Analyzing IT Flexibility to Enable Dynamic Capabilities

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Abstract. The ability to respond to change is an ongoing concern in information systems engineering. Designing flexible and adaptable information technology (IT) solutions is challenging due to difficulties in identifying and predicting adaptation needs influenced by environmental changes and enterprise competitive positioning. In this paper, we draw upon theories in strategic management, particularly conceptions of dynamic capabilities that deal with sustainable advantage, to identify and represent enterprise requirements. This research enables analysis of enterprise transformation by modeling coupling and alignment between IT and organizational capabilities using the i* framework. Potential inflexibilities and impact of changes are studied with analysis of dependency propagations. A hypothetical case using experiences from SOA and BPM implementations demonstrates use of the proposed modeling constructs.

Keywords: Capability modeling · Dynamic capability · i* · Flexibility analysis

1 Introduction

Success of information system (IS) deployment in enterprises relies on proper understanding and analysis of the requirements of the organization [1–3]. Models of business process and services and other business-level artifacts are increasingly used to model and analyze requirements during IS development. Today, as enterprises face highly dynamic environments, information systems must be able to meet requirements that are dynamic and uncertain. When making decisions regarding IT-enabled enterprise transformation and evolution, it becomes important to understand and analyze the strategic objectives behind processes and services [2, 4, 5].

To represent strategic and investment objectives, IS researchers have used the notion of capabilities as an ideal abstract layer [1, 2, 5]. Capability modeling has been used in IS to express investment profile [5], facilitate business-IT alignment [2], plan and design service oriented implementations [4, 5], identify IT capabilities requisites [5, 6] and facilitate runtime adjustment to changing context [4]. Capabilities in enterprise modeling are often associated with goals to represent strategic investment intentions [1, 2, 6]. However the mentioned IS Engineering approaches have used capabilities in the design process without considering their dynamic and evolutionary nature and do not reason on capability development, orchestration and deployment choices.

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Dynamic capability, the ability to intentionally alter capabilities and resources to transform an enterprise to a desirable state, is a source of sustainable advantage in high-turbulent environments [7]. Flexibility of capabilities relates to how manageable they are and enables dynamic capabilities by providing more choices for resource management [8, 9]. Therefore the ability to analyze capabilities characteristics and qualities has a substantial role in the success of capability modeling.

The challenge of facing dynamic and evolving requirements of enterprise software systems is twofold, (1) adaptable and reconfigurable services/systems that can adjust to changes and (2) flexible capabilities and organizational setting that can create and support them. The challenge cannot be addressed with bounded analysis of system context or variability in the technical solutions; because of the dynamic complexities and emergent behaviors that arise from interactions of different entities at the enterprise level [10]. Hence, designers should represent and analyze the socio-technical characteristics of enterprises to capture what kinds of flexibilities are needed when studying the coupling of business and technical architectures.

In this paper we posit using the notions of capability and dynamic capability from the strategic management literature [7], as the integrative concepts that can represent organizational portfolio and analyze its evolution. A modeling approach that enables representation of capabilities requisites, alternatives, complementarities and transformation states is introduced. The approach uses the Strategic Alignment Model (SAM) [11] to extend the i* framework and enable analysis of potential inflexibilities in a particular organizational setting.

2 Related Work in Analysis of Enterprise and IT Flexibility

Research on scenario based architectural tradeoffs [12], design patterns and principles [13] and change impact analysis [14] are examples of studies in IS engineering that facilitate design for changeability. Assessment of the effort required for a change and its rippling effect is a fundamental step in these approaches [12, 14]. However, analysis of flexibility at the enterprise level is different from software flexibility due to the complexities that arise from dynamic relations of entities in the organizational context [10]. Research propositions enable management of enterprise wide implementations of changes. In this section we review approaches that facilitate (1) service-oriented adjustment to changing context, (2) enterprise level modifiability analysis, and (3) quantitative approaches that measure enterprise-level qualities.

Researchers in IS that adopt the notion of capability have not considered social identities, complementarities and alternative development paths of capabilities. They have rather focused on using them to design business aligned services. For example, Zdravkovic et al. [4] propose identification of contextual information for capabilities to enable automated adjustment of services in response to changes in context variables. Therefore the services are only flexible towards a predefined context and one cannot analyze how the enterprise as a whole would react to unanticipated changes.

Modifiability of modeled enterprise solutions has been studied. De Boer et al. [14] facilitate change impact analysis in ArchiMate to trace changes triggered at the business-level. The research takes advantage of semantic relations in ArchiMate and proposes heuristic rules to identify direct and indirect impacts. The analysis is used to signal necessary adjustments to architects. The approach can analyze what-if scenarios regarding changes but cannot identify potential inflexibilities to guide the design and decision making process. In a different approach, Lagerstrom et al. [15] present a meta-model and a PRM quantitative analysis to estimate cost and effort of changes in enterprise software while considering uncertainties. However the approach is more suitable for managing and planning implementation of changes as gathering the required information for the analysis at early stages of decision making is difficult.

A number of approaches offer quantitative analysis of architectural qualities at the enterprise level. Johnson et al. [16] use and extend influence diagrams to depict and trace causality among entities in architectural models. The approach takes advantage of scenario development to represent and compare alternatives. In a slightly different method, Langermeier et al. [17] propose a meta-model and a data-flow based analysis to evaluate organization specific measures. The quantitative information required to perform such analysis is often not available at early stages of decision making. Furthermore the approaches perform analysis on a given architecture and do not capture socio-technical alternatives that influence enterprise level flexibility.

3 Towards Modeling Capabilities and Their Flexibility

Capabilities embed social and technical characteristics attained in their lifecycle which can accommodate or restrain their development choices [6, 18]. Decision makers require the ability to analyze such characteristics such as autonomy [7], complementarities [7] and flexibility [8, 18]. Particularly when designing IT capabilities, alignment to organizational capabilities and strategies plays a major role [3].

The Dynamic Capability View (DCV), first introduced by Teece [7], deals with enterprise evolution using conceptions of capabilities, positions and paths. However DCV only provides implicit guidelines for analysis and decision making. A decision maker should be able to answer questions such as (1) where are the boundaries of a capability and how does it relate to organizational actors, to understand capability identity and autonomy; (2) How does the capability relate to other capabilities, to understand complementarities; (3) what are the alternative design choices; (4) how can one identify causes of inflexibilities; (5) what are the intents behind relations among heterogeneous capabilities such as IT and organizational capabilities?

In this section we first review concepts from DCV and examine the suitability of the i* modeling framework for representing them. We then study flexibility in the context of strategic management as well software architecture, and consider how i* might be extended to represent the alignment intents of IT capabilities.

3.1 Modeling Capabilities from a Strategic Management Perspective

Capability is defined as a set of differentiated skills, complementary assets and organizational routines that provide basis for competitiveness [18]. Capabilities are intentionally developed to realize strategic goals, they are autonomous so as to facilitate decentralization, yet depend on each other to achieve synergy [7]. By modeling capabilities as specialized i* actors, one can depict intentions of capabilities using i* goals and softgoals, point to necessary skillsets and assets as i* resources and describe employed routines as i* tasks within the actor's boundary. The i* framework uses *Actors, Roles, Positions* and *Agents* to depict the social aspects of enterprises. By modeling a capability as a specialized actor, we are able to treat it as a social actor which has an ongoing identity, with responsibilities and (social) dependency relationships with organizational actors and other capabilities. This is motivated by findings in DCV that emphasize the role of collaborative learning process that agents with individual skills participate in and employ their expertise in a particular organizational setting [19]. If capabilities are represented as static properties of agents or roles, it would be difficult to model and reason about the collaborative aspects.

In IS engineering, it is common to consider transitions from an "as-is" to a "to-be" state. However according to DCV the possible paths of transition are constrained by current state of the enterprise (referred to as "position" in DCV) [7]. For example a SOA software infrastructure built on a Microsoft platform would need a software development capability with ".NET" skillsets (a capability development constraint) and a deployment team that can configure and run Windows servers (a deployment constraint). If the solution is adopted at the enterprise level it will impose constraints on the kinds of software-as-a-service solutions that the human resource department can adopt (orchestration constraint). In a previous work [6], the representation of social and technical considerations of capability development, orchestration and deployment alternatives using the i* framework has been discussed.

We use i* dependencies to capture the kinds of complementary relations among capabilities and organizational entities, i.e. capabilities complement one another by fulfilling goals, satisfying softgoals, providing resources, or performing tasks. i* diagrams that depict the overall capability configurations and relationships are called Strategic Dependency (SD) models. The Strategic Rational (SR) models express alternative means of achieving capability intentions and their contribution to quality attributes represented as softgoals while specifying required tasks and resources. Hence the future state of an organization is articulated by a series of choices regarding potential alternatives that shape a transition path from the current state.

3.2 Analyzing Inflexibilities Using Dependency and Alignment Propagation

Our approach draws on conceptions of flexibility from strategic management and IT systems architecture. We identify potential inflexibilities in terms of (1) how tightly they are coupled to other capabilities and organizational entities; (2) how and what kinds of impacts (strategic intent) to expect from a change in a capability throughout the organization. To address the first aspect, we enable analysis regarding the effect of dependencies and their propagation across the organization. Therefore one could answer questions regarding how capability couplings influences value creation and how a change would affect their complementary relations. To address the second aspect, we allow analysis of (1) which dependencies and of what kinds are influenced by a change and (2) propagation of alignment intents of IT and organizational capabilities, to understand what kinds of strategic consequences to expect from a change.

The strategic management literature identifies flexible capabilities that enable enterprise transformation as a necessity to achieve dynamism [8, 9]. Flexibility in strategic management refers to how manageable a capability is; in other words "the ability to deploy and use a capability in multiple settings and conditions without adjusting its nature" [8]. In a study of new development projects, Leonard-Barton recognized that the more enterprises invest in a core capability, the higher the probability of causing rigidities towards new and innovative evolutionary alternatives [18].

In IS engineering, flexibility refers to how easy it is to change a system. Studies identify architectural design principles to enable flexibility such as simplicity, coupling, modularity, interoperability and compatibility, autonomy, scalability and redundancy [13]. Quantifications of flexibility are proposed in software architecture research [12, 20]. Bekkers [21], studies flexibility in e-government and identifies the technical aspect that deals with linkages among variety of systems and networks and the social aspect which deals with participants autonomy and strategic interest.

In order to capture the strategic intent of effective coupling between IT capabilities on one hand and organizational capabilities on the other, we assign an "alignment intent" to each of these dependencies in i* model. By analyzing how these alignment intents propagate across the network of dependencies, we are able to determine the impact of change on the achievement of strategic objectives.

To classify alignment intents, we adopt the well-known Strategic Alignment Model (SAM) by Henderson and Venkatraman [11]. Although the original model was conceived for alignment at the enterprise level, subsequent research has applied it at a finer-grained level, e.g., at the level of alignment between projects [22]. We apply SAM at the level of alignment between capabilities. SAM distinguishes four "perspectives" in strategic alignment depending on the domain in which the alignment is triggered and the path it follows. (1) The ***Strategy Execution*** perspective is triggered by business strategy, influencing organizational infrastructure, and then IT infrastructure. (2) In the ***Technology Transformation*** perspective the objective is set by business strategy, but then IT strategy articulates the requirements, with IT infrastructure implementing the strategy. (3) The ***Competitive Potential*** perspective indicates the ability of IT capabilities to influence enterprise competitiveness. The objective is set by IT strategy, articulated by business strategy, and then adopted by organizational infrastructure. (4) The ***Service*** L***evel*** alignment perspective deals with IT services directly generating value, hence dominating the strategy making process. The objectives are set by IT strategy, appear in IT infrastructure, and then implemented by organizational infrastructure. The mnemonic symbols in Fig. 5 signify the path across the familiar two-by-two grid of the SAM model for each of the four perspectives.

4 Applying Capability Modeling to an SOA Implementation

In this section a hypothetical case of SOA implementation in an educational institute is presented. The models presented in this section give a visual representation of the current state of capabilities and will answer questions such as (1) what are the capabilities? (2) What are their intents and associated routines and resources? (3) How do they collaborate to generate value? In Sect. 5, we build on these models to answer (4) whether the current state of IT capabilities can address changing requirements? (5) What inflexibilities can appear in the future state? Current state of enterprise IT capabilities and immediate organizational capabilities are presented in Fig. 1.

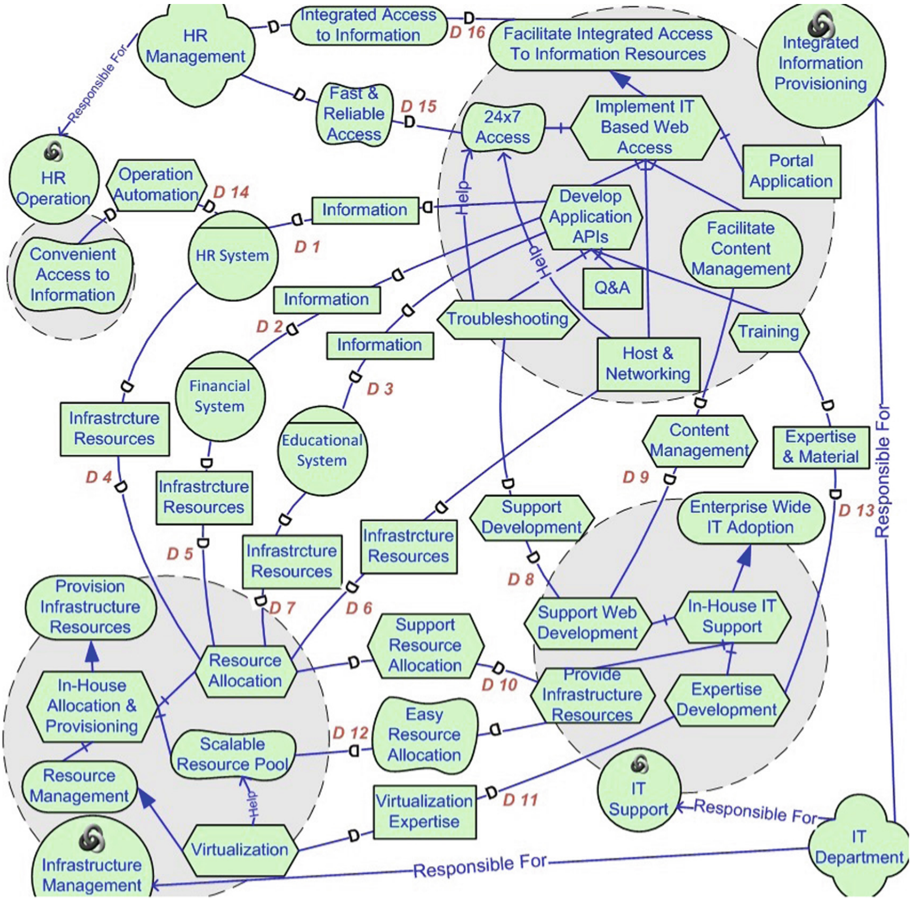

Fig. 1. IT capabilities of the organization - current state (legend same as in Fig. 3)

First the context of the organization and its i* representation is discussed. The enterprise relies on three major IS for its day-to-day operation, *Human Resource (HR) management System*, *Educational System* and *Financial System* represented as i* agents in Fig. 1. These systems are developed and maintained by partner organizations and hosted in-house, hence dependent on the capability of *Infrastructure Management*. The *Infrastructure Management* consists of people, processes, and resources (hard goods and operational budget) within the organization and therefore modeled as a capability. It intends to enable server administration and resource allocation. The *IT* *support* capability intends to facilitate *Enterprise Wide IT Adoption* which is currently achieved by in-house staff and processes. Doing this in-house is only one deployment option among others, as indicated by the use of the i* means-ends relationship. The *Integrated Information Provisioning (IIP)* capability (at the top right corner of Fig. 1) enables personalized access to information. The *IT department* is responsible for decision making regarding mentioned IT capabilities.

We focus our attention on the dependencies that *HR System* has on *HR Operation* and *HR Management*. Similar dependencies exist among *Educational* and *Financial systems* to their corresponding entities but are not shown in Fig. 1 for brevity. Likewise the details of the *HR Operation* capability are not presented as it is not the subject of analysis and decision making. However if the capability models are used for strategic planning one would expect expression of the big picture [5].

In the second step, a dependency propagation graph is introduced in Fig. 2 to allow change impact analysis and determine capabilities role in value creation. The principle used in constructing the graph is based on impact analysis approaches in software architecture [20]. The identifiers in the circles of Fig. 2 correspond to dependency labels of Fig. 1 and the links represent causalities among dependencies. For example, *Virtualization Expertise (D11)* is needed to perform *Virtualization* (in *Infrastructure Management capability)* that enables *Scalable Resource Pool* which in turn will provide *Easy Resource Allocation (D12).* The link between the two dependencies entails the propagation effect of a change from "*D11*" to "*D12*" as shown in the cloud.

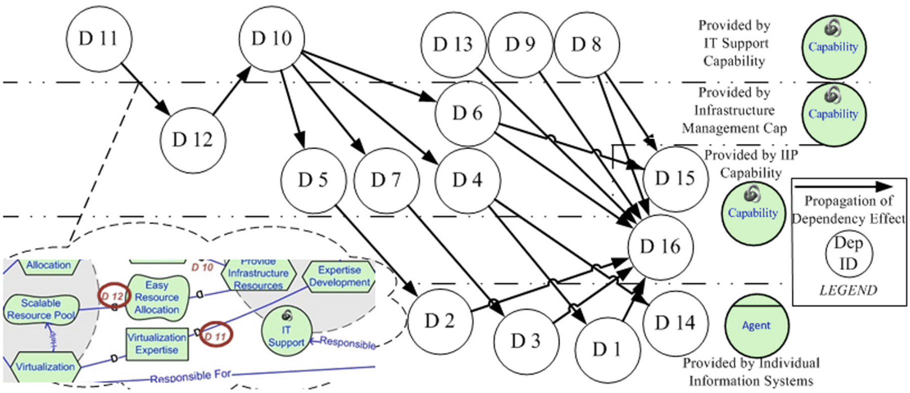

Fig. 2. Dependency propagation graph – showing propagation effect of capabilities dependencies – the closer to the right, the more direct contribution to value creation

Analyzing and tracing the capabilities role in value creation has significant influence in decision making [7]. The requirement is amplified when facing capabilities that are not directly associated with revenue generation such as most IT capabilities [3]. To track capabilities offerings, the nodes in Fig. 2 are presented in vertical segmentations that represent IT capabilities of Fig. 1. For example, "*D15*" and "*D16*" in the third row are provided by the *IIP* capability. The first, second and the fourth row respectively present dependencies provided by *IT Support* capability, *Infrastructure Management* capability, and information systems such as *HR System*.

5 Analyzing Inflexibilities Arising from an SOA Implementation

In this section we first analyze whether the current state of IT capabilities can address changing requirements to enable Business Process Management (BPM) and Business Intelligence (BI). We then study how the expansion of the *Integrated Information Provisioning (IIP)* capability can cause inflexibilities; and point to design requirements for the evolution with the intent to preserve flexibility. Our study, particularly points out requirements for (1) virtualization expertise development and training to overcome potential inflexibilities of the *Infrastructure Management* capability and (2) careful engineering of the *IIP* capability to balance competing requirements of application autonomy and flexible resource orchestration.

In Fig. 3, change requirements for *BPM*, *BI* and *Enterprise Management* capabilities are presented. The *BI* capability relies on *IIP* to facilitate *Access to Business Aligned Data Objects.* The *BPM* capability depends on *IIP* to facilitate *Application Autonomy* while providing *Flexible Access to Information*.

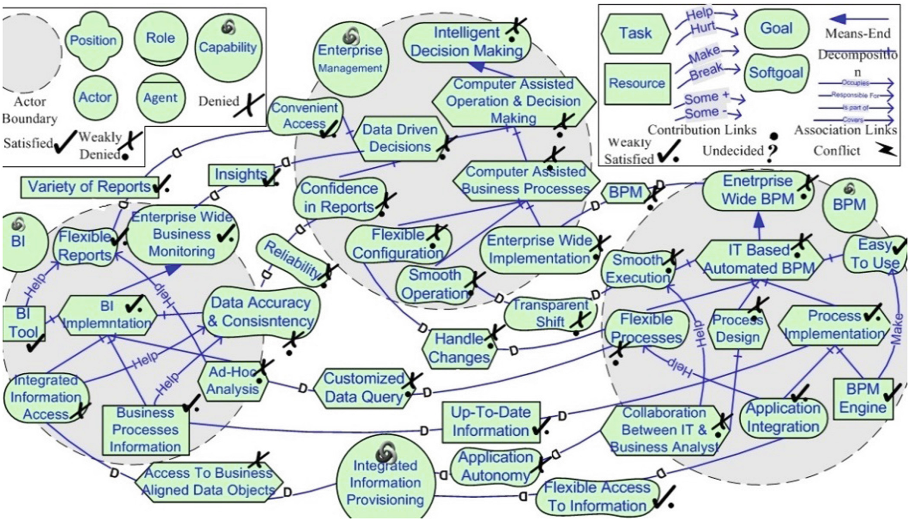

Fig. 3. Change requirement – evaluating orchestration with the current state

A qualitative reasoning approach [23] is adopted to enable analysis of whether *IIP* can satisfy *BPM* and *BI* requirements or not. The current status of the *IIP* capability presented in Fig. 1, i.e. its *Portal Application* and *Content Management* processes, cannot produce *Business Aligned Data Objects.* Furthermore the required *Flexibility* in accessing information and making changes to applications are weakly satisfied.

Therefore the analysis motivates expansion of *IIP* with Service Oriented Architecture (SOA) solutions. In Fig. 4 the future state is presented with the proposed expansion. The decomposition of *IIP* to *Content Management* and *SOA* infrastructure is not shown for brevity. SOA is modeled as a capability because it is more than a software solution and introduces a new architectural paradigm [24]. Introduction of the SOA capability will impact the orchestration of *BI* and *BPM* capabilities.

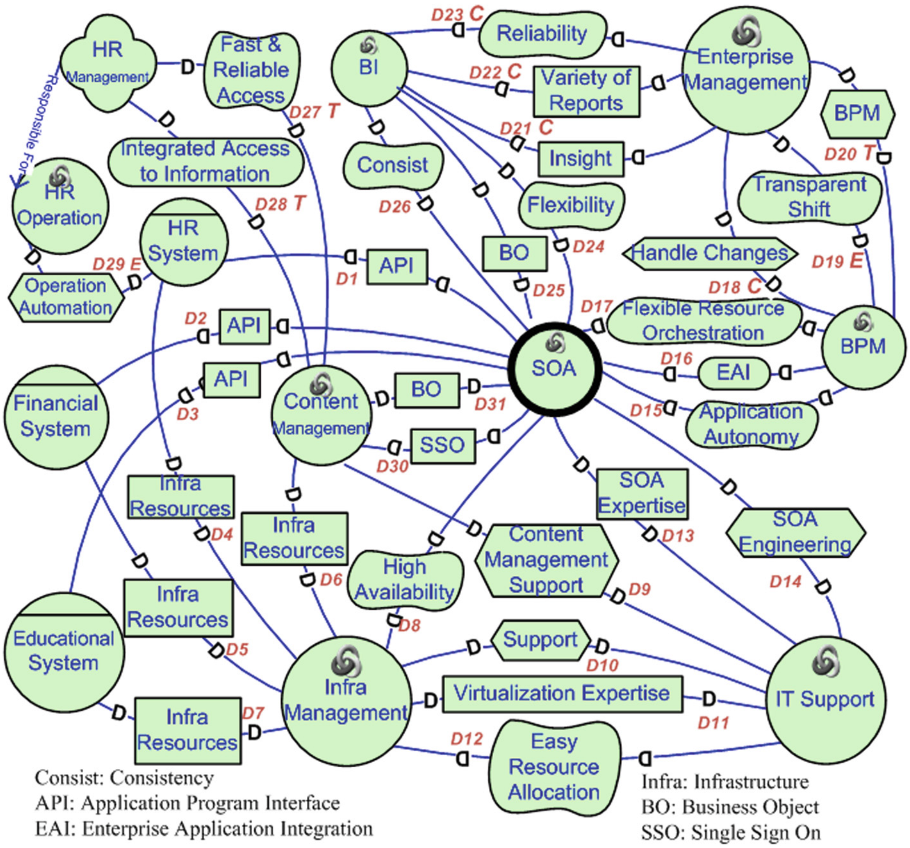

Fig. 4. i* SD model of IT capabilities – future state (legend same as in Fig. 3)

The letters "E", "T" and "C" are assigned to dependencies among IT and organizational capabilities to indicate alignment intent. The letters represent alignment perspectives of SAM [11] as discussed in Sect. 3.2. The *HR Operation Automation* dependency (*D29*) between *HR Operation* and *HR system* is an example of an executive alignment intent presented with an "E" in Fig. 4. Similar to Avison et al. [22], the alignment intent is determined based on the domain that triggers alignment and the path it follows through as described by SAM. For example, "*D27"* and *"D28"* are assigned with a "T" representing technology transformation alignment as the IT department (IT Infrastructure domain) implements systems to provide real-time access to information

(IT strategy domain). However the IT strategy itself is derived by business requirement of *HR Management* (business strategy domain). In contrast "*D18"* and *"D21"* make fundamental changes to the decision making process; thereby indicating a competitive potential alignment and represented with a "C".

The dependency propagation graph in Fig. 5 corresponds to the state presented in the i* SD model of Fig. 4. The number on the bottom of the circles is calculated by counting the propagation effect of the dependencies, meaning the rank for "*D11*" equals to the sum of the ranks of dependees (in this case 10 + 10) plus the number of dependees (in this case 2). This enables ranking the elements by their potential impact. The colors and mnemonic symbols that signify the path across the two-by-two grid of SAM depict alignment intents and their propagation. For example the *Virtualization Expertise (D11)* provided by *IT Support* to *Infrastructure Management* provides executive, transformational and competitive contributions through different routes. The high influential ranking of *Virtualization Expertise (D11)* can cause inflexibilities when scaling IT capabilities without careful planning. In this example, if the necessary training and engineering effort on virtual servers hosting information systems is not provided in advance, adding the *SOA Solution* to the mix can cause resource deficits for support and maintenance. The propagation graph not only points to causes of such inflexibilities but also depicts the kinds of consequences to expect using alignment intents.

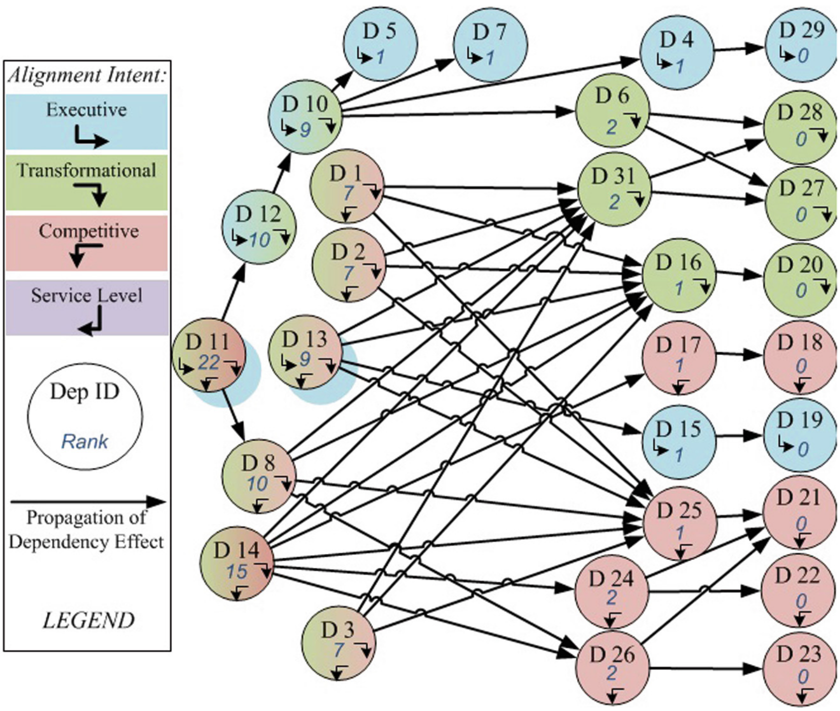

Fig. 5. Dependency propagation graph showing propagation of alignment Intent – potential for causing inflexibilities increase when moving from the right to the left

The *SOA* capability which enables *Flexibility in Resources Orchestration* (*D17*) and provides *Business Objects* (*D24* and *D25*), can raise inflexibilities due to its highly engineered design (*D14*). The commitment to *SOA Engineering* (*D14*) requires heavy investments and limits future choices of the enterprise. The propagation graph facilitates identification of such sensitive elements so the enterprise can mitigate the risk by monitoring and planning before they become rigidities.

6 Discussion and Conclusion

Designing information systems that can adapt and accommodate highly dynamic environments is an ongoing challenge. In this paper, we examined the use of the i* framework to depict capability complementarities and relations to organizational entities. The i* framework was extended to facilitate modeling alignment intents of IT and organizational capabilities. Furthermore by analyzing propagation effects of dependencies, the approach facilitates analysis of value creation, potential inflexibilities and change impacts. Such analysis assists decision makers and designers to identify flexibility requirements for IT capabilities and architecture, therefore enable easier enterprise transformations.

The use of the proposed modeling constructs were demonstrated in a BPM and SOA implementation for a hypothetical case. The analysis revealed the need for careful planning when (1) scaling the institute's infrastructure management and (2) engineering SOA implementation, before deploying new IT capabilities as they both can pose rigidities. Moreover the analysis of dependencies suggest a more gradual and nuanced flow of intent among organizational and IT capabilities in contrast to the clear-cut architectural levels or domains typically adopted in enterprise architecture frameworks, such as business, application and technology. The analysis will enable design of complementary capabilities and allow planning for changes with different intents and consequences whether business or technical.

The analysis in this paper was limited to IT capabilities of the organization. Further investigation and validation of the findings with real case studies and complete capability portfolios is required. Tool support for reading and interpreting the dependency propagation graph is essential as the models grow in size. The use of the dependency propagation graph accompanied with quantification methodologies can enable economic analysis of value creation. However the proposed propagation graph cannot reason on how different quality attributes influence one another. Further investigation on approaches that allow identification of cause and effects of capabilities and their quality attributes to evaluate future behavior of alternatives is required.

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