




RESEARCH PAPER

Economic feasibility and cost-benefit analysis of additive manufacturing in public sector production: Evidence from Indian factories

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ABSTRACT

Purpose: The purpose of the study is to examine the economic sustainability and cost-benefit results of implementing the technologies of Additive Manufacturing (AM) into the production systems of large-scale enterprises in Indian state factories, which is under-researched in the current literature.

Design/methodology/approach: It was developed on the basis of a quantitative research design with the help of a stratified random sampling model, where 397 respondents, who represent both managerial and operational positions, were asked. The data were collected using a five-point Likert-scale questionnaire, and reliability analysis was performed to prove a high internal consistency of the questionnaires (Economic Feasibility $\alpha = 0.89$; Cost-Benefit Perception $\alpha = 0.91$). The analysis used multivariate tests to test the demographic and organizational factors on the perceived feasibility and regression analysis to measure the relationship between perceived economic viability and projected cost benefit realization.

Results: The analysis shows that there is very little effect of gender and age on the perceptions about AM adoption. But organizational designation, especially managerial position, can be a strong influence of expectations on the changes in product quality and operation efficiency. The theoretical basis of the findings lies in Technology Organization Environment framework and Resource based view, which offer the strategic significance of economic viability in technology adoption in the public sector.

Research Implications: The study has implications on the literature by providing empirical evidence on the economic and organizational aspects of AM adoption in the government sector manufacturing that adds to the theoretical debate on integration of technology in emerging economies.

Practical and Social Implications: AM integration is viewed as cost-effective, operationally and strategically advantageous, although there are fears of initial investments and compliance with regulations. The results offer practical lessons to the policymakers and industry leaders to develop investment strategies, training and regulatory frameworks that can expedite the adoption of AM.

Keywords: Additive Manufacturing; Economic Feasibility; Cost-Benefit Analysis; Technology Integration; Indian Public Sector Factories.

1 INTRODUCTION

Mass production techniques have an opportunity to change as the introduction of additive manufacturing (AM) in the industry has changed the way things are done globally (Achillas *et al.*, 2014). Considering the Indian Factories under the state sector, the evaluation of the economic feasibility of employing AM technologies becomes a necessity (Al-Masa'fah, Abushaikh and Bwaliez, 2024). The purpose of this comprehensive cost-benefit analysis is to assess the possible effects, obstacles and prospects of adopting AM in mass production with the Indian Public Sector Factory (Baumers, 2012). Additive manufacturing, often known as 3D printing, is a disruptive

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technique that produces objects layer by layer from digital designs (Priyadarshini *et al.*, 2024). Unlike traditional subtractive production methods, involving cutting away material from a solid block, AM allows the creation of complex geometries with minimal. Its versatility spans various industries, including aviation, the car industry, health care, and consumer goods (Omier, K. and Hoffman, E., 2017).

Integration of AM into mass production processes provides several benefits. First, it allows the creation of tailor-made and complicated components to decrease the on-demand lead time and cut the product cost (Thomas, D. (2015)). Second, AM enables rapid prototypes, enabling you to enhance design and rapid product increase cycles (Ojha, Goyal and Chand, 2023). Moreover, AM will allow supply chains to be simplified due to the decentralization of production and help lower transport expenses and carbon emissions (Rasheed, San and Kvamsdal, 2020). Design flexibility and material performance is enhanced by AM capability to utilize a broad material range of polymers and metals (Lamei, Z., 2021). The economic impact of introducing AMS into mass production in the government sector is varied. On the one hand, the preliminary costs of AM equipment, software and training may be in an economic condition.

This is because, although additive manufacturing has been extensively studied in the firms and developed economies of the private sector, little empirical research has focused on the manufacture system of the public sectors in emerging economies like India. The Indian public sector factories are under specific structural and institutional limitations, such as the bureaucratic levels of decision making, regulatory framework, budgetary responsibility, and socio-economic employment procedures, unlike the private enterprises. Such structural features affect the processes of technology adoption unlike market-driven firms that are privately held. As a result, the conclusions of the research in the private sector or developed economies cannot be directly transferred to the production conditions of the public sector in the emerging economies. Such contextual gap inspires the current study.

Although there is an increased evidence base across the world, there is limited empirical research on the economic viability of AM in the public sector factories in emerging economies (Thomas and Gilbert, 2014). Majority of previous studies concentrate on either the case of the private sector or on the context of a developed economy (Verbooket, Krikke and Salmi, 2024). To fill this gap, the current research provides a cost-benefit analysis of AM integration in factories of Indian public sectors based on quantitative data of different respondents who are in managerial and operational positions (Priyadarshini *et al.*, 2023). This study examines how demographic and organizational factors (gender, age, designation) shape feasibility perceptions, and quantify the link between economic feasibility and perceived cost-benefit outcomes (Singh *et al.*, 2024). By grounding the analysis in a large public-sector context, this work contributes practice-relevant evidence on the conditions under which AM delivers economic value at production scale in India.

2 LITERATURE REVIEW

Despite its promising potential, integrating AM into mass production within Indian public sector factories entails several challenges and considerations. Firstly, there may be a lack of awareness and expertise regarding AM technologies among factory personnel, necessitating comprehensive training programs. Secondly, ensure quality control and certification standards for AM-produced parts; it is necessary to meet regulatory requirements and ensure the reliability of the product (IVKIĆ, I., Buhmann, T., List, B., & Gnauer, C., 2024). Third, it is important to address intangible rights and establish strong cybersecurity measures, especially when working with sensitive design and data. In addition, scalability and repeatability require ongoing research and development work to adapt AM procedures for scalability and repeatability when reducing production costs. Finally, AM adoption in India requires collaboration between industry interests and policymakers (Meller, S., Hao, L., and Zhang, D., 2014) to navigate the regulatory landscape and the policy structure.

Many cases of studies reflect successful integration of AMS into mass production processes in the public sector in the public sector. For example, the Indian Space Research Organization (ISRO) has used AM technologies to create a complex component for satellite systems, which has reduced both cost and lead time. Similarly, Bharat Heavy Electrical Limited (BHEL) has used AM to produce fast prototypes and turbine components, in order to increase operational efficiency and competition (Lynch, P., Hasbrook, C. R., Wilk, J., K. These examples highlight the Public Competition to increase the possibility of the PUBLICS.

Integration of additive manufacturing into large production processes in Indian Factories in the public sector provides major promises of continuing economic viability and competition. Although there are challenges such as initial investments, training, quality control, and regulatory compliance, long-term benefits are appropriate to justify active efforts to adopt AM technologies (Urbanic, RJ, and Saqib, SM, 2019). By taking advantage of AMS skills for adaptation, rapid

prototyping, and optimization of the supply chain, the Indian public sector factory can increase operating efficiency, reduce costs, and promote innovation. It is necessary to remove the challenges with the industry's interests, cooperation between academics and decision makers, and to realize the full potential for AM integration into India's production scenario (Akila, C., Adonis, D., Ekovaau, E., Thhmonidis, M., and Tzetis, D., 2015).

The literature mainly concentrates on the technological developments and process optimization with which additive manufacturing is linked, highlighting the role this approach can play in helping to increase flexibility, smart infrastructure integration, and digital manufacturing capabilities (Kantaros *et al.*, 2025; Okokpujie and Tartibu, 2024). In the meantime, its extensive industrial use is still hindered by a number of issues, including the degradation of materials, reliability of the process, and scalability (Soni *et al.*, 2024; Vanerio *et al.*, 2024). Although these contributions offer valuable information about engineering and technological aspects, minimal information is given on the economic viability and decision-making dynamics that shape adoption, especially at an organizational level. Moreover, most studies are focused on the environment of the private sector and developed economies thus dismissing the institutional complexity, policy limitations, and hierarchical decision-making processes that define manufacturing operations in the public sector in the emerging economies. This poses a huge gap in comprehension of how economic considerations and organizational structure interact to promote the use of additive manufacturing in these settings.

The current research is directed by two primary goals. First, it attempts a systematic evaluation of economic viability of involving additive manufacturing (AM) technologies in mass production processes in the public sector in the public sector. This goal is to evaluate the economic and operational feasibility of using AMS in state companies, where efficiency, cost control, and reliability are important. Second, the purpose of the study is to analyze a comprehensive cost analysis to investigate the extensive economic effects of AM integration on the competition for Indian public sector building and long-term stability. By analyzing both direct financial ideas and indirect strategic benefits, the purpose emphasizes how an adaptation can affect production efficiency, flexibility in the supply chain, and organizational results

2.1 Theoretical framework and hypothesis development

In this research, the theoretical basis is built based on the combination of the approach of Technology-Organization-Environment (TOE) framework, the Resource-Based View (RBV) perspective and the economic decision-making theory. Instead of considering the theories separately, the current research integrates them to present an overall account of additive manufacturing (AM) adoption in the context of manufacturing systems in the public sector.

TOE framework describes the contextual forces that lead to adoption of technology of technology, organizational preparedness and environmental forces (Tornatzky and Fleischer, 1990). In this context, economic feasibility is one of the key technological-organizational analysis criteria that will influence how managers perceive the feasibility and desirability of the implementation of AM technologies.

In addition to this, the concept of Resource-Based View (RBV) regards AM as a strategic ability to strengthen operational flexibility, product customization, and the supply chain responsiveness (Barney, 1991). Nevertheless, RBV implies that competitive advantage of resources can be created only in cases when they are economically feasible and utilized. Thus, economic feasibility is a mediating process by which the capabilities of technology are turned into the perceived organizational value.

Continue reinforcement of this point of view, the economic decision-making theory is that the adoption of innovation by organizational actors is based on the level of expectation utility, cost-effectiveness, and returns expected. In this respect, perceived economic feasibility is a direct determinant of the decision-makers evaluating the general cost-benefit trade-offs related to AM implementation.

Having combined these theoretical lenses, this research study places economic feasibility at a focal point of connection to bridge technological potential (TOE), strategic resource value (RBV) and managerial decision outcomes (economic decision theory). This combined model offers a greater explanation of the process and nature of the formation of cost-benefit perceptions in the contexts of the manufacturing sector in the public sector that places great importance on financial responsibility and strategic rationality.

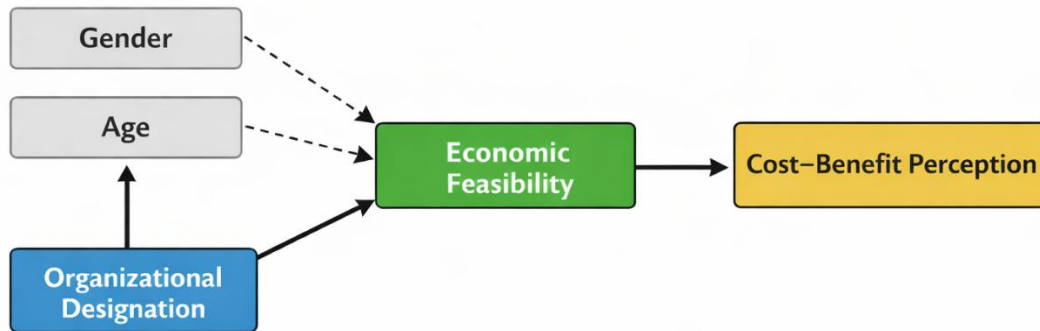


Figure 1 - theoretical Framework of AM Adoption

On this theoretical basis the following hypothesis is put forward:

H1: Cost-benefit perceptions towards additive manufacturing integration in Indian factories in the public sector are positively and significantly affected by economic feasibility.

Besides, technology assessment procedures can be impacted by demographic and organizational factors. Based on the diffusion of innovation theory, (Rogers, 2003), hierarchical role in an organization might influence perceptions of the technological benefit as a result of variation in decision authority and strategic accountability.

H2: Organizational name plays an important role in the perceptions of economic feasibility.

This theorizing engendering enhances the explanatory rationale of the research and places economic feasibility as a core construct of technology adoption and strategic operations management literature.

2.2 Conceptualization of key variables

Economic feasibility

When it comes to this study, the term economic feasibility can be used to denote the perceived financial and operational feasibility of adopting additive manufacturing technologies as part of the mass production procedures. It embodies managerial evaluations on the potential of cost reduction, efficiency, improvements on the supply chain, long-term gains, and strategic alignment. Instead of gauging real financial statements, the construct relates to knowledgeable organisational observations of economic viability in the manufacturing contexts of the public sector.

Cost-benefit perception

Cost-benefit perception reflects the general perception of the respondents regarding the perceived advantages of the additive manufacturing integration in terms of the evaluation of whether the perceived advantages of the additive manufacturing integration surpass the perceived costs, risks, and initial investments. It is a comparative judgment on value realization, improvement of profitability, improvement of competitiveness and sustainability in the long run.

Both constructs are operationalized as multi-item perceptual indices which are in accordance with the previous researches in technology adoption and operations management.

There are three main contributions made in this study. First, it broadens the use of technology adoption literature by empirically confirming the importance of economic feasibility as one of the key defining factors of cost-benefit perception in a public-sector manufacturing-related setting. Second, it adds to the research on the theory of management in the public sector by showing how technological assessment is influenced by hierarchical designation in state-owned business. Third, it offers realistic suggestions to policymakers and the administrators of the public sectors in the third world countries in that economic viability is one of the strategic tools of gaining pace in integrating additive manufacturing.

3 METHODOLOGY

3.1 Population and sample

The study population includes individuals involved in roles such as operations, management, and decision-making in Indian factories in the public sector. In order to achieve different

approaches, participants were drawn from many departments and organizational levels. The final sample consisted of 397 respondents, a size determined through statistical calculations, which assesses the margin of population size, level of trust, and errors. This ensures both representation and statistical reliability of the findings.

3.2 Sampling technique

A stratified random sampling technique was employed to ensure adequate representation across hierarchical levels within public sector manufacturing organizations. The sampling frame consisted of employees working in selected Indian public sector enterprises involved in operations, production, strategic planning, and technology implementation.

Stratification was based on organizational designation, categorized into four groups: low-level managers, mid-level managers, top-level managers, and executives. This criterion was selected because hierarchical position is theoretically associated with differences in decision-making authority, exposure to strategic planning, and evaluation of technological investments.

A proportionate stratified sampling approach was adopted, wherein the number of respondents selected from each stratum reflected their approximate distribution within the organizational structure. This ensured representativeness and minimized sampling bias.

Within each stratum, respondents were selected using simple random sampling techniques. Where employee lists were available, individuals were assigned numerical identifiers and selected using random number generation procedures. In cases where direct lists were not accessible, coordination with departmental administrators ensured unbiased distribution of questionnaires across eligible participants.

This multi-stage sampling approach ensured both representativeness and randomness, thereby enhancing the external validity and replicability of the study.

3.3 Data collection instrument

The primary data collection tool was a structured questionnaire, designed to measure perceptions, approaches, and opinions about AM integration. The instrument included the likert scale, which allows respondents to express different degrees of agreement or disagreement with statements on economic viability and cost-profit dimensions. This design ensured generations of compatible, quantitative data suitable for multiple regression analysis.

3.3.1 Variable operationalization and measurement

The survey instrument consisted of 20 items measuring two constructs: Economic Feasibility (E1–E10) and Cost–Benefit Perception (C1–C10). All items were measured using a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Composite scores were computed using the mean of respective item groups. The full questionnaire is provided in Appendix A. It is crucial to note that the current work employs ex-ante methodological approach to the cost-benefit analysis, i.e. the expected results of the economic activity as perceived by the managers as opposed to the financial accounting of the post-implementation results of the activity. Perception-based economic assessment is widely applicable in the public-sector technology adoption contexts where objective cost information is institutionally constrained.

Economic Feasibility (Independent Variable)

Economic feasibility was measured using ten items capturing perceptions of:

- Cost reduction
- Efficiency improvement
- Long-term benefits
- Product customization enhancement
- Supply chain streamlining
- Reduced import dependency
- Economic growth potential
- Investment justification
- Product quality improvement
- Regulatory manageability

A composite score was calculated by computing the mean of the ten items (E1–E10). Higher

values indicate stronger perceived economic feasibility.

Cost-benefit perception (Dependent variable)

Cost-benefit perception was measured using ten items evaluating:

- Cost savings
- Investment justification
- Operational efficiency
- Competitiveness
- Strategic alignment
- Risk-benefit trade-off
- Production flexibility
- Quality enhancement
- Regulatory feasibility
- Profitability impact

The item assessing whether “risks outweigh benefits” was reverse-coded prior to analysis to maintain directional consistency. A composite score was computed by averaging the ten items (C1–C10). Higher values indicate stronger perceived net benefit of adoption.

3.4 Data collection procedure

There were four steps in the data collection process. To begin with, consent and cooperation with factory officials were secured so that the officials could reach participants and resources required. Second, based on access and preference of the participants, the structured questionnaire was converted to physical or electronic version. Third, enough time was given to deliberate responses with the help of clear directions and reminders. Lastly, the entire questionnaire was located, tabulated and was coded to be analyzed. The collection of data occurred during a structured period of [January 2022-March 2024] through the implementation of structured questionnaires that were sent to the chosen units of the public sector manufacturing. The involvement was voluntary.

Ethical considerations

The research followed the normal research ethics. The involvement was voluntary and the answers were anonymous and no personal identifiable data was gathered. The purpose of the study was explained to the respondents and informed consent was obtained before they participated in the study. The study also adhered to the ethical considerations of organizational research that involved surveys.

Handling of missing data

Out of 540 questionnaires given out, 397 replies were retained in order to be analyzed. Questionnaires that were incomplete or not filled completely were excluded. Since the analyzed variables did not have any missing values in the final dataset, no imputation procedures had to be applied.

Coding of categorical variables

A numerical coding was done on demographic variables. Gender was coded 1= Male and 2= Female. MANOVA was to be analyzed using ordinal codes of age categories and organizational designation levels. Continuous variables as derived mean scores were composite variables (E and C).

3.5 Data processing and analysis

After the data collection, the reactions were collected and recorded in SPSS for processing and statistical analysis. The analytical structure included multiple-compressing tests to evaluate the effect of demographic and organizational variables (gender, age, designation) on perceptions, as well as regression analysis to determine the relationship between economic viability and cost. Reliability and clinical probes were also performed to ensure the validity of the results (Cronbach's

Alpha, VIF, and generality test).

3.6 Methodology framework

The research method is summarized in Figure 2, which shows the sequential stages of the study. The process starts with the choice of research design, followed by population and trial identification, stratification of sampling, and data collection. This figure illuminates the stages of the branches of approval, questionnaire division, and reaction management, which later convert to data processing. Finally, data is stored and analyzed using SPSS, with the diagnosis before reporting the findings. This structure emphasizes the systematic and tough nature of the research design that was used in the study.

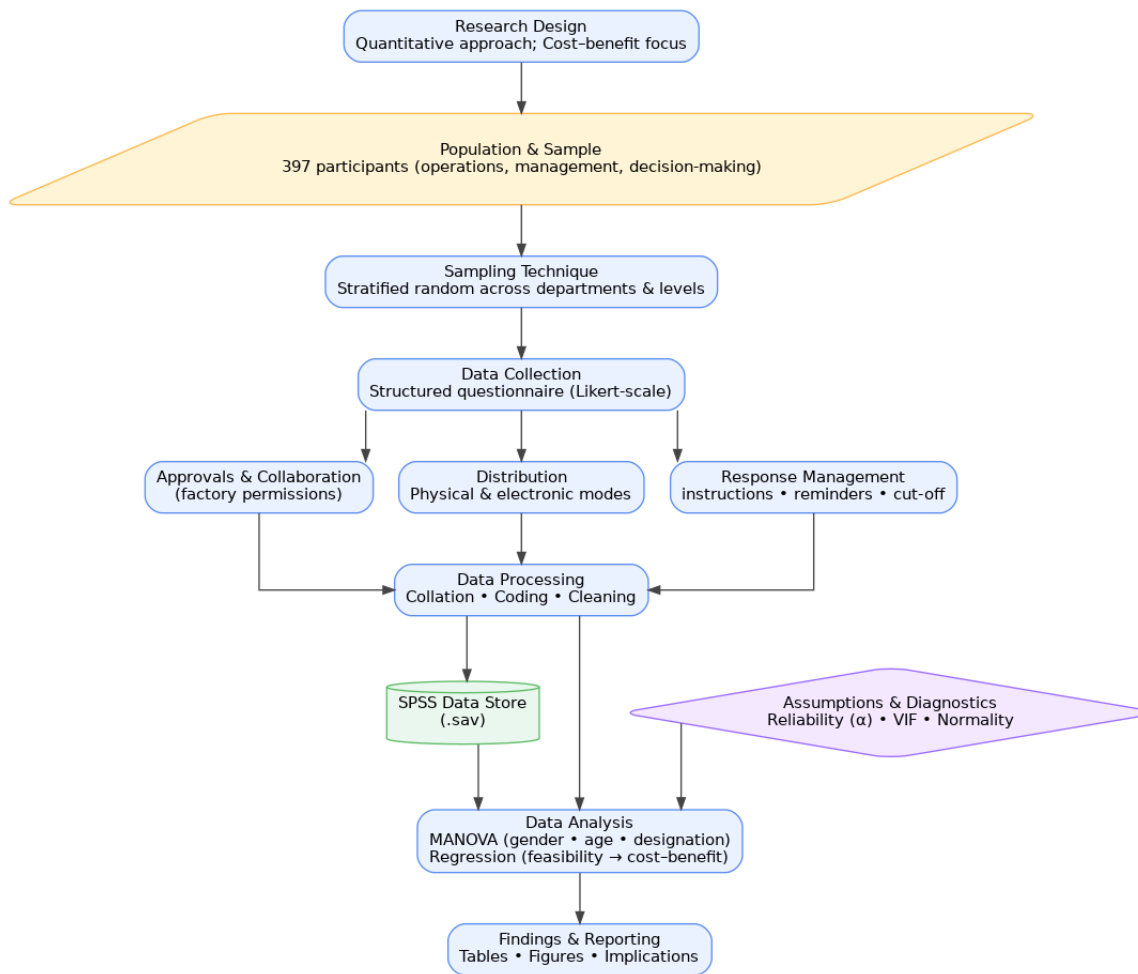


Figure 2: framework for assessing the economic viability of AM integration in Indian public sector factories

3.6.1 Instrument development and measurement approach

The measurement tool has been constructed in a very strict multi-stage approach that guarantees content validity, clarity, and relevance in the context. The first set of items was based on literature on existing knowledge on additive manufacturing adoption, technology investment analysis, and operations management (Thomas, 2015; Mellor *et al.*, 2013; Oettmeier and Hofmann, 2016). These were modified to the context of Indian government sector manufacturing to be sure that both the theory and the applications are contextual.

The instrument was comprised of two constructs, Economic Feasibility and Cost-Benefit Perception with ten items each. They were operationalized on a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) following the previous empirical work in the field of technology adoption.

To determine content validity, the questionnaire was rated by a review panel of three academic scholars in the field of operations and supply chain management, as well as two industry players in the manufacturing sectors of the government. According to their feedbacks, some minor changes were done to enhance wording of meaning, to remove ambiguity, and to achieve contextual

suitability.

The clarity, reliability and interpretability of the instrument were evaluated by carrying out a pilot study using a sample of 35 respondents who were sampled in the same organizational context. The pilot findings also revealed good internal consistency (Cronbachs alpha was more than 0.80 with both constructs) and there were no significant revisions necessary to make, which affirmed that the instrument was suitable in terms of large-scale data collection.

3.6.2 Reliability and construct validation

Measurement scales reliability and construct validity were evaluated through the standard statistical measures. The internal consistency reliability was assessed by employing the Cronbach alpha. The Economic Feasibility construct was highly reliable ($\alpha = 0.89$) and Cost-Benefit Perception construct was highly reliable ($\alpha = 0.91$), which is above the recommended value of 0.70.

Exploratory Factor Analysis (EFA) that involved the principal component extraction with varimax rotation was used to assess construct validity. Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.912 which showed that it was most suitable in factor analysis. Bartlett Test of Sphericity was significant ($p < 0.001$) and supported the fact that the items correlations were large enough to extract a factor.

According to the EFA results, a very strong two-factor structure was found that relates to the theoretical constructs of Economic Feasibility and Cost-Benefit Perception, and it accounts for 67.4% of the overall variance. All items had high factor loadings that were greater than 0.60 on their constructs with little cross-loadings as well, which reflects convergent and discriminant validity of the measurement model.

Convergent validity is observed as the factor loadings and internal consistencies of items in each construct are high and it means that the items are capturing the desired underlying meaning. The distinctiveness of the items into two different factors is a valid support of discriminant validity, and there is no substantial overlap of constructs.

Though a confirmatory factor analysis (CFA) method is often employed in structural equation modeling, the given research paper utilizes a regression-based analysis model. That is why it is possible to consider that EFA is suitable to determine construct validity, which follows the previous empirical researches in the fields of operations management and technology adoption research.

3.7 Demographic profile of respondents

Table 1 presents the frequency and percentage distribution of respondents according to gender, age, and designation within Indian public sector factories. A wide representation of the workforce participating in the study is ensured by the 397 individuals in the total sample size.

Table 1 - Percentage Analysis - Demographic Profile

		Frequency	Percent
Gender	Male	343	86.4
	Female	54	13.6
	Total	397	100.0
Age	Less than 25 Years	34	8.6
	25 - 35 Years	183	46.1
	36 - 45 Years	159	40.1
	Above 45 Years	21	5.3
	Total	397	100.0
Designation	Low Level Manager	23	5.8
	Mid-Level Manager	177	44.6
	Top Level Manager	177	44.6
	Executive	20	5.0
	Total	397	100.0

Source: (Primary data)

3.8 Gender distribution

Male respondents form an overwhelming majority (86.4%) of the sample, while female respondents only represent 13.6%. This obvious imbalance in Indian factories in the public sector traditionally reflects the male-oriented workforce, and emphasizes the need for greater gender diversity in such industrial environments.

3.9 Age distribution

The largest part of the respondents falls within the 25-35 year age group (46.1%), followed by persons in the age group 36–45 years (40.1%). Participants at the age of 25 (8.6%) and those who formed a small ratio of more than 45 or older (5.3%) were tested. This distribution suggests that the workforce is relatively young, with sufficient concentration in early times of center career stages, an age group that is often associated with new techniques such as additive manufacturing compatibility.

3.10 Designation distribution

When it comes to organizational hierarchy, the top-level leaders are equally represented, with 44.6% of each test. Laven level manager (5.8%) and officer (5.0%) constitute a very small relationship. This distribution highlights a work structure that dominates and dominates supervisory roles, which indicates that the notion of AM integration is significantly informed by individuals who take the position of the management authority.

3.11 Economic feasibility of AM integration

Table 2 summarizes the results of the multivariate test and the subsequent tests of between-subjects effects, which were conducted to evaluate the influence of demographic and organizational variables (gender, age, and designation) on perceptions of the economic feasibility of additive manufacturing (AM) integration within Indian public sector factories.

Table 2 - Multivariate Test - Economic Feasibility

Multivariate Tests ^a						
Effect		Value	F	Hypothesis df	Error df	Sig.
Gender	Pillai's Trace	.041	1.633 ^b	10.000	380.000	.095
	Wilks' Lambda	.959	1.633 ^b	10.000	380.000	.095
	Hotelling's Trace	.043	1.633 ^b	10.000	380.000	.095
	Roy's Largest Root	.043	1.633 ^b	10.000	380.000	.095
Age	Pillai's Trace	.065	.843	30.000	1146.000	.709
	Wilks' Lambda	.936	.842	30.000	1116.051	.711
	Hotelling's Trace	.067	.841	30.000	1136.000	.712
	Roy's Largest Root	.037	1.414 ^c	10.000	382.000	.172
Designation	Pillai's Trace	.085	1.110	30.000	1146.000	.313
	Wilks' Lambda	.917	1.111	30.000	1116.051	.312
	Hotelling's Trace	.088	1.112	30.000	1136.000	.311
	Roy's Largest Root	.054	2.055 ^c	10.000	382.000	.027
Tests of Between-Subjects Effects						
Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Gender	Do you believe adding additive manufacturing technologies to mass production processes in Indian public sector enterprises would result in significant cost reductions?	.105	1	.105	.144	.704

	How confident are you that additive manufacturing integration will improve efficiency within Indian public sector factories?	2.668	1	2.668	4.675	.031
	Do you anticipate that incorporating additive manufacturing technologies will result in long-term benefits for Indian public sector factories?	4.009	1	4.009	6.047	.014
	To what extent do you believe that additive manufacturing integration will enhance product customization capabilities within Indian public sector factories?	2.807	1	2.807	4.791	.029
	How likely do you think it is that additive manufacturing integration will streamline supply chain operations in Indian public sector factories?	.880	1	.880	1.389	.239
	Do you perceive additive manufacturing integration as a viable solution for reducing dependence on imported components in Indian public sector factories?	1.495	1	1.495	2.166	.142
	Are you confident that additive manufacturing integration will stimulate economic growth and create job opportunities within the manufacturing sector in India?	1.275	1	1.275	1.667	.197
	How concerned are you about the initial investment requirements for incorporating additive manufacturing technologies into mass production processes within Indian public sector factories?	.110	1	.110	.174	.677
	Do you believe that additive manufacturing integration will lead to improvements in product quality and reliability within Indian public sector factories?	.000	1	.000	.001	.979
	To what extent do you perceive regulatory compliance as a potential challenge for additive manufacturing integration in Indian public sector factories?	.002	1	.002	.003	.958
Age	How much do you think cost reductions from incorporating additive manufacturing technologies into mass production processes in Indian public sector factories would result?	8.721	3	2.907	3.981	.008

	How confident are you that additive manufacturing integration will improve efficiency within Indian public sector factories?	1.772	3	.591	1.035	.377
	Do you anticipate that incorporating additive manufacturing technologies will result in long-term benefits for Indian public sector factories?	.681	3	.227	.343	.795
	To what extent do you believe that additive manufacturing integration will enhance product customization capabilities within Indian public sector factories?	3.173	3	1.058	1.805	.146
	How likely do you think it is that additive manufacturing integration will streamline supply chain operations in Indian public sector factories?	1.383	3	.461	.728	.536
	Do you perceive additive manufacturing integration as a viable solution for reducing dependence on imported components in Indian public sector factories?	1.283	3	.428	.620	.603
	Are you confident that additive manufacturing integration will stimulate economic growth and create job opportunities within the manufacturing sector in India?	.035	3	.012	.015	.997
	How concerned are you about the initial investment requirements for incorporating additive manufacturing technologies into mass production processes within Indian public sector factories?	.468	3	.156	.247	.863
	Do you believe that additive manufacturing integration will lead to improvements in product quality and reliability within Indian public sector factories?	1.462	3	.487	.787	.502
	To what extent do you perceive regulatory compliance as a potential challenge for additive manufacturing integration in Indian public sector factories?	.640	3	.213	.315	.814
Designation	Incorporating additive manufacturing technology into mass production processes in Indian public sector firms could result in significant cost savings, according to your perspective.	1.399	3	.466	.639	.591

How confident are you that additive manufacturing integration will improve efficiency within Indian public sector factories?	.747	3	.249	.436	.727
Do you anticipate that incorporating additive manufacturing technologies will result in long-term benefits for Indian public sector factories?	1.250	3	.417	.628	.597
To what extent do you believe that additive manufacturing integration will enhance product customization capabilities within Indian public sector factories?	.941	3	.314	.535	.658
How likely do you think it is that additive manufacturing integration will streamline supply chain operations in Indian public sector factories?	1.043	3	.348	.549	.649
Do you perceive additive manufacturing integration as a viable solution for reducing dependence on imported components in Indian public sector factories?	1.038	3	.346	.501	.682
Are you confident that additive manufacturing integration will stimulate economic growth and create job opportunities within the manufacturing sector in India?	.637	3	.212	.278	.842
How concerned are you about the initial investment requirements for incorporating additive manufacturing technologies into mass production processes within Indian public sector factories?	3.965	3	1.322	2.091	.101
Do you believe that additive manufacturing integration will lead to improvements in product quality and reliability within Indian public sector factories?	7.328	3	2.443	3.944	.009
To what extent do you perceive regulatory compliance as a potential challenge for additive manufacturing integration in Indian public sector factories?	1.025	3	.342	.505	.679

Source: (Primary data)

3.12 Multivariate analysis

The multivariate results indicate that gender and age do not significantly influence perceptions of economic feasibility across the combined dependent variables ($p > 0.05$). However, organizational designation demonstrates statistical significance under Roy's Largest Root criterion

($p = 0.027$), suggesting that hierarchical position influences at least one dimension of economic feasibility. Therefore, demographic effects are largely limited, with the exception of designation-based differences.

But, on the contrary, designation showed a strong finding on Roy largest root ($p = 0.027$), an indication that the position of managers affects perception of economic viability. This means that the various people in various hierarchical levels, especially at the managerial level, have different assessments towards AM in terms of economic potential.

3.13 Tests of between-subjects effects

The between-subjects tests offer the item-based research of how the respondents rated the particular dimensions of economic feasibility. In the case of gender, none of the items were significant ($p > 0.05$) and this has reaffirmed that the gender does not have a significant impact on the perception of feasibility.

Age-wise, the question is, item To what extent do you think that incorporation of AM into mass production will result into cost savings? was statistically significant ($F = 3.981$, $p = 0.008$). This observation implies that young and old respondents have different opinions on the capability of AM to provide cost savings. Nevertheless, other products (e.g., efficiency, customization, improvement of supply chains) did not differ much between age groups.

To designate, the item "Do you believe that AM integration will result in the improvement of product quality and reliability? was significant ($F = 3.944$, $p = 0.009$). This points out that the level of confidence in AM to improve the quality of its products depends on the managerial hierarchy. Other considerations, like cost savings or supply, chain efficiency, had not been distinguished greatly by name.

3.14 Interpretation

Collectively, these findings indicate that gender and age have little impact on economic feasibility perceptions except that age has differences in terms of cost savings. However, designation happens to be a more essential factor, with the respondents of managerial ranks seeming to be more concerned with the questions of quality and reliability enhancements associated with the adoption of AM. These results highlight the importance of hierarchy in the organizational structure in development of perceptions of economic viability, which have direct outcomes to implementation strategies of technology adoption in the manufacturing sector in the public sector.

3.15 Descriptive statistics: Economic feasibility

Table 3 presents the descriptive statistics of the respondents about their perception regarding the economic viability of adopting additive manufacturing (AM) technologies into mass production process within Indian public sector firms. It has ten key items of a five-point Likert scale, their average and standard deviation.

Table 3 - Descriptive statistics - Economic feasibility

Descriptive Statistics	N	Mean	Std. Deviation
How much do you think cost reductions will result from the use of additive manufacturing technologies in mass production processes in Indian public sector factories?	397	4.2821	.86807
How confident are you that additive manufacturing integration will improve efficiency within Indian public sector factories?	397	4.3350	.75952
Do you anticipate that incorporating additive manufacturing technologies will result in long-term benefits for Indian public sector factories?	397	4.2569	.81927
To what extent do you believe that additive manufacturing integration will enhance product customization capabilities within Indian public sector factories?	397	4.3375	.77324

How likely do you think it is that additive manufacturing integration will streamline supply chain operations in Indian public sector factories?	397	4.2922	.79789
Do you perceive additive manufacturing integration as a viable solution for reducing dependence on imported components in Indian public sector factories?	397	4.2594	.83224
Are you confident that additive manufacturing integration will stimulate economic growth and create job opportunities within the manufacturing sector in India?	397	4.2267	.86980
How concerned are you about the initial investment requirements for incorporating additive manufacturing technologies into mass production processes within Indian public sector factories?	397	4.3073	.79536
Do you believe that additive manufacturing integration will lead to improvements in product quality and reliability within Indian public sector factories?	397	4.2821	.79519
To what extent do you perceive regulatory compliance as a potential challenge for additive manufacturing integration in Indian public sector factories?	397	4.2242	.81812
Valid N (listwise)	397		

Source: (Primary data)

The provided descriptive statistics offer insights into respondents' perceptions regarding the economic feasibility of integrating additive manufacturing technologies into mass production processes within Indian public sector factories. Across all questionnaire items, respondents exhibit consistently positive attitudes, with mean scores ranging from 4.2242 to 4.3375 on a scale of 1 to 5. Particularly noteworthy are respondents' high levels of confidence in additive manufacturing's potential to improve efficiency, enhance product customization capabilities, and streamline supply chain operations, as evidenced by mean scores above 4.3 for these items. Additionally, respondents express strong beliefs in the long-term benefits of incorporating additive manufacturing technologies, with a mean score of 4.2569. Despite their optimism, respondents also acknowledge concerns about initial investment requirements and potential challenges related to regulatory compliance, albeit to a lesser extent. Even though the overall mean scores of items are fairly high, the standard deviation (between 0.74 and 0.91) shows that there is a significant difference in responses. This implies that no uniform type of responses were clumped at the upper end of the scale, though. Also, the regressions and the MANOVAs indicate that there exists a statistical distinction among the organizational designations; the responses were not driven by inflations and discrimination analytically.

3.16 Multivariate tests with between-subjects effects

A cost-benefit analysis of incorporating additive manufacturing technologies into mass production processes in Indian public sector companies is presented in Table 4, along with the findings of a multivariate test and testing of between-subject effects.

Table 4 - Multivariate test - cost-benefit analysis

Multivariate Tests ^a						
Effect		Value	F	Hypothesis df	Error df	Sig.
Gender	Pillai's Trace	.043	1.718 ^b	10.000	380.000	.075
	Wilks' Lambda	.957	1.718 ^b	10.000	380.000	.075
	Hotelling's Trace	.045	1.718 ^b	10.000	380.000	.075
	Roy's Largest Root	.045	1.718 ^b	10.000	380.000	.075
Age	Pillai's Trace	.059	.773	30.000	1146.000	.806
	Wilks' Lambda	.942	.771	30.000	1116.051	.808

	Hotelling's Trace	.061	.769	30.000	1136.000	.810
	Roy's Largest Root	.032	1.212 ^c	10.000	382.000	.281
Designation	Pillai's Trace	.090	1.181	30.000	1146.000	.232
	Wilks' Lambda	.913	1.177	30.000	1116.051	.235
	Hotelling's Trace	.093	1.174	30.000	1136.000	.239
	Roy's Largest Root	.044	1.670 ^c	10.000	382.000	.086
	Tests of Between-Subjects Effects					
Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Gender	Additive manufacturing integration will lead to significant cost savings in Indian public sector factories.	.137	1	.137	.221	.638
	The initial investment required for integrating additive manufacturing technologies is justified by the potential long-term benefits.	.265	1	.265	.370	.543
	Additive manufacturing integration will improve operational efficiencies within Indian public sector factories.	2.089	1	2.089	3.806	.052
	Incorporating additive manufacturing technologies will enhance the competitiveness of Indian public sector factories in the global market.	2.199	1	2.199	3.173	.076
	Additive manufacturing integration aligns with the strategic goals and objectives of Indian public sector factories.	.169	1	.169	.289	.591
	The potential risks associated with additive manufacturing integration outweigh the benefits.	.326	1	.326	.471	.493
	Additive manufacturing integration will result in enhanced flexibility and agility in production processes within Indian public sector factories.	.799	1	.799	1.240	.266
	Additive manufacturing integration will lead to improved product quality and reliability in Indian public sector factories.	.550	1	.550	.703	.402
	The regulatory and compliance challenges related to additive manufacturing integration are manageable for Indian public sector factories.	2.313	1	2.313	2.808	.095
	Additive manufacturing integration will positively impact the overall profitability of Indian public sector factories.	.487	1	.487	.749	.387

Age	Additive manufacturing integration will lead to significant cost savings in Indian public sector factories.	1.075	3	.358	.581	.628
	The initial investment required for integrating additive manufacturing technologies is justified by the potential long-term benefits.	1.042	3	.347	.485	.693
	Additive manufacturing integration will improve operational efficiencies within Indian public sector factories.	2.999	3	1.000	1.821	.143
	Incorporating additive manufacturing technologies will enhance the competitiveness of Indian public sector factories in the global market.	1.460	3	.487	.702	.551
	Additive manufacturing integration aligns with the strategic goals and objectives of Indian public sector factories.	1.829	3	.610	1.039	.375
	The potential risks associated with additive manufacturing integration outweigh the benefits.	.671	3	.224	.324	.808
	Additive manufacturing integration will result in enhanced flexibility and agility in production processes within Indian public sector factories.	.991	3	.330	.513	.674
	Additive manufacturing integration will lead to improved product quality and reliability in Indian public sector factories.	2.925	3	.975	1.246	.293
	The regulatory and compliance challenges related to additive manufacturing integration are manageable for Indian public sector factories.	4.329	3	1.443	1.752	.156
	Additive manufacturing integration will positively impact the overall profitability of Indian public sector factories.	1.334	3	.445	.684	.562
Designation	Additive manufacturing integration will lead to significant cost savings in Indian public sector factories.	2.327	3	.776	1.257	.289
	The initial investment required for integrating additive manufacturing technologies is justified by the potential long-term benefits.	2.149	3	.716	1.000	.393
	Additive manufacturing integration will improve operational efficiencies within Indian public sector factories.	3.507	3	1.169	2.130	.096
	Incorporating additive manufacturing technologies will enhance the competitiveness of Indian public sector factories in the	.439	3	.146	.211	.889

global market.					
Additive manufacturing integration aligns with the strategic goals and objectives of Indian public sector factories.	.419	3	.140	.238	.870
The potential risks associated with additive manufacturing integration outweigh the benefits.	3.006	3	1.002	1.450	.228
Additive manufacturing integration will result in enhanced flexibility and agility in production processes within Indian public sector factories.	.828	3	.276	.428	.733
Additive manufacturing integration will lead to improved product quality and reliability in Indian public sector factories.	3.053	3	1.018	1.300	.274
The regulatory and compliance challenges related to additive manufacturing integration are manageable for Indian public sector factories.	2.529	3	.843	1.024	.382
Additive manufacturing integration will positively impact the overall profitability of Indian public sector factories.	2.510	3	.837	1.287	.278

Source: (Primary data)

3.17 Multivariate test

The multivariate tests for cost-benefit perception indicate that gender, age, and designation do not produce statistically significant effects at the multivariate level ($p > 0.05$ across Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root). However, in the between-subjects analysis, the item related to operational efficiency approached statistical significance ($p = 0.052$), indicating a marginal effect at the univariate level. This borderline value does not indicate a multivariate effect but suggests potential practical relevance requiring cautious interpretation.

3.18 Tests of between-subjects effects

The tests of between-subjects effects were performed to evaluate the influence of specific questionnaire items on the cost-benefit analysis. The results suggest that, overall, most of the questionnaire items did not exhibit a significant effect ($p > 0.05$). However, one item—"Additive manufacturing integration will improve operational efficiencies within Indian public sector factories"—approached significance with a p-value of 0.052. This marginal significance underscores the fact that the perception of the respondents on the changes in the operational effectiveness might be significant in determining the general cost-benefit analysis of additive manufacturing. Alternatively, other products like products associated with cost saving, competitiveness, strategic alignment, risk, regulatory and profitability, did not present any significant values and as such do not seem to have much influence on the perceptions shaping in this regard.

3.19 Interpretation

Combined, the results indicate that demographic factors such as gender, age, or designation do not significantly influence the opinion of the respondents regarding the cost-benefit analysis of integrating additive manufacturing. This indicates a wide agreement among various respondents. Nevertheless, the operation efficiency turns out to be an interesting dimension, and its borderline nature indicates its possible attribute as a determinant of the perceived economy viability. This discovery aligns with advanced insights from descriptive statistics, which revealed strong

confidence among respondents in the ability of additive production to enhance efficiency, adaptation, and supply chain performance. As a result, although demographic factors may not be crucial, the efficiency benefits offered by Additive production rights have attracted further attention to both educational analysis and policy formulation for successful adoption in Indian Factories in the public sector.

3.20 Descriptive statistics of cost-benefit perceptions

The descriptive figures presented in Table 5 present respondents' perceptions of cost-advantage analysis of integration of advanced manufacturing (AM) technologies in large public sector production processes. Overall, the data reveal a consistently favorable approach, with strong consent to the economic viability of AM adaptation, with average values in all objects between 4.21 and 4.32 on a five-point Likert scale.

Table 5 - Descriptive statistics - Cost-benefit analysis

Descriptive Statistics			
	N	Mean	Std. Deviation
Additive manufacturing integration will lead to significant cost savings in Indian public sector factories.	397	4.2746	.78347
The initial investment required for integrating additive manufacturing technologies is justified by the potential long-term benefits.	397	4.2695	.84411
Additive manufacturing integration will improve operational efficiencies within Indian public sector factories.	397	4.3249	.74719
Incorporating additive manufacturing technologies will enhance the competitiveness of Indian public sector factories in the global market.	397	4.2720	.82972
Additive manufacturing integration aligns with the strategic goals and objectives of Indian public sector factories.	397	4.3249	.76390
The potential risks associated with additive manufacturing integration outweigh the benefits.	397	4.2872	.83070
Additive manufacturing integration will result in enhanced flexibility and agility in production processes within Indian public sector factories.	397	4.2544	.79979
Additive manufacturing integration will lead to improved product quality and reliability in Indian public sector factories.	397	4.2116	.88795
The regulatory and compliance challenges related to additive manufacturing integration are manageable for Indian public sector factories.	397	4.2771	.90944
Additive manufacturing integration will positively impact the overall profitability of Indian public sector factories.	397	4.2645	.80596
Valid N (listwise)	397		

Source: (Primary data).

The respondents' opinions about the cost-profit analysis of integrating additive manufacturing technology into large-scale production processes in public sector companies are insightfully revealed by the descriptive data supplied. Nearby, the respondents are expressing a consistently positive attitude, whose average score is on a scale of 1 to 5 from 4,2116 to 4,3249. In particular, respondents showed strong belief in the ability to integrate to lead significant cost savings with an average score of 4,2746. Similarly, the first investment required for integrating the respondents is considered appropriate as a long-term potential benefit, as clarified with an average score of 4,2695. In addition, the respondents estimated the improvement in operating capacity, increased

competition in the global market, and adaptation to strategic goals, with all average scores more than 4.2. Despite their optimism, respondents also acknowledged potential risks associated with the additive manufacturing integration, which is something of an average score of 4,2872. Overall, descriptive figures reflect the favorable perception of the cost analysis of additive manufacturing integration among the respondents in the Indian public sector, which suggests strong support for its adoption and implementation.

3.21 Regression analysis: Effect of economic viability on costs -gain assumptions

The regression analysis indicated that economic feasibility significantly predicts cost-benefit perception ($B = 0.813$, $SE = 0.030$, $\beta = 0.809$, $t = 27.355$, $p < 0.001$). The 95% confidence interval for the coefficient ranged from 0.755 to 0.872, confirming estimate precision. The model explained 65.5% of the variance ($R^2 = 0.655$; Adjusted $R^2 = 0.654$), with $F(1,395) = 748.317$, $p < 0.001$, indicating a large effect size. Recovery analysis presented in Table 6 evaluates the effect of economic viability on cost -advantage -analysis of incorporating additive manufacturing (AM) technologies in large public sector production processes.

Table 6 - Regression Analysis – Impact of economic feasibility of incorporating additive manufacturing technologies on Cost-Benefit

Model Summary						
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate		
1	.809 ^a	.655	.654	.28493		
a. Predictors: (Constant), Economic feasibility						
ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	60.754	1	60.754	748.317	.000 ^b
	Residual	32.069	395	.081		
	Total	92.823	396			
a. Dependent Variable: Cost-benefit analysis						
b. Constant and economic viability as predictors						
Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.794	.128		6.199	.000
	Economic feasibility	.813	.030	.809	27.355	.000
a. Dependent Variable: Cost-benefit analysis						

Source: (Primary data)

- **Model summary:**

With an R-square value of .655, the regression model shows a substantial positive correlation between the cost-benefit analysis and economic feasibility. This suggests that economic feasibility accounts for about 65.5% of the variation in the cost-benefit analysis. After controlling for the number of predictors, the adjusted R-square value stays constant at .654, indicating that the model's explanatory power is still strong. The average difference between the observed and anticipated values is indicated by the standard error of the estimate, which is 0.28493.

Homogeneity of variance-covariance matrices was assessed using Box's M test (Box's M = 7.842, $p = 0.231$), indicating that the assumption was met. Effect sizes were reported using partial eta squared (η^2). The effect of designation on economic feasibility was moderate ($\eta^2 = 0.072$), while its effect on cost-benefit perception was small to moderate ($\eta^2 = 0.058$). Post-hoc comparisons were conducted using Bonferroni correction.

To further assess potential acquiescence or common method bias, Harman's single-factor test was conducted. The first unrotated factor accounted for 34.7% of total variance, below the critical 50% threshold, suggesting that common method variance does not substantially distort the findings.

- **ANOVA:**

Based on the analysis of variance (ANOVA) table, the regression model is very significant ($p < .0001$) meaning that the whole model predicts the variation in the cost-benefit analysis significantly. The F-statistic of 748.317 is also useful in supporting the significance of the model.

- **Coefficients:**

- Regression coefficients show the relationship between the predictor variable (economic feasibility) and the dependent variable (cost-benefit analysis).
- The constant value of the regression has a coefficient of 0.794 with a standard error of 0.128 meaning that when the economic feasibility is zero, the cost-benefit analysis will be 0.794.
- Economic feasibility coefficient is 0.813 with the standard error of 0.030, which means that with a one-unit change in the economic feasibility, the cost-benefit analysis will be predicted to change by 0.813. This coefficient is quite meaningful ($p < .0001$), which means that economic feasibility and the cost-benefit analysis have a strong positive correlation.

In addition to statistical significance, the size of the standardized coefficient ($b = 0.809$) explains a significant practical impact. Perceived economic feasibility has been shown to increase cost-benefit perception by 0.813 units with a one unit increase in perceived economic feasibility, which is significant to the managers. The model accounts 65.5 percent of the variance in cost-benefit perception, which is a high effect size in social science studies. It implies that economic feasibility is not just statistically significant predictor but strategically relevant predictor in the technology adoption decisions in the context of the public sector manufacturing. On the whole, the regression analysis indicates that the issue of economic feasibility has a considerable influence on the cost-benefit analysis of adopting additive manufacturing technologies in Indian factories of the public sector. The expected benefits of the use of additive manufacturing technologies in the mass production processes increase proportionally to the economic viability, which highlights the importance of the economic viability in the decision-making process with regard to adoption and utilization of technology.

3.22 Statistical assumptions and analytical rationale

Prior to conducting MANOVA and regression analyses, key statistical assumptions were systematically evaluated to ensure the robustness and validity of the findings.

MANOVA assumptions

- **Independence of observations** was ensured through the sampling design, where each respondent participated independently.
- **Multivariate normality** was assumed based on the relatively large sample size ($n = 397$), consistent with the Central Limit Theorem.
- **Homogeneity of variance-covariance matrices** was tested using Box's M test (Box's $M = 7.842$, $p = 0.231$), indicating that the assumption was satisfied.

Regression assumptions

- **Linearity** was confirmed through scatterplots of standardized predicted values and residuals, indicating a linear relationship between economic feasibility and cost-benefit perception.
- **Homoscedasticity** was verified using residual plots, which showed no systematic patterns.
- **Independence of errors** was confirmed using the Durbin-Watson statistic ($DW = 2.022$), indicating no autocorrelation.
- **Multicollinearity** was not a concern due to the use of a single predictor variable ($VIF = 1.00$).
- **Outliers and influential observations** were examined using standardized residuals and Cook's Distance. Although a few residuals exceeded ± 3 , Cook's Distance values remained below the critical threshold ($\max = 0.89$), indicating no undue influence on the model.

Common Method Bias

To assess potential common method variance, Harman's single-factor test was conducted. The first factor accounted for 34.7% of total variance, which is below the critical threshold of 50%, suggesting that common method bias is not a significant concern.

Collectively, these diagnostic tests confirm that the assumptions underlying the statistical techniques were satisfactorily met, supporting the reliability and validity of the analytical results.

4 RESULT FINDINGS AND CONCLUSION

The study on additive manufacturing integration in Indian public sector factories reveals a gender imbalance with male respondents accounting for 86.4% of the total sample, while females make up 13.6% as shown in Figure 3(a). The largest age group is individuals aged 25 to 35, accounting for 46.1% of the total sample. The second-largest age group is individuals aged 36 to 45, representing 40.1%. The distribution in Figure 3(b) suggests a relatively young workforce, with a significant proportion falling within the early to mid-career stages. Mid-level managers and top-level managers are equally represented, each accounting for 44.6% of the sample, while low-level managers constitute 5.8% and executives constitute 5.0%. The distribution in Figure 3(c) indicates a balanced representation of mid-level and top-level managerial positions, with fewer respondents holding low-level managerial or executive positions. The study provides insights into the demographic characteristics and organizational hierarchy of the respondents, highlighting the need for further research on the workforce in Indian public sector factories.

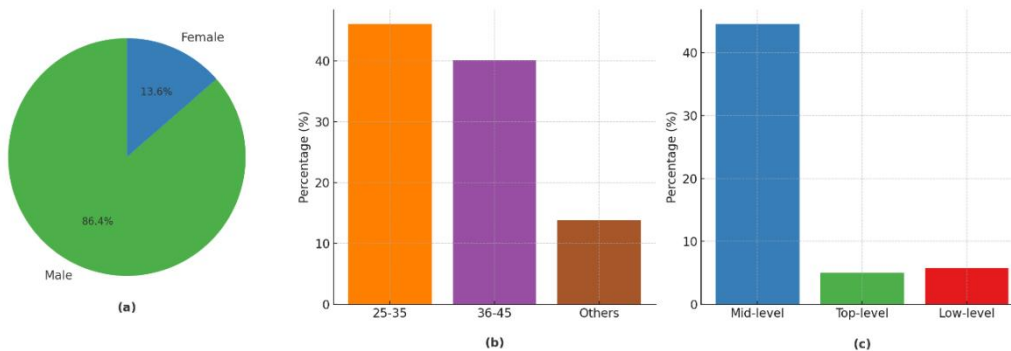


Figure 3 - Demographic distribution of respondents

Regarding organizational hierarchy, mid-level managers and top-level managers form the majority of respondents (44.6% each), indicating strong representation from supervisory and decision-making roles. Low-level managers (5.8%) and executives (5.0%) represent smaller proportions of the sample. Descriptive statistics in Figure 4 reveal respondents' consistently positive attitudes towards the economic feasibility of integrating additive manufacturing technologies into mass production processes. They express high levels of confidence in the potential to improve efficiency, enhance product customization capabilities, and streamline supply chain operations. They also express strong beliefs in the long-term benefits of incorporating additive manufacturing technologies, with a mean score of 4.2569. Despite the concern of early investment requirements and potential challenges related to regulatory compliance, the overall descriptive figures suggest a generally beneficial perception of the economic viability of additive manufacturing integration among Indian public sector factories, indicating a positive approach to adoption and implementation.

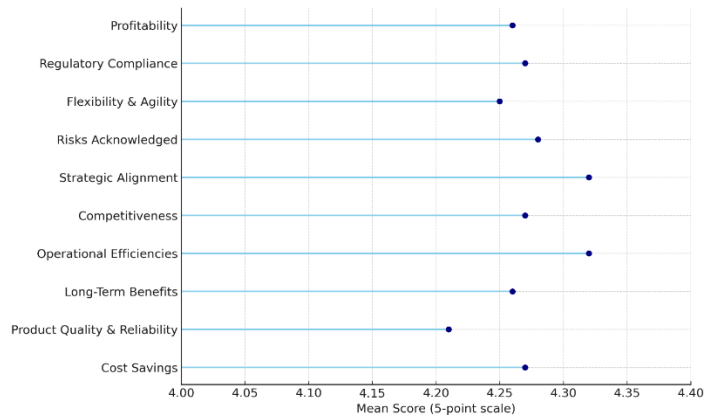


Figure 4 - Perceptions of additive manufacturing

The study looks at how gender, age, and term affect the cost analysis of integrating additive production in public sector factories in India. The results suggest that gender and age costs do not significantly affect the analysis. However, the perceptions of operational capacity may have a significant impact on the cost-profit analysis. Descriptive figures suggest that respondents continuously express a positive attitude towards the integration of additive manufacturing technologies. They believe that integration can cause significant cost savings, to correct initial investments with long-term benefits and improve operating capacity, increase competition in the global market and estimate adaptation with strategic goals. However, they also accept potential risks associated with integration, even though they to some extent. The results suggest that although factors such as gender, age and term cannot affect the cost-profit analysis of additive manufacturing integration, the perception of the operating capacity of the respondents can have a significant impact. Further analysis of specific aspects related to operational capacity and ideas may provide further insight into the general cost-benefit analysis of integrating additive manufacturing technologies in the public sector in public sector. Overall, the descriptive statistics indicate a favorable perception of the cost-benefit analysis of additive manufacturing integration among respondents within Indian public sector factories, suggesting strong support for its adoption and implementation.

The regression model shows a strong positive relationship between economic feasibility and cost-benefit analysis, explaining approximately 65.5% of the variance in the cost-benefit analysis. The adjusted R-square value remains consistent, indicating robust explanatory power. The analysis of variance (ANOVA) table confirms the model's significance, with an F-statistic of 748.317. The regression coefficients provide insights into the relationship between the predictor variable (economic feasibility) and the dependent variable (cost-benefit analysis), as shown in Figure 5. The constant term has a coefficient of 0.794, while the coefficient for economic feasibility is 0.813, indicating a strong positive relationship.

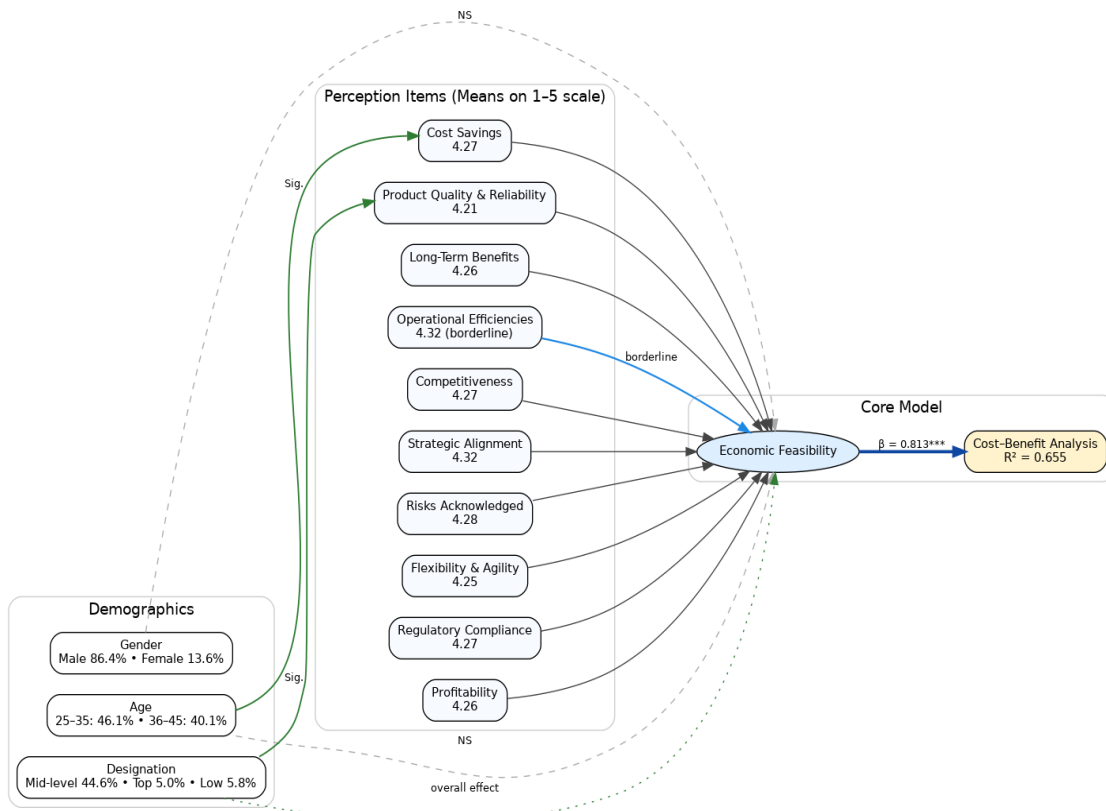


Figure 5 - Influence of demographic and organizational factors on cost-benefit analysis

Note: NS = Non-Significant, dashed grey arrows represent non-significant paths (Gender, Age), Dotted green arrows represent near the conventional 0.05 threshold (Designation), Solid blue arrows indicate strong positive and significant impact (Economic Feasibility → Cost-Benefit Analysis).

The regression analysis suggests that economic feasibility significantly impacts the cost-benefit analysis of incorporating additive manufacturing technologies in Indian public sector factories. As economic viability increases, the expected benefits of integrating these techniques increase, emphasizing the importance of economic viability in the processes of determining technology and implementation.

5 DISCUSSION AND THEORETICAL CONTRIBUTIONS

The results of the current research go beyond the current empirical validation to provide more theoretical understanding of the technology adoption in the publicly managed manufacturing systems. Although most previous research has focused on the adoption of additive manufacturing (AM) in the context of the private sector (or developed economies), the current study highlights the pivotal nature of economic feasibility as a key evaluative tool using which technological value is construed in bureaucratic manufacturing systems. This is in line with the existing literature about the significance of cost-benefit analysis and economic evaluation in the adoption of AM (Thomas, 2015; Okokpujie and Tartibu, 2024).

Based on the Technology Organization Environment (TOE) model, the results indicate that economic feasibility is not just a technological quality but it is a decision-making enabling factor that influences the organizational readiness. It aligns with the previous studies that have shown that the impact of a structured evaluation framework and resource limitations greatly affect the adoption of technology within a complicated organizational environment (Mellor *et al.*, 2013; Handfield *et al.*, 2022). This is less the case in the public sector where accountability and budgetary discipline direct decision making processes and thus technological adoption is more guided by economic justification than innovation orientation.

The view of Resources-Based View (RBV) the study provides valuable insight by showing that the technological capabilities like AM do not necessarily translate into a strategic advantage unless it is deemed economically feasible. This observation confirms previous studies that highlight the importance of technological resources based on their efficient use and managerial interpretation (Oettmeier and Hofmann, 2016; Mehrpouya *et al.*, 2021). In this way, economic feasibility is a conversion process, which connects the perceived organizational value to technological potential.

Moreover, the high explanatory power of economic feasibility ($R^2 = 0.655$) supports the economic decision-making theory, which implies that the organizational actors can assess the innovations in terms of the expected utility and cost-benefits trade-offs. This aligns with previous research that emphasizes the importance of economic rationality in determining the technology adoption process, especially in resource-limited and policy-based settings (Baumers, 2012; Rupp, 2023). Unlike in the private sector where the competitive pressures can spur speedy innovation, the public sector organizations are usually inclined towards the reduction of risks and economic justification.

A significant contribution of this research is that it reveals that the organizational designation is a considerable differentiating factor, whereas demographic variables, including gender or age, do not have much impact. This result corresponds to the literature of the diffusion of innovation, which indicates that the decision authority and hierarchical position are important factors influencing technology perceptions (Rylands *et al.*, 2016). Technology evaluation in bureaucratic organizational structures is highly centralized and the way perceptions are molded is more by position than personal traits.

The research has a number of new theoretical contributions to the operations management and technology adoption literature. First, it redefines economic feasibility as not only an evaluative result, but as a mediating construct of central concern, between technological potential (as explicated by the TOE framework) and strategic resource value (as suggested by the RBV). Second, the research contributes to the current literature by placing the adoption of additive manufacturing in a specific institutional setting of public sector manufacturing in an emerging economy, whereby the processes of decision-making are influenced by bureaucratic frameworks, policy limitations, and accountability frameworks. Third, it emphasizes the importance of the organizational hierarchy that shows that technology evaluation in state enterprises is subject to more significant influence by the role-based authority rather than individual demographics. The combination of these contributions contains a more context-sensitive and theoretically integrated explanation of the adoption of technology in state-owned manufacturing systems.

Theoretical explanation of the effects of demographics

The results show that organizational name plays a significant role in the perception of additive manufacturing viability, but gender does not play a significant role. The organizational decision-making theory and the principles of diffusion of innovation could be used to explain this pattern. Decision making in the application of technology in the public sector enterprise is usually hierarchical and centralized. In managerial duties, there is a direct role in terms of investment analysis, cost management, and strategizing. Thus, employees at a higher level of the organization will be more inclined to evaluate technological feasibility with the help of a strategic and financial perspective.

The relatively high mean values may also reflect the current policy and modernization climate within Indian public sector manufacturing, where digital transformation and self-reliance initiatives have increased institutional support for advanced manufacturing technologies. Therefore, elevated feasibility perceptions may partially reflect broader strategic alignment rather than response bias alone.

Conversely, gender does not influence directly exposure to strategic decision-making processes in this institutional set up. The reason that technology assessment in the public sector manufacturing is not gender-influenced is the indication that the role-based authority structure is ascribed to the technological assessment rather than the demographic attributes. This result supports the conclusion that it is hierarchical position, but not individual characteristics that promote innovation perception within bureaucratic systems.

Traditional financial cost-benefit analysis is usually not available to academic research, and often only done at subsequent investing approval stages in large enterprises of the public sector. Thus the pre-investment evaluative stage is reflected in this study wherein, the perception of economic feasibility on the part of the managers is a critical factor that determines the adoption of technology.

Policy and managerial implications

The findings of this study provide several important implications for policymakers and managers aiming to accelerate the adoption of additive manufacturing in public sector production systems.

- First, given the central role of economic feasibility, policymakers should prioritize the development of structured financial evaluation frameworks for AM adoption. This

includes standardized cost-benefit assessment tools, government-backed feasibility studies, and sector-specific economic benchmarks that reduce uncertainty in investment decisions.

- Second, the strong influence of organizational hierarchy suggests that managerial-level interventions are critical. Training programs should not only focus on technical skills but also on strategic and financial evaluation capabilities, enabling managers to better assess long-term value creation from AM technologies.
- Third, public sector adoption can be accelerated through targeted financial incentives, such as capital subsidies, tax benefits, or low-interest financing for AM infrastructure. These mechanisms can offset high initial investment barriers, which remain a key concern despite overall positive perceptions.
- Fourth, policymakers should promote institutional collaboration between public enterprises, research institutions, and technology providers. Such collaboration can reduce knowledge gaps, improve implementation efficiency, and facilitate the development of context-specific AM applications tailored to public sector needs.
- Finally, regulatory bodies should work towards creating clear and streamlined certification and compliance frameworks for AM-produced components. Reducing regulatory ambiguity will enhance organizational confidence and accelerate adoption decisions in highly controlled public manufacturing environments.

Collectively, these measures can transform positive perceptions of AM into actual implementation outcomes, thereby supporting broader goals of industrial modernization, self-reliance, and digital transformation in emerging economies.

6 LIMITATIONS AND FUTURE RESEARCH

In spite of its contributions, this research has some limitations which they should consider. To begin with, the research employs self-reported perceptual measures and this can create common method bias. Despite the application of statistical diagnostics and scale structuring, it is not completely possible to exclude the possibility of response consistency effects.

Second, the cross-sectional design is a constraint to causal inference. Although the regression analysis reveals a high level of correlation between economic feasibility and cost-benefit perception, longitudinal studies would be able to give more insight into the dynamic process of adoption.

Third, the research is limited to Indian government factory manufacturing companies. Even though this background creates a strong internal validity, it can reduce applicability to a production environment in the private sector or that of diverse production in other countries.

Despite the statistical evaluation of the common method bias, self-report measures might still require the introduction of perceptual bias. Moreover, the cross-sectional nature restricts the longitudinal adoption dynamics or slow performance results.

Longitudinal data, objective financial performance indicators, and multi-source data collection methods may be used in future studies to enhance causal inference and minimize perceptual bias.

Future research could:

- Use longitudinal designs to describe the adoption process.
- Combine objective financial performance measures.
- Carry out comparative analysis between the public and the private sectors.
- Digital maturity or organizational culture are also possible moderating variables.

7 CONCLUSION

This study provides empirical evidence on the economic feasibility and cost-benefit analysis of adopting Additive Manufacturing (AM) in Indian public sector factories. The findings confirm that economic viability is the strongest determinant of perceived cost-benefit outcomes, explaining more than 65% of the variance in adoption attitudes. While demographic factors such as gender and age show little influence, organizational designation—particularly managerial roles—emerges as a critical factor shaping perceptions of AM's ability to improve product quality and reliability. These results highlight that hierarchical decision-making structures play an important role in shaping technology adoption strategies within public manufacturing enterprises.

From an operations and production management perspective, the study emphasizes that AM integration offers significant potential to enhance efficiency, product customization, supply chain agility, and long-term competitiveness. Despite challenges associated with initial investments and regulatory compliance, the overall outlook among respondents remains positive, suggesting that the technology is not only viable but strategically aligned with the modernization goals of public-

sector production systems.

Managerial Implications

1. **Investment Prioritization** – Managers should align AM adoption with economic feasibility studies to ensure return on investment.
2. **Strategic Integration** – AM should be incorporated into production planning and supply chain strategies to enhance agility and competitiveness.
3. **Workforce Development** – Managerial-level training and awareness programs are essential for strengthening confidence in AM's quality and reliability outcomes.
4. **Policy Alignment** – Collaboration with policymakers can mitigate regulatory barriers and accelerate the sustainable integration of AM in public-sector factories.

The study contributes theoretically by integrating the TOE framework and Resource-Based View to explain how economic feasibility functions as a strategic mechanism linking additive manufacturing capability to cost-benefit realization in public sector production systems.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data availability statements

The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality agreements with the participating Public Sector Undertakings (PSUs). However, anonymized data supporting the findings of this study are available from the corresponding author on reasonable request, subject to institutional and organizational data-sharing policies.

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Appendix A: Survey Instrument

Scale Used: All items were measured using a five-point Likert scale:

1 = Strongly Disagree | 2 = Disagree | 3 = Neutral | 4 = Agree | 5 = Strongly Agree

Table A1 - Economic Feasibility (E1–E10)

Item Code	Statement
E1	To what extent do you believe that integrating additive manufacturing technologies into mass production processes within Indian public sector factories will lead to cost savings?
E2	How confident are you that additive manufacturing integration will improve efficiency within Indian public sector factories?
E3	Do you anticipate that incorporating additive manufacturing technologies will result in long-term benefits for Indian public sector factories?
E4	To what extent do you believe that additive manufacturing integration will enhance product customization capabilities within Indian public sector factories?
E5	How likely do you think it is that additive manufacturing integration will streamline supply chain operations in Indian public sector factories?
E6	Do you perceive additive manufacturing integration as a viable solution for reducing dependence on imported components in Indian public sector factories?
E7	Are you confident that additive manufacturing integration will stimulate economic growth and create job opportunities within the manufacturing sector in India?
E8	How concerned are you about the initial investment requirements for incorporating additive manufacturing technologies into mass production processes within Indian public sector factories?
E9	Do you believe that additive manufacturing integration will lead to improvements in product quality and reliability within Indian public sector factories?
E10	To what extent do you perceive regulatory compliance as a potential challenge for additive manufacturing integration in Indian public sector factories?

Table A2 - Cost–Benefit Perception (C1–C10)

Item Code	Statement
C1	Additive manufacturing integration will lead to significant cost savings in Indian public sector factories.
C2	The initial investment required for integrating additive manufacturing technologies is justified by the potential long-term benefits.
C3	Additive manufacturing integration will improve operational efficiencies within Indian public sector factories.
C4	Incorporating additive manufacturing technologies will enhance the competitiveness of Indian public sector factories in the global market.
C5	Additive manufacturing integration aligns with the strategic goals and objectives of Indian public sector factories.
C6	The potential risks associated with additive manufacturing integration outweigh the benefits. (Reverse-coded)
C7	Additive manufacturing integration will result in enhanced flexibility and agility in production processes within Indian public sector factories.
C8	Additive manufacturing integration will lead to improved product quality and reliability in Indian public sector factories.
C9	The regulatory and compliance challenges related to additive manufacturing integration are manageable for Indian public sector factories.
C10	Additive manufacturing integration will positively impact the overall profitability of Indian public sector factories.