ACEMI

کنترل پروژه پیشرفته و ارزیابی عملکرد در پروژه‌های پیچیده

(بر اساس اسناد CII)

فصل هفتم:

ارزیابی فناوری‌ها و استفاده از هوش مصنوعی (AI) در کنترل پروژه

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What we will learn?

- Introduction to Technology Domains and AI Applications in APC
- Evaluation of Technology Domains
- Assessment of Technology Readiness in Projects
- Key AI Applications for Predictive and Pattern Recognition
- Examples of High-Value AI Applications

Introduction to Technology Domains and AI Applications in APC

Technology domains

- During its research and focusing again on **streamlining** APC processes,

  RT-402 characterized **30 prominent** sensing and information technologies,

  all with the **potential to streamline** project controls.

Technology domains

- **Computing technologies** applied to controls focus on the data analysis and generation of information, including **extracting information** from datasets such as videos, texts, or images.
- To **facilitate analysis and comprehension**, the team **grouped existing technologies** into seven technology domains:
  1. Mobile computing
  2. Wearables
  3. Visualization
  4. Automation and robotics
  5. Tracking and tracing
  6. Augmented reality (AR) and virtual reality (VR)
  7. AI.

Technology domains

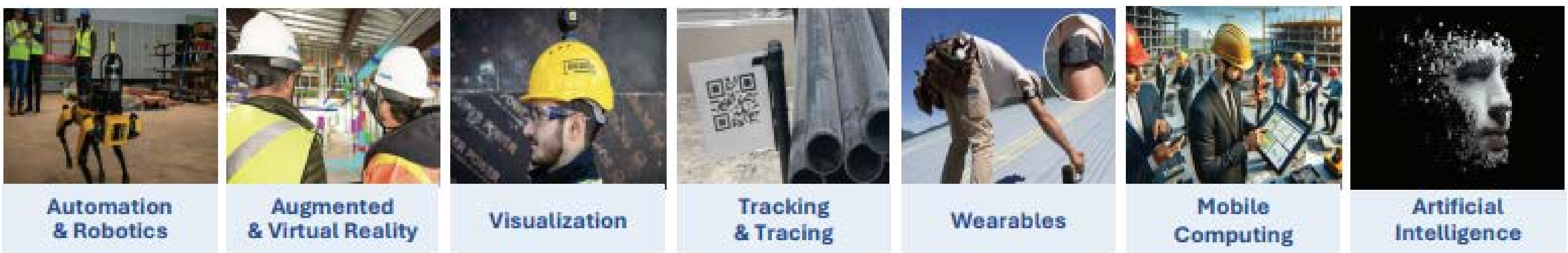

Figure 10. Technology domains

Technology domain groups

Mobile Computing.

- **Mobile devices** include smart watches, smartphones, tablets, laptops, and visualization headsets.
- **Mobile computing** enables to a varying degree the pervasive input, access, manipulation, and retrieval of digital information.
- **Mobile computing** also enables
  1. seamless connectivity,
  2. real-time communication,
  3. data collection, and
  4. information retrieval and
  5. analysis

  regardless of the user's location.

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Technology domain groups

- **Wearables.**
  - Wearables are **biometric devices worn** (e.g., around the arm) by construction workers to **protect** their health and safety and **provide an alert** in case of an imminent or actual health issue or safety incident.
  - Wearable devices are equipped with **location tracking**.
  - While wearables are **designed** for health and safety, they have found applications in **resource management**.
    - ✓ For **project controls**, wearable devices provide essential information on site headcount.

Technology domain groups

Wearables.

- When **combined** with workers' location, supervisors and managers **can assess** whether sufficient workers are **available** in a particular area or for a specific task or trade and reallocate workers accordingly.
- Another **documented application** include mitigating absenteeism, e.g., by **identifying absenteeism patterns** in the the calendar.

Technology domain groups

Visualization.

- **Prevalent visualization** technologies include cameras, 360-degree hardhat-mounted cameras, or Light Detection and Ranging (LiDAR) (i.e., laser scanners).
- Visualization technologies enable detailed visual insights into the construction site to **enhance** site monitoring and controls, safety performance, or inform on installation progress.
- A **fundamental limitation** here is the need for a **direct line-of-sight** between the sensor and the objects or components in a scene.
  - ✓ **Such limitation** is especially notable with **stationary cameras**.

Technology domain groups

Automation and Robotics.

- Technologies include but are **not limited** to robots, drones, autonomous vehicles, and power tools.
- The technologies cover **automated** or **semi-automated** tools, systems, and robots designed to handle repetitive, demanding, hazardous, or complex tasks.
- Automation and robotics products **directly perform** tasks or **aid human workers** in completing tasks, thereby increasing efficiency, precision, safety, and the ability to control and predict production and, hence, time to completion.
- **Complex autonomous** applications, such as autonomous vehicles, require advanced sensors and AI support for real-time decision making.
- A **distinct feature** of automation and robotics is the ability to facilitate, reduce, or virtually eliminate human intervention.

Technology domain groups

Tracking and Tracing.

- Tracking aims to **gather** the location and status of an item using **auto-identification technologies**.
- Tracing focuses on **collecting** and **sharing** the digital thread of information on a tracked item.
- Tracing can **span back** to manufacturing and production, including certifications, test reports, transaction history, and vendor and supplier records.
- Tracking and tracing **applications** in project controls enable the **visibility of equipment and materials** either upstream (within the supply chain) or downstream (at the project site).
- Both technologies are **included in contract agreements**, which at a minimum provides **production/fabrication status** and **possible delays** that could affect planning and scheduling.

Technology domain groups

Augmented Reality & Virtual Reality.

- AR and VR are visualization technologies that aim to create a realistic and interactive experience through head-mounted displays.
- AR overlays digital information onto visuals of the physical world, enhancing the human perception of a scene with virtual information.
- Overlaying the BIM model directly onto the project site, for example, enables an on-the-spot and real-time comparison between the design/plan and actual installation.
- Such comparison informs of progress and facilitates the identification of design issues and construction errors.

Technology domain groups

❑ Augmented Reality & Virtual Reality.

- ❖ VR immerses users in an entirely virtual landscape.
- ❖ When coupled with BIM, VR enables designers to navigate the BIM model and assess the quality of design, errors, or design for maintenance issues.
- ❖ VR has also been used to train safety identification and prevention through virtual settings that enable learning from situations specifically designed to meet the training objectives without exposing the trainees to hazardous scenes.
- ❖ In other sectors, VR is leveraged to train trades in manipulating and repairing equipment.

Technology domain groups

Artificial Intelligence.

- In project controls, **AI** is still in **its infancy**.
- It encompasses various technologies and techniques, such as ML, large language models, convolutional neural networks, and digital twins.
- **AI** offers the ability to **parse vast datasets** and **find patterns** and **evidence** that would otherwise **remain hidden**.

Technology domain groups

- **Appendix III** contains a catalogue of **30 key technologies** grouped by domain.

- The characterization of each technology includes
  - a description of features and capabilities,
  - costs,
  - applications,
  - technology users,
  - user-friendliness,
  - development and commercialization status,
  - intensity of adoption and use, and
  - availability.

Evaluation of Technology Domains

Evaluation of technology domains

- **Before** holding the **three workshops** with the **SMEs**,

  the **team related information** to them about **each technology domain**, including

  1. definitions,
  2. audiovisual information, and
  3. practical applications.

- **Results** regarding their impressions on the technology domains follow.

Technology adoption

- **During** the workshops, the **SMEs identified** the **level of technology** use within their projects. See **Figure 11**.
- Visualization, mobile computing, and tracking and tracing are **consolidated technologies** within the construction industry and are **widely used**.
- This **level of adoption** shows a possible correlation with the maturity or the number of years a technology has been **available**.
- **Wearables**, in contrast, have only emerged **relatively recently**; this could **hinder** their adoption and market diffusion.

Technology adoption

Figure 11. Technology Adoption Rates (n=30)

Technology adoption

- Similar to wearables, **AI currently** has only been adopted in **less than 10 percent** of projects.

- While **AI research and applications** have existed for **more than 15 years**, the vast **majority of the SMEs** have **only been aware of AI** since large language model engines **became popular at the end of 2022**.

Barriers

- The intensity of the barriers against technology adoption was quantified for each technology domain.
- The team's research yielded 12 prevalent barriers:
  1. Purchase costs
  2. Maintenance costs
  3. Unclear or low return on investment (ROI)
  4. Complexity or difficulty of implementation
  5. Complexity or difficulty of use
  6. Difficulty or inability to integrate with other tools or systems
  7. Limited ability to automate tasks
  8. Limited functionality beyond project controls
  9. Lack of/limited awareness or adoption support by project teams
  10. Lack of/limited awareness or adoption support by upper management
  11. Limited project resources
  12. Privacy and cybersecurity issues

Barriers

- The SMEs **rated the intensity** of each barrier on a scale from 1 (null intensity) to 5 (maximum intensity).
- On average, the **top obstacles** against technology adoption in project controls were found to be
  1. integration constraints,
  2. limited project resources,
  3. upfront investment,
  4. difficulty of use, and
  5. unclear ROI.

  See **Figure 12**.
- These **results underscore** the combined importance of organizational support and **technical aspects**.

Barriers

Figure 12. Top Barriers

Analysis of barriers by technology domain

- The team then analyzed the **barriers by domain**.
- That **detailed analysis** provides insights that practitioners should consider when selecting and implementing technologies in support of project controls.

See **Table 6** and **Figure 13**.

Analysis of barriers by technology domain

Table 6. Barriers (n=23)

	Purchase cost	Maintenance cost	Unclear or low ROI	Difficulty to implement	Difficulty to use	Difficulty to integrate
Mobile Computing	1.83	1.57	2.00	1.41	1.48	2.41
Wearables	2.64	2.67	3.00	2.78	2.71	3.05
Visualization	2.45	2.23	2.40	2.68	2.85	3.29
Automation and Robotics	3.96	3.73	3.45	3.45	3.35	3.60
Tracking and Tracing	2.43	2.19	1.95	2.00	2.24	2.55
AR/VR	3.71	2.89	3.21	3.05	3.29	3.33
Artificial Intelligence	3.37	2.76	3.81	3.81	4.00	3.20
Average	2.91	2.58	2.83	2.74	2.84	3.06

Analysis of barriers by technology domain

	Limited ability to automate tasks	Limited functionality beyond controls	Lack of support by project teams	Lack of support by corporate managers	Limited project resources	Privacy and cybersecurity concerns
Mobile Computing	2.16	1.86	1.64	1.68	2.05	3.33
Wearables	2.33	2.32	3.05	2.76	2.95	2.73
Visualization	2.74	2.30	2.73	2.62	2.91	2.45
Automation and Robotics	2.80	2.43	2.90	2.78	3.23	1.90
Tracking and Tracing	1.95	2.00	1.91	2.00	2.23	2.52
AR/VR	2.61	2.55	3.05	3.00	3.57	2.50
Artificial Intelligence	2.00	1.83	3.33	3.17	3.76	3.35
Average	2.37	2.18	2.66	2.57	2.96	2.69

Analysis of barriers by technology domain

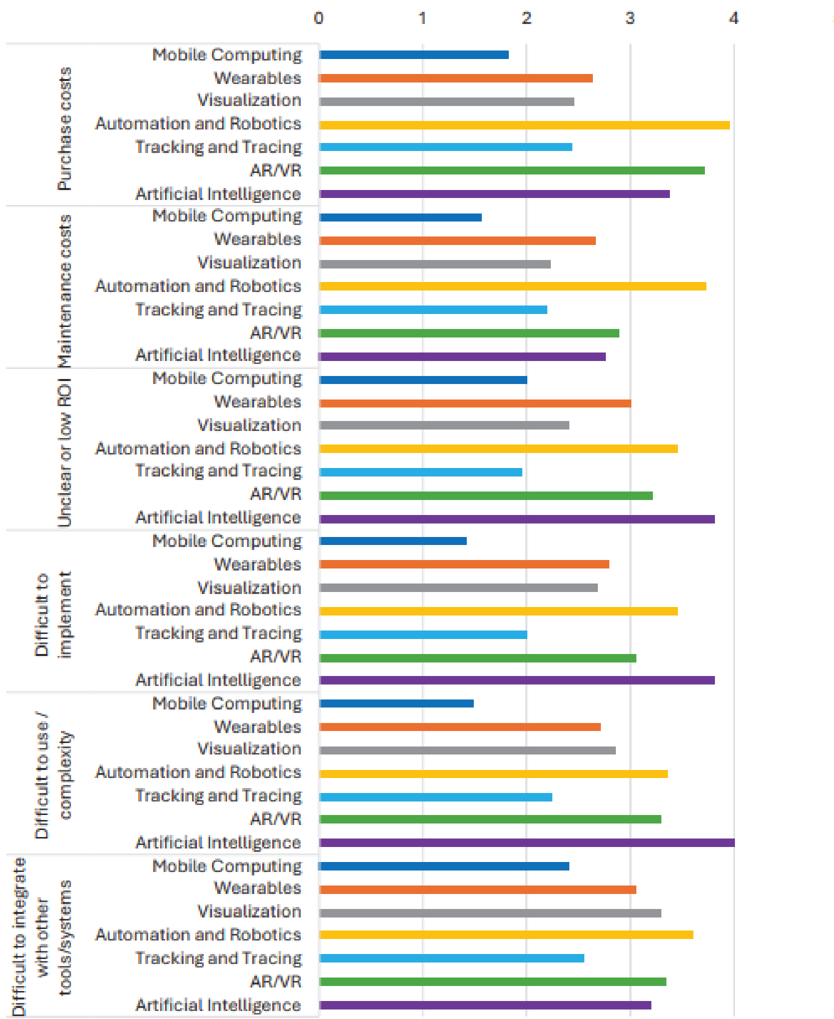

Figure 13. Intensity of Barriers (n=23)

Analysis of barriers by technology domain

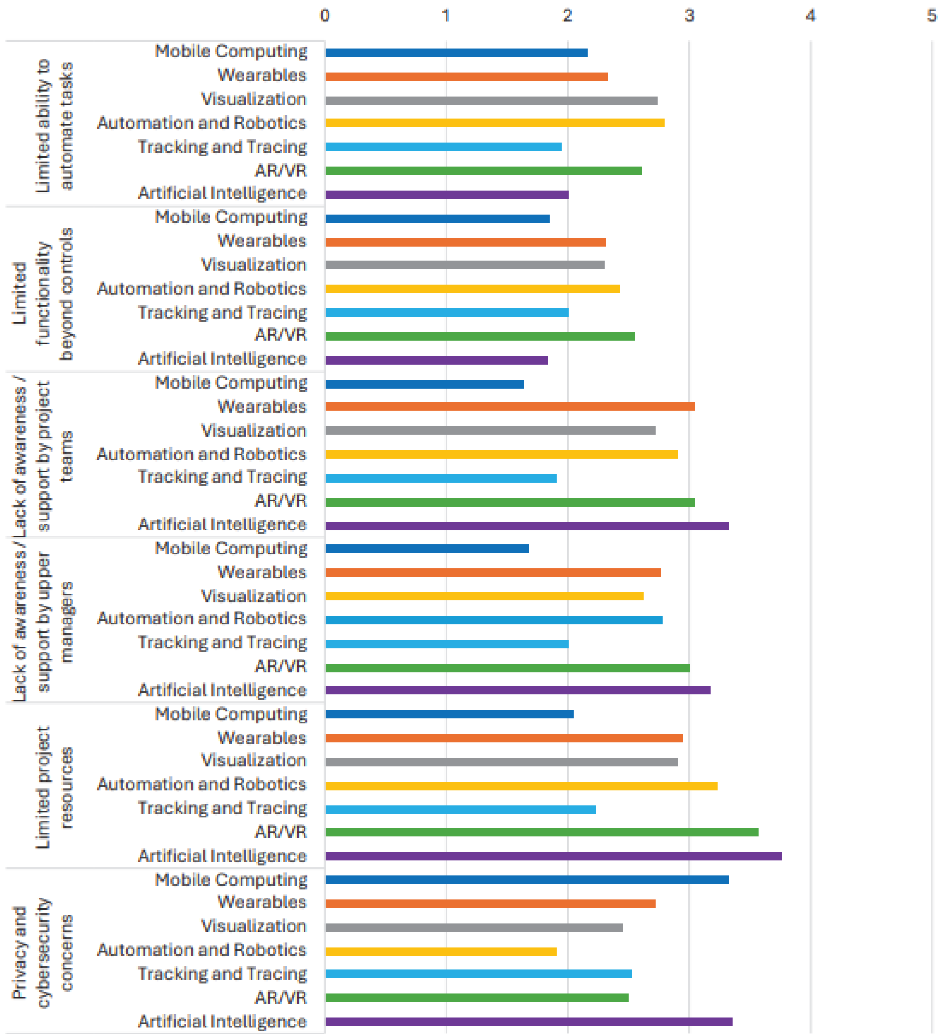

Figure 13. Intensity of Barriers (n=23)

Analysis of barriers by technology domain

- For example, established domains such as mobile computing or tracking and tracing show a **low intensity of barriers**.
- Such prevalent use can be **partially explained** through
  - the **small** and **reliable** **investment** needed for acquisition and implementation,
  - the **high level** of **awareness** among practitioners, and
  - the **low cybersecurity** and **privacy** concerns.
- **Mobile computing**, however, shows the **highest level of cybersecurity** and privacy concerns, **only topped** in this **barrier by AI**.
- **Expensive technology products** such automation and robotics and **AR/VR** show a **dominance of cost-related** and resource barriers.

Analysis of barriers by technology domain

- Regarding AI, this **innovative technology** with applications still in their infancy, is rapidly evolving, and is also **carrying high expectations**.
  - Therefore, the **noticeable intensity** of its **barriers**.
- For one, practitioners **question AI's ROI**.
- Perceived as complex, **AI** is also viewed as **needing sophisticated** use and implementation.
- The **perceived lack of understanding** by project and upper management was also the **highest for AI.**
- Concerns with AI also relate to **privacy** and **cybersecurity**.
- The barriers to AI may ease as its **use increases** and as **practitioners identify ways** to improve on the cyber and privacy issues as it evolves.

Drivers

- **For each technology domain**, the team quantified the intensity of drivers or enablers of adoption.
- The **results revealed nine drivers** that can facilitate adoption:
  1. Proven ability to improve project controls
  2. Technology durability
  3. Technology reliability
  4. Timely access to data and information
  5. Ability to trial and test
  6. Technical attributes and features
  7. Ease of implementation and deployment
  8. Ability to integrate with tools and systems
  9. Ability to contribute to functions beyond project controls

Drivers

- The **SMEs rated the intensity** of each barrier on a scale from 1 (null intensity) to 5 (maximum intensity).
- On average, the **top drivers towards technology** adoption in project controls were
  1. reliability,
  2. ability to improve project controls,
  3. ease of implementation,
  4. ability to trial and test, and
  5. durability.

  See **Figure 14**.
- These drivers emphasize prioritizing operational effectiveness, risk mitigation, and long-term value in technology adoption decisions.

Drivers

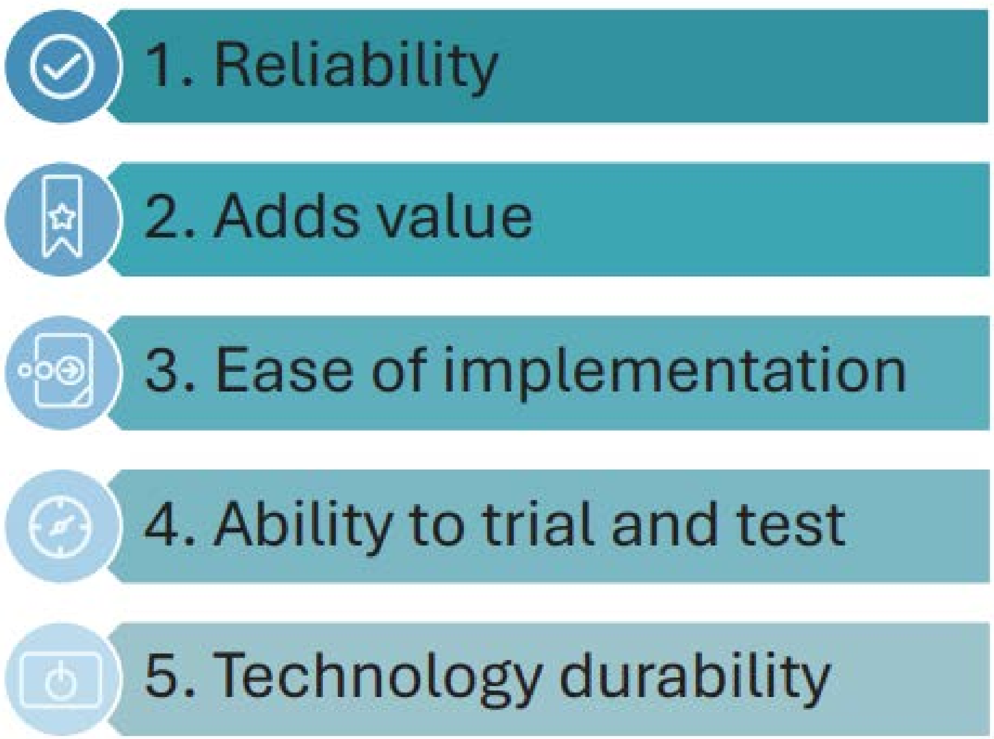

Figure 14. Top Drivers

Drivers

- Additional insights came out of this. See **Table 7** and **Figure 15**.
- Technology domains common to construction projects, such as **mobile computing** and **tracking and tracing**, are **strong drivers** for implementation.
  - Thus, such technology domains show the **highest ability** to improve project controls, **immediate access** to data and information, and **straightforward integration** with other tools and systems.
- In general, practitioners consider **AI applications** to **lack pull for adoption**, with concerns regarding **ease of** implementation, reliability, or durability.
- Again, AI is regarded as the **least durable technology solution**.

Drivers

Table 7. Drivers (n=27)

Project controls	Ability to improve	Durability	Reliability	Immediate data and information access	Triability	Technical attributes & features	Ease of implementation	Ability to integrate	Ability to contribute to other functions
Mobile Computing	4.27	3.88	4.12	4.42	3.90	3.50	3.89	4.04	3.69
Wearables	3.78	3.81	4.19	4.04	3.86	3.32	3.96	3.60	3.38
Visualization	3.85	3.42	4.19	3.83	4.10	3.33	3.88	3.88	3.42
Automation and Robotics	3.60	4.04	4.12	3.83	3.77	3.50	3.85	3.83	3.78
Tracking and Tracing	4.32	3.76	4.40	4.28	3.81	3.14	4.16	4.13	3.88
AR/VR	3.96	3.19	3.54	3.52	3.95	3.19	3.65	3.56	3.54
Artificial Intelligence	3.93	2.85	3.70	3.96	3.67	3.57	3.58	3.81	3.92
Average	3.96	3.57	4.04	3.98	3.87	3.36	3.85	3.83	3.66

Drivers

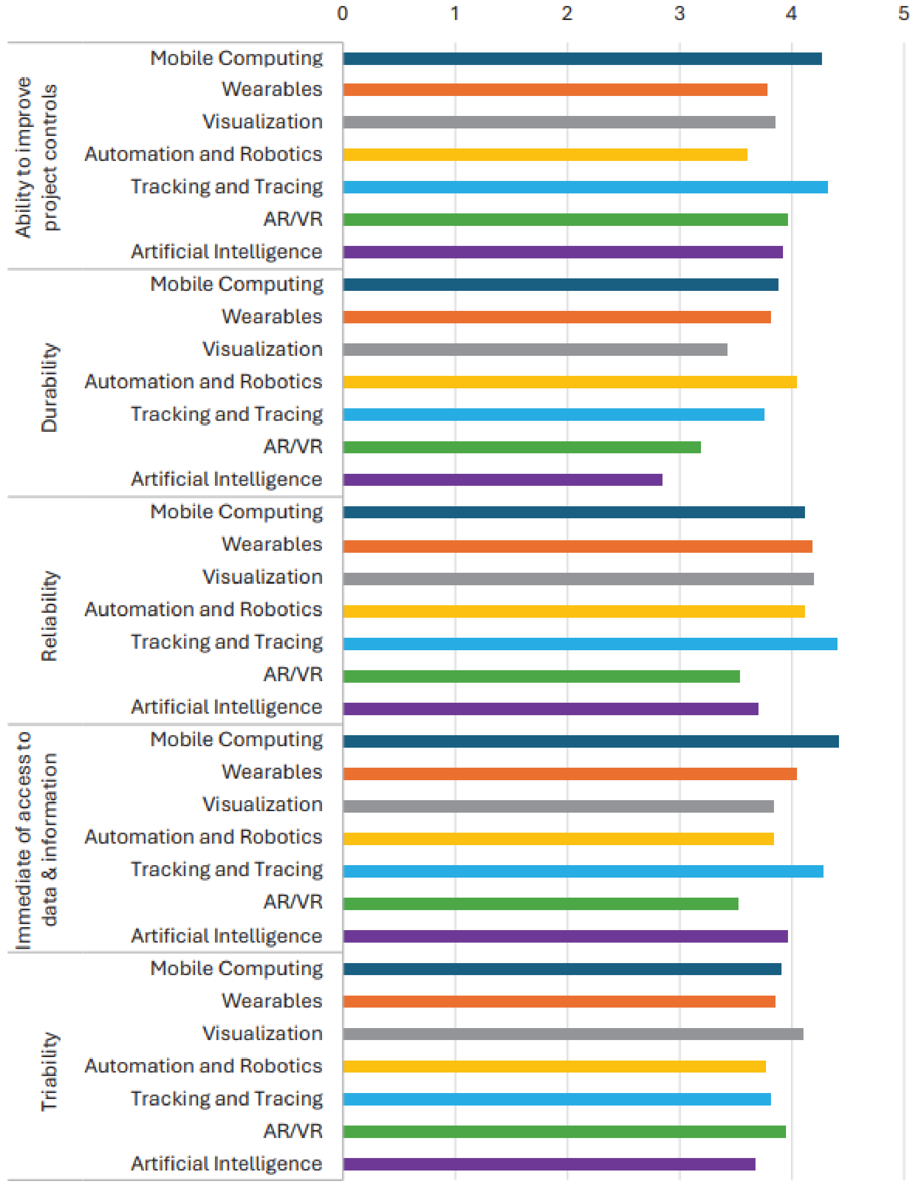

Figure 15. Intensity of Drivers (n=27)

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Drivers

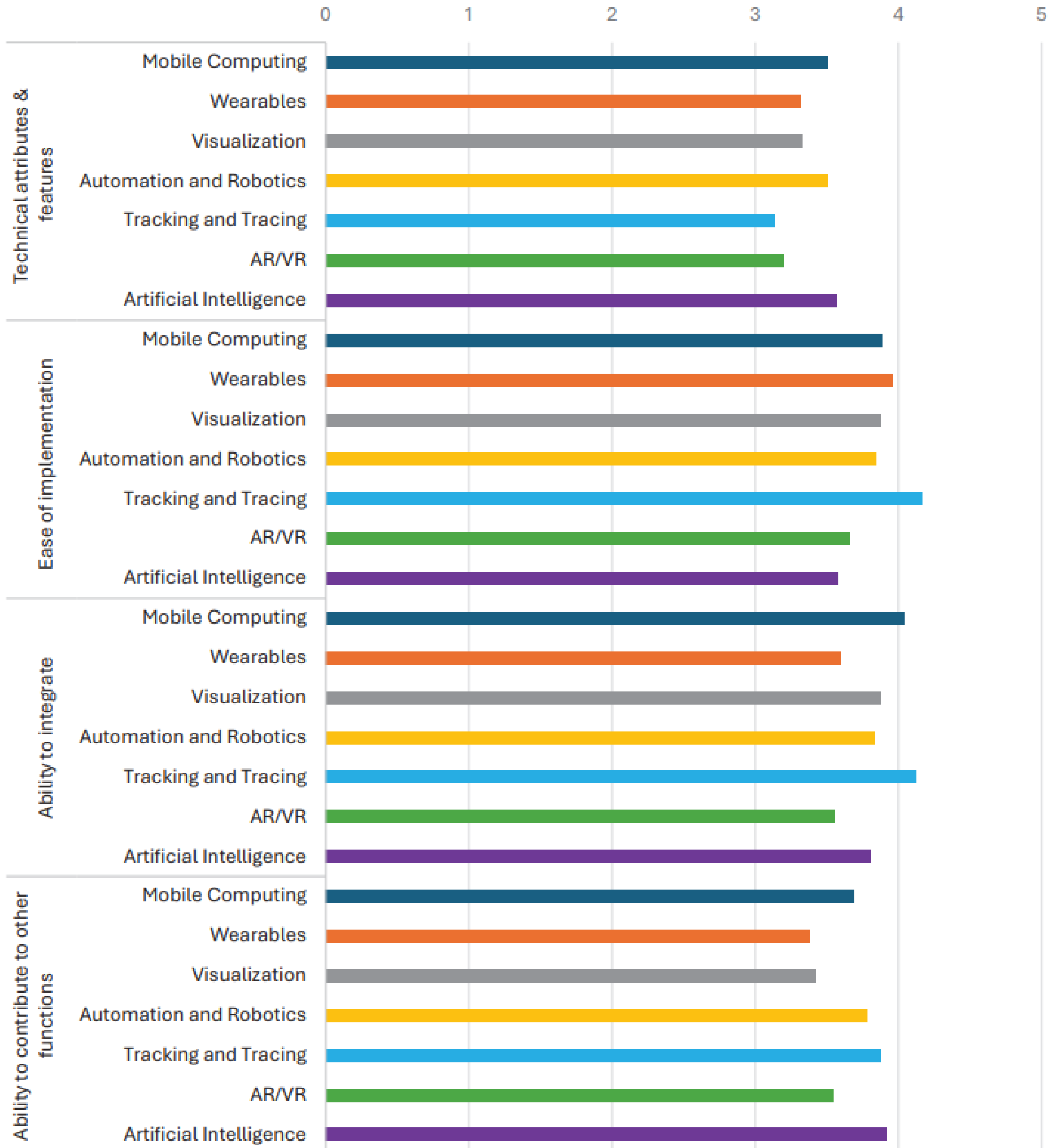

Figure 15. Intensity of Drivers (n=27)

User-related attributes

- The **research team** also quantified the relative importance of user attributes.

- Five key user attributes resulted:
  1. Personnel reduction
  2. Technical capabilities of users
  3. Ability to train and test
  4. Ease of use
  5. Effective customer support

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User-related attributes

- The SMEs **rated each attribute** on a scale from 1 (null) to 5 (maximum).
- The importance of the attributes in **decreasing order** of magnitude were:
    1. customer support and resources,
    2. ease of use,
    3. training resources,
    4. enhancement of user capabilities and skills, and
    5. reduction of personnel.

See **Table 8** and **Figure 16**.

User-related attributes

Table 8. User Factors (n=26)

	Reduction of project controls personnel	Ease of use	Availability of training to optimize performance	Effective customer support and resources	Enhanced user capabilities and skills
Mobile Computing	2.16	4.20	3.60	4.38	3.56
Wearables	2.16	4.20	3.71	4.50	3.50
Visualization	2.16	4.00	3.92	4.63	3.52
Automation and Robotics	2.08	4.13	3.96	4.44	4.08
Tracking and Tracing	2.00	4.29	3.87	4.50	3.42
AR/VR	1.63	3.96	3.88	4.63	3.79
Artificial Intelligence	3.04	4.04	4.12	4.67	3.72
Average	2.17	4.12	3.86	4.53	3.66

Figure 16. Intensity of User Factors (n=26)

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User-related attributes

- The **reduction** of project controls **personnel** is perceived as the **least important factor**.
  - For AI, a **strong expectation** exists of **reducing personnel**.
- Such an expectation can be explained by **AI's ability** to **automate tasks**.
  - Due to AI complexity, there is a perceived need for **customer support**.
- Also, **improving user capabilities** and skills ranks the highest for automation and robotics, likely due to this technology's ability to **automate processes** and tasks in an autonomous or semi-autonomous manner.

Appendix III

- Technology Catalog

Assessment of Technology Readiness in Projects

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Technology readiness

- RT-402 adopted the **Technology Readiness Assessment (TRA) method** to evaluate the **preparedness of technology domains** for their widespread use.
- The concept of **Technology Readiness Levels (TRLs)** was introduced at **NASA** in the **1970s**.
- It was not until the **1980s that NASA** adopted the formal TRA method.
- RT402 adopted **previous CII-generated TRL** definitions and scale in its research on technology readiness.
- The **more technological** development, the **higher its TRL**.
- **Figure 17** illustrates the TRL scale, while Table 9 provides the corresponding definitions.

Technology readiness

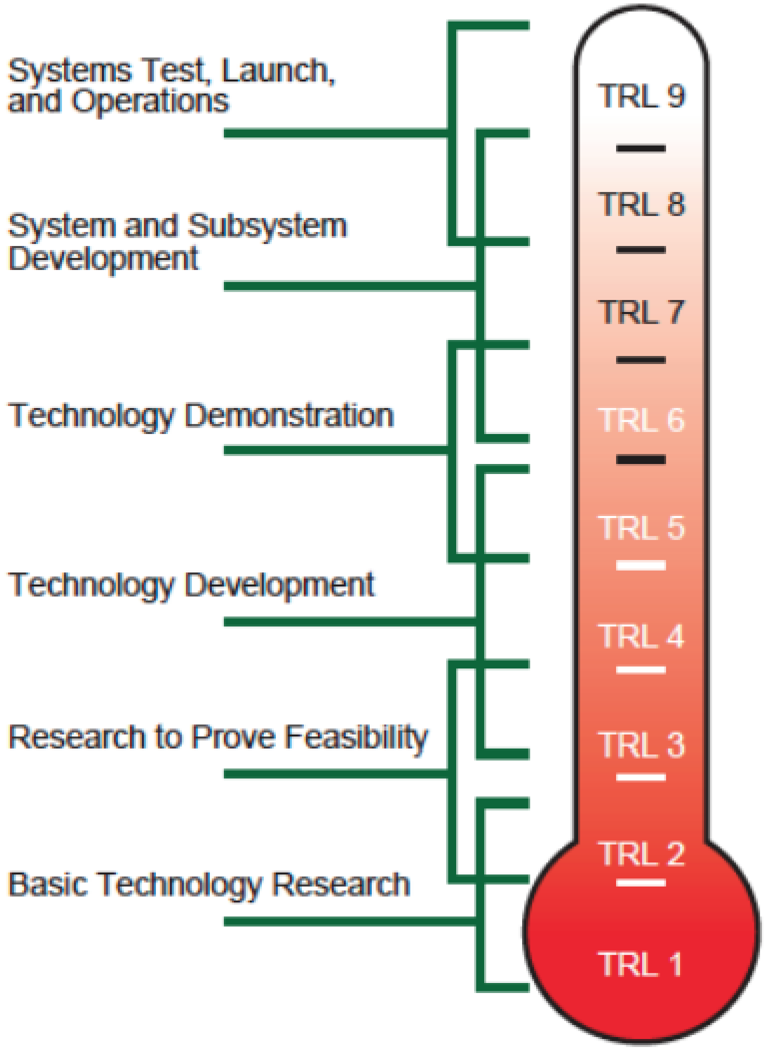

Figure 17. Technology Readiness Levels

Technology readiness

Table 9. Technology Readiness Levels Adapted for this Study

Phase	Technology Readiness Level	Description and Requirements
Basic Research	TRL 1	Initial technology basic principles are qualitatively postulated and observed by initial scientific research. • Do basic scientific principles support the concept? • Has the technology development methodology or approach been developed?
	TRL 2	Potential practical applications and applicability are identified. The potential required procedure or material to reach the goal of using this technology is confirmed. • Are potential system applications identified? • Are system components and the user interface at least partly • described? • Do preliminary analyses or experiments confirm that the application might meet the user's need?
	TRL 3	Initial development of the concepts, which include analytical and experimental proof, has started. • Are system performance metrics established? • Is system feasibility fully established? • Do experiments or modeling and simulation validate • performance predictions of system capability? • Does the technology address a need or introduce an innovation in the field of construction?

Technology readiness

Applied Research	TRL 4	Alpha prototype procedure or system has been tested in the lab within a controlled setting. Results can provide evidence to prove that the targets of the concepts are achievable. • Are end-user requirements documented? • Does a plausible draft integration plan exist, and is • component compatibility demonstrated? • Were individual components successfully tested in a laboratory setting (a fully controlled test setting where a limited number of critical functions are tested)?
	TRL 5	Prototype procedure or system has been tested in a simulated setting. Results show that the target can be achieved in a relevant setting. • Are external and internal system interfaces documented? • Are target and minimum operational requirements • developed? • Is component integration demonstrated in a laboratory setting (i.e., fully controlled setting)?

Technology readiness

Development	TRL 6	Prototype procedure or system has been piloted on multiple projects with confirmed positive effects (beta prototype system level). • Is the operational setting (i.e., user community, physical setting, and input data characteristics, as appropriate) fully known? • Was the prototype tested in a realistic and relevant • setting outside the laboratory? • Does the prototype satisfy all operational requirements when confronted with realistic problems?
	TRL 7	Concept of the prototype procedure or system has been accepted by enterprise-wide deployment (integrated pilot system level). • Are available components representative of production components? • Is the fully integrated prototype demonstrated in an operational setting (i.e., real-world conditions, including the user community)? • Are all interfaces tested individually under stressed and anomalous conditions?
	TRL 8	Actual procedure or system is qualified and completed through multiple deployments, proving the validation and positive impact of the technology (pre-commercial demonstration). • Are all system components form-, fit-, and function- compatible with each other and with the operational setting? • Is the technology proven in an operational setting (i.e., meets target performance measures)? • Was a rigorous test and evaluation process completed successfully? • Does the technology meet its stated purpose and functionality as designed?

Technology readiness

Implementation	TRL 9	Actual procedure or system proves the effectiveness of the technology through successful operations in the operating setting. Technology is ready for full commercial deployment and has become a new proven, impactful, and sustainable enterprise standard. • Is the technology deployed in its intended operational setting? • Is information about the technology disseminated to the user community? • Is the technology adopted by the user community?

Technology readiness assessment

- **RT-402** assessed the readiness of **each technology domain** through workshops.

- **Table 10** contains the average TRL scores.
- Mobile computing and tracking and tracing were scored with **ratings equivalent** to **final development stages**.
- **AI scored the lowest TRL**, capturing the industry **perception that AI applications** are **not yet ready.**
  - Such a readiness level indicates that **AI applications** are **still in development** and are **pending acceptance if not validation**.

Technology readiness assessment

Table 10. Technology Readiness (n=28)

Mobile Computing	7.96
Tracking & Tracing	7.64
Visualization	6.79
Automation & Robotics	6.18
Wearables	5.89
AR/VR	5.70
Artificial Intelligence	4.39

Technology readiness assessment

- The team contrasted the TRL ratings against the ability of technology domains to enable APC. See **Figure 18** and **Figure 19**.
- The technologies with the most promise to enable **APC are AI**, **mobile computing**, **wearables**, and **tracking and tracing**.
- While **AI's TRL** was the **lowest**, it holds the **highest promise** to enable APC.
- Such a contrast indicates the need for industry organizations and technology providers to promote R&D in **AI-driven applications**.
- In contrast, **AR/VR and visualization**, being **both visual-driven tools**, show the **lowest promise** of enabling APC.

Technology readiness assessment

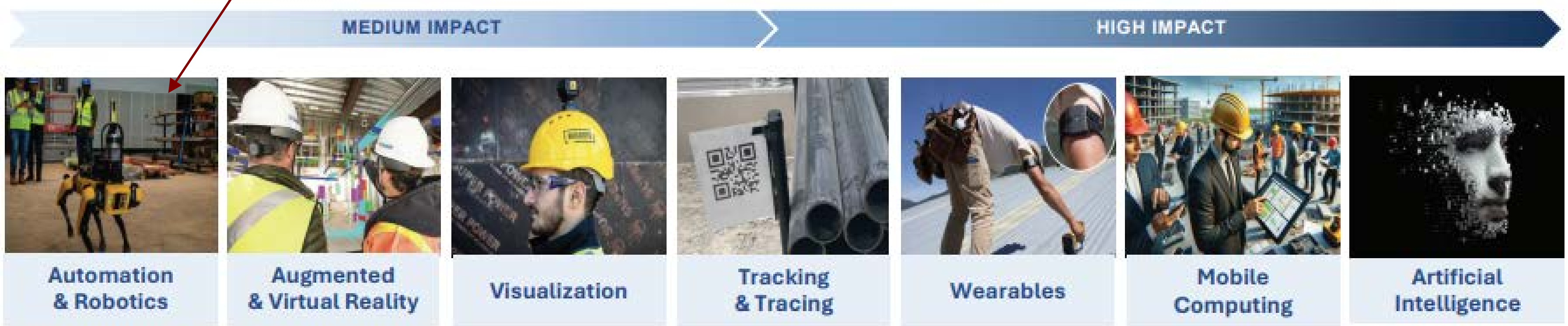

Figure 18. Technology Impact on APC

Technology readiness assessment

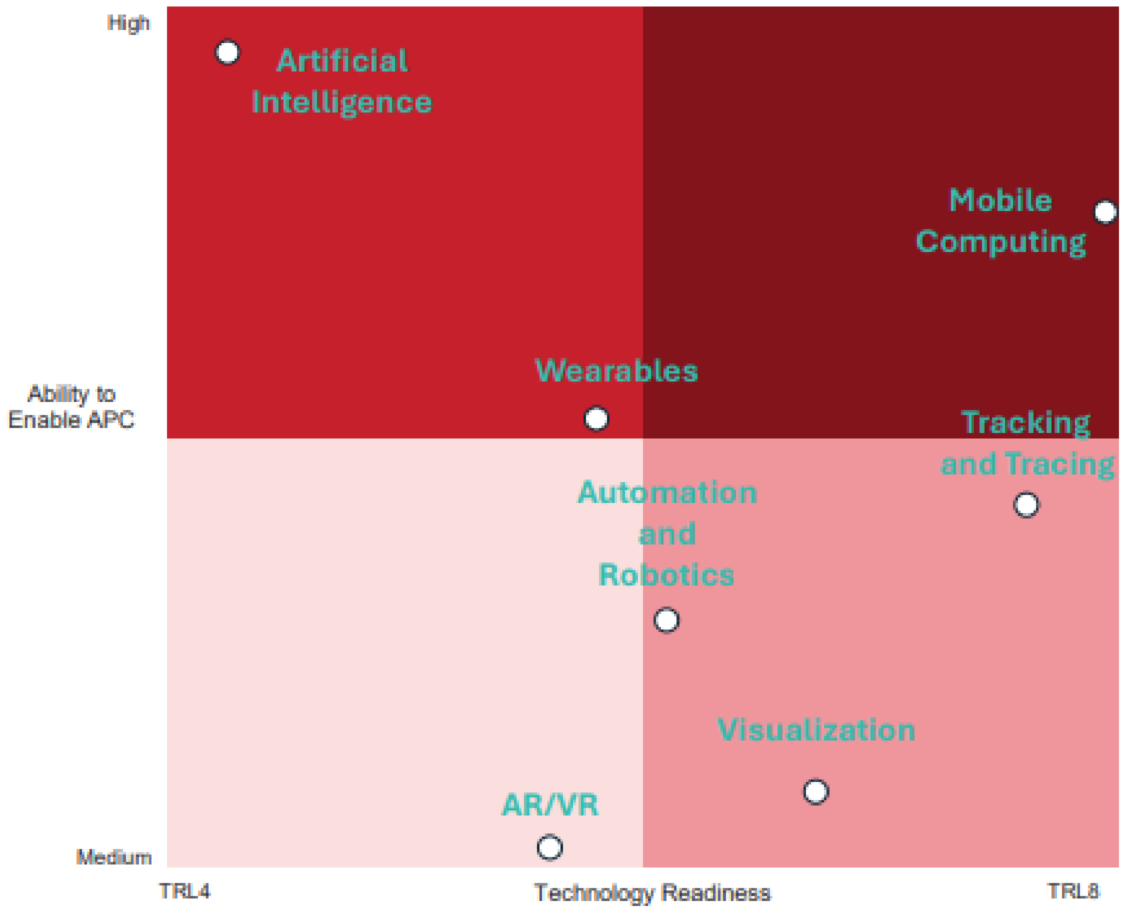

Figure 19. Technology Readiness (n=28) vs. APC Enabling Ability (n=27)

Key AI Applications for Predictive and Pattern Recognition

High-value AI applications

- During **RT-402's journey**, SMEs repeatedly expressed a **growing expectation** regarding **AI** and **its potential applications** in project controls.

- The **massive amounts of data** that projects accumulate can eventually be leveraged by **intelligent reasoning mechanisms** to learn and then inform project teams and stakeholders.

- **Large datasets**, however, are **not necessarily enough** to **enable effective AI** applications.

High-value AI applications

- **Technology service providers** expressed **concerns to RT-402** that **most** owner and contractor organizations **could not enable intelligent functions** on their **legacy datasets.**

- For an **intelligent application to learn** and thus **generate insights from historical project data**, the data must meet **key requirements**.

High-value AI applications

- Common requirements include:
  - **Volume.**
    - ✓ **Sufficient data volume** is needed to train AI models.
    - ✓ **Larger datasets** result in **better** training and more accurate insights.
    - ✓ Data quality and the context that the data represents, however, are **equally important**.

High-value AI applications

- Common requirements include:
  - **Edge-case representation.**
    - For an **intelligent reasoning mechanism** to provide insights into a given project scenario, **such a scenario** must have been included in the **training**.
    - In **construction**, infrequent events have **sometimes** proven to have a **high impact** on performance.
    - This is likely because project **teams do not expect** them or are completely unaware of the possibility of such an event.
      - An example of a high-impact/ low-frequency event is COVID-19.
    - Like humans, intelligent reasoning mechanisms cannot predict what they are not trained to recognize.
    - Thus, project teams can **only expect intelligent insights** into **situations** and **scenarios** for which data has been **previously captured**.

High-value AI applications

- Common requirements include:
  - **Current, clean, consistent, and complete data.**
    - ✓ AI insights also depend on the goodness of the data used to train algorithms.
    - ✓ **Data quality** is critical.

High-value AI applications

- Common requirements include:
  - **Current, clean, consistent, and complete data.**
    - ✓ **Current.** The data on an ongoing project must reflect its actual status to result in accurate insights.
    - ✓ **Clean.** Data must be free from inaccuracies, duplicate entries, inconsistencies, and errors.
    - ✓ **Consistent.** Data must remain uniform across projects and datasets, inclusive of but not limited to fields, frequency, and format. Consistency of data maintains referential integrity and enables data flow and transformations between records and datasets.
    - ✓ **Completeness.** This ensures all necessary data and information on projects has been captured and is available for analysis.

Statistical and AI imputation techniques exist to fill missing values whenever a large majority of data points have been captured.

High-value AI applications

- Common requirements include:
  - **Granularity.**
    - The **level of detail** in the data determines the **maximum level of detail** that can be **expected** in the results.

High-value AI applications

- Common requirements include:
  - **Metadata.**
    - ✓ Metadata informs practitioners and AI in the context of a dataset.
    - ✓ It contributes to data analysis, searchability, communication of relevant issues, informing data flow and transformations, and reusability of datasets.
    - ✓ Metadata includes data access, restrictions, schema, documentation, limitations, or sources.
    - ✓ It also includes contextual project information such as dates, locations, objectives and scope, contractual strategy, procurement strategy, stakeholder organizations, and project team capabilities.

AI and the SME Workshops

- During **RT-402's workshops** with the SMEs, a preferred topic of **inquiry was AI**.
- To provide **guidance on the latter**, brainstorming was leveraged during t**hree consecutive workshops** to explore **high-value AI applications** in project controls.

AI and the SME Workshops

- SMEs were asked to individually **brainstorm applications** and **rank them** based on their ability to control a project effectively.

- Their responses were consolidated into **46 high-value AI applications**.

- An additional workshop was leveraged to rank their value. See results in **Appendix IV.**

AI and the SME Workshops

- The **five most valuable AI applications** are:
  1. Anticipating and addressing potential risks and opportunities in labor management
  2. Providing opportunities/alternate actions to optimize schedule performance
  3. Optimizing onsite labor
  4. Integrating data
  5. Assessing and mitigating schedule discrepancies and delays

  These **high-value AI applications** were generated with the **intent** to develop **AI applications** in project controls.

Examples of High-Value AI Applications

Examples of High-Value AI Applications

- Appendix IV - High-Value AI Applications

موسسه مهندسی و مدیریت ساخت علوی پور (ACEMI)

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