An ontology for integrated digital EA maturity and performance modelling

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Abstract. Digitalisation is gaining considerable attention from enterprises aiming to improve their maturity and performance using digital enterprise architecture (EA). However, the challenge is how to assess and enhance often disconnected but related digital EA maturity and performance outcome elements. To address this research challenge, this paper proposes an integrated digital enterprise architecture maturity and performance (DEAMP) ontology. This ontology aims to assist organisations in understanding and assessing their digital maturity (DM) level and associated performance outcomes. This is important to understand whether there is a positive change in the performance level (effect) through improving a DM level (cause). A design science research (DSR) method, along with a skeletal enterprise modelling approach, have been used to develop and evaluate the proposed DEAMP ontology. Further, this ontology is represented as a knowledge graph (KG), which can be tailored and used by researchers and practitioners to capture and process DM and performance data for better outcomes as appropriate to their enterprise context and scope.

Keywords: Digital Maturity, Digitalisation, Performance, Ontology, Knowledge Graph. Enterprise Architecture

1 Introduction

Digital technology opportunities and threats led many organisations to go through a digital transformation journey to achieve their profitability, growth or competitiveness goals. Digitalisation or digital transformation is a process of change that involves leveraging emerging digital technology [1] by individuals and enterprises [2], ecosystems, and industries [3]. Digitalisation-related changes may impact or improve performance outcomes [4]. Also, digitalisation maturity levels could be associated with strategic performance gain [5]. However, organisations often encounter challenging situations in understanding and measuring the impact of digitalisation [4] maturity on organisation performance [6].

This paper is a part of the ongoing research investigating the integration of digital maturity (DM) and performance outcomes. This ongoing research builds on our earlier systematic reviews, which indicated the need and provided motivation and foundation for integrating often two disjoin but related digital and performance elements [6, 7].

This earlier work also draws our attention to the need for the theoretical and practical holistic understanding of the integration of DM and performance elements for informed decision making to uplift digitalisation for performance outcomes. As a result, this research aims to integrate the level of DM and related performance outcomes for well-informed decision-making from the holistic enterprise architecture (EA) perspective. The EA lens provides a layered approach to integrate the DM and performance elements [8]. Also, adopting the EA approach may help understanding the maturity of the digital enterprise design components (e.g. people, process, capability), their relationships to each other and performance outcomes [9, 10].

In this paper, we propose an integrated DM and performance ontology, which is represented as a knowledge graph (KG) to link and model the DM levels and performance outcomes. As ontology defines explicit knowledge understanding for better communication and analysis, a KG is knowledge representation of entities, relationships and their instances to capture data and generate insights related to digital maturity and performance [11]. This will help decision-makers who are interested to understand integrated DM and performance outcomes. In summary, KG can be used by the modelling platform developers to support the capturing and processing of the integrated digital EA maturity and performance elements and data. The integration of DM to performance outcomes is important to identify the maturity and related performance gaps, which will then be used to create actions and a roadmap to address those gaps.

The structure of this paper is as follows. Firstly, it discusses the research background and related work. Then, it describes the research method and the development of the digital enterprise architecture maturity and performance (DEAMP) ontology. Finally, before the discussion and conclusion, it discusses the evaluation of the DEAMP ontology's practical relevance and applicability using a KG example.

2 Research background and related work

2.1 Digital Maturity

There are several definitions of DM, and no universally accepted single definition [12]. Here, this paper focuses on the change in maturity levels. The maturity term generally represents an anticipated reality or change to achieve desirable outcomes [13]. Digital maturity, on the other hand, is closely associated with the degree of digital transformation, which could be associated with better organisational performance [12]. DM can mirror the outcomes of digital transformation efforts from technological and managerial aspects [14]. It can be used to evaluate the current and target levels of digitalisation or maturity with a view to navigate the gaps and intended investment decision-making [15]. Achieving a higher level of maturity needs to be aligned with an organisation's strategic goals and key performance indicators (KPIs) [12]. Commonly, maturity models are multilevel frameworks that define different organisational capabilities and development levels [16].

2.2 Organisational performance

Organisational performance represents the outcomes of effectively achieving the organisational goals and objectives [17]. Those outcomes could cover financial and non-financial outcomes [18]. Hence, there are different methods to model organisational performance outcomes, such as the balanced scorecard (BSC) [19] and strategic measurement analysis and reporting technique (SMART) [20]. On the one hand, the BSC measures customer, internal, innovation/learning and financial performance in a chain of cause-and-effect, leaving the performance measurements to be derived from the organisation's strategy [19]. On the other hand, SMART is an operational performance-oriented framework that consists of four levels. It is a pyramid of objectives and measures that integrate strategy with operational performance-focused measurements. In this paper, along with EA, we used the results and determinants framework [21] as a theoretical lens to study and model performance indicators (PIs) [6]. This framework has two main types of performance elements: results (lagging factors as financial, competitiveness performance measurement dimensions) and determinants (leading factors as resource utilisation, innovation, flexibility, and quality performance measurement dimensions). Each performance dimension has its related types of measures. For instance, financial performance targets the profitability, liquidity and market ratios. Thus, the results and determinants framework has been selected because it provides technology-independent six generic dimensions or classes for performance measurement: Competitiveness, Financial, Quality of Service, Flexibility, Resource Utilisation and Innovation. Also, it provides insight into what each performance dimension can measure.

2.3 Enterprise Architecture

EA provides a holistic view of an organisation's architecture design and implementation plan [9, 10] to improve performance outcomes [22–24]. There are several EA frameworks. For example, Zachman's [25] framework provides a generic ontology. In contrast, The Open Group Architecture Framework (TOGAF) [26] provides a generic architecture development method. However, Zachman and TOGAF initiated in a traditional architecture methods and ontologies context. Thus, this study uses the adaptive EA [27] meta-framework, which originated in the digitalisation context and digital ecosystem, and can be used to design situation-specific EA frameworks and capabilities [27]. The adaptive EA has been used because it provides broader coverage and additional layers such as interaction, facility and environment layers when compared to existing frameworks (e.g. TOGAF, Zachman). Also, it consists of explicit performance outcome-driven adaptive EA design layers [28] that can be integrated to attain strategic goals and objectives in the context of digital enterprise [29]. Adaptive EA was used because it provides a systematic layered approach and elements for designing and evolving digitally-enabled enterprises. Also, EA driven approach has been used because it provides a holistic illustration of the organisation's architecture design, underpinning components and their digital transformation roadmap and implementation planning [9, 10].

Adaptive EA [27] offers guidance on six architecture layers: Interaction, Human, Technology, Environment, Facility, and Security layers. Each layer has its underpinning concrete elements as follows: (1) the interaction layer includes the actors and their interactions via different digital touchpoints, channels, and overall journey experience, (2) the human layer covers the business, information, social and professional architecture domains, (3) the technology layer covers infrastructure, application, data and platform architecture domains, (4) the security layer deals with the security concern of every other element or factor across other layers, (5) environmental layer includes PESTEL (Political, Economic, Social, Technological, Environmental and Legal) elements and (6) the facility layer covers heating, ventilation, air conditioning (HVAC), spatial, energy and ancillary elements. Besides these six EA layers, adaptive EA achieves its adaptability through 3 main activities to identify and analyse changes and then deciding the appropriate response to those changes for adaptations across EA layers and elements. Fig. 1 illustrates the integration of performance and DM from the Adaptive EA perspective.

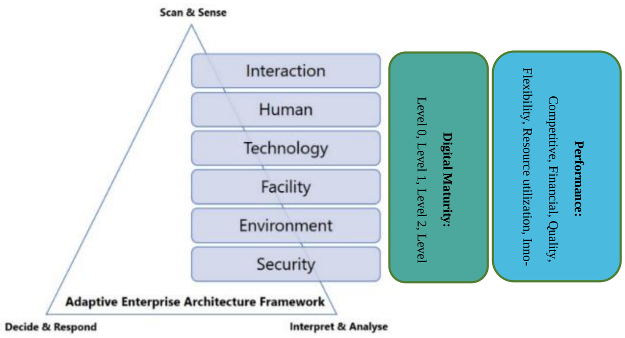

Fig. 1. Adaptive EA layers [8, 27, 30] integrated with 6 levels of DM [7] and Results and Determinants performance dimensions [21]

2.4 Integrating DM and performance from EA perspective

Organisations undergoing digital transformation or digitalisation are required to frame their digitalisation vision to capture the digitalisation need, strategy and future outcomes [31]. Consequently, this may require unpacking the influence of digitalisation on organisational architecture aspects and their performance [32]. The interdependence of digitalisation, strategies and other organisational elements indicates that digitalisation may not clearly specify the complex mechanisms of organisational performance impact [32]. This indicates an important knowledge gap or disconnect among digitalisation maturity, organisational performance, strategies and other organisational aspects. It has been reported that assessing maturity and linking it to organisational performance is an important consideration [33]. This is because a higher level of maturity may link to higher performance outcomes [13]. Also, on another note, adopting the EA approach may help in understanding the organisation's design components, their relationships to each other and performance factors [34]. Thus, we propose to investigate and link maturity level and organisation performance outcomes using EA perspective. This will help to address a lack of linking and understanding between DM level and organisation performance outcomes.

To unpack and analyse the impact of DM levels on performance outcomes from EA perspective, we used an adaptive EA [27] framework. It offers relevant layers for conceptualising the digital enterprise, which is appropriate to the scope of this study. Also, it originated in the context of digitalisation and the digital ecosystem. Since the adaptive EA does not offer detailed performance outcomes indicators, we adopted the results and determinants framework [21] to cover organisational performance and map it to the adaptive EA layers (Fig. 1). On the other hand, DM levels were adopted from our previous study as it was conducted from EA perspective [7]. Other frameworks or theories might also be used to form similar studies; however, this study is limited to two relevant frameworks (1) adaptive EA and (2) results and determinants. Future studies might use other appropriate frameworks, theories, and perspectives relevant to their study context and scope.

2.5 Ontology and knowledge graph

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Ontology is "an explicit specification of a conceptualisation" [35]. This conceptualisation can include the definition of a set of concepts, their meanings and relationships [36], as they are the fundamental constructs of conceptual modelling [37]. Generally, ontology provides a consensual understanding of a field for better knowledge communication [38]. Thus, in this paper, we proposed a DEAMP ontology to conceptualise DM and performance elements for explicit knowledge understanding and their integration. It is anticipated that this will lead to effective communication when assessing and improving DM for desired performance outcomes [36]. DEAMP ontology can be represented using several approaches, such as the KG used in the paper, because of its flexible nature in representing real-world entities and their relationships [39]. KG congregates and models real-world knowledge in a network of entities (nodes) and relationships (edges) connecting different entities [11]. As such, ontology displayed in a graph can be considered as a KG if it is populated with instances. Thus, we used the KG because it is useful to represent the connected elements and their instances, such as the integrated performance and maturity elements [39]. In summary, the use of the KG-based approach is deemed appropriate to model the integrated DM and performance ontology elements and their relationships. This also complements the current efforts around KG for conceptual modelling [40, 41].

3 Research Method

This research is conducted using the design science research (DSR) method [42], which is helpful to design, build and evaluate the proposed ontology as an artefact. DSR is used because it enables the development and evaluation of novel artefacts for a purpose [43, 44]. On another note, DSR can provide a systematic foundation to tackle complex organisational design-related problems [45]. To develop the DEAMP ontology, we followed a skeletal enterprise modelling approach [36]. This approach is found to be suitable for integrating two different but relevant concepts of DM and performance. While other approaches such enterprise ontology can address building EA ontology [36], however, here the focus is on integrating DM and performance elements across EA layers.

The applied DSR includes five steps (Fig. 2). Firstly, we identified the research problem based on the research background and related work. Secondly, we applied creative and analytical thinking to produce an initial tentative design of the DEAMP. Detailed research was conducted to develop the DEAMP design. In the evaluation step, the DEAMP was evaluated. The development and evaluation are iteratively performed to evaluate and evolve the DEAMP. Finally, the outputs and knowledge contributions are identified and reported in the last step to conclude the research.

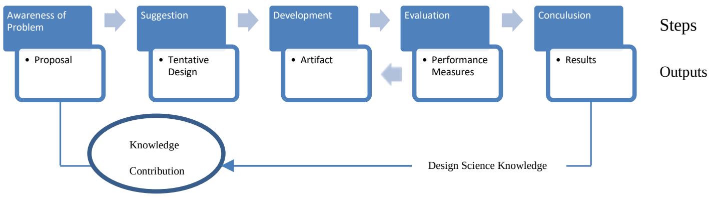

Fig. 2. DSR approach

As indicated earlier, in DSR, this research uses skeletal enterprise modelling method [36] to construct the DEAMP. It consists of four steps: purpose, scope, build and evaluate/revise [36]. The first and second steps include reasons to build the ontology and set of structured concepts to satisfy identified requirements. The third step requires producing, arranging and structuring concepts' definitions to build the ontology. The fourth step is to evaluate the developed ontology using pre-defined criteria. In summary, a DEAMP ontology is iteratively developed by applying an enterprise modelling approach [46]. We organised this ontology development into four iterations. In the first iteration, we reviewed existing studies on DM models and performance outcomes related to digitalisation to identify the key concepts and their relationships. We detailed those concepts in the second and third iterations and modelled them using the graph modelling approach to build the ontology. Then, we evaluated the ontology using an example scenario (fourth iteration).

4 DEAMP Ontology

This section focuses on the first three iterations that include the purpose of the ontology, key concepts, and the DEAMP graph. In the first iteration, we reviewed the existing literature about DM models and digitalisation performance outcomes separately, as reported in earlier published studies [6, 7]. We synthesised 30 different DM models using a theoretical lens (adaptive EA) [27]. Also, we synthesised digitalisation performance outcomes using two theoretical lenses (adaptive EA [27], results and determinants framework [21]). Subsequently, we integrated the main concepts and relationships extracted from our previous studies [6, 7] to develop the DEAMP. The EA design-driven DEAMP can be used to assess DM and performance outcomes across adaptive EA layers and their underpinning elements (fig. 3).

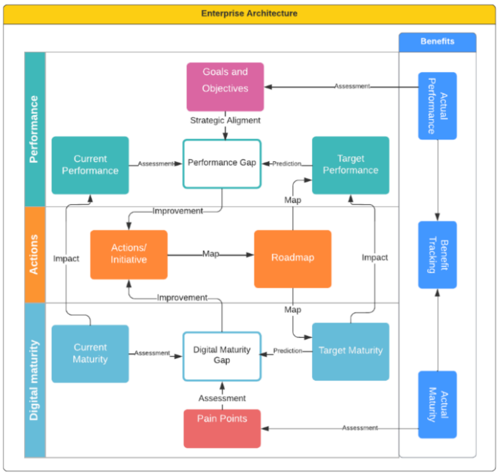

Fig. 3. DEAMP conceptual framework

The DEAMP is organised into four areas: performance, digital maturity, actions and benefits. Performance assessment can be done to define the performance gaps in alignment with the organisation's goals and objectives. Similarly, a DM assessment can be conducted to determine the DM gaps based on the underpinning pain points across the EA design. As the current and target DM impact current and target performance, these assessments can then lead to initiate actions to fill the integrated performance and maturity gaps to uplift DM for performance gain. These actions can be included in a roadmap to map to target DM and performance, which is a sequence of actions, timeline, their dependency and priority. Finally, benefits monitor the actual DM and performance outcomes resulting from implementing the actions roadmap (post actions roadmap's implementation). It tracks the resolved pain points and realised goals and objectives according to the desired target maturity and performance levels.

In the second iteration, we adopted a graph-based modelling approach [46] to represent the DEAMP concepts, properties and their relationships. This will serve as an ontology for the EA-driven DM and performance assessment. The graph-based approach provides knowledge as labelled nodes that represent entities (concepts), and labelled arrows as the relationship between nodes. We used Neo4j graph database to implement the DEAMP graph as a first step to demonstrate the applicability of the proposed work. We used Neo4j because it is a scalable and robust open-source native graph database

[47]. Neo4j stores data as nodes and edges that represent entities and relationships. Both nodes and edges can have properties in the form of key and value pairs.

Here, we first focus on the taxonomy aspect of the graph model to highlight the structure of EA-driven DEAMP. The initial graph-based model shows that architecture has an architecture domain and relevant elements. Then, the architecture element is associated with a set of PI (performance indicator) gap, DM gap, objective, action, pain point and benefit. (see fig. 4)

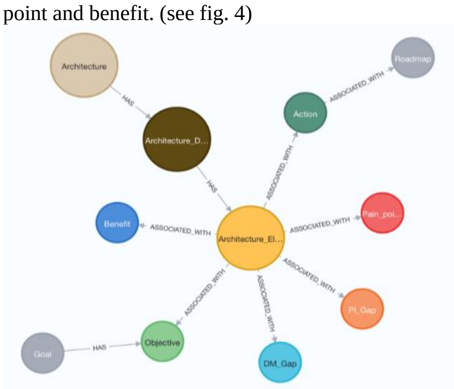

Fig. 4. Initial DEAMP graph-based model

In the third iteration, a full graph was produced (fig. 5) with concepts and their definitions (Table 1). This captures the ontology aspect of the DEAMP. Additional concepts were added to capture the meanings of the key concepts as classes and attributes. For example, to detect the gap in performance, PI gap uses a set of current and target performance (CPI, TPI), and the same logic goes for DM, current and target (CDM, TDM). The CPI and TPI reflect the impact of CDM and TDM. Also, an action considers PI gap, DM gap, goal and pain point of a specific element and is associated with a roadmap. Moreover, five concepts have a set of dimensions that could be detailed to get additional dimensions. The architecture domain includes business and information as the architecture elements (people, process, capability, information) and roadmap (timeline, dependency and priority). Other domains, such as technology and security, can also be considered. On the other hand, we defined six levels of DM as attributes for the DM level class. For instance, level 0 represents the absence of digitalisation or basic digitisation, whereas advanced level 5 represents innovative, data-driven and adaptable aspects. These levels are further explained in Table 1. Also, PI type includes six different dimensions such as financial, quality and resource utilisations that could be further into more detailed and specific PIs under each PI type. (See Fig. 5, Table 1) Due to the visual constraint of the class labels in Fig. 5, some element labels may not be fully visible. Please see the class label column in Table 1.

Fig. 5. Full DEAMP graph-based model

Table 1. DEAMP concepts and their definitions

Class Label	Concept	Definition	Reference
DM_Gap	DM gap	A level of DM that represents a gap in the DM	[7]
CDM	Current DM	A level of DM that represents the current level of the DM	[7]
TDM	Target DM	A level of DM that represents the target level of the DM	[7]
DM_Level	DM level	It represents the six levels of the DM	[7]
	Level 0	None - Absence of digitalisation or basic digitisation	[7]
	Level 1	Beginner - Digitally aware or ad-hoc digitalisation	[7]
	Level 2	Learner - adopting digital practices	[7]
	Level 3	Intermediate - Consistent, defined, integrated and digitally enabled	[7]
	Level 4	Advanced - Completely developed, predictable and proactive	[7]
	Level 5	Expert - Innovative, data-driven and adaptable	[7]
Class Label	Concept	Definition	Reference
PI_Gap	Performance gap	A set of PIs that represents a gap in performance outcomes	[6]

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Class Label	Concept	Definition	Reference
CPI	Current PI	A set of PIs that represents current performance outcomes	[6]
TPI	Target PI	A set of PIs that represents target performance outcomes	[6]
PIType	PI Type	Represent the six types of PI	[6]
Financial	Financial	Represent the financial PIs	[6]
Competitiveness	Competitiveness	Represent the competitiveness PIs	[6]
Resource_Utilisation	Resource Utilisation	Represent the resource utilisation PIs	[6]
Quality	Quality	Represent the quality PIs	[6]
Innovation	Innovation	Represent the innovation PIs	[6]
Flexibility	Flexibility	Represent the flexibility PIs	[6]
Architecture	Architecture	A business area in the enterprise architecture design	[27]
Architecture_Domain	Architecture domain	A domain of the enterprise architecture design within a business area (business or information of the human layer)	[27]
Architecture_Element	Architecture element	An element of the architecture domain (People, Capability, Process or Information)	[27]
Goal	Goal	A description (statement) of what the organisation wants to achieve	[48]
Objective	Objective	A scalable description of a goal	[48]
Pain_point	Pain point	A problem or solution of a problem that was unfinalised	[27, 49]
Action	Action	Initiatives defined by the organisation to improve DM level for desired performance gain.	[48]
Roadmap	Roadmap	A sequence of actions based on timeline, dependency and priority	[4, 27]
Timeline	Timeline	A period of time needed to implement an action	[27]
Dependency	Dependency	Represent the dependency between actions	[27]
Priority	Priority	The priority of an action	[27]
Benefit	Benefit	Gain or value realisation via implementing the roadmap	[50]
Actual_M	Actual Maturity	A level of DM that represents the actual DM level after or while implementing the roadmap	[7, 50]
Actual_P	Actual Performance	A set of PIs that represent the actual performance after or while implementing the roadmap	[7, 50]

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5 Indicative Evaluation

This study provides an indicative elevation of the DEAMP ontology using an example scenario (fourth iteration). For this example scenario, we created fictitious test data to create the instance of the DEAMP reflecting a real-world marketing domain example as an indicative proof of concept validation.

The scenario is about a fictitious marketing ABC company. This company initiated a digital transformation initiative to improve overall performance by assessing and improving their DM. Their focus is on assessing and improving marketing business domain. Thus, a business architecture layer from the EA is used to understand the business marketing domain capabilities. As such, the marketing business domain can contain several business capabilities, such as advertise and manage customer relationships etc. Here, as an example, we focused on the "manage customer relationships" capability and captured the current and target DM levels, goals, pain points and current and target performance indicators (PIs). Also, the related current, target PIs and gap are defined in alignment with the company's related goals and objectives. The instance of the example scenario on DEAMP is shown in table 2 and fig. 6. It can be observed that manage customer relationships capability (architecture element) indicates a gap (1 level) between the current and target DM state due to the duplicate accounts in the CRM (Customer Relationship Management) system as a pain point. On the other hand, one of the related PI to this capability is income which needs an increase of 15% based on the difference between the current and target income (linked to the company profit/ income objective). Thus, improving the performance management process by implementing a new dynamic online CRM system is the proposed action to uplift the DM to gain an increase in income (performance outcome). This action is anticipated or assumed to take 100 days with a high priority on a digital transformation roadmap. Further, post action implementation, actual DM levels and performance can be tracked to capture whether the hypothesised (target) performance and DM improvements are reached. This example can be further explored using other related goals, objectives, pain points and PIs. Yet, it has been limited to one related aspect for the purpose of demonstration. Fig. 6 shows how the example scenario and data are used to demonstrate the use of the proposed DEAMP ontology as a KG.

Table 2. DEAMP instantiation

Labelled Nodes	Instances	Instances Details
Architecture	Marketing	
Architecture Domain	Business	
Architecture Element	Cap01	Capability 01: Manage Customer Relationships
Current DM	L01	Level 01
DM Gap	1 Level	1 level difference between the current and target DM
Target DM	L02	Level 02
Labelled Nodes	**Instances**	**Instances Details**
Current PI	F01	Financial Indicator 01: Income
PI Gap	+15%	15% increase to up lift current income to target income
Target PI	F01	Financial Indicator 01: Income
Pain Point	PP01	Pain Point 01: Duplicate accounts in the CRM systems
Goal	G01	Goal 01: Improve Productivity
Objective	Obj01	Objective 01: Increase Company Profits/Income (15%)

Action		Ac01	Action 01: Implement a new dynamic online CRM system
Roadmap	Timeline	100 days	
	Depend-ency	NA	
	Priority	High	
Benefit	Actual M	-	-
	Actual P	-	-

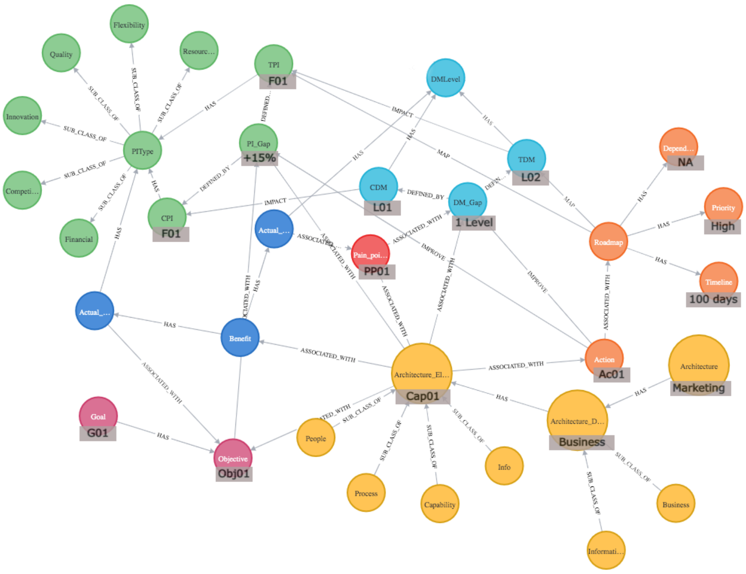

Fig. 6. The instance of DEAMP graph-based model with the example scenario

6 Discussion and Conclusion

Digitalisation is gaining considerable interest from academia and industry. However, there is a lack of understanding about the linking and impact of digitalisation maturity on organisational performance outcomes. This paper attempts to combine these two important areas into an integrated DEAMP ontology. As a result, this integrated DM and performance indicate several advantages. First, it can provide a systemic approach to link the previous isolated DM and performance concepts via an integrated ontology. Second, once they are integrated, we can then study the impact of a change in maturity on the performance outcomes and vice versa. Third, we can develop a performance outcome-driven approach to set the desired maturity level. Fourth, we can monitor and track the integrated maturity and performance outcomes. Finally, it can provide us with a lens to study the degree of maturity and its relevance to the degree of performance gain.

In conclusion, DEAMP ontology can be used for assessing and navigating DM, as well as linking it to performance results through activities and initiatives from the EA perspective. This intends to improve understanding of DM levels and their impact on performance outcomes when developing digital roadmaps and action plans. The applicability of the proposed DEAMP ontology is demonstrated with the help of an example scenario. This initial evaluation indicates the practical relevance and applicability of the proposed ontology. Future research will conduct additional experiments to evaluate and evolve the proposed DEAMP ontology.

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