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Modularity And The Coordination Of Complex Work

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MODULARITY AND THE COORDINATION OF COMPLEX WORK

Modularity is a way of organizing work into relatively self-contained clusters of tasks that are integrated by system-level integrators, enabling other participants to focus their efforts on coordinating work within their own module. Some theorists have argued that modularity is an effective response to complexity and the information processing demands associated with it, while others have argued that complexity calls for reduced levels of modularity. In this paper we offer competing hypotheses from existing theories, then integrate multiple theoretical perspectives to develop new hypotheses regarding modularity and its adaptation under conditions of increasing complexity. We explore these hypotheses empirically in a professional service context to discover whether organizational participants respond to higher levels of client complexity by increasing or decreasing the modularity of their coordination with each other, and to determine the impact of their response on client outcomes. We discuss implications for modularity theory and for the design of the system integrator role.
(152 words)

Key words: modularity, coordination, complexity, professional services

INTRODUCTION

When work processes grow increasingly complex, it becomes challenging to coordinate each task with every other task. One solution is to decompose complex work into relatively self-contained clusters of tasks – subassemblies or modules – that are free-standing until they are joined together to form a complete product or service. This design solution is called modularity. Simon (1973) argued that there are advantages to decomposing work in this way and argued furthermore that complex systems must be designed in this way in order to survive. Similarly, Weick (1976) described modular or loosely coupled systems as an effective response to complexity. Skeptics have suggested to the contrary that the increasing complexity of work calls for tighter, not looser, coupling among organizational units (e.g. Sabel Zeitlin, 2004). In this paper we offer competing hypotheses from existing theories, then integrate multiple theoretical perspectives to develop new hypotheses regarding modularity and its adaptation under conditions of increasing complexity. We explore these hypotheses empirically in a professional service context to discover whether organizations respond to higher levels of complexity by increasing or decreasing modularity, and to determine the impact of that response on performance.

Decomposability and Loose Coupling

Simon (1973) argued that work systems, like complex systems more generally including biological and computing systems, can be decomposed into constituent parts that operate in relative isolation from each other. The advantage of a decomposable system is that its "loose horizontal coupling permits each subassembly to operate dynamically in independence of the detail of the others; only the inputs it requires and the outputs it produces are relevant for the larger aspects of system behavior" (1973: 16). Moreover, decomposability is a feature of complex systems, Simon argues, because it provides "the most viable form for any system of even moderate complexity" (ibid: 27), allowing such systems to survive over time. Without decomposability, complex work could not be accomplished effectively due to prohibitive requirements for information processing, and due to the bounded rationality that characterizes human actors. Decomposability simplifies the interdependencies between modules and enables greater focus on the critical task interdependencies within a given module.

Weick (1976) argued that loose coupling enables different elements to be responsive to each other while retaining separate dynamics and separate identities. According to Orton and Weick (1990), modularity is a form of loose coupling that offers particular advantages in complex environments. If problems develop in one part of the system, that part can be sealed off from the rest of the system, giving greater stability to the total system. In addition, because each component of the organization can adapt to its own environment, coordination costs between modules are reduced. Perrow (1984) found that systems that are highly interconnected were more likely to behave in unpredictable ways and argued that systems with high 'interactive complexity' and tight coupling inevitably result in failure.

At the core of these arguments is the notion that modularity is essential for complex systems because it reduces information processing requirements and the potential for widespread failure by reducing interdependencies between modules, thus enabling participants to focus more attention on coordinating interdependencies within their own modules.

***Hypothesis 1a*:** A higher degree of modularity (understood as weak ties between modules) will be found under conditions of greater complexity.

***Hypothesis 2a*:** Modularity (understood as weak ties between modules) will be more effective under conditions of greater complexity.

Theories of Inter-Organizational Relations and Coordination

Sabel and Zeitlin (2004) argue to the contrary that modularization undermines the ability of organizations to coordinate, innovate and learn. The disadvantages of modularization they argue are particularly acute in the new economy due to the increasing interdependence of work and the increasing interdependence between organizational components. Modularity is strictly limited due to the "impossibility of establishing standard design interfaces so comprehensive and stable that customers and suppliers can in effect interact as if operating in spot markets for complex components or subassemblies without jeopardizing their long-term survival" (ibid). Participants must routinely "question and clarify their assumptions about their joint project using methods such as benchmarking, co-location of personnel, problem-solving teams and quality standards that enable the parties to reconsider the partitioning of tasks across boundaries in a way that modularization does not allow" (ibid). Other theorists have argued for the benefits of tight coupling across organizations, with the implication that these benefits increase under conditions of complexity (e.g. Powell 1990; Grandori and Soda 1995; Helper MacDuffie and Sabel 2003; Gittell and Weiss 2004). As complexity increases, the boundaries between clusters of tasks arguably need to become more permeable to enable feedback and learning to occur.

There is a basis in coordination theory for these concerns about modularity. Coordination theory has long argued that both task interdependence and complexity affect information requirements and thus the bandwidth that is needed to address those information requirements (Thompson 1967; Galbraith 1973; Daft and Lengel 1986). According to relational theories of coordination, communication and relationship ties provide a powerful source of information processing capacity or bandwidth for coordinating work (Crowston and Kammerer 1997; Gittell 2002; Faraj and Xiao 2006). By extension, work processes that are either highly interdependent or highly complex require relatively strong communication and relationship ties for their successful coordination. Conversely, work processes with low levels of task interdependence or complexity can be successfully coordinated through weak communication and relationship ties.

These theories of coordination and inter-organizational relations therefore appear to be opposed to the previous hypotheses. In particular, they suggest that we should expect to find *less* modularity under conditions of greater complexity. Furthermore, we should expect modularity to be *less effective*, the greater the complexity of the process.

> ***Hypothesis 2a:*** A lower degree of modularity (understood as weak ties between modules) will be found under conditions of greater complexity.
>
> ***Hypothesis 2b*:** Modularity (understood as weak ties between modules) will be less effective under conditions of greater complexity.

Integrating the Two Perspectives

We would argue that certain aspects of both perspectives are correct. Many theorists who have described modularity as a response to complexity have also been explicit about the need for coordination across modules. Early coordination theorists Lawrence and Lorsch (1968) argued that although differentiation is needed to respond to complex environments, differentiation must be complemented by a reciprocal degree of integration, accomplished through coordinating mechanisms that bring the differentiated parts together again for the effective working of the whole organization. Eisenhardt and Brown (1998) argued similarly that to reduce information overload, organizations must be comprised of modular units that are only partly connected to each other, but that they must also strive to avoid too little coordination. Complexity theorists also argue for balance, claiming that the most adaptive systems are those that exist "at the edge of chaos," in a state that is poised between too much and too little connection (Carroll and Burton 2001).

More recent theories of modularity have recognized explicitly the need for integration across modules and have argued that system integrators, participants whose job is to weave together discrete modules into a coherent process, are inherent in the concept of modularity (Sosa et al 2003). A well-designed system integrator role enables a work process to be modularized without loss of coordination. Without decreasing the modularity of a system, system integrators serve as linkages between the various modules. According to this understanding of modularity, integration across modules by system integrators rather than by people in the modules themselves can be seen as an essential characteristic of a modular system (Sosa et al 2003; Baldwin and Clark 2000; Baldwin 2004). Baldwin and Clark (2004) suggested that in order to effectively modularize a system, three components are needed, each of which plays an essential role. First, the architecture of the system needs to be defined, which in essence means that it needs to be clear what the modules are. Second, the interfaces between the modules need to be specified, which means that how the modules will interact must be well defined. Third, there is a need to establish that the modules are working together, a role that is placed in the hands of system integrators.

In effect, these modularity theorists recognize the benefits of modularity for keeping information processing demands manageable while also recognizing the need for coordination across modules. They therefore define modularity as including not only weak ties between modules but also a system integrator who coordinates between modules without distracting participants from their areas of focus. However, they do not address explicitly the question that is central to our paper – how should modular systems respond to increased complexity? We propose the following. We suggest that two adaptations of modular systems are needed as the complexity of the work increases. First, ties within modules should become stronger while ties between modules remain weak. Second, ties by system integrators should become stronger while ties between modules remain weak. In a modular system therefore, we suggest that both ties within modules and ties between the system integrator and each module should become stronger as the complexity of the work process increases, while direct ties between modules remain weak enabling participants to maintain focus.

Hypothesis 3a: A higher degree of modularity (understood as weak ties between modules *and* strong ties between system integrators and each module) will be found under conditions of greater complexity.

Hypothesis 3b**:** Modularity (understood as weak ties between modules *and* strong ties between system integrators and each module) will be more effective under conditions of greater complexity.

These hypotheses are similar to the first set we offered above. But here we define modularity to include not only weak ties between modules but also strong ties by system integrators whose role it is to integrate across modules, and whose role it is to intensify their integration efforts when complexity increases information processing needs, calling for greater bandwidth to achieve coordination. These hypotheses thus suggest common ground between the early view of modularity as put forward by Simon (1958) and Weick (1976), and the information processing concerns put forward by coordination theorists and theorists of inter-organizational relations (Helper MacDuffie and Sabel 2003; Sabel and Zeitlin 2004).

METHODS

In this study, we explore modularity in a professional services setting, focusing on the post-surgical care of patients who underwent knee replacement surgery. We sampled patients who received joint replacement surgery in one particular focal hospital, and followed them in the six weeks after surgery as they moved through the stages of post-surgical care in the hospital, then in a rehabilitation facility and then at home. Some patients went directly from the hospital to home and did not receive rehabilitation care, while others received care at the rehabilitation facility but did not receive care at home. Based on interviews with care providers prior to and during this study, we anticipated that the stages of care (hospital, rehabilitation, home) formed the basis for a modular task structure. See Figure 1 for a depiction of the stages of care. Care providers depicted post-surgical care for these patients as having higher degrees of task interdependency and coordination within settings than between them, and also depicted the interfaces between stages of care as being fairly well defined. Representative comments from our interviews are presented in an appendix that is available upon request. In addition, a fuller description of the task structure and care process can be found in Weinberg et al (2007).

[Insert Figure 1 about here.]

Data Collected for this Study

Patients were eligible for inclusion in this study if they were admitted to the focal hospital for primary, unilateral total knee arthroplasty with a diagnosis of osteoarthritis between November 2003 and May 2004. All eligible patients were sent an initial survey prior to their surgery, asking them to participate and to answer questions regarding their pre-operative status. We received 222 responses to 357 surveys that were sent to eligible patients, for an enrollment rate of 62 percent.

We surveyed a sample of the patient's care providers at six weeks after discharge. For each patient, we identified and surveyed a subset of the different types of care providers responsible for the patient at the hospital, rehabilitation, and home stages of care as well as care providers who potentially played the role of systems integrators. See Table 1 for the types of providers who were surveyed, and the types of providers they were surveyed about.

We surveyed a total of 1389 providers who were assigned to the 222 patients enrolled in our study. A total of 519 providers responded, for a response rate of 37 percent. We obtained names of care providers in the different settings from patients and also from hospital records. In a number of cases, we could not get the names of a particular provider but rather their position within a particular organization (e.g. physical therapist at ABC rehabilitation facility). Surveys were mailed to providers, and two followup phone calls were made to ensure receipt of the survey and encourage response. Our attempts to reach particular providers by phone were less successful when the providers were not readily identifiable. We anticipate that respondents may differ from non-respondents in their level of interest in patient care coordination and also in their accessibility for coordination. If so, our measures of coordination will be upwardedly biased. However we have no reason to expect this upward bias to be different for within module, between module and system integrator coordination, given that all respondents were asked about both types of coordination, nor to be different for providers who cared for more complex patients and those who cared for less complex patients. We therefore do not expect response bias to influence the results of our hypothesis testing.

[Insert Table 1 about here.]

Modularity of Coordination

Consistent with the theories above, a modular system should exhibit coordination ties *within* modules that are stronger than the coordination ties *between* modules, and coordination ties *by system integrators* that are stronger than the coordination ties *between* modules. We propose furthermore that these dimensions of modularity can be conceptualized as continuous variables. We define Modularity1 as the ratio of tie strength within modules to tie strength between modules, and Modularity2 as the ratio of tie strength with system integrators to tie strength between modules. For each ratio, values greater than 1 indicate modularity, and higher values for each ratio indicate progressively higher degrees of modularity.

$$\text{Modularity1} = \frac{\text{strength of coordination ties within modules}}{\text{strength of coordination ties between modules}}$$

$$\text{Modularity2} = \frac{\text{strength of coordination ties with system integrators}}{\text{strength of coordination ties between modules}}$$

To assess the combined impact on performance of these two dimensions of modularity, we define a third variable called Modularity3, which is the ratio of tie strength within modules plus tie strength with system integrators, to tie strength between modules.

$$\text{Modularity3} = \frac{\text{strength of coordination ties within modules + with system integrators}}{\text{strength of coordination ties between modules}}$$

Tie strength is measured for this study using a network measure called "relational coordination." The instrument to measure relational coordination in healthcare settings was developed and tested in Gittell, et al (2000), based on a survey that was initially used to measure relational coordination among employees in the flight departure process (Gittell 2000). Consistent with recommendations by Marsden and Campbell (1984) and Levin and Cross (2004), relational coordination is a metric based on multiple indicators of tie strength that are highly interrelated – communication frequency, communication quality and relationship quality. This metric has been used to assess the overall level of coordination within a healthcare setting, and patient-specific coordination in a healthcare setting, but has never before been used to assess patient-specific coordination across multiple settings as in this study. The same instrument was given to each type of provider that was surveyed for this study. Responses were measured on five-point Likert-type scales.

Modules were pre-identified based on stage of post-surgical care – hospital, rehabilitation, and home. To measure relational coordination *within modules*, a set of seven scores (frequent, timely, accurate, problem-solving communication, shared goals, shared knowledge, mutual respect) was computed for each respondent based on his or her responses regarding the providers who worked in the same module. The seven scores were combined into a single index, with a Cronbach's alpha of 0.83, called relational coordination *within modules*, measured for each individual respondent regarding a specific patient. To measure the strength of ties *between modules*, a similar set of seven scores was computed for each respondent by averaging his or her responses regarding providers in all modules other than his or her own. These seven scores were then combined into a single index, with a Cronbach's alpha of 0.80, called strength of ties *between modules*, measured for each individual respondent regarding a specific patient.

Based on interviews describing task structure and work process, we identified three potential system integrators: primary care physicians, managed care case managers, and informal caregivers (patient's family members or friends who helped with care). To measure the strength of ties *with system integrators*, a similar set of seven scores was computed for each respondent by averaging his or her responses regarding each of the system integrators. These seven scores were then combined into a single index, with a Cronbach's alpha of 0.85, called relational coordination *with system integrators*, measured for each individual respondent regarding a specific patient. Each of these indices well exceeds the minimum alpha of 0.70 traditionally used as an indicator of internal reliability (Nunnally 1978).

Complexity

In healthcare, complexity of the work process arises from the complexity of the patients who are being treated, as indicated by measures such as patient age or overall health. Complexity is also a function of the treatment or procedure that is being performed; however in this study, all patients received knee arthroplasty, or knee replacement, so there was no variation in complexity of the treatment or procedure other than variations arising from differences among the patients themselves.

To assess differences among patients that could give rise to complexity, we gathered patient age from hospital records and assessed overall health through the patient survey using the overall health measure from the SF-36 (Stewart Hayes and Ware 1988). For purposes of analysis, both age and overall health were coded as dichotomous variables. High complexity patients were then defined for this study as patients who were either older than 75 (20 percent of the sample) or who reported poor or fair overall health (16 percent of the sample), together comprising 31 percent of the sample.

Outcomes

Outcomes for this study include three indicators of the quality of patient care. We used a single item measure of patient satisfaction based on the question: "Overall, how would you rate your care in the past six weeks?" measured twelve-weeks post-surgery. We also measured the patient's clinical outcomes at six weeks post-surgery. Given that all patients in this study suffered from osteoarthritis, the two key clinical outcomes expected from their surgery were reduced joint pain and increased joint mobility. The survey questions included five items relating to pain and seventeen items relating to mobility from the WOMAC, a validated self-administered osteoarthritis instrument (Bellamy et al 1988). The survey questions asked about the amount of pain and degree of difficulty with mobility (five potential responses from none to severe) experienced in the past 48 hours during common activities. To minimize missing values, responses were included for all patients who completed at least eighty percent of the items in each of the indices. The mean of the non-missing values for each item was assigned to missing values for that item.

Analyses

To visualize patterns of coordination and the degree of modularity in those patterns, we used a matrix form of analysis originally developed by Steward (1981) and further developed by Eppinger and his colleagues (e.g. Sosa et al 2003). This form of analysis is known as a Dependency Structure Matrix (DSM). We formed a matrix with providers from the three stages of care – hospital, rehabilitation and home care – down one side, and providers from the same stages of care across the top. We added a final row and column for those parties who were expected to play the system integrator role in this setting – primary care physicians, informal caregivers and managed care case managers. We surveyed 8 provider types about their coordination with 14 provider types, so our matrix is therefore asymmetric. Observations about the 6 provider types that were not surveyed are reported only from the perspective of others, not from their own perspective, making this an asymmetric matrix of coordination ties. Still, all coordination ties in the matrix are measured from the perspective of at least one of the two providers in each relationship. In each cell of the matrix is the mean level of relational coordination on a 5-point scale, reported by the provider type along the left axis with respect to the provider type along the top axis, regarding the particular patient about whose coordination the provider was being surveyed.

The total number of observations for each provider category is shown in the bottom row of the matrix. We see that of the total 519 surveys received, 519 included responses about the surgeon who was responsible for the patient in question. By contrast, only 452 of the 519 surveys received included responses about the hospital care case manager who was responsible for the patient in question, while 467 of the 519 surveys included responses about the hospital nurses who were responsible for the patient in question, and so on.

Using the values in this matrix, we computed the mean level of relational coordination within modules, the mean level of relational coordination between modules, and the mean level of relational coordination with each of the system integrators. We then computed Modularity1 and Modularity2. To test the impact of patient complexity on the degree of modularity, we divided the patient sample into high and low complexity (based on age or overall health) and computed Modularity1 and Modularity2 under conditions of high and low complexity, assessing significance of difference through analysis of variance (ANOVA in STATA).

To test the impact of modularity on patient outcomes, we used random effects regression analysis with patient as the unit of analysis and the surgeon (n=4) as the random effect to account for possible similarities in outcomes between patients who received surgery from the same physician. We regressed our measures of modularity on each of the three quality indicators described above – patient satisfaction, freedom from joint pain, and joint functioning. Control variables included patient complexity, gender, marital status and psychological well being for all outcome models, as well as pre-operative joint pain and functioning (measured prior to surgery), and whether the surgery was a first time joint replacement or a revision, for the clinical outcome models. To test for the moderating effect of complexity, we use the multiplicative method recommended by Schoonhoven (1981), multiplying Modularity1, Modularity2 and Modularity3 by patient complexity then entering their products into the regression models.

FINDINGS

Modular Patterns of Coordination

Table 2 shows the dependency structure matrix we built from the coordination data collected for knee replacement patients. Each cell of this matrix includes the mean level of relational coordination reported by the provider type listed in the left-hand column, with the provider type listed in the top row. A total of 519 provider responses were received. The number of provider survey responses included in that mean is shown in each cell, in parentheses.

First consider an example of "within module" coordination. In the second row of the table, first column, we see that 80 hospital physical therapists responded about their coordination of care with the surgeon regarding a patient in our study. The mean level of relational coordination that they reported was 3.4 on a 5-point scale. Since both the hospital physical therapist and the surgeon work at the hospital stage of care, this is an example of "within module" coordination. Then consider an example of "between module" coordination between the physical therapist providing hospital care and the rehabilitation physiatrist providing rehabilitation care. Looking further along that same row at the fourth column, we see that 39 hospital physical therapists responded about their coordination of care with the rehabilitation physiatrist regarding a patient in our study. (The difference between the 80 responses and the 39 responses is due to the fact that about half of the patients in our study went from the hospital to rehabilitation facilities before receiving home care while the other half went directly from the hospital to home.) We see that the mean level of relational coordination that hospital physical therapists reported with the rehabilitation physiatrist was 1.1 on a 5-point scale.

[Insert Table 2 about here.]

Looking at the entire matrix, we can see that all of the shaded cells on the diagonal represent within module coordination, all of the unshaded cells represent between module coordination, and all of the shaded cells along the bottom and far right column represent coordination by system integrators. In a modular system, we would expect the shaded cells on the diagonal to exhibit higher levels of relational coordination than the unshaded cells. Based on this definition, the matrix shows clear evidence of modular coordination patterns. We see that all of the shaded cells (within module) have levels of relational coordination that are greater than 3 on a 5-point scale, while nearly all of the unshaded cells (between module) have levels of relational coordination that are less than 3 on a 5-point scale. There is one exception – physical therapists at the home stage of care reported higher levels of relational coordination with the hospital surgeon (3.5) than was typical for between-module coordination in this work process.

We also expect the ties between the modules and the system integrators to be stronger than the relatively weak ties that exist between the modules themselves, in a fully modular system, given the need for integration across modules. We therefore expect the shaded cells along the bottom and far right hand column of Table 2 to have stronger ties than the unshaded cells. This expectation is only partially met. We see that only the informal caregiver has strong ties (greater than 3 on a 5-point scale) with at least one provider in each module. The primary care physician has no strong ties with anybody, and the managed care case manager has relatively strong ties only with the hospital case manager and the rehabilitation case manager.

The top row of Table 3 summarizes mean values of coordination for all patients from Table 2 and provides measures of Modularity1 and Modularity2 for all patients. We see that mean relational coordination within modules for all patients was 3.94 on a 5-point scale, while mean relational coordination between modules was 1.87 on a 5-point scale, and mean relational coordination by system integrators was 2.20 on a 5-point scale. Modularity1, the mean ratio of within to between module tie strength, was 2.29, substantially greater than 1, suggesting that this work process meets the first criteria for modularity. Modularity2, the mean ratio of system integrator tie strength to between module tie strength, was 1.64, also greater than one, suggesting that this work process meets the second criteria for modularity. Tasks in this work process have been clustered into relatively freestanding modules, with stronger coordination ties within modules than between them, while system integrators in the aggregate play the role of coordinating across those modules.

Looking inside the aggregate measure of system integrator ties, however, we see that the system integrators play their roles somewhat unevenly. Of the system integrators, the informal caregiver has by far the strongest ties with the modules, at 2.90, while the primary care physician and the managed care case manager have ties of 1.78 and 1.82 respectively.

[Insert Table 3 about here.]

Impact of Complexity on Modularity

How does modularity respond to complexity in this work process? Results on Table 3 suggest that modularity *increases* in response to patient complexity. Relational coordination within modules was significantly stronger for more complex patients (p=0.0094), and relational coordination with system integrators was also significantly stronger for more complex patients (p=0.0231), while there was no significant difference in relational coordination between modules for more complex patients (p=0.5932). Modularity1, the ratio of within module coordination to between module coordination, was 2.39 for high complexity patients and 2.25 for low complexity patients, a difference that is statistically significant (p=0.0371), while Modularity2, the ratio of system integrator coordination to between module coordination, was 1.72 for high complexity patients and 1.61 for low complexity patients, a difference that is only marginally significant (p=0.0807). Taken together, these results suggest that coordination for knee replacement patients is modular along both dimensions, and that modularity along both dimensions increases with the complexity of the patient. But the change in Modularity2 is only marginally significant given the variability in the response of system integrators to complexity.

Breaking apart the aggregate measure of system integrator coordination, we see that for high complexity patients, coordination by primary care physicians increased from 1.72 to 1.91 (p=0.0680), a change that was only marginally significant, and coordination by managed care case managers increased from 1.62 to 2.25 (p=0.0002). Informal caregiver coordination did not differ between high and low complexity patients, though informal caregivers continued to have stronger ties than either the primary care physician or the managed care case manager for both high and low complexity patients.

Performance Effects of Modularity, Moderated by Complexity

How does the modularity of provider ties affect performance of this work process, and how is that effect moderated by patient complexity? Regression results are shown in Table 4 for Modularity1, in Table 5 for Modularity2, and in Table 6 for Modularity3, our combined measure of Modularity1 and Modularity2. On Table 4, we see that Modularity1 positively predicts outcomes of interest, including increased freedom from pain (r = 5.04, p = 0.004) and increased joint functioning (r = 3.11, p = 0.037), but that it is associated with weaker clinical outcomes for more complex patients relative to less complex patients, including lower levels of freedom from joint pain (r = -6.45, p = 0.042) and lower levels of joint functioning (r = -6.36, p = 0.022).

On Table 5, we see that Modularity2, measured as the ratio of system integrator tie strength to between module tie strength, does not directly predict any of our patient outcomes of interest. But as with

Modularity1, Modularity2 is associated with weaker outcomes for more complex patients relative to less complex patients, including lower levels of freedom from joint pain (r = -12.80, p = 0.067) and lower levels of joint functioning (r = -13.32, p = 0.021).

Table 6 shows that Modularity3, our combined measure of Modularity1 and Modularity2, is associated with increased freedom from pain (r = 3.90, p = 0.005) and marginally associated with increased joint functioning (r = 2.11, p = 0.073). But as with Modularity1 and Modularity2, this combined measure of modularity is also associated with weaker outcomes for more complex patients relative to less complex patients, including lower levels of freedom from joint pain (r = -5.68, p = 0.020) and lower levels of joint functioning (r = -5.53, p = 0.008).

Taken together, these results suggest that Modularity1 and Modularity2 as well as the two dimensions of modularity combined (Modularity3) are associated with worse outcomes for more complex patients than for less complex patients, or in other words that complexity reduces the effectiveness of modularity for achieving outcomes in this setting. In sum, Hypothesis 3a is supported, but Hypothesis 3b is not.

[Insert Tables 4, 5 and 6 about here.]

DISCUSSION

In this study, we found clear evidence of modularity in a professional service setting, and evidence of increased modularity under conditions of increased complexity, consistent with Hypothesis 3a. We also found that system integrators increased their role in coordination under conditions of complexity thus increasing bandwidth at the interfaces between modules. Though we found some positive performance effects of modularity, however, we found that modularity was less effective under conditions of increased complexity, contrary to Hypothesis 3b. What we do not know for certain is why modularity – defined as weak ties between modules as well as strong ties with system integrators – was less effective under conditions of complexity. These findings may suggest that modularity is a flawed design response to complexity, or they may indicate instead that the conditions of a well-designed modular system were not all in place. In particular, our data suggested that the reduced performance of modularity under complexity that we observed may be due to a poorly designed system integrator role.

As noted above, Baldwin and Clark (2004) suggested that in order to effectively modularize a system, three components are needed. First, the architecture of the system needs to be defined, which means that it needs to be clear what the modules are. This condition was met in our system because the stages of care for joint replacement patients were clearly defined. Second, the interfaces between the modules need to be specified, which means that how the modules will interact must be well defined. This requirement was met in our system, at least from the perspective of participants who explained how each module interacted with the other modules primarily through written information exchanged in a standardized format. Third, there is a need to ensure that the modules are working together, a role that is placed in the hands of system integrators.

Our findings suggest that system integrators did indeed play a coordination role in this modular work system. However, we found that the system integrator role was played unevenly with the strongest role played by the least expert party (informal caregivers) and the weakest role played by the most expert party (primary care physicians). Our results from the dependency structure matrix on Table 2 show that the only system integrators who were consistently active across the continuum of the service process were the informal caregivers, who were arguably the least able to deal with conditions of higher complexity due to significant information asymmetries arising from their lack of professional training. On Table 3 we saw that as complexity increased, informal caregivers did not significantly increase the strength of their ties with the different modules. One possibility is that informal caregivers are not able to respond to increased complexity because they lack the technical knowledge necessary to effectively integrate across the modules. Schilling's (2000) theory of modularity argues that customer ability and willingness to combine the components or coordinate between them is a critical factor enabling modularity, as is the customer's ability to assess the quality and interaction of the components. We question whether customers or their family members meet these requirements for effectively playing the role of system integrator in the healthcare system and other professional service settings given the complexity of information involved and given the significant information asymmetries that exist between themselves and the professionals whose work they are called upon to coordinate.

Managed care case managers did increase the strength of their ties with the modules under conditions of increased complexity but due to uneven activity across all the stages of care, as seen in Table 2, they may not fully fulfill the role of the system integrator in responding to increased complexity, perhaps due to poorly defined roles and responsibilities as patients move across stages of care. While primary care physicians responded to increased complexity with increased strength of ties with each of the modules, their ties were still the weakest of any participant in the system.

In essence, our findings do not allow us to conclude definitively that modularity is less effective under conditions of increased complexity. Rather we have reason to suspect that the lack of a strong and effective system integrator role may be the cause of decreasing effectiveness of modularity under increased complexity. However, our data also do not allow us to conclude that, if the system integrator role were stronger and better defined, we would find positive performance effects for modularity under increased complexity.

Contributions

The primary contribution of this paper is to integrate and build upon existing theory to better understand modularity's effectiveness under conditions of complexity. Theories of decomposability (Simon 1973) and loose coupling (Weick 1976) suggest that modularity is an effective response to complexity because it helps to reduce complexity by simplifying the interfaces between modules and by enabling those who are working within each module to better focus their efforts on the critical task interdependencies within. Theories of coordination (e.g. Daft and Lengel 1986) and inter-organizational relations (e.g. Sabel and Zeitlin 2004) argue to the contrary that complexity calls for more integrative patterns of coordination. Building on more recent modularity theory (Baldwin and Clark 2000; Sosa et al 2003; Baldwin 2004), we argued that modularity is an effective response to complexity to the extent that it not only simplifies the interface between modules, but also provides system integrators to coordinate the flow of work between those modules. We proposed further that this system integrator role should expand under conditions of greater complexity, thus strengthening modularity theory by incorporating the concerns of coordination theorists regarding the need for increased bandwidth as information processing requirements expand.

This paper further contributes to the modularity literature by introducing the idea that there are two distinct but necessary dimensions of modularity – strong ties within modules relative to ties between modules, and strong ties by system integrators relative to ties between modules. We operationalized these two dimensions of modularity in such a way that their implications for performance could be empirically tested, thus suggesting a novel empirical approach for addressing important theoretical debates regarding the value of modularization as well as for offering insights that are useful to practitioners who want to evaluate the systems that they manage.

A third contribution of this paper is to provide a deeper understanding of the alternative system integrators who operate in professional service contexts, including the customer and his or her proxies, and the understanding that these system integrators are not necessarily well suited for their jobs. We found that customers themselves played the most extensive system integrator role in this system. Schilling (2000) suggested that one criterion for effective modularity in a service setting is that the customer is sufficiently knowledge to play a system integrator role. Building on her argument, one potential weakness of the system we have studied is the inability of consumers to play the system integrator role effectively given the deep levels of expertise held by professionals in the system. Indeed, customers in this system may play the system integrator role by default rather than by design, to compensate for the relatively weak roles played by other system integrators (Donelon et al 2002; Weinberg Lusenhop Gittell and Kautz 2007).

From the perspective of coordination theory, system integrators can be seen as a particular type of boundary spanner or liaison, that is, people whose primary task is to integrate the work of other people (Galbraith 1973). Galbraith's conceptualization of the boundary spanner role is consistent with the system integrator role in a modular system. Previous work suggests that boundary spanners need a broad range of capabilities in order to be effective. Aldrich and Herker (1977) suggested that boundary spanners play an information processing role in which they collect, filter, translate, interpret and disseminate knowledge from external parties to members of their organization so that the organization is better able to monitor and adapt to changes in the environment. It is not clear that consumers of professional services are in a position to play these roles in a work process dominated by professionals. Healthcare may be even more extreme than other professional services in the sense that customers often need to partake of health services with little advance notice or choice, and at the time of need may be undergoing emotional and other stressors that detract from their ability to play the system integrator role.

Beyond information-processing requirements, boundary spanners also require certain relational capabilities including social awareness (Caldwell and O'Reilly 1982), the ability to read contextual cues when translating across boundaries (Tushman and Scanlan 1981), the ability to build trust (Currall and Judge 1995), and the ability to build shared goals, shared knowledge and mutual respect among participants (Gittell 2002). In other words, boundary spanners are effective when they can build connections between people who work in different areas of expertise. But even customers with high levels of relational competence may be hard pressed to build connections across professionals who are themselves competing for power and status, as is often the case in healthcare (Abbott 1993; Wicks 1998).

A related issue to consider with regards to the system integrator role and the design of an effective modular system is the power that a system integrator has over decision-making within the modules. Where we seem to see modularity most widespread and effective is in situations where there are either very well defined interfaces between modules, a large firm in the market that has the power to define to buyers or suppliers how it wishes sub-components of a product or service to integrate, or a combination of both. We hypothesize that the effectiveness of the system integrator is dependent on that system integrator having influence over how the modules interact. In this study the qualitative data suggest that the system integrators have very little decision-making influence over the modules, which we believe may be reducing their effectiveness. This lack of decision-making influence may be due to underlying issues of hierarchy that exist between physicians, nurses, and other providers on one hand and patients and their families on the other hand, and is something that should be considered for further research in determining what aspects of the system integrator role influence their effectiveness and consequently the effectiveness of a modular system.

A final contribution of this study is to illustrate how modularity can adjust to differences in complexity at the sub-system level, in this case, at the level of the individual client. Health care is largely characterized by temporary groups of providers who have the ability to adjust their actions on a case-by-case basis within the broad boundaries set by the organizations involved. Failure by providers to adjust their actions sufficiently to account for patient differences can have negative implications for a patient's health outcomes. The design of this study has allowed us to focus on these fine-grained adjustments at the margins rather than on wholesale changes in the modular structure of the system; in other words this study illustrates the impact of changes in modularity in practice as compared with changes in modularity in design. The ability of participants in a system to adjust the modularity of their coordination patterns at this micro level suggests that system may have greater flexibility to address the needs of a range of inputs than has previously been thought. Though it appears participants in the system explored here did not adjust their coordination patterns adequately to account for differences in client complexity, the potential for micro-adjustments has been suggested nevertheless, with applicability that may extend beyond client-to-client variability to include project-to-project variability as well.

Limitations and Future Research

There are several limitations of the current study that future researchers are urged to address. As noted above, we surveyed 8 provider types about their coordination with 14 provider types, so our dependency structure matrix is therefore asymmetric. Observations about the 6 provider types that were not surveyed were reported only from the perspective of others, not from their own perspective. Still, all coordination ties in the matrix are measured from the perspective of at least one of the two providers in each relationship.

In addition, our study did not explore systematically every condition that is believed to be important for effective modularization from the perspective of modularity theory. One critical factor is the modularity of the underlying pattern of task interdependence (von Hippel 1980) or the separability of task clusters based on the absence of synergistic combinations (Schilling 2000). Although we had good reason to suspect that the stages of care (hospital, rehab, home) were the basis for a modular task structure, based on interviews of care providers conducted for this study, we did not measure task interdependence quantitatively. Ideally, the pattern of task interdependence should be quantified in addition to measuring the patterns of coordination, to ascertain that the modularity found in the patterns of coordination corresponds to the underlying task structure (Sosa et al 2003) and not, for example, to some underlying system dysfunction.

Another condition for effective modularization is the existence of well-defined interfaces between modules. Modularity theory predicts that for modularity to be effective, protocols or rules must be developed in order to clearly define the interfaces between modules of the work process (Baldwin and Clark 2000; Sosa et al 2003). Protocols, routines and standard operating procedures are relatively low-bandwidth coordinating mechanisms that facilitate the interface between tasks (Daft and Lengel 1986; Argote 1982; Gittell 2002; Faraj and Xiao 2006). Even when task interdependencies cluster into distinct modules, effective modularization can be inhibited by the absence of relatively well-defined protocols or rules governing the handoffs between the modules. Moreover, researchers have found that boundary objects can be designed to facilitate the interface between tasks by providing a clear representation of the work in process (e.g. Carlile 2002). In healthcare, clinical pathways have been developed or are currently under development for many diseases and conditions, providing a process map for governing the interfaces between stages of care (e.g. Bohmer 1998; Gittell and Weiss 2004). For knee replacement patients in the study reported here, these protocols included a three-page discharge form summarizing basic patient information, evaluations of patient status from care providers who worked with the patient at previous stages of care, and their recommendations for further treatment. Our interviewees expressed the belief that these standard protocols for handoffs resulted in well-defined interfaces, but this belief was not tested for its accuracy.

Future research is therefore needed to explore how protocols and other boundary objects are used to define the interfaces between modules, how they contribute to effective modularization, and how their role might change as complexity increases. Future research is also needed to take our findings regarding system integrators to the next level. In particular, we suggest that in future research carried out in professional service settings, alternative system integrator role designs be assessed for their ability to respond effectively to changes in complexity and for their ability to contribute to desired system outcomes, paying particular attention to the obstacles that customers face in their role as system integrators.

In conclusion, this paper contributes theoretical insights regarding modularity's effectiveness under conditions of complexity, as well as a novel empirical approach for measuring two distinct dimensions of modularity and assessing their impact on performance. These contributions have the potential to help modularity and coordination theorists reach new frontiers in the search for ways to manage complexity.

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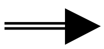
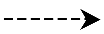
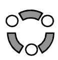
Figure 1: Stages of Care for Joint Replacement Patients



Represents patients' care trajectory



Represents coordination between stages



Represents coordination within stages

Table 1: Providers Who Were Surveyed, and About Coordination With Whom

Providers Surveyed		**Each Was Surveyed About Coordination With**	
Stage of Care	**Provider Type**	**Stage of Care**	**Provider Type**
Hospital	Physical Therapist	Hospital	Surgeon
	Case Manager		Physical Therapist
			Case Manager
Rehabilitation	Physical Therapist	Hospital	Physiatrist
	Case Manager		Nurse
			Physical Therapist
			Case Manager
Home	Nurse	Home	Nurse
	Physical Therapist		Physical Therapist
			Case Manager
System Integrator	Primary Care Physician	System Integrator	Primary Care Physician
	Informal Caregiver		Informal Caregiver
			Managed Care Case Mgr

Table 2: Dependency Structure Matrix[1]

		Hospital			Rehabilitation				Home		System Integrator		
		Physician	Case manager	Physical therapist	Physician	Nurse	Case manager	Physical therapist	Nurse	Physical therapist	Primary care physician	Informal care giver	Managed care case manager
Hospital	Case manager	**3.5** (35)	1.3 (4)	**4.3** (34)	1.1 (21)	2.2 (23)	2.6 (23)	2.3 (23)	2.5 (29)	2.2 (33)	2.5 (34)	**3.6** (34)	**3.9** (29)
	Physical therapist	**3.4** (80)	**3.8** (75)	**4.1** (45)	1.1 (39)	1.2 (39)	1.1 (38)	1.4 (39)	1.1 (67)	1.3 (65)	1.1 (73)	1.9 (72)	1.2 (37)
Rehab	Case manager	2.1 (36)	2.2 (35)	1.9 (35)	**3.6** (35)	**4.3** (35)	**4.5** (41)	**4.4** (35)	2.2 (28)	1.9 (29)	1.8 (33)	**3.3** (34)	2.7 (21)
	Physical therapist	2.3 (41)	1.7 (41)	2.1 (41)	**3.8** (41)	**4.2** (41)	**4.2** (41)	**4.6** (31)	1.5 (29)	1.8 (33)	1.4 (39)	**3.0** (39)	1.5 (21)
Home	Nurse	2.7 (68)	1.5 (63)	1.3 (64)	1.2 (32)	1.2 (32)	1.2 (32)	1.3 (31)	**4.5** (37)	**4.0** (67)	2.1 (65)	**3.4** (66)	1.5 (33)
	Physical therapist	**3.5** (89)	1.8 (81)	1.9 (85)	1.6 (44)	1.6 (44)	1.5 (44)	1.9 (43)	**3.8** (84)	**4.3** (25)	2.0 (87)	**3.3** (87)	2.1 (40)
System Integrator	Primary care physician	2.2 (50)	1.5 (46)	1.3 (49)	1.4 (24)	1.7 (24)	1.8 (20)	1.7 (21)	1.5 (44)	1.4 (45)	1.2 (6)	1.9 (45)	1.3 (30)
	Informal care giver	**3.3** (120)	1.8 (111)	2.4 (114)	2.1 (60)	**3.0** (60)	2.1 (59)	2.8 (60)	**3.3** (100)	**3.6** (103)	1.9 (114)	---	1.2 (56)
Obs		519	456	467	296	298	298	283	418	400	445	337	267

[1] Shaded areas indicate where strong ties were expected if stages of care serve as the basis for modularity. Strength of ties is measured on a five-point scale. Strong ties are defined as ties > 3, and are indicated in bold and underlined. Row labels indicate the types of care providers who were surveyed, and column headings indicate the types of care providers they were surveyed about. Number of respondents is shown in parentheses in each cell. Total responses = 519.

Table 3:
Differences in Provider Tie Strength by Complexity of Patient

	Tie Strength Within Modules	Tie Strength Between Modules	Tie Strength with System Integrators	Tie Strength with System Integrator (Primary Care Physician)	Tie Strength with System Integrator (Informal Care Giver)	Tie Strength with System Integrator (Managed Care Case Manager)	Modularity1 Within Module Ties Between Module Ties	Modularity2 System Integrator Ties Between Module Ties
All Patients	3.94 (1.03)	1.87 (.82)	2.20 (1.01)	1.78 (1.07)	2.90 (1.26)	1.82 (1.30)	2.29 (.60)	1.64 (0.68)
Observations	343	343	516	495	452	267	349	516
Low Complexity (<=75 years old, health=good/excellent)	3.84 (1.10)	1.85 (.82)	2.13 (1.00)	1.72 (1.07)	2.88 (1.27)	1.62 (1.18)	2.25 (.65)	1.61 (0.65)
Observations	226	226	355	346	309	182	231	355
High Complexity (>75 years old or health=fair/poor)	4.14 (.82)	1.90 (.82)	2.35 (1.02)	1.91 (1.07)	2.95 (1.25)	2.25 (1.44)	2.39 (.49)	1.72 (0.74)
Observations	117	117	161	149	143	85	118	161
Significance of difference (p-value)	.0094	.5932	.0231	.0680	.6046	.0002	.0371	.0807

Table 4:
Patient Outcomes as a Function of Modularity1
(Within Module Ties/Between Module Ties),
Moderated by Complexity[2]

	Satisfaction with Care	Freedom from Joint Pain	Joint Functioning
Modularity1	.21+ (.097)	5.04** (.004)	3.11* (.037)
Modularity1*Complexity	-.07 (.752)	-6.45* (.042)	-6.36* (.022)
Complexity (> 75 years old or fair/poor health)	.02 (.966)	20.21* (.013)	15.40* (.027)
Psychological Well-Being	.01* (.012)	.09 (.316)	.13+ (.095)
Gender (female = 1)	-.27 (.203)	.61 (.850)	-.31 (.912)
Race (white = 1)	-.32 (.585)	-8.03 (.198)	-4.19 (.427)
Marital Status (married = 1)	-.08 (.733)	2.00 (.555)	.07 (.982)
Revision	---	-5.83 (.720)	-24.02+ (.079)
Pre-Operative Pain/Function	--	.25** (.003)	.32*** (.000)
Constant	3.18*** (.000)	44.43*** (.000)	44.52*** (.000)
Overall R Squared	.12	.17	.29
Observations	111	134	130

***p<0.001 **p<0.01 *p<0.05 +p<0.10

[2] These results are based on robust cluster regression models with patient as the unit of analysis, clustered by acute care physician (n=4).

Table 5:
Patient Outcomes as a Function of Modularity2
(System Integrator Ties/Between Module Ties),
Moderated by Complexity[3]

	Satisfaction with Care	Freedom from Joint Pain	Joint Functioning
Modularity2	.10 (.720)	4.96 (.214)	0.97 (.771)
Modularity2*Complexity	.41 (.380)	-12.80+ (.067)	-13.32* (.021)
Complexity (> 75 years old or fair/poor health)	-.66 (.287)	20.29* (.028)	17.17* (.025)
Psychological Well-Being	.02** (.003)	.12 (.183)	.17* (.023)
Gender (female = 1)	-.22 (.292)	.14 (.967)	-1.01 (.719)
Race (white = 1)	.04 (.929)	-9.35 (.105)	-5.52 (.249)
Marital Status (married = 1)	-.19 (.389)	-.41 (.905)	-.69 (.813)
Revision	---	-4.95 (.765)	-24.26+ (.077)
Pre-Operative Pain/Function	--	.21* (.015)	.27*** (.000)
Constant	3.05*** (.000)	53.61*** (.000)	52.26*** (.000)
Overall R Squared	.11	.14	.28
Observations	113	136	132

***p<0.001 **p<0.01 *p<0.05 +p<0.10

[3] These results are based on robust cluster regression models with patient as the unit of analysis, clustered by acute care physician (n=4).

Table 6:
Patient Outcomes as a Function of Modularity3
(Within Module + System Integrator Ties/Between Module Ties),
Moderated by Complexity[4]

	Satisfaction with Care	Freedom from Joint Pain	Joint Functioning
Modularity3	.16 (.125)	3.90** (.005)	2.11+ (.073)
Modularity3*Complexity	.02 (.904)	-5.68* (.020)	-5.53** (.008)
Complexity (> 75 years old or fair/poor health)	-.07 (.912)	25.24** (.007)	20.30* (.010)
Psychological Well-Being	.01* (.012)	.09 (.310)	.13+ (.088)
Gender (female = 1)	-.26 (.224)	.55 (.865)	-.52 (.853)
Race (white = 1)	-.32 (.582)	-7.33 (.240)	-3.96 (.451)
Marital Status (married = 1)	-.12 (.596)	1.17 (.727)	-.27 (.926)
Revision	---	-5.48 (.736)	-24.00+ (.079)
Pre-Operative Pain/Function	--	.25** (.003)	.31*** (.000)
Constant	3.11*** (.000)	42.44*** (.000)	44.84*** (.000)
Overall R Squared	.12	.17	.29
Observations	111	134	130

***p<0.001 **p<0.01 *p<0.05 +p<0.10

[4] These results are based on robust cluster regression models with patient as the unit of analysis, clustered by acute care physician (n=4).