Designing Organizations of Human and Non-Human Knowledge Workers

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Abstract. A robust body of research demonstrates that intentionally designing organizations generally has positive impacts on their performance and, by extension, goal attainment. Furthermore, a predominant view exists of such organizations as human-centric systems. However, the increasing ubiquity of artificial intelligent agents means it might be time to reimagine organizations as ecosystems composed of both human and non-human knowledge workers—and to purposefully design them as such. In the context of the development and production of a key component for a new electronic device, this paper provides two computational scenarios that describe how organizations might employ artificial intelligent agents and compares the impacts on performance. Based upon these results, this paper recommends that future studies investigate organizational missions most likely to benefit from non-human knowledge worker employment, the assignment of expertise and role negotiation between human and non-human knowledge workers, and when operational performance targets make employment of non-human knowledge workers worthwhile.

Keywords: Non-Human Knowledge Workers · Organizations · Organizational Design · Human-Machine Ecosystems · Organizational Performance

1 Introduction

Over the last 70 years, scholars and practitioners alike have found that well-designed organizations generate more robust organizational performance, which enhances goal attainment. Therefore, the purposeful design and engineering of organizations conditions goal attainment, such as value generation for stakeholders [1, 2]. The considerable body of work describing the effects organizational designs have on performance has generally considered organizations as human-centric systems [1–7]. However, organizations increasingly employ artificial intelligent agents in their organizational technologies. Therefore, the view of organizations as human-centric systems likely limits the relevancy of earlier organization theory (OT) and computational organization theory (COT) studies to modern and emerging organizations. Furthermore, the general treatment of artificial

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intelligent agents as parts of an organization's set of technical systems likely places unnecessary limits on organizational performance, thereby raising the question—*can a more relevant framework for designing organizations be developed?*

This paper reimagines organizations as complex systems in which a technical core composed of human knowledge workers (HKWs) and non-human knowledge workers (NHKWs) collaboratively perform tasks to attain goals. Departing from a general view of organizations as human-centric systems, this recharacterization of organizations and organizational technologies is likely to result in more optimal performance [7] and more relevant OT and COT studies. This paper begins with an overview of knowledge work, HKWs, and NHKWs. Next, organizational technologies are described, along with impacts NHKWs might have on them. An elementary example is then provided, using information from an empirical study regarding the launch of a personal electronic device (PED). Lastly, recommendations for future studies are offered.

1.1 Knowledge Work

Knowledge work drives the economies of the United States and other countries, making the performance of organizations characterized by knowledge work important to scholars and practitioners, alike.[1] *Knowledge work* refers to tasks that apply knowledge to knowledge and generate knowledge [8], such as analyzing military intelligence and scientific research, respectively. In comparison, *service work* applies knowledge to generally routinized tasks [8], such as troubleshooting hardware systems. Knowledge work and the processing of relevant information are inextricably linked because knowledge and information, themselves, are inextricably linked.[2] Therefore, organizations provide a particularly germane framework for investigating the performance of knowledge work and the impacts that NHKWs might have on organizational performance and, ultimately, goal attainment.

1.2 Human Knowledge Workers

HKWs are those individuals for whom knowledge work is the primary attribute of the tasks they perform. Importantly, it is the nature of a task that determines if it is knowledge work, not the nature of the individual performing the task [8]. Decision-making exemplifies knowledge work; decision-making intrinsically involves applying knowledge to knowledge in the gathering and processing of information to choose between options [9–12]. In contrast, presenting the results of choosing between options represents service work because it involves applying knowledge to performing a generally routinized set of activities (i.e., developing and delivering a presentation). Further, an individual can perform both knowledge and service work. The same individual who decided between investment options (knowledge work) can also develop and deliver a presentation on the results (service work). Ultimately, the volumetric proportion between knowledge and service work performed characterizes an individual as a knowledge or service worker.

[1] *Organizations* are fundamentally information processing and communication systems [2–4].

[2] *Knowledge* is information structured with perspectives, intuition, and experience [12–13]. *Information* is data with relevant context and *data* are numerals and symbols (logical and mathematical) with minimal context.

1.3 Non-Human Knowledge Workers

NHKWs co-exist with HKWs to perform tasks contributing more directly to organizational performance and, by extension, goal attainment. Despite their foundational algorithmic nature, NHKWs are more than advanced artificial intelligent agents—they are synthetic knowledge workers purposefully designed and encoded into organizations to relieve HKWs of cognitive tasks [14]. What distinguishes NHKWs from other forms of artificial intelligent systems is the conjunction of knowledge work, more comprehensive incorporation into organizational structures, algorithmic power, and task-level assignments commensurate with HKWs. The more comprehensive integration into organizational structures and technologies enables NHKWs to contribute more impactfully because NHKW performance is not limited unnecessarily by sub-optimal employment. Although adequate algorithmic power is a necessity, it is not a sufficient condition for an artificial intelligent agent to perform as a NHKW. This means that, although an artificial intelligent agent might have comparable or greater algorithmic power than a NHKW, the more limited organizational integration limits the impact they have on performance. Meanwhile, expert, robotic process automation, and similar technical systems generally lack the organizational encoding, algorithmic power, and operational employment characteristics necessary to perform knowledge work and, therefore, as NHKWs.

2 Organizational Technologies

An organization's technology describes how it accomplishes its mission and attains goals. In other words, an organizational technology refers to how an organization transforms raw inputs, including information and knowledge, into outputs, such as products and services [14, 15]. The technical core is composed of individuals, like knowledge workers, involved in the technological transformation process. Technical core personnel use techniques (i.e., methods performed via processes and mechanisms) to perform tasks, which are individual activities or sets of activities. To accomplish tasks, technical core personnel make use of technical systems, which are physical and non-physical resources, such as intellectual, hardware, software, and facility capabilities.

Divisions of labor between technical core members generate interdependencies that can impact organizational performance. *Interdependence* describes the degree to which outcomes rely upon inputs from others, including knowledge, information, and materials [16]. Three forms of interdependencies generally characterize organizations: pooled, sequential, and reciprocal [17]. *Pooled interdependence* describes cases in which resources needed by multiple tasks are centrally located and there is no workflow between the tasks themselves, such as providing heating and cooling independently to multiple work areas. *Sequential interdependence* describes cases in which the outputs of one task are inputs to a subsequent task, such as on an assembly line. *Reciprocal interdependence* describes cases in which the outputs of one task (task A) are used subsequently in other tasks (tasks B and C) and the outputs of the subsequently performed tasks are returned to the original task (task A) for use, such as in research and development. Concurrent task performance generally results in a greater volume of reciprocal interdependencies, which necessitates more robust task coordination because of the increased likelihood that changes in tasks B or C generate changes in task A [18]. This added collaboration workload can significantly affect organizational performance.

3 An Example

The launch of a new PED in 1998 necessitated the accelerated development of a then-new application specific integrated circuit (ASIC) and production of several prototypes in less than a year. The aggressive project schedule resulted in additional task interdependencies and coordination workload, which added to the total workload volume, thereby impacting task and organizational performance [18]. By using *POW-ER*, a validated engineering COT software application, and the validated computational model of the ASIC project [18–21], potential impacts of NHKWs on task and organizational performance are explored.[3]

3.1 POW-ER

POW-ER is a computational modeling and simulation software application that provides scholars and practitioners a means of engineering organizations. *POW-ER* enables users to investigate the impacts that organizational designs, task assignments and interdependencies, and hidden work have on performance. In many cases, the hidden workload associated with task coordination, rework, and resolving ambiguity between team members is not included in organizational models [18–20]. Consequently, the impacts that such activities have on task and organizational performance receives inadequate attention until too late—when the project is in, or about to be in, extremis necessitating herculean efforts to attain organizational goals. To address hidden workload, *POW-ER* uses the construct of total workload volume to capture the sum of task work, rework, and coordination work volumes and their impacts on performance.[4]

3.2 An Accelerated Launch

The 1998 launch of a new PED and development of a new ASIC, in particular, provides a robust backdrop for investigating impacts NHKWs might have on organizational performance. Meeting the deadline for the tradeshow at which the company planned to announce its new PED meant the project team had to accelerate the design and manufacture of an ASIC to roughly five months—a little more than half the normally allotted time [18]. Such an aggressive schedule resulted in team members performing tasks concurrently that they might have otherwise performed sequentially, which introduced additional reciprocal interdependencies. This, in turn, increased the coordination workload on team members [18–20]. Because ASIC development would consume nearly

[3] *POW-ER* is the enhanced version of the *Virtual Design Team* (*VDT*) developed by the Center for Integrated Facility Engineering [18–20]. *SimVision* is the commercialized version.

[4] *Coordination work volume* is the sum of communication, decision-making, and waiting time volumes [18–20]. *POW-ER* measures work volumes in full-time equivalent (FTE)-days, which represents the equivalent working time of an individual in a 24-h period. For the ASIC project, an FTE-day was eight hours [18, 21].

half the time the company had before the trade show, significant design and production delays could have proved disastrous for the company. Therefore, rapidly identifying and addressing emergent issues added to the existing supervisory and coordination workload.

Figure 1 provides a simplified organizational model of the ASIC design and production effort. The project starts with team members developing the needed specifications (i.e., the *Develop Spec* task) before next performing three tasks—*Implement Data Model*, *Implement User Interface (UI)*, and *Implement Analysis System*—concurrently with reciprocal dependencies between them [21]. Each of these three tasks provide inputs to the next task, *Integrate Systems*, which subsequently feeds the *Systems Integration Test* task. Completion of the *Systems Integration Test* task results in attaining the *Ready for Systems Test* milestone, meaning ASIC development is ready for its *UI Stress Test* and *Analysis Stress Tests*, which are performed concurrently. The *Software (SW) Design Coordination* task provides the *Data Architect*, *SW Project Manager*, *UI Team*, *Analysis Team*, *Integration Team*, and *Customer Representative* team positions a means to coordinate task performance and resolve issues in a *Group Status Meeting*. Individuals and sets of individuals filling team positions compose the technical core. A more comprehensive discussion regarding the operationalization of OT and COT theoretical constructs in *POW-ER* is available in [18–22].

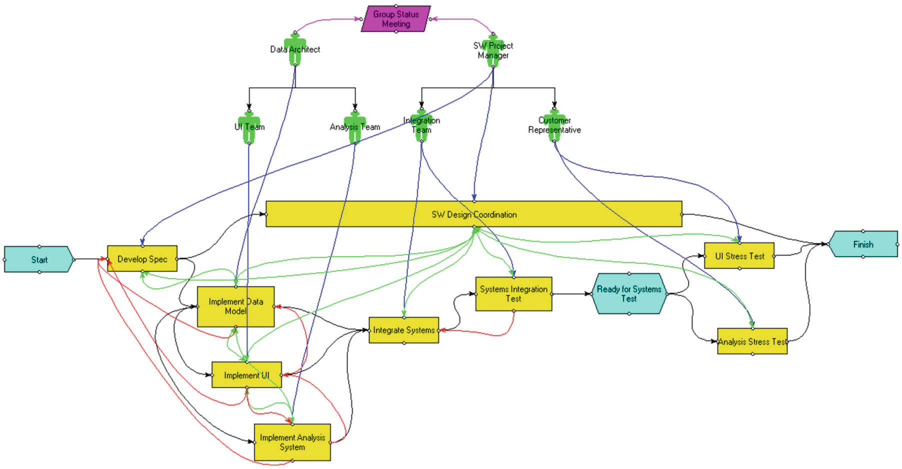

Fig. 1. The baseline organizational design for ASIC development and production depicts tasks, milestones, interdependencies, team positions, supervisory relationships, task assignments, communication linkages, and rework. Tasks and milestones are represented with yellow and blue trapezoids, respectively. Task interdependencies are denoted with black arrows. Team positions are represented with green silhouettes of humans; supervisory relationships are denoted with black arrows between positions. Task assignments are identified by blue arrows. Communication linkages are indicated by green arrows and team meetings are represented with magenta parallelograms. Potential rework between interdependent tasks is depicted with red arrows. Source: [21].

3.3 Comparative Trials

Two toy-problem [19] experiments provide for preliminary investigation into the conjecture that NHKWs more optimally impact organizational performance when performing tasks versus activities, *ceteris paribus* [14].[5] To take advantage of prior empirical research [18, 21] and for simplicity, all tasks are considered knowledge work, making all team members knowledge workers. Using the baseline scenario [21], two experiments provide likely lower and upper bounds on NHKW impacts on organizational performance, based upon activity- versus task-level work assignments.

The baseline scenario includes probabilistic estimates for four project-level properties—communication, noise, functional exceptions, and project exceptions—strengthening the realism of computational results. *Communication* represents the likelihood that team members need to exchange information with others based upon the degree of reciprocal interdependencies and task ambiguity [18–22]. *Noise* estimates the probability that communications unrelated to the ASIC project disturb personnel. *Functional exceptions* represent the probability a team member must rework part of their own tasks without impacting others. *Project exceptions* represent the chance problems arise that impact interdependent tasks and generate rework. The probabilities assigned to the four properties are 0.2, 0.1, 0.1, and 0.1, respectively [21].

The first experiment represents an artificial intelligent agent performing activity- versus task-level work, as an artificial intelligence (AI)-enabled task monitoring system (TMS) that continuously monitors project status and alerts team members of issues that could affect performance. To model this scenario, the parameters of the *Group Status Meeting* were modified such that, instead of a single 90-min meeting each week [21], team members receive updates every workhour. To minimize the impacts of such frequent updates on task performance, the duration of updates is limited to one minute. This scenario should result in more limited impacts on organizational performance because of the sub-optimal employment of artificial intelligent agent capabilities.

The second experiment scenario represents NHKW employment by substituting a NHKW for a HKW. In this case, the artificial intelligent agent performs knowledge work, possesses adequate algorithmic power, is organizationally encoded, and operates at the task level. Substituting a NHKW for a HKW on the *Analysis Team*, which consists of a single HKW in the baseline scenario [21], generates a more relevant comparison. This scenario should result in more significant impacts on performance because it more fully employs NHKW capabilities. Table 1 summarizes the three scenarios.

For the purposes of this paper, it is assumed that there is no variance in HKW productivity throughout the day, there is no change in rework volume because of task

[5] Empirical investigation of how NHKWs might affect organizational performance is limited to toy problems regarding task-level work prior to a more comprehensive investigation.

Table 1. Scenario comparison.

	Baseline	Experiment 1	Experiment 2
Role of the artificial intelligent agent	None	AI-enabled TMS	*Analysis Team* NHKW
Performs knowledge work		X	X
Possesses adequate algorithmic power		X	X
Is organizationally encoded		X	X
Performs task-level work			X
Anticipated impacts on organizational performance		Limited	More significant

fatigue, and the productivity of one NHKW is equivalent to four HKWs.[6] For each scenario, 1,000 simulations were run using a seed value of 1.0 for comparability.

3.4 Results

Figure 2 displays simulation results from the three scenarios with project tasks along the vertical axis and calendar dates along the horizontal axis. Red-colored bars indicate critical path tasks, blue-colored bars identify tasks not on the critical path, and grey-colored bars identify the float, or slack, available before the task impacts project completion. Diamonds represent project milestones and simulated task durations are displayed for the baseline, AI-enabled TMS, and *Analysis Team* NHKW scenarios from top-to-bottom.

In the baseline scenario simulation, the ASIC project team is projected to complete its work in 230 workdays. The task that most significantly impacts project completion and, therefore, organizational performance is *Implement Analysis System* with a simulated duration of 98 workdays. An AI-enabled TMS, the second scenario, has minimal impact; simulated results indicate the project will finish one day sooner. In contrast, the substitution of a NHKW for a HKW, the third scenario, generates more significant impacts with simulated project completion 59 workdays (26%) sooner than the baseline scenario. This same substitution further results in a 73-workday (75%) reduction in the duration of the task that most significantly impacts organizational performance in the baseline scenario. Impacts on other task and organizational performance parameters, such as rework volume, are generally negligible for the three scenarios.

[6] During an eight-hour workday, it is assumed a HKW takes a 30-min meal break, two 15-min breaks, and loses an hour to non-project disruptions, meaning a HKW performs six hours of task-related work during one FTE-day. In contrast, the nature of a NHKW means such breaks are likely unnecessary and that a NHKW does not experience the same performance limitations as HKWs [23]. Thus, a single NHKW can work a total of 24 h in a 24-h period, the equivalent of four HKWs.

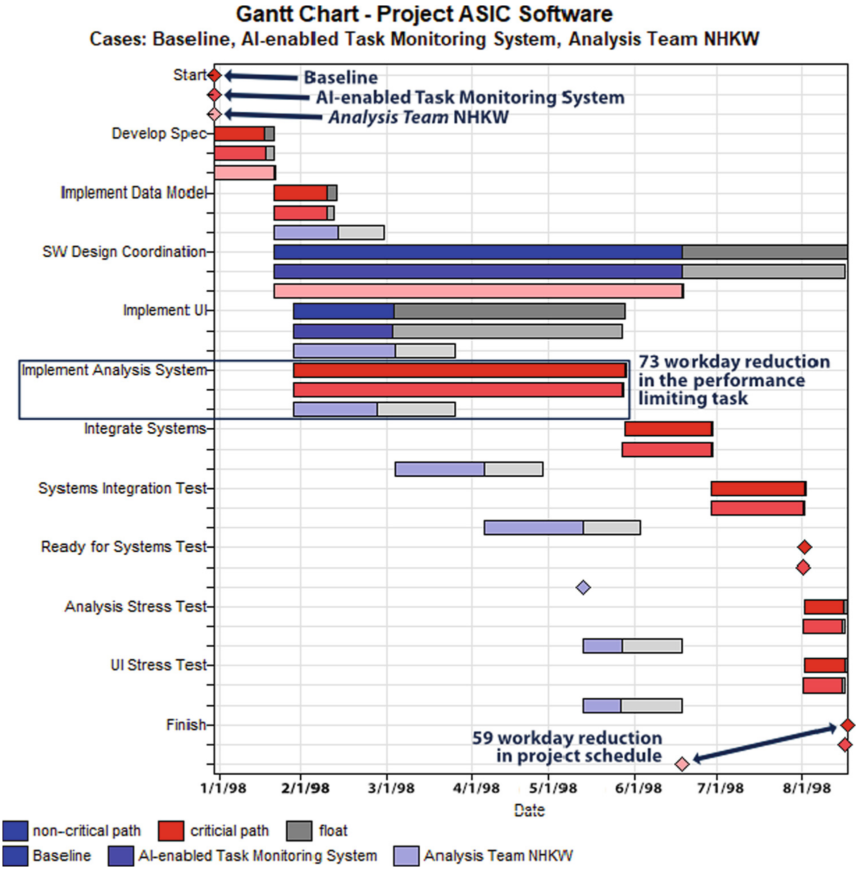

Fig. 2. Simulated durations, in work-days, for ASIC project tasks are displayed for the three scenarios with diamonds representing project milestones Adapted from: [21].

4 Discussion

Earlier studies that demonstrate intentionally designing organizations result in more optimal performance also appear to apply to ecosystems composed of HKWs and NHKWs. Designing such organizations means the reconception of a popular view of organizations as human-centric systems [1–7]. This paper juxtaposes two scenarios—an organization that incorporates artificial intelligent agent capabilities at the activity level with an organization that more optimally employs a NHKW at the task level. The former scenario also represents an organization that incorporates an artificial intelligent agent as a technical system, while the latter scenario represents an organization that employs the same capabilities as a member of its technical core.

Preliminary results, while limited, are telling and consistent with expectations. First, when the ASIC project team more optimally employs a NHKW, the impacts to simulated organizational performance are significant—an estimated 26% reduction in project duration. Second, the same results eclipse the simulated results from the less optimal approach of using the same artificial intelligent agent capabilities as a technical system. The results are likely because the NHKW is not limited by limitations on human performance [14, 23]. Notably, only the NHKW *Analysis Team* scenario resulted in a simulated project duration (171 days) close to the allotted five-month window.

This paper has several limitations. First is the relatively narrow discussion of the effects NHKWs might have on organizational design and performance. Only two cases, both rudimentary, are considered, thus meriting a more thorough assessment. Second, the exploration of NHKW characteristics is generally limited to the overarching construct and their operational employment. A more comprehensive investigation of relevant characteristics is needed. Third, assumptions regarding knowledge worker productivity warrant refinement. Notwithstanding these limitations, the use of a validated COT tool and information from a prior empirical study make the results more compelling by eliminating effects from using a non-validated tool and uncorroborated information.

Future studies should further explore the extent to which NHKWs impact organizational design, performance, and, by extension, goal attainment. Four recommended focus areas are: (a) the organizational missions most likely to benefit from NHKW employment; (b) the identification and assignment of expertise within HKW and NHKW organizations; (c) role negotiation between HKWs and NHKWs; and (d) when operational performance targets make NHKW employment worthwhile.

5 Conclusion

It is not a matter of *if*, but *how* organizations will more optimally employ artificial intelligent agents. A rich body of scholarly work, corroborated by practice, demonstrates that purposefully designing organizations positively impacts performance. The increasing presence of artificial intelligent agents means it is likely time to reimagine and redesign organizations as ecosystems composed of HKWs and NHKWs. In the context of an ASIC development and production project, this paper presented two scenarios and computationally demonstrated that intentionally designing and incorporating NHKWs into organizations can significantly impact organizational performance. The accelerating use of such artificial intelligent agents makes the rapid formalization and operationalization of NHKWs an imperative—for scholars and practitioners, alike.

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References

1. Burton, R., Obel, B.: Strategic Organizational Diagnosis and Design: The Dynamics of Fit, 3rd edn. Springer Science Business Media, LLC, New York (2004)
2. Galbraith, J.: Organization Design. Addison-Wesley Publishing Co., Menlo Park (1977)
3. March, J., Simon, H.A.: Organizations. John Wiley & Sons Inc., New York (1958)
4. Cyert, R., March, J.: A Behavioral Theory of the Firm. Cambridge University Press, Cambridge (1963)

5. Mayo, E.: The Social Problems of an Industrial Civilization. Andover Press, Andover (1945)
6. Daft, R., Lengel, R.: Organizational information requirements, media richness and structural design. Manage. Sci. **32**(5), 554–571 (1986)
7. National Academies of Sciences: Engineering, and Medicine: A Decadal Survey of the Social and Behavioral Sciences: A Research Agenda for Advancing Intelligence Analysis. National Academies Press, Washington D.C (2019)
8. Drucker, P.: The rise of the knowledge society. Wilson Q. **17**(2), 52–71 (1993)
9. Arrow, K.: The Limits of Organizations. W. W. Norton & Company Inc., New York (1974)
10. Cohen, M., March, J., Olsen, J.: A garbage can model of organizational choice. Adm. Sci. Q. **17**(1), 1–25 (1972). https://doi.org/10.2307/2392088
11. Mortimore, D., Canan, M., Buettner, R., Jr.: Two probability theories and a garbage can. Comput. Math. Organ. Theory (2023). https://doi.org/10.1007/s10588-023-09378-3
12. Carley, K.: On the evolution of social and organizational networks. In: Andrews, S., Knoke, D., Bacharach, S. (eds.) Research in the Sociology of Organizations: Networks in and Around Organizations. Emerald Publishing Ltd., Somerville (1999)
13. Hollingshead, A., Fulk, J., Monge, P.: Fostering intranet knowledge sharing: an integration of transactive memory and public goods approaches. In: Hinds, P., Kiesler, S. (eds.) Distributed Work, pp. 335–355. MIT Press, Cambridge (2002)
14. Mortimore, D., Aten, K., Buettner Jr., R.: A new technology rises: non-human knowledge workers and decision-making in a system of complex systems. In: Proceedings of the 18th Annual System of Systems Engineering Conference, Villeneuve d'Ascq, France (2023). https://doi.org/10.1109/SoSE59841.2023.10178624
15. Perrow, C.: A framework for the comparative analysis of organizations. Am. Sociol. Rev. **32**(2), 194–208 (1967). https://doi.org/10.2307/2091811
16. Ren, Y., Argote, L.: Transactive memory systems 1985–2010: an integrative framework of key dimensions, antecedents, and consequences. Acad. Manage. Ann. **5**(1), 189–229 (2011). https://doi.org/10.1080/19416520.2011.590300
17. Thompson, J.: Organizations in Action. Routledge, New York (2003)
18. Levitt, R.: Organizational Design as "Virtual Adaption": Designing Project Organizations Based on Micro-Contingency Analysis (2005)
19. Jin, Y., Levitt, R.: The virtual design team: a computational model of project organizations. Comput. Math. Organ. Theory **2**(3), 171–196 (1996)
20. Levitt, R.: Computational modeling of organizations comes of age. Comput. Math. Organ. Theory **10**(2), 127–145 (2004)
21. *POW-ER*. (Version 3.4a): Collaboratory for Research on Global Projects
22. Collaboratory for Research on Global Projects: *POW-ER* Documentation for *POW-ER* 2.0. Stanford University, Stanford (2006)
23. Carley, K., Behrens, D.: Organizational and individual decision making. In: Sage, A., Rouse, W. (eds.) Handbook of Systems Engineering and Management, 1st edn. John Wiley and Sons, Inc., New York (1999)