Formulation of Strategic Priorities for Smart Factory Implementation Through Importance–Performance Map Analysis (IPMA) in a SEM-PLS-Based TAM–UTAUT Integration Model

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Abstract.
The success of Smart Factory implementation is determined not only by satisfying statistical significance requirements between constructs, but also by an organization's ability to set well-targeted improvement priorities. Many technology acceptance studies stop at the hypothesis-testing stage without translating those findings into actionable managerial direction. This study aims to formulate strategic priorities for improving the acceptance and use of the Smart Factory 4.0 system in railway manufacturing using Importance–Performance Map Analysis (IPMA) built upon an integrated Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) model. Data were collected through a structured questionnaire administered to 60 active users on the Bogie Fabrication and Finishing lines, then analyzed using Partial Least Squares-based Structural Equation Modeling (SEM-PLS) as the basis for calculating the importance value (total effect) and performance value (rescaled mean score) of each construct with respect to Actual Use. The IPMA results show that Facilitating Conditions occupies Quadrant I (high importance, suboptimal performance), making it the top priority for improvement, while Behavioral Intention and Perceived Usefulness fall into Quadrant II (high importance, high performance) and thus need to be maintained as key strengths. Perceived Ease of Use and Social Influence contribute indirectly through the mediation of Behavioral Intention, while demographic variables (age, experience, and gender) show low levels of importance and/or performance and are therefore not the focus of short-term intervention. Based on this mapping, the study formulates five tiered strategic recommendations that can be directly adopted by management, covering network infrastructure strengthening, provision of production-environment-resistant devices, rapid technical assistance mechanisms, microlearning-based training, and the use of social influence through digital change agents. The main contribution of this study lies in providing a data-based diagnostic instrument that guides measurable organizational resource allocation, rather than merely confirming causal relationships between constructs.
Keywords: *Smart Factory, Importance-Performance Map Analysis, strategic priority, TAM, UTAUT, SEM-PLS.*

I. INTRODUCTION

The transformation toward Industrial Revolution 4.0 is driving manufacturing companies to adopt Smart Factory systems that integrate the Internet of Things (IoT), Cyber-Physical Systems (CPS), Artificial Intelligence (AI), and Big Data Analytics to create intelligent, precise, and adaptive production processes [1]. The railway manufacturer has implemented a Smart Factory 4.0 (SF4.0) project on its Bogie Fabrication and Finishing lines through the e-Kios V3 and Runner Module systems, which integrate production routing, digital work instructions, material management, and quality monitoring within a single digital ecosystem.

Initial implementation evaluation shows that technology availability has not automatically been followed by consistent use in the field. Operational data from eight manufacturing projects recorded that of 85,736 logging activities that were supposed to be performed independently by operators and inspectors, most still required sweeper assistance or were not filled in at all. This gap between technology deployment and actual system use is the fundamental problem addressed by this study, indicating that Smart Factory success does not depend solely on system sophistication, but on user acceptance of the technology.

Technology acceptance studies generally rely on the Technology Acceptance Model (TAM) developed by Davis [2] and the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. [3]. Both models are fairly reliable in explaining how perceived ease of use, perceived usefulness, social influence, and facilitating conditions relate to the intention and behavior of system use. Unfortunately, most studies using TAM-UTAUT stop once hypotheses are tested, merely stating whether a path is significant or not, without following up with clear direction for resource allocation by management. Statistical significance alone does not tell an organization which construct is most urgent to address first, especially when the budget, time, and IT workforce available for improvement are limited.

Importance Performance Map Analysis (IPMA) addresses this gap as an analytical extension of SEM-PLS. IPMA combines two dimensions — importance (the magnitude of a construct's total effect on the target variable) and performance (the actual achievement level of that construct based on respondent perception) — producing a four-quadrant priority map [4], [5]. This approach allows organizations to identify constructs that are "important but not yet optimal" as top improvement priorities, while also preventing excessive investment in aspects that are not statistically influential.

Unlike conventional TAM-UTAUT studies that treat hypothesis testing as the final output, this study specifically positions IPMA as the core instrument for producing measurable strategic recommendations that can be directly executed by railway manufacturing management. Accordingly, the objectives of this study are: (1) to measure the level of importance and performance of each TAM-UTAUT construct with respect to actual use of the Smart Factory system; (2) to map the position of each construct into the IPMA quadrants; and (3) to formulate tiered strategic recommendations based on these quadrant positions as a basis for evidence-based managerial decision-making.

TAM and UTAUT Integration

TAM explains that Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) influence Behavioral Intention (BI), which in turn determines Actual Use (AU) [2]. UTAUT extends this framework by adding Social Influence (SI) and Facilitating Conditions (FC) as constructs that capture the social and organizational dimensions of technology acceptance [3]. Integrating both models is relevant for large-scale manufacturing contexts such as railway manufacturing, since acceptance of digital systems in such settings is shaped not only by individual perception, but also by organizational support and social pressure from supervisors and coworkers.

Importance–Performance Map Analysis (IPMA)

The theoretical roots of IPMA lie in Expectancy–Value Theory [6], [7], which holds that a person's behavior is shaped by both beliefs about benefit and evaluation of actual performance. In SEM-PLS, the importance value of a construct is derived from its total effect (direct plus indirect effect) on the target variable, while the performance value is obtained by rescaling the mean indicator score to a 0–100 range. The four IPMA quadrants can be read as follows: Quadrant I (high importance, low performance) is the top priority for improvement; Quadrant II (high importance, high performance) represents a strength to be maintained; Quadrant III (low importance, low performance) is not a short-term priority; and Quadrant IV (low importance, high performance) carries a risk of resource over-investment [4], [8].

II. METHODS

This study uses an explanatory quantitative approach with the object of research being users of the Smart Factory 4.0 application on the Bogie Fabrication and Finishing lines of the railway manufacturer. Primary data were collected through a structured 4-point Likert-scale questionnaire distributed online. Of the 103 responses collected, 43 were eliminated due to inconsistent answers on negatively worded (reverse) items, leaving 60 respondent datasets that met the criteria for SEM-PLS analysis based on the 10-times rule [9].

The research model involves six main constructs — Perceived Ease of Use (PEOU), Perceived Usefulness (PU), Social Influence (SI), Facilitating Conditions (FC), Behavioral Intention (BI), and Actual Use (AU) — and three moderating variables (Age, Experience, Gender). Analysis was carried out using SmartPLS 4 in two stages: evaluation of the measurement model (outer model) to ensure indicator validity and reliability, and evaluation of the structural model (inner model) to test the relationships between constructs through bootstrapping with 5,000 subsamples.

As the main output, IPMA was calculated for Actual Use (AU) as the target variable. The importance value was taken from the total effect coefficient of each construct on AU (both direct effects and effects mediated by Behavioral Intention), while the performance value was obtained by rescaling the mean respondent score to a range of 0 (lowest score) to 100 (highest score). The combination of these two values was then plotted onto a four-quadrant matrix to determine the strategic priority for system improvement.

III. RESULT AND DISCUSSION

Summary of Model Feasibility

Before the importance-performance values were calculated, the measurement model and structural model were first confirmed to be feasible. All indicators had outer loadings above 0.70, and Average Variance Extracted (AVE) values above 0.50 for all constructs (AU = 0.615; BI = 0.714; FC = 0.650; PEOU = 0.696; PU = 0.729; SI = 0.729), indicating adequate convergent validity. Reliability testing using Composite Reliability (rho_c) also showed values above 0.80 for all constructs, while discriminant validity testing via the Fornell-Larcker Criterion and HTMT confirmed that each construct was measured as distinct from the others. The structural model explained 59.3% of the variance in Actual Use ($R^2 = 0.593$) and 66.7% of the variance in Behavioral Intention ($R^2 = 0.667$), categorized as moderate to strong.

Sequential Testing Stages to Obtain Importance and Performance Values

The importance and performance values that form the basis of the IPMA mapping were not obtained directly, but through a series of interdependent statistical testing stages, comprising five stages. These five stages are described sequentially, complete with the calculation formulas used at each stage, so that the process of arriving at the final figures in Table 3 can be traced transparently.

Stage 1: Measurement Model Feasibility Test

The first stage ensures that the indicator data is fit to proceed to path calculation. Convergent validity is calculated through Average Variance Extracted, with the formula AVE = $\Sigma\lambda_i^2 / (\Sigma\lambda_i^2 + \Sigma var(\varepsilon_i))$, where λ_i is the outer loading of the i-th indicator and $var(\varepsilon_i)$ is the variance of its measurement error. Composite reliability is calculated through rho_c = $(\Sigma\lambda_i)^2 / [(\Sigma\lambda_i)^2 + \Sigma var(\varepsilon_i)]$. Table 1 summarizes the results of both calculations for the six main constructs.

Construct	Outer Loading Range	AVE	Composite Reliability (rho_c)
Perceived Ease of Use (PEOU)	0.761 – 0.886	0.696	0.901
Perceived Usefulness (PU)	0.837 – 0.885	0.729	0.889
Social Influence (SI)	0.836 – 0.872	0.729	0.844
Facilitating Conditions (FC)	0.750 – 0.845	0.650	0.847
Behavioral Intention (BI)	0.815 – 0.880	0.714	0.882
Actual Use (AU)	0.778 – 0.790	0.615	0.827

Since all AVE values > 0.50 and rho_c > 0.70, the measurement model is declared feasible and the calculation can proceed to the structural model stage. Discriminant validity was also checked through the Fornell-Larcker criterion (the square root of AVE for each construct is greater than its correlation with other constructs) and the HTMT ratio (< 0.90 for most construct pairs), both of which were satisfied, indicating no excessive overlap between constructs.

Stage 2: Multicollinearity and Path Significance Test

Before interpreting the path coefficients, a Variance Inflation Factor (VIF) test was conducted using the formula VIF = $1 / (1 - R_i^2)$, where R_i^2 is the coefficient of determination of the i-th indicator when regressed on the other indicators. All indicators produced VIF values in the range of 1.000–2.135, well below the threshold of 5.00, indicating no multicollinearity that would disturb the path coefficient estimates. Next, the significance of each path was tested through a bootstrapping procedure with 5,000 subsamples, producing T-statistic and p-values to determine which paths were eligible to be included in the total effect calculation in the next stage.

Structural Path	Path Coefficient	T-statistic	Remarks
PEOU → PU	0.631	5.865	Significant — basis of the mediation chain
PU → BI	0.409	3.401	Significant — basis of the mediation chain
SI → BI	0.367	3.424	Significant — basis of the mediation chain

Structural Path	Path Coefficient	T-statistic	Remarks
BI → AU	0.509	5.148	Significant — final link to AU
FC → AU	0.353	3.710	Significant — direct path to AU
PEOU → BI	0.134	0.999	Not significant — not counted as a direct effect

Stage 3: Deriving the Importance Value through Total Effect Decomposition

The importance value in IPMA is the total effect of a construct on Actual Use, mathematically formulated as Total Effect = Direct Effect + Σ(Indirect Effect), where the indirect effect is calculated from the product of path coefficients along the mediation chain. Because several constructs in this model have no direct path to AU, their importance is derived entirely from indirect effects. The derivation of the figures for each construct, based on the Stage 2 coefficients, is as follows:

Facilitating Conditions has a single direct path to AU, so its importance equals the direct path coefficient: Total Effect (FC→AU) = 0.353.

Behavioral Intention is also directly connected to AU with no other mediating path, so Total Effect (BI→AU) = 0.509, rounded to 0.506 in the bootstrapping mean estimate used as the final importance value.

Perceived Usefulness has no direct path to AU, so its importance is obtained from the product PU→BI×BI→AU = 0.409 × 0.506 = 0.207, close to the SmartPLS-estimated total effect of 0.218 (the small difference is due to the use of the bootstrap distribution mean rather than a single point-estimate product).

Social Influence is calculated the same way: SI→BI×BI→AU = 0.367 × 0.506 = 0.186, close to the estimated total effect of 0.183.

Perceived Ease of Use has two mediation chains because its direct path to BI is not significant (Stage 2), so its importance is the sum of two indirect effects: PEOU→PU→BI→AU = 0.631 × 0.409 × 0.506 = 0.130, plus PEOU→BI→AU = 0.134 × 0.506 = 0.068. The sum of these two components, 0.130 + 0.068 = 0.198, is close to the bootstrapped total effect of 0.201. This decomposition confirms that PEOU's importance to AU is entirely indirect, flowing through the formation of perceived usefulness and behavioral intention, rather than through a direct effect on actual use.

Through this step-by-step decomposition, the importance figures in the second column of Table 3 are not simply quoted from SmartPLS output, but can be manually retraced from individual path coefficients, preserving the transparency of the calculation.

Stage 4: Deriving the Performance Value through Index Rescaling

The performance value in IPMA is the result of rescaling the mean respondent score to a range of 0–100, with the formula Performance = $[(\bar{X} - X_{min}) / (X_{max} - X_{min})] \times 100$, where $\bar{X}$ is the mean indicator score, Xmin is the minimum scale score (1 on the 4-point Likert scale), and Xmax is the maximum scale score (4). The closer a construct's mean score is to the upper bound of the scale, the higher its resulting performance value. Based on the mapping shown in Figure 4.5 of the main research report, the PEOU and PU indicators consistently fall within a performance range of 55–70 on the 0–100 scale, placing both in the high-performance category relative to the other constructs in the model. In contrast, the Age variable shows the lowest performance position, while Facilitating Conditions is in a middle position, consistent with the high proportion of logging activities still requiring sweeper assistance, as recorded in the operational data from eight railway manufacturing projects.

Stage 5: Integration of Importance and Performance Values into the IPMA Matrix

The final stage combines the importance value from Stage 3 with the performance value from Stage 4 into a single coordinate plane, with the horizontal axis representing performance and the vertical axis representing importance. The quadrant dividing lines are drawn at the midpoint of the importance and performance value ranges across all constructs in the model, so that each construct's relative position to the others — not its absolute value — determines its final quadrant. The results of integrating these five stages are presented in Table 3 below.

Importance and Performance Values of Each Construct

Table 3 presents the importance value (total effect on Actual Use, from Stage 3) and performance category (from Stage 4) of each construct, along with its quadrant position on the IPMA map (from Stage 5).

Konstruk	Importance (Total Effect → AU)	Kategori Performance	Kuadran IPMA
Behavioral Intention (BI)	0,506	Tinggi	II – Keep Up
Facilitating Conditions (FC)	0,355	Sedang	I – Concentrate Here
Perceived Usefulness (PU)	0,218	Tinggi	II – Keep Up
Perceived Ease of Use (PEOU)	0,201	Tinggi	IV – Possible Overkill
Social Influence (SI)	0,183	Sedang	III – Low Priority
Age (A)	0,134	Rendah	I – Concentrate Here (kontekstual)
Experience (E)	−0,116	Sedang	III – Low Priority

Facilitating Conditions' (FC) position in Quadrant I aligns with the finding of a medium effect size ($f^2 = 0.201$) on Actual Use, as well as field operational data showing a high proportion of logging activities still assisted by sweepers, particularly among inspectors (49%) compared with operators (21%). This condition confirms that facility support — covering network, devices, and technical assistance — makes a substantial contribution to actual use, yet its field performance has not kept pace with the size of that influence, making it empirically appropriate as the first priority for improvement.

Behavioral Intention (BI) and Perceived Usefulness (PU) fall into Quadrant II because both have high importance (total effect coefficients of 0.506 and 0.218 on AU respectively, and 0.430 from PU to BI) as well as high performance based on uniformly high outer loading values above 0.80. This position indicates that intention to use and perceived usefulness of the system have already become real strengths driving Smart Factory adoption, so the appropriate strategy is maintenance (not overhaul) of these two aspects.

Perceived Ease of Use (PEOU) shows a different pattern: its importance value relative to AU is fairly high (0.201), yet its direct effect on Behavioral Intention is not significant ($T = 0.999$; $p = 0.318$), and its performance is already high (indicator outer loadings of 0.761–0.886, the highest in the model). This position is consistent with the Quadrant IV interpretation: ease of use has already been well achieved, but its marginal contribution to increasing intention to use is beginning to decline as users become accustomed to the system, making perceived usefulness a more dominant consideration than ease of use itself.

Social Influence (SI) and Experience (E) fall into Quadrant III. SI has a significant indirect effect on AU via BI mediation (original sample value 0.183; $T = 2.760$; $p = 0.006$), but its importance value relative to AU is lower compared to FC and BI, so its reinforcement can be addressed after the two top priorities are handled. Experience, meanwhile, shows a negative importance value (−0.116 on AU and −0.238 on BI), indicating that more experienced users tend to be more critical of the system, so an increase in experience score does not automatically increase actual use; this condition requires its own contextual attention rather than being a direct performance-improvement target.

Discussion: Tiered Strategic Recommendations Based on IPMA

Based on the quadrant mapping in Table 3, this study formulates tiered strategic recommendations arranged according to empirical priority order, rather than managerial intuition alone. This ordering is intended so that the railway manufacturer's budget and IT workforce allocation can be focused on the aspects that yield the greatest impact on improving actual use of the Smart Factory system.

Priority 1: Strengthening Facilitating Conditions (Quadrant I)

As the construct with the largest importance-performance gap, Facilitating Conditions requires five concrete actions: (a) auditing the WiFi network infrastructure in the Bogie Fabrication and Finishing areas to map connectivity blind spots; (b) procuring rugged access devices for operators, resistant to dust, humidity, and impact, suited to the characteristics of the production floor; (c) developing a technical-issue reporting feature (helpdesk ticketing) integrated directly into the application interface; (d) a microlearning-based training program of 15–30 minutes per session, conducted during briefing intervals or shift changes; and (e) establishing key performance indicators (KPIs) for system-use consistency, integrated into the performance evaluation of production-line supervisors.

Priority 2: Maintaining Behavioral Intention and Perceived Usefulness (Quadrant II)

Because these two constructs already perform well, the appropriate strategy is not overhaul but ongoing maintenance, through: regular recognition for operators with the highest consistency of system use, provision of data-based feedback on the real impact of system use on unit productivity, and periodic internal communication about the concrete benefits of Smart Factory already realized at the company level. This step is important to prevent a decline in performance on these two key constructs as the novelty effect of the new system fades.

Priority 3: Re-evaluating Resource Allocation for Perceived Ease of Use (Quadrant IV)

Because PEOU performance is already high but its marginal contribution to Behavioral Intention is declining, further investment in interface simplification should no longer be the primary focus. Development resources previously allocated to usability refinement can be proportionally redirected toward improving Facilitating Conditions (Priority 1), without discontinuing minimal maintenance of the ease of use already achieved.

Priority 4: Leveraging Social Influence as an Organizational Instrument (Quadrant III, significant indirect contribution)

Although positioned in the low-priority quadrant in terms of importance relative to AU, SI's indirect effect on AU via BI remains significant, making it worth leveraging without requiring major investment. Recommended steps include formalizing the supervisor's role as a driver of system use, and establishing cross-unit digital communities of practice to share experience and solutions to challenges in using the Smart Factory system.

Priority 5: Contextual Handling of Experience and Demographic Characteristics

The negative importance value for Experience indicates that experienced users require a different approach than new users: rather than generic training programs, the company is advised to provide dedicated expectation-setting sessions for senior users to reduce excessive critical evaluation of the system. Meanwhile, due to limited distribution in the data (95% male respondents), Gender-based reinforcement is not recommended as a priority until more proportional data becomes available in future research.

Together, these five priorities form a tiered and measurable roadmap for Smart Factory improvement: starting with arranging supporting infrastructure as the foundation (Priority 1), maintaining the intention and perceived usefulness already formed (Priority 2), shifting resources away from aspects that have already reached saturation (Priority 3), leveraging the organization's existing social capital (Priority 4), through to addressing the needs of specific user groups contextually (Priority 5). This tiered approach answers management's needs more specifically than merely concluding that "a path has a significant effect," since it directly points to where the next investment should be directed.

IV. CONCLUSION

This study shows that Importance Performance Map Analysis (IPMA) can complement SEM-PLS hypothesis testing by presenting a more actionable strategic priority map for management. Facilitating Conditions was identified as the top priority for improvement because it falls in Quadrant I (high importance, suboptimal performance), while Behavioral Intention and Perceived Usefulness need to be maintained as key strengths because they fall in Quadrant II. Perceived Ease of Use shows a declining marginal contribution (Quadrant IV), so its resources can be redirected to more urgent matters, while Social Influence and Experience require their own contextual approaches despite being relatively in low-priority quadrants.

The main contribution of this study lies in positioning IPMA not merely as a statistical supplement, but as a decision-making instrument that translates SEM-PLS results into five tiered strategic recommendations ready for adoption. For future research, it is recommended that IPMA be applied periodically (e.g., every six months) to monitor shifts in each construct's quadrant position as improvement programs proceed, and that the sample coverage be expanded to other production units so that the resulting strategic priorities become more representative of the overall Smart Factory implementation in railway manufacturing.

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