [online]. [2023-06-29]. Available from: https://www.cnb.cz/en/monetary-policy/forecast/

[De Clerck 2016] De Clerck, Q. et al. How Total is a Total Cost of Ownership? World Electric Vehicle Journal, 2016, Issue 8, page 736–747. DOI: 10.3390/wevj8040742

[ECB 2021] ECB – European Central Bank. The year at a glance 2020. 2021 [online]. [2023-06-29]. Available from: https://www.ecb.europa.eu/pub/annual/html/ar2020~4960fb81ae.en.html

[ECB 2022] ECB – European Central Bank. The year at a glance 2021. 2022 [online]. [2023-06-29]. Available from: https://www.ecb.europa.eu/pub/annual/html/ecb.ar2021~14d7439b2d.en.html

[ECB 2023] ECB – European Central Bank. Eurosystem staff macroeconomic projections for the euro area countries – december 2022. 2023 [online]. [2023-06-29]. Available from: https://www.ecb.europa.eu/pub/projections/html/ecb.projections202212_eurosystemstaff~6c1855c75b.en.html#toc2

[Eurostat 2022] Eurostat. Harmonised annual inflation rate. 2023 [online]. [2023-03-12]. Available from: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tec00118

[Geissbauer 2015] Geissbauer, R. et al. PwC's 2016 Global Industry 4.0 Survey: Industry 4.0: Building the digital enterprise. 2015 [online], [2020-05-08]. Available from: https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-buildingyour-digital-enterprise-april-2016.pdf

[Grznar 2020] Grznar, P. et al. Modeling and Simulation of Processes in a Factory of the Future. Applied Sciences-Basel, July 2020, Volume 10, Issue 13, eISSN 2076-3417, DOI: 10.3390/app10134503

[Horejsi 2020] Horejsi, P. et al. A Smart Factory in a Smart City: Virtual and Augmented Reality in a Smart Assembly Line. IEEE ACCESS, 2020, Volume 8, Page 94330-94340, ISSN 2169-3536, DOI: 10.1109/ACCESS.2020.2994650

[IFR 2017] IFR – International Federation of Robotics, The Impact of Robots on Productivity, Employment and Jobs. IFR, 2017 [online]. [2023-06-29]. Available from: https://ifr.org/img/office/IFR_The_Impact_of_Robots_on_Employment.pdf

[IFR 2022] IFR – International Federation of Robotics, World Robotics Report 2022. IFR, 2022 [online]. [2023-06-29]. Available from: https://ifr.org/downloads/press2018/EN-WORLD-2022-OCTOBER-13_IFR_press_release_World_ Robotics_2022.pdf

[Kalouda 2011] Kalouda, F. Financial management of company (in Czech). Pilsen: Vydavatelstvi a nakladatelstvi Ales Cenek, 2011, ISBN: 978-80-7380-315-5

[Kislingerova 2007] Kislingerova, E. Managerial Finances (in Czech). Prague: C.H. Beck, 2007, ISBN: 978-80-7179-903-0

[Kleinova 2005] Kleinova, J. Economical Evaluation of Production Processes (in Czech). Pilsen: UWB, 2005, ISBN: 80-7043-364-7

[Lee 2015] Lee, D. Universal Robots' UR3 Makes Table-Top Automation Easy, Safe and Flexible. World industrial reporter, 2015 [online]. [2023-06-29]. Available from: https://worldindustrialreporter.com/ universal-robots-ur3-makes-table-top-automation-easy-safe-and-flexible/

[Liao 2017] Liao, Y. et al. The impact of the fourth industrial revolution: a cross-country/region comparison, Production [online]. 2017, issue Nr.28, [2023-06-29]. Available from: https://www.scielo.br/j/prod/a/hRmXgtCKq6qbwMkK4nVkj8g/#, DOI: 10.1590/0103-6513.20180061

[Malaga 2020] Malaga, M and Ulrych, Z. Physical modelling of the Industry 4.0 concept. ed. Soliman, K.S. EDUCATION EXCELLENCE AND INNOVATION

MANAGEMENT: A 2025 VISION TO SUSTAIN ECONOMIC DEVELOPMENT DURING GLOBAL CHALLENGES, Seville, Spain, April 01-02, 2020, page: 17540-17549, ISBN 978-0-9998551-4-0

[McKinsey & Company 2019] McKinsey & Company, Industrial robotics: Insights into the sector's future growth dynamics. McKinsey & Company, 2019 [online]. [2023-06-29]. Available from: https://www.mckinsey.com/~/media/mckinsey/industries/advanced%20electronics/our%20insights/growth%20dynamics%20in%20industrial%20robotics/industrial-robotics-insights-into-the-sectors-future-growth-dynamics.ashx

[MRR 2019] MRR – Market Research Reports, World's Top 10 Industrial Robot Manufacturers. MRR, 2019 [online]. [2023-06-29]. Available from: https://www.marketresearchreports.com/blog/2019/05/08/world%E2%80%99s-top-10-industrial-robot-manufacturers

[MSI TEC 2021] MSI TEC. Collaborative Robot ROI Calculator. MSI TEC, 2021 [online]. [2023-06-29]. Available from: https://msitec.com/robot-roi-calculator/

[Murphy 2017] Murphy A. Industrial: Robotics Outlook 2025. Deepwater Asset Management, 2017 [online]. [2023-06-29]. Available from: https://deepwatermgmt.com/industrial-robotics-outlook-2025/

[Narodni iniciativa Prumysl 4.0 2015] Narodni iniciativa Prumysl 4.0. Industry 4.0 initiative (in Czech) Ministerstvo prumyslu a obchodu, 2015, Prague [online]. [2023-06-29]. Available from: https://www.mpo.cz/assets/dokumenty/53723/64358/658713/priloha001.pdf

[Pearce 2016] Pearce, J.M. Return on investment for open source scientific hardware development. Science and Public Policy, April 2016, Volume 43, Issue 2, page 192–195. DOI: 10.1093/scipol/scv034

[Pollak 2021] Pollak, M. and Kocisko, M. Design and Implementation of 3D Printing Using a Universal Printing System on the Robot Arm UR5. TEM Journal – Technology Education Management Informatics, Nov 2021, Volume 10, Issue 4, Page 1895-1899, ISSN 2217-8309, DOI: 10.18421/TEM104-53

[Pollak 2022] Pollak, M. and Kocisko, M. Development of a Knowledge System for Data Management of the Pre-Production Stages. TEM Journal – Technology Education Management Informatics, Nov 2022, Volume 11, Issue 4, Page 1774-1779 ISSN 2217-8309, DOI: 10.18421/TEM114-44

[Reznicek 2013] Reznicek, P. The standard for sanitary facilities and changing rooms has been in force since February 2013 (in Czech). 2013 [online], [2023-06-29]. Available from: https://voda.tzb-info.cz/normy-a-pravni-predpisy-voda-kanalizace/10702-norma-pro-vybaveni-hygienickych-zarizeni-a-saten-plati-od-unora-2013

[RIA 2023] RIA - Robotic Industries Association. ROI Robot System Value Calculator. RIA, 2023 [online]. [2023-06-29]. Available from: https://www.automate.org/robotics-roi-calculator

[Rudy 2022] Rudy, V. et al. Design of Metallurgical Production in the Context of Industry 4.0. ADVANCES IN SCIENCE AND TECHNOLOGY-RESEARCH JOURNAL, 2022, Volume 16, Issue 5, Page 271-276, ISSN 2080-4075

[Rüßmann 2015] Rüßmann, R. The Future of Productivity and Growth in Manufacturing Industries. Boston Consulting Group, 2015 [online]. [2023-06-29]. Available from: https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries

[Sniderman 2016] Sniderman, B. et al. Industry 4.0 and manufacturing ecosystems, Exploring the world of connected enterprises. Deloitte University Press, 2016 [online], [2023-06-29]. Available from: https://www2.deloitte.com/content/dam/Deloitte/de/Documents/consumer-industrial-products/Deloitte-Industry-4-0-and-manufacturing-ecosystems.pdf

[Synek 2011] Synek, M. et al. Managerial Economics (in Czech). Prague: Grada, 2011, ISBN: 978-80-247-3494-1

[TIE 2023] T.I.E. Indusitrial & Robots. Return On Investment. T.I.E. Indusitrial & Robots, 2023 [online]. [2023-06-29]. Available from: https://www.robots.com/roi

[Yaskawa 2023] Yaskawa Motoman. Robotic Welding System Payback Calculator. Yaskawa Motoman, 2023 [online]. [2023-06-29]. Available from: https://yaskawapartners.com/robotic-system-savings-calculator/

[Zamfir 2016] Zamfir, M. et al. Return On Investment – Indicator for Measuring the Profitability of Invested Capital. Valahian Journal of Economic Sciences, 2016, Issue 7. DOI: 10.1515/vjes-2016-0010

CONTACTS

Ing. David Zenisek
e-mail: zenisekd@fst.zcu.cz
Ing. Tomas Broum, Ph.D.
e-mail: broum@fst.zcu.cz
Doc. Ing. Michal Simon, Ph.D.
e-mail: simon@fst.zcu.cz, Telephone: +420 37763 8431
Department of Industrial Engineering and Management, Faculty of Mechanical Engineering, University of West Bohemia in Pilsen, Pilsen, Czech Republic, 301 00