

Appendix A2: Identified 2nd Level Challenges with References

Constrains:

2 nd Level Challenge	References
Cybersecurity	Nwasuka and Nwaiwu (2024), Ghasemi et al. (2024), Elahi et al. (2023), Luo et al. (2023), Manuel Parente and Marques (2020), Patalas-Maliszewska et al. (2024), Mantravadi et al. (2020), Moreira et al. (2024), Rakholia et al. (2024), Agrawal et al. (2023), Abdulghani and Winkler (2023), Dieste et al. (2022)
Data Privacy and Data Security	Culot et al. (2024), Rakholia et al. (2024), Moreira et al. (2024), Mantravadi et al. (2020), Mathieu et al. (2024), Dieste et al. (2022), Roshid et al. (2024), Xu et al. (2021a), Elahi et al. (2023)
Ethical Concerns	Moreira et al. (2024), Rakholia et al. (2024), Mathieu et al. (2024), Abdulghani and Winkler (2023), Elahi et al. (2023)
Environmental Impact	Prashar et al. (2022), Rakholia et al. (2024), Zhang et al. (2024), Panzer and Bender (2022), Dieste et al. (2022), Vivas et al. (2024), Wang et al. (2021), Abdulghani and Winkler (2023)
Legal Complicence	Rakholia et al. (2024), Panzer and Bender (2022), Yin and Li (2023)
Psychological Impact on Workers	Elahi et al. (2023), Moreira et al. (2024), Rakholia et al. (2024), Mathieu et al. (2024), Abdulghani and Winkler (2023), Patalas-Maliszewska et al. (2024), Dieste et al. (2022)
Simulation - Reality Gap	Moreira et al. (2024), Rakholia et al. (2024), Mathieu et al. (2024), Abdulghani and Winkler (2023)
Trustworthy and Reliable AI	Rakholia et al. (2024), Vivas et al. (2024), Panzer and Bender (2022), Shang et al. (2023), Fatima and Rahimi (2024), Shang et al. (2023), Ahamed et al. (2024), Wang et al. (2020)

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Data-Related

2 nd Level Challenge	References
End-to-End Digitalization and Data Availability	Culot et al. (2024), Rakholia et al. (2024), Ahamed et al. (2024), Moreira et al. (2024), Patalas-Maliszewska et al. (2024), Shakeri et al. (2023), Xu et al. (2021a), Oh et al. (2020)
Data Collection and Data Volume	Usuga Cadavid et al. (2020), Luo et al. (2023), Culot et al. (2024), Rakholia et al. (2024), Ahamed et al. (2024), Rahmani et al. (2022), Mathieu et al. (2024), Degu Workneh and Gmira (2022)
Data Exchange	Usuga Cadavid et al. (2020), Frazzon et al. (2020), Manuel Parente and Marques (2020), Qin and Lu (2021), Ahamed et al. (2024), Agrawal et al. (2023), Xu et al. (2021a), Culot et al. (2024), Mantravadi et al. (2020), Dieste et al. (2022), Patel et al. (2023)
Data Quality	Herrmann et al. (2022), Manuel Parente and Marques (2020), Chaudhary et al. (2023), Mathieu et al. (2024), Friesen et al. (2022), Fatima and Rahimi (2024), Waubert de Puiseau et al. (2022), Culot et al. (2024), Rakholia et al. (2024), Shang et al. (2023), Ahamed et al. (2024), Degu Workneh and Gmira (2022), Dieste et al. (2022), Xu et al. (2021a), Estesio et al. (2023), Wang et al. (2020)
Interoperability	Ghasemi et al. (2024), Luo et al. (2023), Qin and Lu (2021), Prashar et al. (2022), Parente et al. (2020), Agrawal et al. (2023), Qin and Lu (2021), Huang et al. (2023), Rakholia et al. (2024), Ahamed et al. (2024), Vivas et al. (2024), Degu Workneh and Gmira (2022), Roshid et al. (2024), Friesen et al. (2022)
Real-Time Data	Tang et al. (2024), Herrmann et al. (2022), Nwasuka and Nwaiwu (2024), Frazzon et al. (2020), Xu et al. (2021a), Ghasemi et al. (2024), Prashar et al. (2022), Qin and Lu (2021), Manuel Parente and Marques (2020), Ahamed et al. (2024), Vivas et al. (2024), Fatima and Rahimi (2024), Prashar et al. (2022)
Data Type Diversity	Xu et al. (2021b), Luo et al. (2023), Rakholia et al. (2024), Mathieu et al. (2024), Dieste et al. (2022)

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Entry Barriers

2 nd Level Challenge	References
Technological Infrastructure	Shang et al. (2023), Vivas et al. (2024), Degu Workneh and Gmira (2022), Panzer and Bender (2022), Culot et al. (2024), Rakholia et al. (2024), Fatima and Rahimi (2024), Estes et al. (2023), Abdulghani and Winkler (2023), Xu et al. (2021a), Ramzey et al. (2024), Manuel Parente and Marques (2020), Nwasuka and Nwaiwu (2024)
Financial Barriers	Elahi et al. (2023), Prashar et al. (2022), Culot et al. (2024), Moreira et al. (2024), Rahmani et al. (2022), Culot et al. (2024), Rakholia et al. (2024), Agrawal et al. (2023), Mathieu et al. (2024), Abdulghani and Winkler (2023), Dieste et al. (2022), Roshid et al. (2024)
Lack of Knowledge	Usuga Cadavid et al. (2020), Oh et al. (2020), Elahi et al. (2023), Nwasuka and Nwaiwu (2024), Moreira et al. (2024), Agrawal et al. (2023), Xin et al. (2021), Ghasemi et al. (2024), Herrmann et al. (2022), Degu Workneh and Gmira (2022), Dieste et al. (2022)
Skilled Workforces	Rakholia et al. (2024), Moreira et al. (2024), Xu et al. (2021a), Culot et al. (2024), Ahamed et al. (2024), Rahmani et al. (2022), Agrawal et al. (2023), Virmani and Ravindra Salve (2023), Mathieu et al. (2024), Abdulghani and Winkler (2023), Qin and Lu (2021), Dieste et al. (2022), Roshid et al. (2024), Elahi et al. (2023)
Organizational Culture & Change Management	Culot(2024), Moreira(2024), Rakholia(2024), Xu(2021), Ahamed (2024), Abdulghani (2023), Dieste (2022)
Training Times	Zhang and Zhu (2025), Degu Workneh and Gmira (2022)
Uncertain Added Value	Rahmani et al. (2022), Dieste et al. (2022), Xu et al. (2021a)
Solution Adaption to Real-World	Inayathullah and Buddala (2025), Patalas-Maliszewska et al. (2024), Rakholia et al. (2024), Zhang et al. (2024), Waubert de Puiseau et al. (2022), Panzer and Bender (2022), Vivas et al. (2024), Fatima and Rahimi (2024), Mathieu et al. (2024), Estes et al. (2023), Wang et al. (2020), Yin and Li (2023), Friesen et al. (2022), Xu et al. (2021a)

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PPC -Tasks and -Integration

2 nd Level Challenge	References
Complexity in Operational PPC	Usuga Cadavid et al. (2020), Luo et al. (2023), Ma et al. (2023), Lohmer and Lasch (2021), Frazzon et al. (2020), Zhang and Zhu (2025), Rahmani et al. (2022), Panzer and Bender (2022), Qin and Lu (2021), Shang et al. (2023), Ahamed et al. (2024), Rahmani et al. (2022), Degu Workneh and Gmira (2022), Rashidifar et al. (2022), Prashar et al. (2022), Frazzon et al. (2020), Wu et al. (2024)
Decentralized Decision Making	Parente et al. (2020), Qin and Lu (2021), Herrmann et al. (2022), Halty et al. (2020), Parente et al. (2020), Panzer and Bender (2022), Dieste et al. (2022)
Diversity of Product Varieties	Prashar et al. (2022), Manuel Parente and Marques (2020), Qin and Lu (2021), Oh et al. (2020), Ma et al. (2023), Wu et al. (2024), Inayathullah and Buddala (2025), Rahmani et al. (2022), Nguyen et al. (2022)
Integrating AI	Elahi et al. (2023), Rakholia et al. (2024), Mathieu et al. (2024), Fatima and Rahimi (2024), Xu et al. (2021a)
Updating Software Solutions	Mathieu et al. (2024), Vivas et al. (2024), Panzer and Bender (2022), Culot et al. (2024), Estes et al. (2023), Dieste et al. (2022)
Multi-Objectives Goals	Lohmer and Lasch (2021), Rashidifar et al. (2022), Halty et al. (2020), Qin and Lu (2021), Ghasemi et al. (2024), Villalonga et al. (2021), Rahmani et al. (2022), Wang et al. (2021), Vivas et al. (2024), Degu Workneh and Gmira (2022), Parente et al. (2020), Chaudhary et al. (2023)