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Model-Based Holistic Multidimensional View on Digital Engineering Investments Appraisal

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Abstract

The digital engineering landscape's rapid evolution necessitates innovative investment appraisal. Model-Based Systems Engineering (MBSE) provides a holistic, multidimensional approach, empowering stakeholders in informed decision-making and efficient resource allocation. This study delves into MBSE techniques for digital engineering investments, emphasizing their significance for strategic decision-making and resource optimization. A systematic literature review identifies existing MBSE approaches, forming the basis for a comprehensive framework. The proposed framework integrates various dimensions for evaluating digital engineering investments, including technological innovation, organizational capabilities, market dynamics, and financial considerations. By considering these dimensions collectively, organizations can better understand their investments' potential impact and value. Key components of the framework include advanced modelling techniques such as system dynamics and scenario analysis, which enable the exploration of complex interdependencies and uncertainties inherent in digital engineering investments. Additionally, the framework incorporates qualitative assessments alongside quantitative metrics to capture a broader range of factors influencing investment outcomes. By adopting this multidimensional view, decision-makers can better anticipate and mitigate risks while maximizing the value generated from their investments. This abstract's model-based holistic, multidimensional view offers a structured approach to strategic decision-making regarding digital engineering investments. By leveraging this framework, organizations can confidently navigate the complexities of the digital landscape and optimize their investment strategies for long-term success while optimizing resource allocation.

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1. Introduction

In the context of complex technological advancements, the term 'digital engineering' broadly encompasses a variety of advanced technologies, methods, and tools employed in the field to tackle complex problems and create innovative solutions. The emergence of this term is closely linked to the digital transformation of industrial engineering and the evolution of advanced manufacturing.[1] Digital engineering is a multidisciplinary field that merges the aspects of computer science, engineering, and technology to model, analyze, and optimize complex systems. This includes digital twin technology, Industry 4.0, data analytics, artificial intelligence (AI), *etc*.,[2] enabling a data-driven approach to solve classical engineering and management tasks. Through the integration of diverse disciplines and techniques, digital engineering has the potential to revolutionize the approach to complex problems and drive technological innovation. Nearly the same principles are claimed within the concept of Industrial Information Integration Engineering (IIIE), first mentioned in 2007[3] as the Industrial Integration of Information and Communication Technologies (ICT) and further applied in a diverse field of application.[1] Since then, the widespread application of ICT has empowered the development of a holistic view of manufacturing and industrial engineering processes, resulting in the ideas of digital engineering. As mentioned by Voth and Sturtevant,[4] the highly integrated nature of modern

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engineering processes requires a Model-Based Systems Engineering (MBSE) approach. MBSE can be founded on contiguous disciplines,[5,6] thus enabling a multidisciplinary holistic approach towards solving the new and classical challenges of industrial engineering. This allows us to conclude that, within digital engineering, many aspects that have not been considered before might be investigated and developed. From this point of view, a holistic approach towards assessing the efficiency of investments in technology, resulting in a model-based approach, claims its high application value. A model-based approach has been developed based on system analysis, simulation, and detailed integration of many functions and operations within an enterprise.[7] Moreover, the proposed approach can be considered a proactive tool for addressing the challenges of complex system management. It allows stakeholders to see the relevance of investments in digital solutions based on a multidimensional approach. We consider a company's financial and investment aspects in time, costs, and demand. Demand as a dimension and metric allows the stakeholder approach to be linked with the operative management perspective. Although the tradeoffs between costs and time have been studied previously, there needs to be a research gap in considering all three dimensions simultaneously, which is referred to as a holistic view of the appraisal process. Comprehensive attempts to define the tradeoffs between time and cost have been proposed by experts using approximation algorithms,[8] genetic algorithms,[9] and others.[10] highlight the need to consider costs and demand as variables in a decision-making process and the time value of investment - ‘a dollar today worth more than a dollar tomorrow.’ We suggest further development of this idea based on discounted cash flow analysis and investigate decision-making on investment in digital solutions based on the Du Pont model,[11] which describes the basic correlation between net income and total assets. The rapid pace of technological advancement and market evolution introduces significant uncertainties and complexities not adequately addressed in existing frameworks. Decision-makers require robust tools and methodologies to navigate these uncertainties and make informed investment decisions in a dynamic and uncertain environment. Thus, the research gap lies in the development of a comprehensive framework that:

- Integrates multiple dimensions, including technological innovation, organizational capabilities, market dynamics, and financial considerations, into a unified approach for assessing digital engineering investments.
- Incorporates MBSE modelling techniques and scenario analysis to account for uncertainties and risks inherent in the digital landscape.
- Provides decision-makers with actionable insights to optimize investment strategies and enhance long-term value creation.
- This article emphasizes applying MBSE techniques for investment appraisal across a diverse range of complex digital engineering technologies. This approach facilitates a deeper understanding of the challenges and opportunities for assessing and investing in advanced technologies. By examining digital engineering's complex technologies from a broader perspective, this article aspires to offer a flexible and adaptable framework applicable to various projects and investment situations.

2. Literature review

This literature review explores the topic of a model-based, holistic, multidimensional view of digital engineering investment appraisal. The focus is on the benefits and challenges of using a holistic approach to appraise digital engineering investment. The literature overview demonstrated that the MBSE approach has a wide application field: manufacturing,[12-14] supply chain management,[15] healthcare,[16] environmental studies,[17] ICT,[18] corporate culture,[19] management[20] and others. The common point refers to the aim of MBSE sequenced in the methodological integration of attributes (*e.g.*, requirements, functions, and limitations) and models within multiple dimensions.[21] Despite the holistic nature of MBSE, it is aimed at managing the complexity of the system[21] or even reducing it.[13] The governing and systematic nature of MBSE does not restrict its application in creating cyber-physical systems.[12-14] Therefore, MBSE is a conceptual approach for developing new models and frameworks. Research by Maleki[16] emphasizes the importance of incorporating financial and non-financial factors into investment appraisal models for digital engineering projects. Their study suggests that more than traditional financial metrics are needed to capture digital investments' long-term value creation potential adequately. Researchers integrate qualitative assessments and scenario analysis to demonstrate how organizations can better understand digital engineering initiatives' economic viability and strategic implications. Ahmad *et al*.[18] underscore the critical role of technological innovation and organizational capabilities in driving successful digital engineering investments. They propose a framework that evaluates the alignment between technological capabilities and strategic objectives, highlighting the importance of organizational readiness and agility in adopting new technologies.

Furthermore, researchers emphasize the need for continuous monitoring and adaptation to technological advancements to sustain competitive advantage in the digital era. The dynamic relationship between market dynamics and strategic alignment in digital engineering investments. Their study highlights the importance of market intelligence and strategic foresight in identifying emerging opportunities and threats. By integrating market analysis with strategic planning, organizations can proactively adjust their investment strategies to capitalize on market trends and maintain relevance in increasingly competitive markets.

Recent research by Masior *et*.[21] introduces an integrated digital engineering investment appraisal approach, combining system dynamics modelling with scenario analysis. Their study demonstrates how such approaches can capture the complex interactions between technological, organizational, and market factors, enabling decision-makers to assess the robustness of investment strategies under various scenarios. By simulating different investment scenarios, organizations can identify potential risks and opportunities and develop contingency plans to mitigate risks and maximize returns.

However, how does it change when financial analysis and investment appraisal are conducted? The research question arises: How do experts perceive the correlation and common application of the MBSE approach to investment project appraisal in digital technologies? We conducted a systematic literature review to answer this question using a comprehensive search of electronic databases, including Google Scholar, ScienceDirect, and IEEE Xplore. The search was done using title, abstract, and author-specified keywords on the terms "digital engineering investment," "model-based appraisal," and "holistic view. “Articles published in peer-reviewed journals, conference proceedings, and books during the last 10 years (2013-2022) were included. The literature on model-based holistic, multidimensional views on digital engineering investment appraisal underscores the imperative for integrated frameworks that transcend traditional silos and embrace the complexities of the digital landscape. Building upon prior research, the current study contributes novel insights by integrating advanced modelling techniques with comprehensive scenario analysis and decision support mechanisms. By leveraging these advancements, organizations can navigate uncertainty, capitalize on opportunities, and drive sustained value creation in their digital engineering investment endeavours. The total volume of articles related to words in a search has been increasing, and this refers to the growing interest of the academic community in the issues considered. We used VOS viewer software to construct and visualize the bibliometric data of the sources containing the keywords Fig. 1.

The findings of the systematic literature review suggest that a model-based holistic, multidimensional view of digital engineering investment appraisal is a valuable approach for organizations to evaluate the benefits and costs of digital engineering investments. The approach considers multiple dimensions, such as financial, technical, operational, and strategic, to provide a comprehensive view of investment.

2.1 Benefits

The benefits of using a model-based holistic, multidimensional view of digital engineering investment appraisal include the following:

- Improved decision-making: the approach provides a comprehensive view of the investment, enabling organizations to make informed decisions about investing in digital engineering.
- Better alignment with organizational goals: the approach considers multiple dimensions, including strategic alignment, to ensure that the investment aligns with the organization's goals.
- Improved risk management: the approach considers risks associated with the investment, such as technical and operational risks, to ensure that the investment is viable and sustainable.

2.2 Challenges

The challenges of using a model-based holistic, multidimensional view of digital engineering investment appraisal include the following:

Data availability: the approach requires a significant amount of data to be collected and analyzed, which can be challenging for organizations that need more resources.

Complexity: the approach requires specialized knowledge and skills to be implemented effectively.

Cost: the approach can be costly, particularly for small and medium-sized enterprises (SMEs).

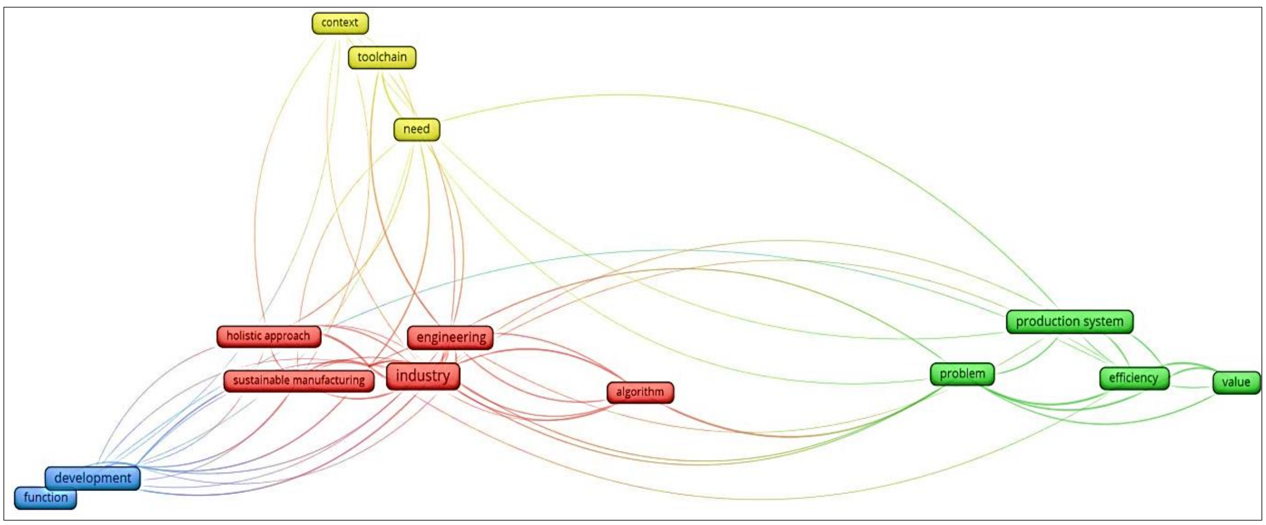

Fig. 1 Bibliometric data analysis of publications with the keywords, abstract or title, including "digital engineering investment", "model-based appraisal", and "holistic view “terms.

In summary, the coherent development of modern models and methods assumes a multidimensional holistic approach based on synergy and integration.[22] The complexity of these models should provide decision-makers with transparent, analytically assessed, and agile solutions to increase the system's overall performance efficiency.

3. Experimental

3.1 Material & method

The literature overview has proven the idea of a highly applied and methodological value of the proposed model-based holistic, multidimensional view on assessing efficiency investment in digital engineering. As mentioned earlier, MBSE, directly referring to the holistic approach proposed by the authors, should be considered from three dimensions: time, costs, and demand. In such well-known models, return on assets (ROA), return on investment (ROI), total value of ownership (TVO), Cost Effectiveness Analysis (CEA), and others are sequenced just as a point on the surface of the 3-D cube (Fig. 2).

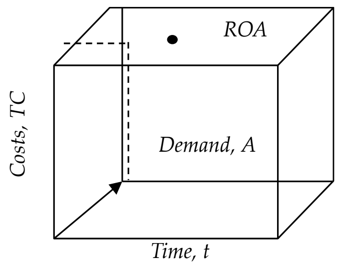

Fig. 2 The multidimensional approach to investment appraisals.

As shown in Fig. 1, obtaining results based on the classical *ROA* model (aimed at demonstrating the efficiency of asset usage) only allows for considering time and cost dimensions. We suggest improving this view and considering demand in the *ROA* equation. It should be mentioned that almost all financial analytical models can be revised this way. This proposal is partly justified by the idea that the decision-making process in investment planning highly depends on operative metrics, including costs, value and intensity of demand, and cycle duration. Operative management metrics in investment planning are important, as the operative management level is traditionally the closest to consumers. As the set of tasks to be solved at each of the management levels[23] increases with the data and process complexity, we suggest defining a new level – the service one–focused on final consumers and their needs, which is especially relevant in terms of the demand-driven market (Table 1).

The proposed framework Table 1 considers specific tasks to be solved using digital engineering tools at the strategic, tactical, operative, and service management levels.[24] Also, it highlights the relevance of applying a three-level model to investment scale calculations, as it benefits managers with different responsibilities and stakeholders. As shown in Table 1, the complexity of the tasks to be solved increases from levels IV to I. Investing in digital engineering occupies a unique role at the strategic management level (based on tactical, operative, and service metrics), as it is a highly asset-consuming process. Investments in the digital transformation of manufacturing companies, warehouses, transportation hubs, multiservice centres, and others require precise analysis based on the revised models and methods. It also significantly transforms the business processes. Another point highlighting the need to revise traditional investment appraisal models in application to digital engineering is justified by the need to consider the costs of designing and implementing digital technologies and reducing the investment cycle.[25] While investing in the digital engineering infrastructure, companies perform three main tasks:

- Designing duration and phases of the investment cycle;
- Analysis of fluctuating parameters affected by investments;
- Choice of the investment model.

The necessary condition for accepting the investment project is a positive balance in hand *C(t)*at any given time interval. *C(t)* is justified as the cumulative sum of cash flows ($C_S(\tau)$) on calculation steps before the current (0) period (t):

$$C(t) = \sum_{\tau=0}^{t} C_S(\tau), \tag{1}$$

where τ calculation step, preceding the current defining period *C(t)*.

A negative *C(t)*s ignals the need to attract additional financial resources to the project. At the same time, a positive *C(t)* releases free financial aid on the *t*-step.

When evaluating an investment project's efficiency, multi-temporal indicators should be compared by discounting them to the value in the initial period.[10] Using the concept of cash flows, the following indicators for evaluating the effectiveness of investment projects can be applied: net present value (*NPV*), profitability index, internal rate of return, and payback period. *NPV* is defined as the sum of the current effects during the entire period reduced to the present (factual or 0) period:

$$NPV = C_o + \sum_{n=1}^{N} \left(\frac{1}{1+k}\right)^n c \tag{2}$$

where k is a discount rate.

The best option should be chosen based on the higher NPV value when comparing the two options. The proposed Equation may link any stochastic parameter (*e.g.*, demand or price) with time (see Fig. 1). If there is a need to consider the issue of investing in digital solutions, the problem becomes even more complex: planning, realization, control, and efficiency assessment tools should be introduced to see the outcome and tradeoffs between the costs and time spent on implementation. The classical Du Pont model covers these points in the first vision, as the generalized values of net income and assets are considered. Further development of the model allows for the inclusion of demand-related metrics:

$$ROA = \frac{(C_p.A) - TC - H}{C_p(S_m + S_C) + CA} \tag{3}$$

where price per product $ / unit;

A – Demand volume, units;

TC – total costs, $;

Sm, Sc are the order sizes of the current and safety stock, respectively, units;

Table 1. A framework of different management-level tasks for the industrial company.

Strategic management level
Manufacturing capacity
Forecast of the demand allocation, intensity and nature (stochastic or deterministic)
Number of facilities and their allocation
Storage capacity
Make or buy problem (MOB): insourcing or outsourcing
Value added created for the customer
Resource allocation
Tactical management level
Equipment for the manufacturing process
WiP (work-in-progress) and counterparts' dislocation
Master-plan schedule
Job-Shop Scheduling Problem (JSSP)
Vehicle routing problem (VRP)
Order processing (push or pull view)
Operative management level
Customer order management
Order picking
Customization procedures
JIT manufacturing principles
Rework
Delivery Schedule
Service level
Last-mile delivery
Return flow management
Resale of returned items (if there are no defects)
Insurance
Information support
Convenient location of pick-points
Processing customer feedback
Reclaim work with defective goods
Sales support

H – Income tax, $;
CA – total company assets volume, $.
As we can see from Equation (3), several parameters are stochastic and may fluctuate significantly over several years. Based on the discounted cash flow analysis (DCFA),[26] we consider these fluctuations over n periods by including net present value (*NPV*) and considered as net income in Equation (1); thus, it takes the following way:

$$ROA = \frac{NPV - H}{C_p(S_m + S_C) + CA} \quad (4)$$

By following the logic of the Du Pont model and changing the numerator and denominator of Equation (4), there might be modelled combinations leading to the target results stated by the stakeholders (investors), where *NPV* is analyzed through n periods. The adjusted *ROA* equation (3) focuses on costs and demand. We suggest a 3D approach - costs, time, and demand–so that the model-based approach for digital technology appraisal can be sequenced as a formula:

$$ROA = \frac{C_o + \sum_{n=1}^{N}(\frac{1}{1+k})^n C_n - H}{C_p(S_m + S_C) + CA} \quad (5)$$

The proposed Equation should have the following requirements:
Identification of the period duration, $n = 1,...k$ years;

Define the stochastic (time-varying) parameters (or factors) that will change over n periods. Representation of the uncertainty rate for each fluctuating parameter (probability of event)

The definition of *NPV* starts from the last point (retrospective view) and, step-by-step, is processed to the 0 (the present time) period. In each of the considered periods, the expected profit (*EP*), the present value of the expected profit (*PVEP*), and total expected profit (*TEP*), wherein the 0 periods, *TEP* is replaced with the expected *NPV*. The equations for the functions above are as follows:

$$EP_i = p \cdot (C_p \cdot A - TC_i) = p \cdot (R_i - TC_i) \quad (6)$$

where a probability of the increase or decrease of the parameters.

$$PVEP_i = \frac{EP_i}{1+k} \quad (7)$$

$$TEP_i = EP_i + PVEP_i \quad (8)$$

The calculation of *EP, PVEP, and TEP* is conducted for each of the n periods; consequently, it is impossible to process the calculations for period i without completing calculations on these functions at the i+1 period. Simultaneous calculations of *NPV* linked to *ROA* allow the application of a holistic MBSE approach to three considered dimensions: time, costs of obtaining digital engineering tools,[27] and demand to obtain more precise digital engineering investment appraisal.

3.2 Calculation example

Let us assume that an industrial company must decide to invest in digital solutions to solve the job-shop scheduling problem (JSSP) under the strategy of smart manufacturing development.[28] In this case, several issues must be considered in investment planning and appraisal. Total costs (*TC*) should include designing and implementing digital technology. Define the variables that may change owing to the implementation of digital technology in a short or middle time horizon.

Payback period;

Probability of increasing or decreasing of deterministic variables;

Acceptable *ROA* level;

Optimization procedures are planned during the considered period, reflecting any component of Equation (3).

We processed the calculations for the modelled industrial case for three years. The initial data for this case are listed in Table 2.

Table 2. Initial data for calculations on investment appraisal to digital engineering.

Variable	Notification	Description	Value
Demand	A	Demand volume per year	100000
Price	C_p	Price per product, $	1,2
Costs	C	Costs to manufacture a unit of the product	
Discount rate	K	Assume a deterministic value	0,1
Demand fluctuation	-	Expected increase or decrease value	0,2
Probability rate	P	Binominal distribution	0,25
Revenue	R	Revenue per one manufactured and sold item, $	1,22
Total capital assets	CA	Fixed assets are taken, not depending on the manufactured volume, $	100000
Taxes	H	$, in total	66000

S_m and S_c are current and safety stocks, respectively, assuming that the smart manufacturing transformation due to digital engineering in a company[29] helps to follow the ideas of lean manufacturing and lean production; S_m is defined as A (demand value), and S_c is defined as an averaged volume of S_m ($S_m/2$). All remaining values used in the calculations can be defined with the given data (Table 2). Microsoft Excel was used to calculate the developed model. The materials and methods outlined above provide a structured approach for researching a model-based holistic, multidimensional view of digital engineering investment appraisal. Integrating quantitative analysis, qualitative assessment, and scenario analysis techniques enables decision-makers to make informed investment decisions that align with organizational goals and objectives. The results of the MBSE approach are presented using a dynamic scheme in Microsoft Excel, and by changing the parameters, the most desirable target metrics (*NPV, TC, ROA*) can be obtained.

4. Results and discussion

As the calculation example shows, diversified links between market-relevant metrics, such as demand or price, are connected to the industrial operational process regarding costs and inventory management. Finally, these links are brought to the generalized financial performance indicator, *ROA*, defined by considering *NPV*. By changing specific parameters in the model (for example, probability rate, costs, demand, and inventory costs), stakeholders and company managers may plan, organize, and analyze the investment project in digital engineering.[30] With a specific generalization rate, the proposed MBSE approach can be used for investment appraisal of any project. Nevertheless, we assume that the question of investment appraisal becomes more complex when considering digital technologies. Digital engineering, as a set of state-of-the-art informational technologies within integrated industrial applications,[31] deserves special attention. Because of the need to consider implementation costs, demand and price fluctuations, and payback periods, investments in digital engineering should be measured using revised models. The limitations of the proposed methodology are the short or middle planning horizon; otherwise, the forecasted rate and probability of the increase or decrease in certain variables may not be relevant. To better understand the effect of each investment solution, we suggest developing an investment cycle phase plan (ICPP). ICPP will help to create digital engineering architecture aligned with an enterprise's physical infrastructure Table 3.

The given ICPP highlights the significant influence of any investment planning solution on industrial companies. Moreover, when the investment cycle is completed, there are still responses from the industry implementation and operational support of the digital architecture. Note that each step of the investment ICPP requires the application of an analytical model. Consider the stage 'Analyzing alternatives to investments.' To address this issue, we can use each alternative's Profitability Index (*PI*). *PI*is defined by dividing the sum of the discounted inputs by the discounted financial outputs (based on the input-output analysis[32,33]):

$$PI = \frac{\sum_{t=0}^{T} \Delta C_{in}(t) \times \frac{1}{(1+k)^t}}{\sum_{t=0}^{T} \Delta C_{out}(t) \times \frac{1}{(1+k)^t}} \quad (9)$$

where $\Delta C_{in}(t)$ is the inward cash flow defined in the t-step, and $\Delta C_{out}(t)$ is the outward cash flow defined in the t-step? PI is tightly connected with *NPV*: if the latest is positive, *PI* is more than 1, and vice-versa. If *PI* exceeds 1, the investments in the project are highly efficient; if *PI* is equal to 1, the investment project is paid off; and if *PI* is less than 1, the investment project is hardly paid off.

Table 3. Main stages of the investment cycle phase plan for digital engineering.

Investment cycle phase	Industrial response
Research and development (R&D) initiatives	Business process operations to be changed by applying digital solutions
Analyzing alternatives for investments	Operational or economic efficiency considered
Project proposal	Targeted operational excellence is defined
Financial transfer on obtaining the digital solution	Developing digital engineering architecture
Payback period	Designing or customizing information systems Implementation of IT Support operations of the digital architecture

Another possible investment appraisal approach may be based on considering *IRR*, the Internal Rate of Return (IRR), defined as the discount rate (*k*g) of the fully paid-off investment project, where discounted inward and outward cash flows are equal. To substitute the discount rate (*k*) in Equation (9) with (*k*'), we obtain *NPV* equal to zero, where *IRR* is the solution of the Equation.

$$\sum_{t=0}^{T} C_S(t) \times \frac{1}{(1+k')^t} = 0 \quad (10)$$

where $C_S(t)$ summarizes the cash flow of the investment project in the *t*-step.

NPV appraisal allows us to assume the effectiveness of investment, while IRR is compared with the return rate required by the stakeholder. The investments are worth considering if *IRR* equals or exceeds the required return rate. Investments planned by the project are not appropriate.

The last step of the ICPP is called the 'Payback period'; for digital engineering, it is not the least point, as digital transformation requires a total change of many business processes, efficient assessment systems and everlasting operational support. Additional financial aid might be required if the initial investment appraisal is not précised at this stage. While making financial-related decisions should be considered that the payment for a certain technology or project can be a single payment or a series of payments distributed over time. In most cases, payment of medium- and long-term bank debts, commercial credits, lease payments, the creation of special-purpose funds, *etc*., is assumed to be a series of payments made through regular intervals and called a financial payment flow. A series of subsequent stable payments issued at certain intervals can also be called financial rents or annuities. It features the number of payments made during a year, frequency of interest accrual, and moment of payments received (at the beginning, middle, or end of the year). The generalized features of financial rent are used in financial analysis, strategic planning, and access to efficient bank credit and leasing contracts. Thus, annuities in investment project appraisal can be considered for further research and aligned with *IRR* and *PI*.

The description of possible models to be applied to each ICPP emphasizes the importance of a holistic, multidimensional approach to the problem of investment appraisal. In particular, relevance to this issue is given by the digital transformation of the modern world, where implementing particular IT solutions should be analyzed on a multilevel basis. Therefore, further research should focus on developing a sophisticated revised model for each ICPP step. Note that considering particular industries, such as service providers or system integrators, may require adjusted models within the ideas presented in this article. Therefore, the proposed methodological approach is a perspective for further revision and development of particular industrial cases. The existing models are listed in the following,

[A] Real-time information integration framework
[B] Financial logistics models
[C] Model-Based Systems
[D] Fully polynomial-time approximation schemes

4.1 Accuracy

The Model-based holistic, multidimensional view of digital engineering investments appraisal approach aims to accurately evaluate the potential benefits and risks of digital engineering investments by taking a comprehensive, multi-faceted approach. This holistic view considers a wide range of factors and impacts, providing a more accurate representation of the potential outcomes of an investment. One of the key factors contributing to this approach's accuracy is the use of data-driven models. These models utilize historical data, industry benchmarks, and predictive analytics to forecast the potential return on investment (ROI) and other key performance indicators (KPIs). Table 4 shows the comparison of accuracy. Using these data-driven models improves the appraisal's accuracy based on concrete data rather than subjective estimates. Another important aspect of this approach is its multidimensional nature. Traditional investment appraisal methods often focus solely on financial metrics such as ROI and payback period, neglecting other factors such as customer satisfaction, employee engagement, and operational efficiency. Fig. 3 shows the computation of accuracy.

The model-based holistic, multidimensional view considers these various dimensions, providing a more accurate

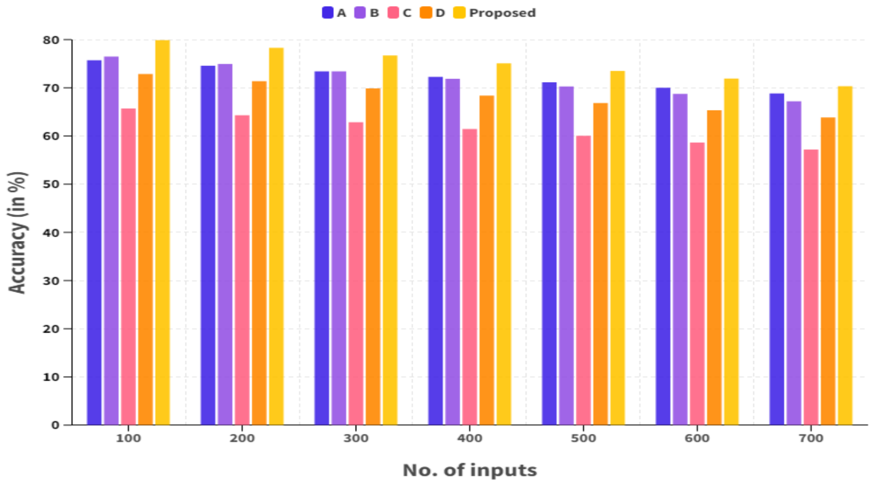

Fig. 3 Computation of accuracy.

Table 4. Comparison of Accuracy (in %).

No. of Inputs	A	B	C	D	Proposed
100	75.71	76.50	65.69	72.86	79.89
200	74.57	74.95	64.28	71.36	78.29
300	73.42	73.40	62.86	69.86	76.70
400	72.28	71.85	61.45	68.36	75.10
500	71.13	70.30	60.03	66.86	73.51
600	69.99	68.75	58.62	65.36	71.91
700	68.84	67.20	57.20	63.86	70.32

and well-rounded assessment of the potential impact of a digital engineering investment.

4.2 Precision

Precision in the context of a Model-based holistic, multidimensional view of digital engineering investments appraisal refers to the degree of accuracy and consistency in evaluating and analyzing digital engineering investments. It involves considering multiple dimensions and interrelated factors to provide a comprehensive and reliable assessment of the potential value and risks of investing in digital engineering projects. Table 5 shows the computation of precision.

Table 5. Comparison of precision (in %).

No.of Inputs	A	B	C	D	Proposed
100	82.71	84.50	73.69	79.86	84.89
200	81.57	82.95	72.28	78.36	83.29
300	80.42	81.40	70.86	76.86	81.70
400	79.28	79.85	69.45	75.36	80.10
500	78.13	78.30	68.03	73.86	78.51
600	76.99	76.75	66.62	72.36	76.91
700	75.84	75.20	65.20	70.86	75.32

Precision is crucial in digital engineering investment appraisal as it enables decision-makers to make informed and strategic choices based on a thorough understanding of these investments' potential benefits, costs, and risks. A precise appraisal considers the investment's holistic view, including technological, financial, organizational, and strategic aspects, to understand the expected outcomes comprehensively (Fig. 4).

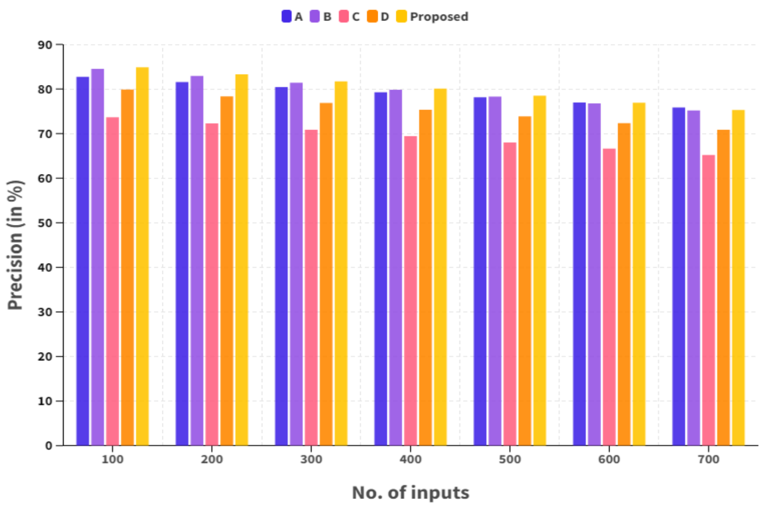

Fig. 4 Computation of precision.

A precise model-based holistic view can also help to identify potential predictors and indicators of success or failure in digital engineering investments. By considering different dimensions, such as cost-effectiveness, technical feasibility, and marketability, a multidimensional view can provide a more accurate prediction of the likely outcomes of the investment. Furthermore, a precise appraisal can also assist in optimizing investment decisions by determining which projects or initiatives are most aligned with an organization's goals, capabilities, and resources. It helps avoid unnecessary investments and ensures that the ones made are strategically aligned with the organization's overall objectives and direction.

4.3 Recall

The model-based holistic, multidimensional view of digital engineering investment appraisal focuses on thoroughly evaluating digital engineering initiatives' potential return on investment (ROI). It takes into consideration multiple dimensions that have an impact on the success of digital engineering investments. Recall in this context refers to the ability to accurately remember and retrieve information about these dimensions and their influence on the appraisal of digital engineering investments. It includes understanding the various components of the model, such as technological, organizational, and economic factors, and how they interact with each other. Table 6 shows the computation of recall.

Recall is important in this model because it helps decision-makers make informed and effective decisions about investing in digital engineering initiatives. By recalling and understanding the different dimensions and their interrelationships, decision-makers can accurately assess a specific investment's potential benefits, risks, and costs. Recall is essential in ensuring that all relevant factors are considered during the appraisal process. Fig. 5 shows the computation of recall.

It helps prevent bias and provides a comprehensive approach to evaluating digital engineering investments. The recall is crucial to the model-based holistic, multidimensional view of digital engineering investment appraisal. It enables decision-makers to thoroughly evaluate the potential ROI of digital engineering investments and make informed decisions.

Table 6. Comparison of Recall (in %).

No. of Inputs	A	B	C	D	Proposed
100	78.71	80.50	68.69	75.86	80.89
200	77.57	78.95	67.28	74.36	79.29
300	76.42	77.40	65.86	72.86	77.70
400	75.28	75.85	64.45	71.36	76.10
500	74.13	74.30	63.03	69.86	74.51
600	72.99	72.75	61.62	68.36	72.91
700	71.84	71.20	60.20	66.86	71.32

4.4 F1-score

The f1-score measures the overall performance of a model-based holistic, multidimensional view on digital engineering investment appraisal. It is calculated by taking the harmonic mean of precision and recall, where precision measures the proportion of relevant results among all the retrieved results, and recall measures the proportion of relevant results retrieved. In digital engineering investment appraisal, a high f1-score would indicate that the model-based holistic, multidimensional view can accurately identify and evaluate relevant factors for making investment decisions in the digital engineering field. Table 7 shows the computation of F1-Score.

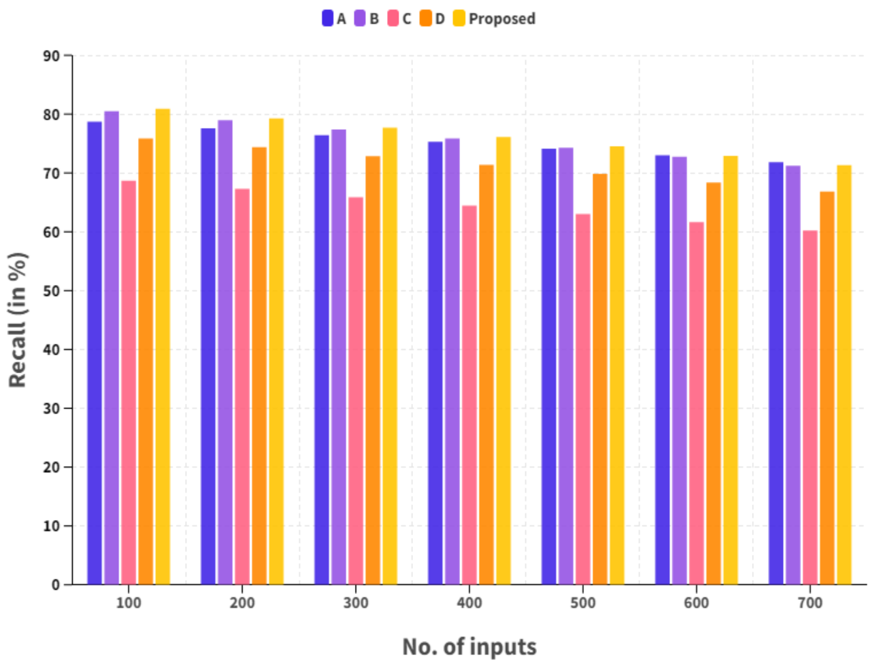

Fig. 5 Computation of recall.

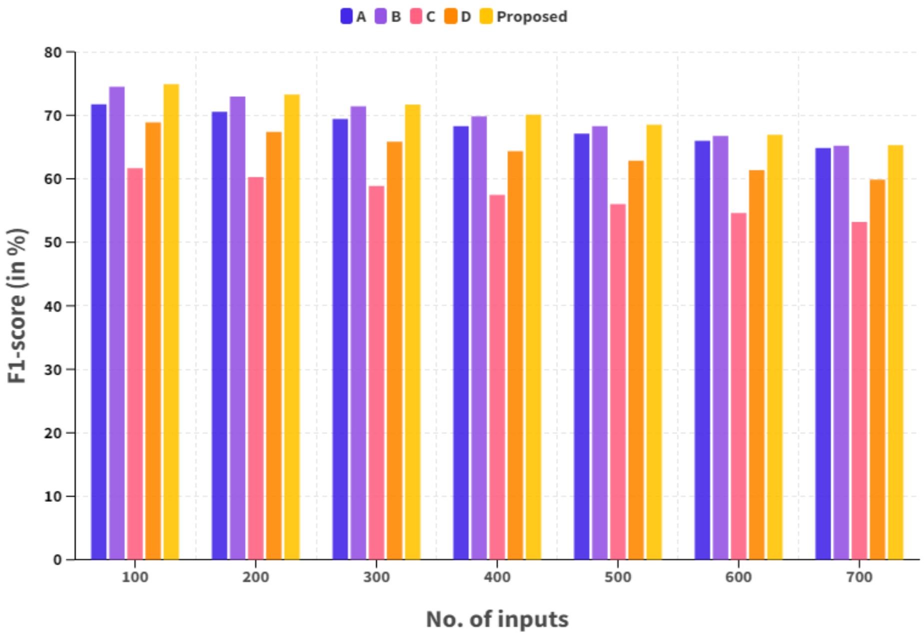

Fig. 6 Computation of F1-Score.

Table 7. Comparison of F1-Score (in %).

No. of Inputs	A	B	C	D	Proposed
100	71.71	74.50	61.69	68.86	74.89
200	70.57	72.95	60.28	67.36	73.29
300	69.42	71.40	58.86	65.86	71.70
400	68.28	69.85	57.45	64.36	70.10
500	67.13	68.30	56.03	62.86	68.51
600	65.99	66.75	54.62	61.36	66.91
700	64.84	65.20	53.20	59.86	65.32

The F1 score considers precision and recall, making it a more comprehensive and balanced measure than individual metrics. This means that a high F1 score reflects high precision, indicating that the model can accurately identify relevant factors, and high recall, indicating that the model can retrieve all relevant factors. Fig. 6 shows the computation of the F1 Score.

The F1-score is based on the harmonic mean; it gives more weight to lower values, making it a more reliable measure for imbalanced datasets. It is particularly useful in digital engineering investment appraisal, where the number and importance of different factors may vary greatly. The results indicate that when approached strategically and holistically, digital engineering investments can yield significant value and competitive advantage. By integrating financial analysis, technological innovation, organizational capabilities, market dynamics, and strategic alignment, organizations can make informed investment decisions that drive innovation, efficiency, and growth.

4.5 Limitations

While the model-based holistic, multidimensional view on digital engineering investment appraisal offers valuable insights and guidance for decision-makers, it is important to acknowledge several limitations inherent in the study: The findings and conclusions of the study may not be universally applicable to all organizations or industries. The research context, sample characteristics, and specific investment scenarios considered in the study may limit the generalizability of the results. Data availability and quality need to be improved to analyze and interpret findings. Limited access to comprehensive and reliable data sources may impact the accuracy and robustness of the research outcomes. The evolving nature of the digital landscape introduces inherent uncertainties and complexities that need to be fully captured in the research. Digital engineering investments are subject to dynamic technological trends, market disruptions, and regulatory changes, which may challenge predictive modelling and scenario analysis. Qualitative technological innovation assessments, organizational capabilities, and market dynamics involve subjective judgments and interpretations. Differences in perspectives and biases among stakeholders may influence the validity and reliability of qualitative findings. The study focuses primarily on evaluating digital engineering investments from a strategic and financial perspective. While the multidimensional framework encompasses various dimensions, certain factors, such as social and environmental impacts, may need to be fully addressed in the analysis. The study is conducted within a specific timeframe, which may limit the depth and breadth of analysis. Long-term implications and sustainability considerations of digital engineering investments may require extended monitoring and evaluation beyond the scope of the research time frame. External factors beyond the researcher's control, such as economic conditions, geopolitical events, and technological disruptions, may influence investment outcomes and performance. These externalities may introduce additional sources of uncertainty and risk beyond the study's scope. Despite these limitations, the research provides valuable insights and methodologies for evaluating digital engineering investments and informs strategic decision-making in the digital age. Future research endeavours may address these limitations through enhanced data collection methods, longitudinal studies, and interdisciplinary collaborations to further advance understanding in this critical domain.

5. Conclusion & recommendations

In conclusion, this study's model-based holistic, multidimensional view provides a comprehensive framework for evaluating and appraising digital engineering investments. By integrating financial analysis, technological innovation, organizational capabilities, market dynamics, and strategic alignment, this approach offers decision-makers a nuanced understanding of their investments' potential impact and value. This study focuses on the challenge of investment appraisal. The authors assume that traditional approaches should be revised and adjusted due to new trends: the evolving economic environment, industrial informational integration, and digitalization. Therefore, this study aimed to develop a complex approach to the investment appraisal of technologies related to digital engineering. We conducted a comprehensive literature review to achieve this goal and described the main benefits and challenges of the supposed holistic view of model development. Our study focuses on a model-based, holistic, and multidimensional view of investment appraisal in digital engineering. To meet the scope of the research, we propose using an adjusted *ROA* model, including *NPV*, market-related variables, and current and safety stock, taking the stochastic nature of these parameters. The numerical example demonstrates the robustness and transparency of the proposed approach. Each metric is feasible regarding its effect on the goal function and is linked with other variables. Focusing on critical metrics allows for an adaptable approach to appraising investments in other solutions or projects apart from digital engineering. The findings also underscore the importance of balancing short-term financial objectives with long-term strategic goals in digital engineering investments. While financial metrics provide valuable insights into investment returns and profitability, qualitative assessments are equally critical for evaluating intangible factors such as technological feasibility, organizational readiness, and market dynamics. The discussion further extends the need for organizations to continuously monitor and adapt their investment strategies in response to evolving market conditions and technological advancements. Digital engineering investments require agility, flexibility, and a willingness to embrace change to remain competitive in today's dynamic business environment. Finally, the results underscore the importance of leveraging advanced modelling techniques and decision-support systems to support investment decision-making. By integrating quantitative models, qualitative assessments, and scenario analysis tools, organizations can confidently enhance their decision-making capabilities and navigate the complexities of digital engineering investments. The proposed MBSE approach can benefit scholars and entrepreneurs by supporting stakeholders and top managers in decision-making. By embracing these methods, organizations can strengthen their ability to adapt to the ever-changing digital engineering environment and resist the economic risks of a poor investment appraisal process. Further research will focus on designing and revising investment models according to the ICPP, as the investment solutions considerably impact a company's business process excellence.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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