**Appendix H**

This appendix expands the results related to the empirical countermeasures found through the Delphi Study. Specifically, in the main paper, the countermeasures are grouped in different categories and a set of guidelines to adopt the same countermeasure to cope with different challenges is proposed. However, for the sake of clarity and brevity, the comparison of the empirical countermeasures with the ones reported in the literature is presented in this appendix. The comparison further highlights the presence of a gap between literature and practice,

As depicted in Table H1, the challenges reported by scholars (from C1 to C15) are well addressed in the literature in terms of countermeasures, although practitioners highlight additional ones. On the other hand, most of the challenges identified by practitioners (from C16 to C23) are, unsurprisingly, not address.

**Table H1**: Alignment between the countermeasures proposed by practitioners and the ones proposed by literature

|  |  |  |
| --- | --- | --- |
| **Challenge** | **Countermeasures** | |
| **From Practice** | **From Literature** |
| Data Heterogeneity (C1) | C1-CO1; C1-CO2 | |
|  | * Adopt generative artificial intelligence * Adopt data augmentation techniques * Introduce physical knowledge for the prediction * Proposal of guidelines for appropriate data collection * Develop an Asset Administration Shell * Adopt graph-based approaches * Adopt multi-modal ML |
| Data Scarcity (C2) | C2-CO1; C2-CO2; C2-CO3; C2-CO4 | |
|  | * Prefer semi-supervised or unsupervised learning * Adopt oversampling techniques to reduce the impact of imbalanced datasets * Adopt generative artificial intelligence * Adopt data augmentation techniques * Adopt domain adaptation and domain alignment techniques * Adopt one-shot learning * Adopt visual interactive labelling * Adopt zero-shot learning * Adopt Reinforcement Learning * Adopt multi-instance representation paradigm * Adopt multilabel paradigm |
| Data Storage (C3) | C3-CO1; C3-CO2; C3-CO3 | |
| Training Complexity (C4) | C4-CO1; C4-CO2; C4-CO3 | |
| Machine Learning Model Selection (C5) | C5-CO1; C5-CO3 |  |
| C5-CO2 | |
|  | * Definition of guidelines to select the best model |
| Computational Complexity (C6) | C6-CO3 |  |
| C6-CO1; C6-CO2; C6-CO4 | |
|  | * Adopt parallel computing * Adopt edge computing or fog computing (extension of cloud computing) * Adopt distributed or decentralized ML * Adopt compression methods (e.g., parameter compression, pruning, distillation) |
| Feature Selection (C7) | C7-CO1 | |
|  | * Adopt DL that performs feature selection on its own * Proposal of guidelines to identify appropriate feature selection methods * Adopt feature/data fusion methods |
| Data Privacy (C8) | C8-CO1 | |
|  | * Adopt distributed security mechanism * Adopt Federated Learning * Adopt blockchain principles * Adopt efficient random distribution scheme * Adopt ML to detect potential attacks |
| Infrastructure Selection (C9) | C9-CO1 |  |
| High Infrastructure Cost (C10) | C10-CO1; C10-CO2 |  |
| C10-CO3 | |
| Low Quality/Noisy Data (C11) | C11-CO1 | |
|  | * Introduce domain expertise |
| One Model for One Machine (C12) | C12-CO2 |  |
| C12-CO1 | |
|  | * Adopt “learning without forgetting” (integration of transfer learning, multitask learning, and continual learning) |
| Machine Learning Model Interpretability (C13) | C13-CO3 |  |
| C13-CO1; C13-CO2 | |
|  | * Adopt explainable artificial intelligence * Adopt physic-induced (or physic-informed) ML and introduce prior knowledge * Adopt feature visualization * Adopt coarse localization maps |
| Machine Learning Result Interpretability (C14) | C14-CO4 |  |
| C14-CO1; C14-CO2; C14-CO3 | |
|  | * Adopt explainable artificial intelligence |
| Sensor Selection (C15) | C15-CO1; C15-CO2 |  |
| Specialized Workforce (C16) | C16-CO1; C16-CO2 |  |
| Workforce Resistance (C17) | C17-CO1; C17-CO2; C17-CO3 |  |
| Managerial Support (C18) | C18-CO1 |  |
| Machine Update (C19) | C19-CO1; C19-CO2 |  |
| Trust in Machine Learning (C20) | C20-CO1; C20-CO2 |  |
| Dynamic Market (C21) | C21-CO1; C21-CO2 |  |
| Certification (C22) | C22-CO1; C22-CO2 |  |
| Workforce Training (C23) | C23-CO1; C23-CO2 |  |
| Accuracy Issue (C24) | C24-CO1 | |
|  | * Combine different algorithms (ensemble methods) |