ABSTRACT

Structural interdependence, or the resources and workflows as well as goal and reward systems that connect team members, tasks, and jobs, is a thriving area in organizational science. Emerging evidence across multiple fields suggests that interdependence is a fundamental component to many aspects of workplace functioning. Its operationalization, though, both with respect to measures in empirical studies and indices across various theories, has yet to receive an integrated discussion. This paper reflects on how the constructs and ideas subsumed under structural interdependence are assessed and indexed to guide management research in this area. We provide a taxonomy of measurement devices and indices that fosters the alignment of theory and measurement, point out discrepancies and assumptions, describe unanswered questions, and present actionable next steps for research. In short, our paper begins a conversation about structural interdependence measurement best practice.

Opportunities and recommendations for structural interdependence measures and indices

The nature of work is changing such that the connections between tasks and actors are increasingly relevant levers for understanding and benefiting from human capital. Five times as many Americans are employed in service jobs compared to those in manufacturing and production (Ford & Bowen, 2008; Parker, Wall, & Cordery, 2001), signaling the shift from a manufacturing economy of additive tasks to a market economy of knowledge and service in which organizational success is driven by the complex interplay between customers, employees, and stakeholders. Changes in information, communication, and transportation technology fueled flatter firm hierarchies, virtual and telework, and teams as the building blocks of modern organizations (Mathieu, Tannenbaum, Donsbach, & Alliger, 2014) where employees must manage work flows and coordinate their activities to perform at high levels (Kozlowski, 2012). Organizational scientists now emphasize questions about connections and interdependence among employees who collaborate with and receive feedback from their coworkers (Grant & Parker, 2009) because the interplay of task and social relations among team members is thought to either relate to outcomes such as collective efficacy, cohesion, behavioral processes, and performance (Courtright, Thurgood, Stewart, & Pierotti, 2015) or create the context in which team behaviors unfold through time (Baard, Rench, & Kozlowski, 2014; Marks, Mathieu, & Zaccaro, 2001). Understanding the nature of dependence among actors will enable organizations to better design, train, develop, and motivate personnel for effective teamwork, whereas endeavors that fail to consider interdependence have “little relevance to building knowledge in the work groups and team literatures” (Kozlowski & Bell, 2003, p. 363).

Interdependence or dependency (defined later) has received increasing attention among organizational researchers, and most tie their work in some way to the notions of Thompson’s (1967) task workflows, Mohr’s (1971) writing on the extent to which individuals perceive that they have “one person” jobs, or Penning’s (1975) bases of interconnectedness. Bell and Kozlowski (2002) present a typology of virtual teams where interdependency is one of the main features distinguishing different team types; Morgeson, Garza, and Campion (2012) and Grant and Parker (2009) review the work design literature and present task interdependence as a key feature for understanding organizational behavior; Kiggundu (1981) presents a theory of how interdependence relates to feelings of responsibility to one’s work; Lenox, Rockart, and Lewin (2007) use interdependence in their theory on why firms rise and fall within an industry over time; and Puranam, Raveendran, and Knudsen’s (2012) theory incorporates organization design, information processing, and interdependence. Empirical studies on interdependence, both as a predictor and outcome, slowed after initial reports by Ven, Delbecq, and Koenig (1976) and Cheng (1983) but have recently reemerged in the literature (e.g., De Dreu, 2007; Grant, 2008; Hertel, Konradt, & Orlikowski, 2004; Lee, Shin, & Kim, 2018).

Although these reviews, theories, meta-analyses, and empirical studies have increased our understanding of interdependence in organizations and teams, its measurement and operationalization have yet to be unified or organized. Items sometimes measure interdependence without attending to (and perhaps confounding) its various directions, such as initiated and received (Kiggundu, 1981) or reciprocal (Pearce & Gregersen, 1991). There are different domains that it can apply to, such as role, task, or outcome dependence (Wageman, 1995), different levels of abstraction, such as whether the measure applies to the individual, dyad, group, or firm (Mansfield & Pollins, 2003), and it has been proposed as a way to create typologies both for teams and tasks (Lee, Koopman, Hollenbeck, Wang, & Lanaj, 2015). Many of these issues have been refined conceptually, especially within a recent meta-analysis by Courtright et al. (2015), but the literature contains little guidance on where the field stands with respect to interdependence measurement. Moreover, there are theoretical indices, observational measures, self reports, discrete task counts, workflow images used in supervisor interviews, formal equations for agent-based models, network indices, and algorithms for computing dependence based on resource exchanges all as methods of indicating the level of interdependence in a given setting. The purpose of this paper is to organize this material, provide a taxonomy of interdependence measures, and link measures to specific purposes so that future research can appropriately align measurement with theory.

The contributions of this paper are as follows. First, we provide a resource for identifying various interdependence measures and their purpose. Gathering the array of measures into a single location allows us to better understand what they capture and how they can be used, notice inconsistencies and areas for improvement, and provides directions for future research. Each of these components will be discussed in this paper. By organizing and reflecting, we are also able to place attention on old indices that are useful but have been underappreciated. Interdependence measurement today is dominated by self reports, but there were a number of relevant theoretical indices proposed in the 60’s, 70’s, and 80’s that we hope to re-highlight. Second, we draw attention to aggregation and the multi-level nature of interdependence. As discussed later, there is a growing emphasis on initiated, received, and reciprocal interdependence as various arrangements at play in a task environment. Although researchers acknowledge that these constructs are related, their measurement occurs without discussion about the appropriate way to aggregate or compile one construct to another. We recast this discussion in terms of Chan’s (1998) composition framework and multi-level theory to better appreciate the various levels that interdependence can subsume. Third, any clarity that comes from interdependence measurement should advance theory in this area. By reflecting on how interdependence is operationalized and measured, new ideas emerge that we hope ignites better theory. Seeing all of the measures at once also helps identify confounds that merit theoretical scrutiny in future work. Finally, our paper is a launching point for research, argument, and hopefully eventual consensus on the merits of various interdependence indices. Our literature has witnessed heated debates about agreement indices, structural equations modeling fit statistics, difference scores, diversity indices, and how to appropriately represent person-environment fit. All of these areas worked out best methods, practices, and interpretations of various indices. Our paper is a signal that interdependence deserves something similar.

We begin by discussing interdependence and its various dimensions. Next, we present our taxonomy and way of organizing the interdependence measures and indices. After unpacking and reviewing the material, we discuss challenges, provide recommendations, and point to next steps for research.

# Structural Interdependence

Interdependence has been discussed across many reviews in fields ranging from organizational psychology to political science, strategy, and management (Dalton, Todor, Spendolini, Fielding, & Porter, 1980; Fan & Lang, 2000; Lenox et al., 2007; Wegman, Hoffman, Carter, Twenge, & Guenole, 2018). Theoretical clarity on its different forms was provided in a meta-analysis by Courtright et al. (2015); we follow their organization to introduce this material. Structural interdependence refers to features of the team – such as resources and workflows as well as goal and reward systems that can be deliberately manipulated by team leaders and members – that define the interconnectedness of team members (Wageman, 1995). Courtright et al. (2015) note that,

team members and leaders choose low [structural] interdependence when they structure tasks on an individual basis with a pooled product, when they form the team with resources redundant across team members, or when they establish goal and reward systems that primarily emphasize individual contributions over collective outputs. In contrast, they choose high [structural] interdependence when members simultaneously work on all aspects of the task, when they intentionally form groups with members processing varied access to resources, or when they establish goal and reward systems that primarily emphasize collective outputs. (p. 3).

Structural interdependence is distinct from teamwork behaviors such as planning, monitoring progress, confidence building, and backup behaviors (Marks et al., 2001), which are referred to collectively as behavioral processes in the teams literature (DeChurch & Mesmer-Magnus, 2010). Shea and Guzzo (1987) and Wageman (1995) referred to actual team behaviors and interactions as an alternative form of interdependence, called behavioral interdependence, meaning, for example, if workers on assembly line “A” interact more than workers on assembly line “B” then those in “A” have greater behavioral interdependence. But Courtright et al. (2015) note that this idea is largely captured within the behavioral processes described in teams reviews. Our paper focuses on measures and theoretical indices for structural interdependence.

# Forms of Structural Interdependence - Task and Outcome

Different labels exist for the various dimensions of structural interdependence, but they can largely be classified within two areas: task and outcome interdependence. Task interdependence refers to “the degree to which taskwork is designed so that members depend upon one another for access to resources and create workflows that require coordinated action” (Courtright et al., 2015, p. 4). It captures what Mathieu, Maynard, Rapp, and Gilson (2008) called means interdependence, what Naylor and Dickinson (1969) called work structure, Shaw’s (1963) cooperation requirements dimension, what Ven et al. (1976), McCann and Ferry (1979), and Thompson (1967) called task interdependence or the notion of workflow patterns, what DeChurch and Mathieu (2009) call process interdependence, what Arthur et al. (2012) called team relatedness and workflow, O’Brien’s (1968) notions of collaboration and coordination, and the dimensions of role theory outlined by Oeser and Harary (1962). Research in this area focuses on how tasks are divided among the group, the precedence relationships among tasks and roles, the extent to which members depend on one another for skills, data, materials, information, and other resources, the combination of task accomplishments into a final product, the extent to which members work individually versus in a group, and the flow of materials across members.

Outcome interdependence refers to “the degree to which the outcomes of taskwork are measured, rewarded, and communicated at the group level so as to emphasize collective outputs rather than individual contributions” (Courtright et al., 2015, p. 4). It captures what Puranam et al. (2012) called agent interdependence, what Barrick, Bradley, Kristof-Brown, and Colbert (2007) called psychological interdependence, what Pennings (1975) called social interconnectedness, what Tjosvold (1986) called goal interdependence, and the notions of payoff differences with respect to what Victor and Blackburn (1987) called reflexive, fate, and behavioral control. Research in this area focuses on whether goals and feedback are provided at the individual versus team level, the nature of rewards and whether they are contingent on individual or group contributions, and how performance is aggregated and communicated back to the actors.

# Taxonomy and Classification

Although researchers operationalize interdependence in a variety of ways, they can largely be partitioned into two domains: self reports and theoretical indices. Self reports are administered to team members, leaders, or supervisors and the individuals are then asked to indicate their perceived interdependence, whereas theoretical indices are formulas or methods for researchers to compute values of interdependence based on theorized or observed workflow patterns, goal structures, or task interactions. Within each of these broad discussion areas (i.e., self reports and theoretical indices) we discuss task and outcome interdependence and also further distinctions such as initiated and received (defined below) interdependence, whether the measure is used at the individual or team level, example items and uses, and provide recommendations, critiques, and research agendas for future work.

## Self Reports

Table 1 presents self-report measures of task interdependence. Items in this space assess perceptions about workflow patterns and the extent to which one or more tasks must be completed before others are initiated. Sample items include, “One task needs to be performed before the other task” (Wong & Campion, 1991), and “Unless my job gets done, other jobs cannot be completed” (Morgeson & Humphrey, 2006). A handful of both individual and team level measures exist. Items at the individual level assess how one individual perceives his or her task in relation to others, e.g. “The way I perform my job has significant impact on others” (Pearce & Gregersen, 1991), whereas team level measures emphasize dependence without reference to any single individual, “Within my team, jobs performed by team members are related to one another” (Lee et al., 2018). As shown, most scales emphasize the individual level; a few contain both individual and team-referent items.

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Insert Table 1 about here

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Researchers using self reports have also distinguished between initiated, received (Kiggundu, 1981), and later reciprocal interdependence (Pearce & Gregersen, 1991). All are forms of task interdependence, but initiated occurs when “work flows from the focal employee to others” (Grant & Parker, 2009, p. 324), whereas received interdependence emphasizes how the focal employee is affected by work from others (Kiggundu, 1981). When both occur, the focal node is said to be under reciprocal interdependence. Morgeson and Humphrey (2006) provide a scale for both initiated and received interdependence, whereas Pearce and Gregersen (1991) provide items that measure reciprocal interdependence and *independence*. Other existing measures tend to emphasize reciprocal (e.g., Campion, Medsker, & Higgs, 1993; Wong & Campion, 1991) or mix items that reflect initiated, received, and reciprocal interdependence (e.g., Lee et al., 2018; Pennings, 1975).

Individuals typically respond to task interdependence items with respect to all of their tasks, meaning that a focal individual is asked not about a defined activity such as giving a presentation but, instead, about her perceived interdependence in general. The exception is a study and measure provided by Arthur et al. (2012). These researchers created a list of tasks that F-16 pilots completed during their training, gathered subject-matter-expert ratings of the interdependence among those tasks that could be used as an “objective” standard, and then created measures that were completed by individual pilots concerning their perceptions of interdependence *for each individual task*. The perceptions that emerged from the self reports then matched the SME-classified high, medium, and low task interdependent activities. The questionnaire provided by the authors is reprinted in Figure 1. For each task, individuals were asked to rate the extent to which they were required to work with other team members and then mark the pattern of workflow, such as pooled, sequential, or reciprocal. These authors also uniquely differentiate between team-relatedness, or the extent to which successful performance requires task interdependence, and team workflow, or the type of task interdependence as defined by Thompson (1967). The images of task relationships shown in their “team workflow” box are the same as those in Ven et al. (1976) and Thompson (1967): the questionnaire used by Ven et al. (1976) is shown in Figure 2. As shown, the images represent increasingly task interdependent work arrangements, moving from independent to sequential, reciprocal, and then team. Note that Bell and Kozlowski (2002) called the last task interdependence type “intensive” rather than “team.” In Arthur et al. (2012), members are asked to rate each task with respect to the task interdependence work flow type, whereas in Thompson (1967) and Ven et al. (1976) individuals used the images to describe the nature of their work as a whole.

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Insert Figure 1 about here

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Insert Figure 2 about here

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Moving to outcome interdependence, Table 2 shows self reports currently in the literature. Items in this space assess perceptions about shared goals, e.g., “My work goals come directly from the goals of my team” (Campion et al., 1993) or benefits contingent on group rather than individual contributions, e.g., “Many rewards from my job are determined in large part by my contributions as a team member” (Campion et al., 1993). There are a number of both individual (De Dreu, 2007) and team-referent (Janssen, Van De Vliert, & Veenstra, 1999; Zhang, Hempel, Han, & Tjosvold, 2007) measures. Campion et al. (1993) provide two separate scales, one for goal and the other for reward interdependence, whereas other researchers assess only goal interdependence (Zhang et al., 2007), reward interdependence (De Dreu, 2007), or use items that tap both domains (Janssen et al., 1999).

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Insert Table 2 about here

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### Challenges, Recommendations, and Next Steps

#### 1 Multi Level Composition and Compilation. Our tables reflect whether items assess individual or team perceptions of task/outcome interdependence, and readers will probably consider that notion with a section title labeled “multi-level,” but the levels issue we draw attention to, instead, is among initiated, received, and reciprocal self reports. Many other discussions about appropriately moving from individual to team measures exist (James, 1982), and those ideas should of course be considered as both individual and team-level interdependence items are in the literature (see tables 1 and 2), but the idea that reciprocal is on a different level than initiated or received has gone unnoticed. In our view, initiated and received task interdependence concern the perceptions of a single node. Reciprocal interdependence, though, requires multiple (at least two) nodes with shared perceptions about interdependence.

To appreciate this idea fully, work up from an understanding of initiated and received at the individual level. Initiated has to do with work flowing out of a given node, and is assessed with items such as, “Unless my job gets done, other jobs cannot be completed.” Received also concerns a single node, but it concerns work flowing into a given node, “My job cannot be done unless others do their work.” These are perceptions at the individual level regarding a given task or job. When both are at play, researchers label the measure as reciprocal and use items such as, “The way I perform my job has a significant impact on others” and “My own performance is dependent on receiving accurate information from others.” Our concern is not with the items or assessed construct, but with its label. To say that something is reciprocal is to imply words such as mutual, common, joint, corresponding, and complementary, meaning that more than one node has to agree with the pattern of in and out flows. This idea leads to an additional, untapped area for researchers to assess, which is the extent to which the perceptions of task outflows from one individual are shared by task inflow perceptions from another. If Jacob perceives outflow from his task in the direction of Roxanne, does Roxanne share that perception in the form of receiving inputs from Jacob? In our view, that is what reciprocal means – an emphasis on two nodes and their shared perception of workflow that is consistent with Thompson’s original 1967 writing and Van de Ven et al.’s 1976 instrument.

What we are arguing for as next steps, then, is one of two directions. Either the current label given to reciprocal items such as those in Table 1 is replaced by a new term, such as “both,” “full-flow,” or “IR interdependence” (meaning that both initiated and received interdependence are perceived but *only for one individual*) and reciprocal is reframed to mean what we described above, or – and probably the more reasonable approach given that reciprocal measures already exist – future research considers how to extend reciprocal and perhaps introduce a new term that captures agreement between task in-and-out flows as originally implied by Ven et al. (1976). Again, given that reciprocal already exists in the literature and a number of measures are at play, it makes sense to leave the label as is and adopt the second approach in future work.

Irrespective of the route, future work can leverage existing discussions in Chan (1998) and Kozlowski and Klein (2000) for how to proceed. An additive approach would simply sum or average the scores from two nodes regarding their task interdependence, whereas a direct consensus approach would entail an additional agreement score to justify aggregation. The more rigorous approach would be to provide both “I” and “We”-referent questions to both nodes, use an agreement index on the “I” scales to justify aggregation, and treat the “We”-phrased measure as the higher-level construct. Essentially, we are recasting the idea of initiated/received versus reciprocal into a levels idea from individual to dyadic.

#### 2 Task, Job, Person. The second tension is whether the focal node is a task, job, or person. Descriptions differ across reviews and theories. For instance, Kiggundu (1981) describes initiated interdependence as the degree to which work flows from a particular *job* to one or more other jobs, whereas Grant and Parker (2009) state that it occurs when work flows from a particular *employee* to others. These differences carry over into measurement items, which sometimes refer to tasks, e.g., “How well one task is performed has a great effect on how well the other task can be performed” (Wong & Campion, 1991) and at other times reflect the person or job, “My job cannot be done unless others do their work” (Morgeson & Humphrey, 2006).

In our view, there is a greater tension here than a simple wording difference. It is a theoretical and empirical question as to whether the mechanisms differ if the focal node of interdependence is a task, job, or person. If they do, it remains to be seen how much of an effect that has across the various measures. But the notion we want to point out is that measures should align with theory. If the theory and arguments being tested concern tasks, it may not be appropriate to use items that refer to jobs. Wong and Campion (1991) have argued that jobs are aggregations of tasks, which means that theorizing about one but measuring the other without justifying the translation in either direction would be untenable in the same sense as theorizing about individuals but measuring only team-level variables (Kozlowski, 2012).

#### 3 Purpose and Inference. Much like the application of a statistical model to data, we recommend that researchers think hard about the inference they wish to make and use that reasoning as a basis for which measure to choose. Our tables provide references and can be used as a guide for where to turn given a researcher’s particular interest. When the focal nodes are tasks and researchers are interested in reciprocal task interdependence, Wong and Campion’s (1991) scale can be used. If, instead, the focal nodes are people and their jobs in general and researchers are interested in received interdependence only, Morgeson and Humphrey’s (2006) scale can be employed. The questionnaire designed by Arthur et al. (2012) is a good option when researchers have already conducted a task analysis and have enough information to inquire about individual tasks. Both goal and reward interdependence can be assessed at the individual level with items provided by Campion et al. (1993).

By presenting these various resources and providing some traction on interdependence measurement, our literature will hopefully avoid unnecessary construct proliferation and/or contamination. As noted at the beginning of our paper, and made clear in Courtright et al. (2015), there are many different labels that sometimes refer to the same kind of dependence or researchers haphazardly switch between one label and another. At other times, different interdependence notions are chosen la carte and then recombined to seemingly introduce an entirely new idea or construct. We recommend identifying the specific form of interdependence of interest first, finding appropriate measures, and being consistent throughout one’s reasoning, writing, and measurement.

## Theoretical Indices

Researchers have also operationalized interdependence by presenting a number of formulas or methods for calculating an interdependence value outside of any perception by an individual enmeshed within the task network. An index of task interdependence, for example, could come from a count of the number of task precedence relationships that exist in a unit, or, in other words, the number of tasks that require other tasks to be completed before they themselves can occur. The value of interdependence in these measures, therefore, comes from the researcher either presuming task relationships and structure in a theory or observing it in the field, although the latter is far less common.

Table 3 depicts interdependence indices. The first five come from the organizational science literature, whereas the last three are pulled from the computer science and software engineering literatures. Indices provided by O’Brien (1968) and others cohere most directly with the notion of task interdependence represented in self reports, so we begin there. First, consider task precedence indices provided by O’Brien (1968), Wood (1986), and Oeser and O’Brien (1967) – row one of Table 3. These indices quantify the amount of precedence relationships in a task network. As shown in the images, when task one must be completed before task two, which must be completed before task three, which must be completed before task four, the index is greater than when tasks one, two, and three feed into task four but none of the first three tasks require precedent completions. In other words, a low value of the index means that tasks can be completed irrespective of the status of other tasks, performance on one does not depend on the performance or completion of another. Oeser and O’Brien (1967) originally introduced this index simply as the “task by task” matrix in their structural role theory, which was adopted and transformed slightly by O’Brien (1968) and called the inter-task coordination index, and later used as part of a task complexity taxonomy by Wood (1986) and labeled coordinative complexity. The index associated with Oeser and O’Brien’s (1967) task by task matrix can take on any positive, real value (zero included), whereas the inter-task coordination index provided by O’Brien (1968) is bounded by 0 and 1. Wood’s (1986) coordinative complexity index is identical to O’Brien’s (1968) inter-task coordination index. Note that the values we use in the example image include 10 and 3, so they come from Oeser and O’Brien’s (1967) task by task matrix, but the other index would also classify the first task structure as more interdependent given the greater number of precedence relationships.

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Insert Table 3 about here

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Row two of Table 3 presents another common theoretical task interdependence index that is often ignored or confounded in self report ratings: the extent to which individuals work jointly on tasks. Now, the emphasis is not on precedence relationships or the extent to which tasks must be completed before others, but on the allocation of people to tasks and the extent to which people overlap in those assignments. To what extent is a given task completed by one or multiple individuals? Oeser and Frank (1962, 1964) originally introduced this index in their person by task matrix within structural role theory, and, as with the other index, O’Brien (1968) later adopted it and provided a scaling between 0 and 1 that he called inter-position collaboration. The images show two possible ways to assign two individuals to two tasks. In the first, each task is completed by a single individual so the index takes on a low value, whereas the index increases for the second arrangement where task one undergoes joint performance by both individuals.

The next row of Table 3 describes the NK model of interdependence presented in the strategy literature by Lenox et al. (2007). This index captures the complexity of task or activity configurations within a unit. Imagine a unit or team with four tasks, A, B, C, and D, and assume that A depends on B and there are no other task dependencies. Take task A to be “training” and task B to be “find a manager to train the unit,” where each can take on a binary value, 0 or 1, in which the options for A include error management or active learning whereas those for B include two different managers, Joe and Kelly. We can represent an arrangement in a task vector, such as [0, 1], which, in this case, means that the unit received error management training by Kelly, whereas the vector [1, 1] would mean that the unit received active learning training by Kelly. Given that A depends on B in this example, there are four task vectors that may produce unique values of performance for the unit: [0, 0], [0, 1], [1, 0], and [1, 1]. Said differently, the results of tasks A and B with respect to unit performance (or any other relevant outcome) could potentially differ in four ways due to the task arrangements that stem from interdependence. When task A depends not only on B but also on C, there are eight unique (binary) configurations, and when A then also depends on D there are 16 unique (binary) configurations. This index, therefore, represents the increasing number of potential results as tasks begin to depend on one another.

The next three task interdependence indices in Table 3 come from software engineering and computer science: syntactic, workflow, and logical dependency (Bitton, Millman, & Torgersen, 1989; Cataldo, 2007; Cataldo, Mockus, Roberts, & Herbsleb, 2009; Gall, Hajek, & Jazayeri, 1998; Levchuk, Levchuk, Meirina, Pattipati, & Kleinman, 2004). Before discussing them, it helps to briefly unpack common work activities for programmers. Imagine an individual who writes a script that will eventually become a website for a blog about cooking, music, and current events. The blog contains posts about the various topics, images displayed on each page, an interesting design in the background, links to similar material on other sites, and compiled reports on US trends garnered from scraping data across the web. Often, code for different tasks will be stored within different scripts. One script may scrape and clean data from the web while another searches for and prepares links to other relevant material. A third script contains the text for each post, a fourth prepares images and charts. A master script then references each of these individual scripts and ultimately compiles the website, and, back down a level of abstraction, each individual script may reference yet other scripts that initiate basic functions and objects. All of the ways in which these various scripts “reference” one another, or pull code from different sources, creates dependence in a similar way that tasks more familiar to organizational psychologists do. The other aspect that merits attention before discussing dependence is commits. After writing code for one or several files, a programmer then commits her changes either to be checked by others or maintained indefinitely by the website. With these basic notions in mind, syntactic, workflow, and logical become easier to understand.

Syntactic dependency refers to the number of code references either across all scripts or within a single file. When Justin’s code references two other files, A and B, his script is said to have less syntactic dependency than Rachel’s code that references six other files. The units of comparison could also be entire sets of scripts rather than single files. Think back to the cooking, music, and current events blog mentioned above, perhaps its code, as an entire unit, contains greater syntactic dependency than the files, as a unit, from another site on sports commentators within the US. Whenever a script or set of scripts reaches elsewhere for additional code, syntactic dependency increases.

Logical dependency is similar, but it incorporates commits. Essentially, this index captures the extent to which files, when worked on, require other scripts to be updated within the same commit or time window. Think of a progression of task or script updates: on Monday, Roger updates script (task) A and B, and he does the same on Tuesday and Wednesday. On Thursday and Friday, however, he updates script (task) Z only. Scripts A and B then have greater logical dependency than script Z – those files demonstrate greater interdependence because they were modified within the same time period.

Workflow dependency, finally, is the degree centrality of the person with the greatest degree centrality out of all of the people working on a script. Imagine two different scripts, A and B, each with an assortment of different people writing their code. Susie, Sarah, Savannah, Sam, and Sheryl write code within script A, whereas Robert, Rachel, Rome, Rupert, and Robin write code within script B. Out of all the people working on script B, Rome has the greatest degree centrality (4). Sarah, on the other hand, has the greatest degree centrality out of all of the people working on script A (10). Script A, then, is said to have greater workflow dependency than script B.

Indices of outcome, rather than task, interdependence were presented in Victor and Blackburn’s (1987) writing on interdependence theory. They unpacked what is essentially a game theory framework for describing and quantifying actions and outcomes for two or more individuals. The matrix representation used in their paper is identical to normal form games in economics where players are situated either on the row or the column, along with their possible actions, and the values in the matrix represent the rewards, outcomes, or utilities for the row/column player. The example reprinted in Table 3, for instance, shows that the sales manager receives an outcome of 5 when she conducts action A2 while the credit manager conducts action B1. All of the examples described in their theory use actions and activities, but the ideas generalize to tasks as well. The index that we draw attention to is a number that Victor and Blackburn (1987) call the index of dependence that captures the extent to which the rewards/outcomes for one player are determined by the other player’s tasks or actions (this number is not the specific value within an outcome matrix, such as 5 or -4 in the top right cell). For example, for a given move by the credit manager, the sales manager does not change her outcome by switching from action (task) A1 to action (task) A2. In other words, the outcomes associated with the network of tasks or actions are determined by the actions/tasks of the row player but not the column player. In this case, then, the index of dependence for the sales manager is 1, meaning that her outcomes are completely determined by the other player’s actions (tasks).

The index of dependence is computed for every individual in the game so that each person receives his or her own (potentially) unique value, but Victor and Blackburn (1987) also provide a team-level index called the index of correspondence which captures the overlap between rewards governed by an individual’s own actions (tasks) and those governed by other’s actions (tasks). Imagine a system in which all players have some control over their outcomes given their task choices. Susan, for instance, can choose between writing (task 1) or scheduling meetings (task 2) and those tasks lead to different outcomes such that she has a preference for one over the other. Jackie also has task choices; she can choose to analyze data (task 1) or update the scripts for her shared website with Susan to improve its security (task 2). To the extent that Jackie’s task choices influence Susan’s outcomes irrespective of whether Susan chooses to write or schedule, Susan’s index of dependence will increase – her outcomes depend not only on her actions or tasks but also on Jackie’s. The index of correspondence, conversely, is about the alignment of choices under one’s own control with those not under one’s own control. To what extent does the unit share preferences for actions, task completions, or task choices? One individual can collect different rewards for making different choices, but rewards are also determined by the other players’ choices. To what extent do those two tensions align?

### Recommendations, Challenges, and Next Steps

#### 1 Overlap Among Indices and Self Reports. Having discussed both the indices and self reports, we can discern their similarities and differences. The self reports tend to include the individual as the focal node and consider perceptions across all tasks, whereas the indices are more distinct: researchers created indices for task-task relationships, person-task assignments, and total task configurations. The exception among the self reports is Wong and Campion (1991): their survey refers to tasks as the focal nodes rather than using “I” or “Job”-referent items. For this reason, we expect their measure to be most similar in its nomological network to the inter-task coordination index presented by O’Brien (1968).

Another implication with respect to whether a person or task is the focal node is the extent to which the measure is robust to changes in the node identity. The inter-task coordination index, for example, distinguishes between work flowing from task to task and the people assigned to various tasks, whereas many of the self reports – as well as the images in Ven et al. (1976) – refer simply to work flowing from person to person. There is no reason why some of the theoretical indices could not be modified to also capture the more general notion of person to person work exchanges, meaning that they should be robust, but perceptions about task interdependence captured within the self reports may differ dramatically when the referent is a single individual and his general job versus a single task and its requirements.

Another difference is that the indices capture a number of nuanced forms of task interdependence that may or may not be subsumed within the more general self report items. One of the most discussed aspects within the papers presented by O’Brien (1968), Oeser and Harary (1964), and Oeser and Harary (1962) is the notion of joint performance where two or more individuals work on the same task. This idea is not directly assessed in self reports, although it is possible that it finds its way into items such as “The way I perform my job has a significant impact on others.”

Finally, there is no study that assesses alternative methods or discusses best practices for capturing fit between a theoretical index and perceptions of interdependence. Perceptions measured via a self report are compared to a standard in Arthur et al. (2012) and Sherman and Keller (2011). Both studies use supervisors as SMEs and have them rate the interdependence of various tasks by showing them the images presented in Figure 2 – those ratings are taken as an objective comparison in Arthur et al. (2012) and Sherman and Keller (2011) refer to the SME ratings as latent interdependence. Although neither study compares self reports to the theoretical indices presented here, they can be taken as starting points for future work on fit methods. Research in this area would also benefit from a paper by McCann and Ferry (1979) on interdependence perceptions. These authors identify several factors that they predict influence perceptions of interdependence, including, for instance, the number, amount, and frequency of resources exchanged per unit of time. Again, their discussion does not concern “true” interdependence between nodes but the variables thought to influence perceptions. They also identify a number of moderators such as the uncertainty in the environment and individual differences in the perceiver. Although it is a theory paper without data backing or denying its claims, future work could use McCann and Ferry (1979) as a theoretical guide to determine variability in interdependence perceptions and how those do or do not overlap with interdependence captured in some of the indices presented here.

#### 2 Index Dynamics. We discussed the indices, and many of them are presented, as single snapshots of a given arrangement among nodes. It would also be fruitful to consider the transition rules from moment to moment as indices develop through time. Wood (1986) notes that many aspects of interdependence deserve attention as to how they transition from one time point to the next, including the set of tasks required, their arrangement, and the relationships between tasks and the product. There are number of routes for research in this area.

A straightforward direction would be to consider index self-similarity through time by relating an index at to its value at . There are many reasons why interdepence, both task and outcome, may either remain stable or change from one time point to the next, but even when it changes it must change from where it was at the previous moment and therefore will likely retain some level of self-similarity or autoregression.

Another interesting application is to recognize that the tasks in O’Brien’s (1968) inter-task coordination index could also be construed as time points. The author provides an index about relationships among nodes such as t1, t2, and t3, but there is no reason why those nodes must be separate tasks rather than one task repeating itself through time or subtasks completed at different time points within one global task. Seen in this view, the index would represent precedence relationships across time rather than across tasks. Other indices might also be created that quantify the stability or changes of interdependence relationships within a time window. Although we hesitate to call these broad-view ideas “dynamic” given that they emphasize general patterns across all time within the situation rather than moment to moment transitions (DeShon, 2012), they could still be very useful.

#### 3 Purpose and Inference. A point that we want to continually make is that researcher choices regarding measurement and indices should follow the inference they wish to make and the purpose of their study. With the tables, figures, and explanations provided in this paper, we hope to more easily direct researchers to their measure of interest. If the interest is task interdependence with tasks as the focal node, syntactic dependency or the inter-task coordination index are viable options. If the interest falls more with respect to joint task duties, a researcher should opt for the collaboration index. Given the breadth of constructs and ideas subsumed within the broad idea of interdependence, it is important to be consistent across theory and measurement.

# Discussion

Structural interdependence is one of the key features that drives organizational activity. Few theories on team behavior, leadership, or effective unit performance find merit without acknowledging some aspect of task workflows, the connections among actors, resource partitioning, or the amount of congruence among individual and group goals. Researchers have even gone so far as to say that the possibility for a group to be greater than the sum of its parts is a direct function of interdependence (Tziner & Eden, 1985). Given its importance, the field has seen an array of measures and theoretical indices emerge, all capturing somewhat different aspects. In the 60’s, 70’s, 80’s, and 90’s a range of indices based on task and person matrices were advanced, but recently the field’s dominate method for assessing interdependence has been self reports. Our paper reflected on this material, organized the measures into a coherent taxonomy so that future work can more readily apply the various measures, and raised questions and assumptions to facilitate sound practice within interdependence measurement. Moreover, discussion regarding interdependence indices and measurement is far behind what we have witnessed in related areas such as agreement indices (e.g., Kozlowski & Hattrup, 1992) or fit statistics. The purpose of this paper is to call attention to this domain and ignite research in this area.

Throughout, we acknowledged tensions in dependence measurement. We close by providing clear recommendations on how researchers should represent and interpret dependence in their work.

First, researchers should think hard about the purpose of their study and the inference they are trying to make before selecting an interdependence measure. Do not choose a measure simply because it is easy to find or convenient. We provide references and example items for a large list of measures that should help researchers identify a measure that captures what they are after. Without clarity regarding the process or construct researchers wish to make inferences about, finding an adequate measure or way to operationalize it is unwarranted. Our tables can be used to identify interdependence measures of various types at different levels. If, for example, the interest is initiated interdependence at the individual level, a researcher could use the subscale provided by Morgeson and Humphrey (2006), whereas measures provided in Table 2 on outcome interdependence can be used for researchers interested in the degree to which the outcomes of taskwork are measured, rewarded, and communicated so as to emphasize collective outputs rather than individual contributions. Moreover, Arthur et al. (2012) provide a particularly useful scale when researchers have already conducted (or have the resources to conduct) a task analysis and can ask subjects workflow questions regarding each task that they complete.

Second, researchers should align theory with measurement. Inferences regarding levels that are not measured are said to be misspecified. Rousseau (1985) originally spoke about this issue with respect to individuals and organizations, where misspecification referred to collecting individual-level data and using it to make (spurious) inferences about organizations. The same reasoning applies to tasks and jobs. Wong and Campion (1991) state that a job “is an aggregation of tasks assigned to a worker. When the same set of tasks are performed by more than one worker, those workers … have the same job” (p. 825). Misspecification occurs when researchers collect task-level data but make inferences about jobs – an aggregated, higher-level construct – or when researchers collect job or person-level data but direct their inferences down a level and speak about tasks. If the theory and reasoning apply to jobs, then jobs should be the referent within the measurement device, and if the theory and reasoning refer to tasks, then tasks should be the measured unit.

Finally, our review and tables provide clarity on dependence interpretation. We refer readers to the original sources if they wish to learn more about computing a specific index, our focus is on interpreting various indices. The self-report measures are straight-forward: a high score on a task interdependence device indicates greater perceived workflow requirements, precedence relationships, or resource partitioning than a low score, whereas outcome interdepenedence self-reports assess the extent to which goals or rewards are (perceived to be) determined by collective rather than individual contributions. The structrual interdependence indices are less common and so are not as familiar, but they are interpreted as follows. Indices provided by O’Brien (1968), Wood (1986), and Oeser and O’Brien (1967) capture precedence relationships: a greater value indicates that tasks must be completed before others, whereas a low value indicates that tasks can be completed independently. Indices provided by O’Brien (1968) and Oeser and Frank (1962, 1964) reflect joint taskwork: a greater value indicates that tasks are completed simultaneously by a greater number of individuals, whereas a low score indicates that each task is completed by a single or few individuals. Syntactic, workflow, and logical dependency all capture the extent to which scripts (tasks) require material from other scripts (tasks). A high value of syntactic dependency, compared to a low value, means that one script (task) uses material from many other scripts (tasks). A high value of logical dependency, compared to a low value, means that a given script (task) requires other scripts (tasks) to be updated within the same time window – programmers call these time windows commits, but they could represent any timespan of interest. A high value of workflow dependency, compared to a low value, indicates that a given script (task) undergoes changes by someone with many connections to other people and their tasks. The NK model of interdependence (Lenox et al., 2007) captures the number of configurations as tasks begin to depend on one another. A high value indicates that there are many task orientations, each potentially resulting in different outcomes for the individual, group, or organization. Indices provided by Victor and Blackburn (1987) assess outcome interdependence. A high value of their index of dependence means that outcomes for a given individual are determined by the tasks of others in his or her unit, whereas a low value reflects independent rewards – any changes in rewards or outcomes stem from the individual’s tasks only. Moving to the index of correspondence, a high value reflects overlap among rewards determined by one’s own tasks with rewards determined by other’s tasks, whereas a low value means that rewards determined by one’s own tasks do not align with rewards determined by other’s tasks. In other words, a low value reflects incentives to act only on tasks that are rewarded at the individual level.

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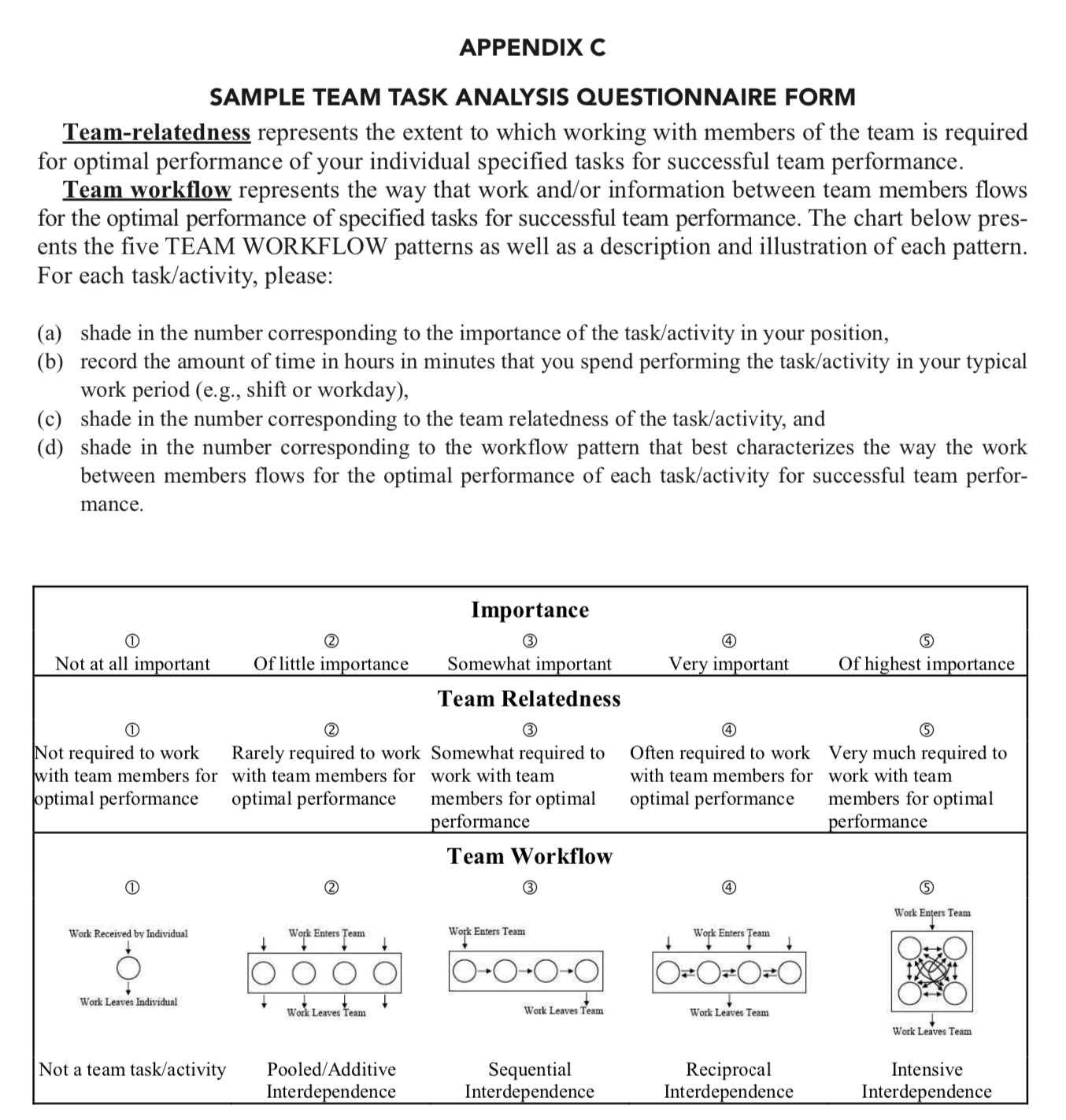
Zhang, Z.-X., Hempel, P. S., Han, Y.-L., & Tjosvold, D. (2007). Transactive memory system links work team characteristics and performance. *Journal of Applied Psychology*, *92*(6), 1722.

Table 1.

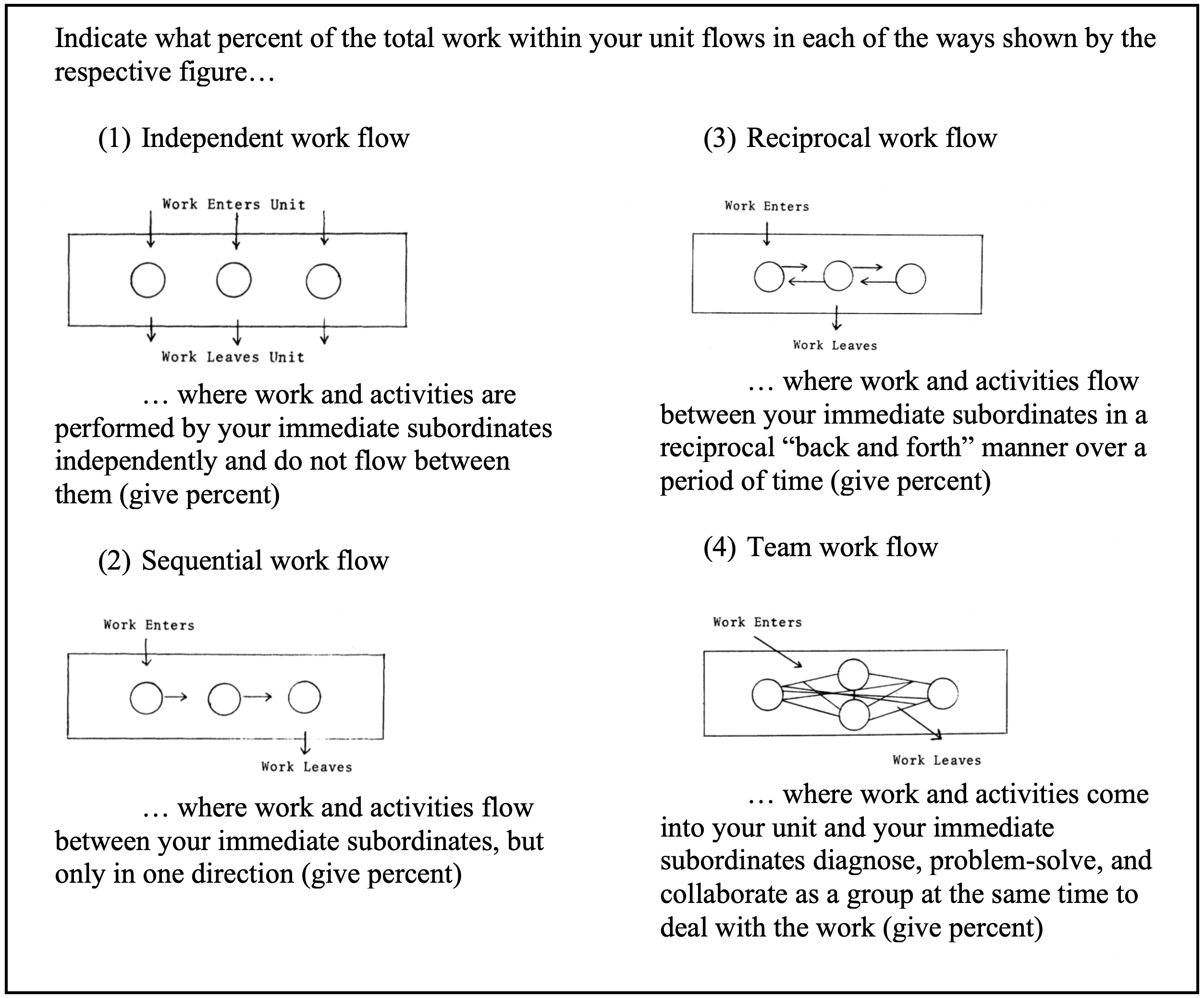
Task Interdependence – the degree to which taskwork is designed so that members depend upon one another for access to critical resources and create workflows that require coordinated action

* *Note: Example items in italics*

|  |  |  |
| --- | --- | --- |
|  | Interdependence Type | Level |
| Morgeson & Humphrey, 2006 (A)   * *The job requires me to accomplish my job before others complete their job* * *Unless my job gets done, other jobs cannot be completed* | Initiated | Individual |
| Morgeson & Humphrey, 2006 (B)   * *The job depends on the work of many different people for its completion* * *My job cannot be done unless others do their work* | Received | Individual |
| Wong & Campion, 1991   * *How well one task is performed has a great effect on how well the other task can be performed* * *One task needs to be performed before the other task* | Reciprocal | Individual |
| Pearce & Gregersen, 1991   * *The way I perform my job has a significant impact on others* * *My own performance is dependent on receiving accurate information from others* | Reciprocal | Individual |
| Campion, Medsker, & Higgs, 1993   * *I cannot accomplish my tasks without information or materials from other members of my team* * *Other members of my team depend on me for information or materials needed to perform their tasks* | Reciprocal | Mix |
| Ashworth, 2007   * *I have to obtain information and advice from others on my team to complete my work* * *I have to work closely with others on my team to do my work properly* | Mix | Individual |
| Ariel, 2000   * *To what degree do team members need to work closely together* * *To what degree do team members need to coordinate their work efforts* | Mix | Team |
| Liden, Wayne, & Bradway, 1997   * *Group members frequently must coordinate their efforts with each other* * *The way individual members perform their jobs has significant impact upon others in the group* | Mix | Team |
| Mohr, 1971   * *Mine is pretty much a one-person job; there is little need for checking or working with others* | Mix | Individual |
| Pennings, 1975   * *Dependent on others for advice and other decisional inputs* | Mix | Individual |
| Lee, Shin, & Ki, 2018   * *I cannot accomplish my tasks without information or materials from other members of my team* * *Within my team, jobs performed by team members are related to one another* | Mix | Mix |
| Wageman & Gordon, 2005   * *We worked as a team – not a collection of individuals with their own tasks to perform* * *My work was not done until everyone had done his or her part* | Mix | Mix |



*Figure 1.* Arthur et al.’s (2012) task interdependence questionnaire based on individual tasks. Participants are asked to shade in team relatedness and team workflow responses for each task.



*Figure 2.* Workflow questions presented by Van de Ven et al. (1976) and Thompson (1967).

Table 2.

Outcome Interdependence – the degree to which the outcomes of taskwork are measured, rewarded, and communicated so as to emphasize collective outputs rather than individual contributions

* *Note: Example items in italics*

|  |  |  |
| --- | --- | --- |
|  | Interdependence Type | Level |
| Zhang, Tjosvold, & Hempel, 2007   * *The goals of team members go together* * *When our team members work together, they usually have common goals* | Goal | Team |
| Campion, Medsker, & Higgs, 1993 (A)   * *My work goals come directly from the goals of my team* * *My work activities for a given day are determined by my team’s goals for that day* | Goal | Individual |
| Campion, Medsker, & Higgs, 1993 (B)   * *Many rewards from my job are determined in large part by my contributions as a team member* * *My performance evaluation is strongly influenced by how well my team performs* | Reward | Individual |
| De Dreu, Carsten, & West, 2001   * *When one or more team members excel in their work, I benefit from that* | Reward | Individual |
| Ashworth, 2007   * *Members of our team are informed about the goals we should attain as a unit* * *Members of our team receive feedback on the basis of our collective performance* | Mix | Team |
| Janssen, Vliert, & Veenstra, 1999   * *Benefits for one team member involved benefits for others* * *Gain for one team member meant gain for others* | Mix | Team |
| Van Der Vegt, Enmans, & Van De Vliert, 2000   * *Group members are informed about the goals they should attain as a group* * *Group members receive feedback on the basis of their collective performance* | Mix | Team |

Table 3.

Structural Interdependence Indices

|  |  |  |
| --- | --- | --- |
|  | Interdependence Type | Level |
| O’Brien, 1968 – Intertask Coordination  Wood, 1986 – Coordinative Complexity  Oeser & O’Brien, 1967 – Task x Task Matrix   * *Purpose: index the extent of precedence relationships among tasks* | Task | Either |



|  |  |
| --- | --- |
| Value | |
| 10 | 3 |

|  |  |  |
| --- | --- | --- |
|  | Interdependence Type | Level |
| O’Brien, 1968 – Interposition Collaboration  Oeser & Frank, 1962, 1964 – Person x Task Matrix   * *Purpose: index the extent to which people work jointly on tasks* | Task | Either |



|  |  |
| --- | --- |
| Value | |
| 0 | 0.5 |

Table 3 continued.

|  |  |  |
| --- | --- | --- |
|  | Interdependence Type | Level |
| Lenox, Rockart, & Lewin, 2007 – NK Model of Interdependence   * *Purpose: index the increasing number of potential results as tasks become dependent on one another* | Task | Either |

* Example
  + Task (or activity) A depends on B = 4 potential results
  + Task (or activity) A depends on B and C = 8 potential results
  + Task (or activity) A depends on B and C and D = 16 potential results
    - Potential results = 2N where *N* = the number of dependent tasks

|  |  |  |
| --- | --- | --- |
|  |  |  |
| Syntactic Dependency   * *Purpose: index the number of instances where a script references code from another script* | Task | Either |

* Example
  + In script A, I reference data or objects or functions from 3 other scripts
  + In script B, I reference data or objects or functions from 8 other scripts
    - Script A has greater syntactic dependency than B

|  |  |  |
| --- | --- | --- |
|  |  |  |
| Workflow Dependency   * *Purpose: index the degree centrality of the most central individual that works on a script* | Task | Either |

* Example
  + Bobby (degree centrality = 5), Susan (1), and Jill (2) work on script A
  + John (3), Jackie (2), Bill (4), and Roger (1) work on script B
    - Script A has greater workflow dependency than Script B

|  |  |  |
| --- | --- | --- |
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| Logical Dependency   * *Purpose: index the extent to which a file requires other files to be modified during the same commit* | Task | Either |

* Example
  + During commit “Morning,” John works on file A which also requires him to work on files B and C
  + During commit “Afternoon,” John works on file M which is not dependent on any other files
    - File A has greater logical dependence than file M

Table 3 continued.

|  |  |  |
| --- | --- | --- |
|  | Interdependence Type | Level |
| Victor & Blackburn, 1987 – Index of Dependence   * *Purpose: index the extent to which rewards are determined by other player’s actions (tasks) rather than one’s own* | Outcome | Individual |

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Sales Manager – Player A | |
|  |  | A1  Approve | A2  Disapprove |
| Credit Manager – Player B | B1  Approve | -2, 5 | -4, 5 |
| B2  Disapprove | 0, 0 | 2, 0 |

|  |  |
| --- | --- |
| Value | |
| Index for player A = 1 (outcomes are completely determined by other player’s actions (tasks)) | Index for player B = 0.33 |

|  |  |  |
| --- | --- | --- |
|  |  |  |
| Victor & Blackburn, 1987 – Index of Correspondence   * *Purpose: index the extent to which, across the team, rewards determined by an individual’s own actions (tasks) are aligned with rewards determined by other’s actions (tasks)* | Outcome | Team |