DECISION NETWORKS AND COMMAND ORGANIZATIONS

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Contents

Summary

The changing patterns of today's world impose new requirements on many modern organizations, ranging from military establishments to agile manufacturing systems and commercial enterprises. With the benefits of new information technologies now under development, the competition will be won by an organization that can best utilize both its resources and its critical information to achieve its goals. This implies the need for much greater emphasis on realistic modeling of distributed organizations in which the human participants are the focus.

This article provides a selective overview of decision networks performing distributed hypothesis testing and command organizations executing specific missions, and illustrates the key issues via a series of examples. We begin with the problem of modeling a single decision maker (DM) in binary event detection tasks, and show that the expertise of an individual DM can be characterized by a relative operating characteristic (ROC) curve. Then we consider a distributed version of the event detection (hypothesis testing) problem, wherein multiple distributed DMs cooperate as a team to reach a final decision. Key findings in this case are that the aggregated organizational expertise is operationalized by a *team* ROC curve, and that the jointly optimal decision procedures at each DM are in the form of *coupled* operating points on their individual ROC curves.

Using the distributed detection paradigm, we illustrate the impact of task structure on the performance of organizations with different designs. We conclude that the architecture of an organization must be matched correctly to its task structure to achieve superior performance, leading to the concept of *congruence*. We elaborate on this concept in terms of a trade-off between decision performance and internal communication, and develop a method for synthesizing congruent organizational structures. This is followed by a discussion on the need to seek a proper balance among task scheduling, resource allocation, and decision hierarchy, and the development of a methodology for modeling missions and synthesizing the concomitant congruent, robust and adaptive organizations. Finally, we conclude with a summary of current results in heterarchical and holonic organizations and future research directions.

1. Introduction

The changing patterns of today's world impose new requirements for many modern organizations, ranging from military establishments to agile manufacturing systems and commercial enterprises. With the benefit of new information technologies now under development, the competition will be won by an organization will best utilizes both its resources and its critical information to achieve its goals. This implies the need for much greater emphasis on realistic modeling of distributed organizations in which the human participants are the focus.

A key asset of a successful organization is its design: the goals and strategies, the underlying expertise, information about the environment, the structuring of task solution processes, the assignment of people to positions; in short, the way the organization functions. Oftentimes the value of an organizational design is explicitly assessed, as in the following example from Mackenzie:

> A bank in a Southern US state wanted to acquire another bank; and it had two alternative banks in the same city block which could be acquired. Both banks had a book value of approximately $ 15,000,000, but one had more market value because it was better run and more profitable. The better bank asked $30,000,000 and the other asked $18,000,000. Because both operated in the same market with the same technology, *a premium of $12,000,000 was placed on the organizational design of the better bank*.

As the above example illustrates, the efficacy and performance of an organization depend on its structure, its decision processes, and the task environment. The challenge is to develop and validate scientific models that reveal the complex mechanisms of interaction among task and organizational structures, strategies, and performance. The validated models can then provide guidelines for designing superior organizations.

This article provides a selective overview of decision networks performing distributed hypothesis testing (event detection) and command organizations executing specific missions. The problem scope and complexity of event detection and mission execution often require that the information acquisition, processing, and decision-making functions be distributed over a team of decision-making units (agents, sensors, in general: DMs), arranged in the form of a decision network or a command organization. In distributed event detection, DMs have access to partial observations about the true outcome of an uncertain environment. When the available information is distributed among the members of an organization, they must cooperate as a team to reach a final decision. Generally, DMs have uncertain knowledge about *different* local events (local hypotheses), which are only probabilistically related to the global event (team task, or global hypothesis). In the process of team decision making, quantified versions of local opinions are transmitted along prearranged communication lines, and individual assessments are aggregated into a final team decision. Thus, team expertise is a result of coupled *individual* and *team*-level processes. In addition, since communication within an organization is typically costly (sometimes even restricted), data exchange among DMs must be kept to a minimum level. Numerous real-life situations conform to this paradigm. Some representative examples include: a naval commander deciding whether a contact is hostile or friendly, based on reports from several heterogeneous sensors; an emergency manager deciding whether or not to evacuate a town based on hurricane forecasts; votes of stock holders deciding on the acquisition of a new business; a physician making a diagnosis based on the results of multiple diagnostic tests. We illustrate the key issues of single human and team decision making in the context of event detection via a series of examples.

Example 1: Heimann examines the evolution of organizational design of NASA's reliability and quality assurance system for the space shuttle Challenger as a function of political pressure either to prevent bad launches (Type I error or false alarms) or to increase resource utilization (which results in fewer Type II errors or misses). The *true* expertise of a decision maker in the context of binary decision problems is a collection of probabilities of detection (hit) and false alarms (P_d, P_f) for all possible preferences. The locus of (P_d, P_f), whose graphical representation is called a relative operating characteristic (*ROC*) curve, represents the accuracy (reliability) of a DM. As an illustrative example of a single decision-making unit, we determine the ROC curve of a unit component of Marshall Space Flight Center (MSFC), based on Heimann's data. The MSFC is to decide whether the proper course of action is to launch (or not to launch) based on a set of observed data available to the unit. The concepts of Type I and Type II errors will be elaborated further in Section 2.

When multiple distributed decision-making units cooperate as a team to reach a final decision, the team expertise is a result of coupled *individual* and *team* level processes, as the following example illustrates.

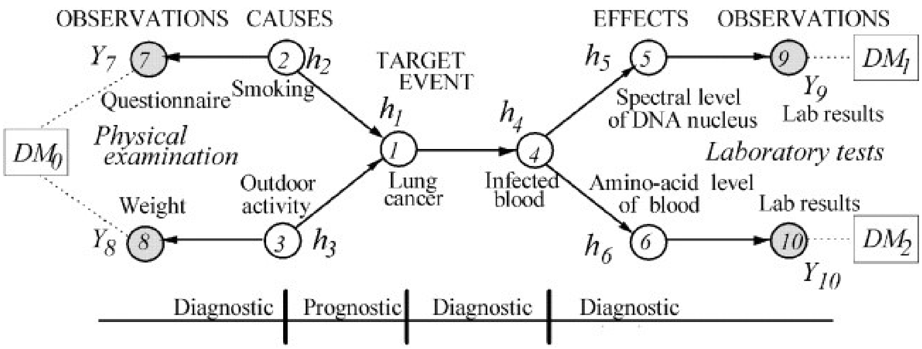

Figure 1. Collaborative evaluation of a medical task (Example 2).

Example 2: Oncologists, pathologists, and radiologists frequently decide, as a team, whether or not a patient has cancer. Each expert develops a local decision on a component problem and these local decisions are aggregated into a global assessment. In order to illustrate this *team-level* decision process, consider the following hypothetical medical diagnosis problem of estimating the probability that a patient has lung cancer (see Figure 1). A physician (DM_0) estimates the probability of this event by examining the patient (when the patient first suspects the cancer), and calling for additional tests to see whether the blood cells are infected or not. It is known that the true state of a blood cell is ultimately determined by its two attributes:

- the amino acid level of the blood, and
- the spectral level of the DNA nucleus.

The cell is infected if and only if the values of both of these attributes are high. The physician calls upon two experts in the respective fields (DM_1 and DM_2) to decide on the amino acid and spectral levels. Because of measurement errors, the results of laboratory tests may not be accurate. However, by combining the local decisions of DM_1 and DM_2 with DM_0's own initial hypothesis, the accuracy of diagnosis can significantly be improved (Figure 1). The concepts of diagnostic and prognostic tasks alluded to in Figure 1 can be viewed as building blocks of a more complex set of tasks. A task structure is of *diagnostic* type if the observable attributes are evaluated to determine the non-observable cause, whereas it is of *prognostic* type if the causes are observable and the target event is the effect.

One important feature of this problem is the distributed nature of data processing: DM_0 aggregates preprocessed information in the form of local estimates of consultant DMs. Moreover, each DM determines the true state of a different (local or global) event. The key issues in this case are:

- how to make local decisions (e.g., amino acid and spectral level) in the context of a global problem (i.e., lung cancer);
- how to combine local decisions on different events into an overall global decision; and
- how external and internal parameters (such as prior probabilities of events or local expertise of DMs) affect the optimal decision strategies.

In this problem, the organizational structure is uniquely determined by the task due to the division of (non-overlapping) local expertise of different DMs. A key finding in this case is that the aggregated organizational expertise of cooperating DMs is operationalized by a *team* relative operating characteristic (*TROC*) curve: that is, the locus of the detection and false alarm probabilities of the final decision, and that the jointly optimal decision procedures at each DM are in the form of *coupled* operating points on their individual *ROC* curves.

The next example illustrates the need for matching an organizational structure to the task environment.

Example 3: An enterprise produces three different products. It has three different functional departments: manufacturing, finance, and sales, associated with each product. The number of employees is about the same in each department. This enterprise is considering the following two binary tasks (see Figure 2):

- Is the company better off switching its employee benefit plan to a new provider or not, based on a majority vote of the employees?
- Can the company afford to pay the usual amount of dividends to shareholders at the end of the current fiscal year or not?

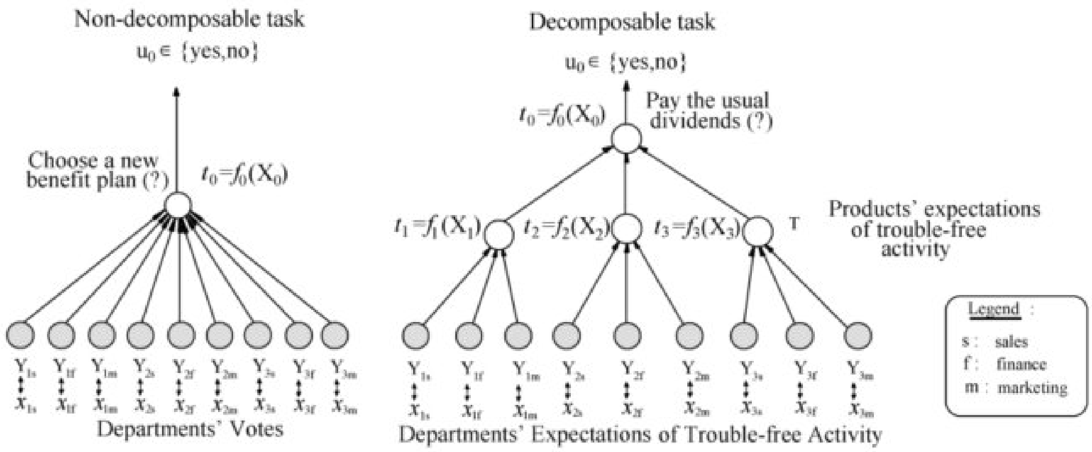

Figure 2. Non-decomposable and decomposable task graphs of Example 3. (Y_{kjs} are noisy observations of variables $x_{kj}; k=1,2,3; j=s, f, m$. The variables $X_0 = X = \{x_{kj}\}$, $X_1 = X = \{x_{1j}\}$, $X_2 = X = \{x_{2j}\}$, $X_3 = X = \{x_{3j}\}$, and $X_1 \cup X_2 \cup X_3 = X_0$)

It is known from previous experience that at least two of the three products need to meet their sales expectations in order to make the payment possible. Furthermore, it is assumed that, in order to meet a sales plan, at least two related departments should predict trouble-free activity in their respective areas. It is also known from prior experience that one department's problem can be solved by emergency measures.

As we shall see in Section 3, these two tasks are representative of non-decomposable and decomposable tasks, respectively. The space of feasible organizational designs in this case is not restricted to a single candidate organization, with different organizational structures achieving different decision accuracies for each of these two tasks. Thus, the proper choice of an organizational structure is contingent upon the specific task structure; that is, organizations must be matched to (or congruent with) the task environment to achieve superior performance.

The importance of congruent organizational structures in minimizing the amount of communication within an organization is illustrated by the following example.

Example 4: In wartime situations, a fast and accurate information exchange is vital for ensuring that subunit tasks are carried out in a coordinated manner. Indeed, intelligence preparation of the battlefield has become the centerpiece of current intelligence doctrine. It comprises the knowledge of the environment (e.g., enemy, terrain, weather), together with the integration of this knowledge into an overall assessment of the global situation. A special feature of such intelligence problems is that the information originates from a variety of sources. Furthermore, each individual subunit contributes to the common view by sharing local observations relevant to other subunits, and, at the same time, draws upon these observations when developing an appropriate course of action.

Consider the process of how military commanders assess the outcome of an encounter with enemy forces. The raw data about the area, such as terrain maps, aerial photos, and satellite pictures, are evaluated to determine the overall mobility measure of the area (such as GO, SLOW–GO, or NO–GO). Similarly, current readings of air temperature, pressure, and humidity are combined into a weather forecast (e.g., with outcomes: SUNNY, RAIN, or SNOW). Confidence estimates of terrain mobility and of the weather forecast are then combined into projections on future positions of the friendly and the enemy forces (Figure 3). Ultimately, decision alternatives are developed and evaluated on the basis of *a posteriori* probability of the event of interest.

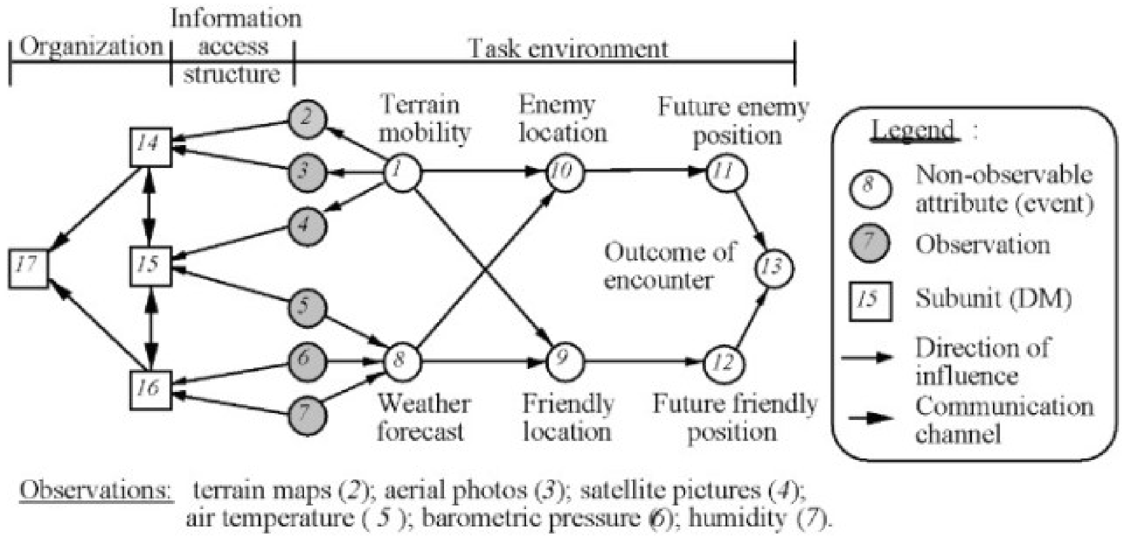

Figure 3. Joint task-organization graph of Example 4

It is evident that organizational decision making is a multi-level phenomenon combining individual information processing activities with a system-level aggregation procedure under a specific task environment. This leads to a multi-level optimization problem aimed at achieving maximal reliability of an organization for specified optimization criteria (in our context, minimal level of communication). The requirement of minimal communication (for maximal performance accuracy) is vital in order, for example, not to reveal the information to the hostile intelligence sources. Key issues related to this problem are:

- the optimal information access structure (who should measure what);
- the optimal distributed data aggregation procedure (who should compute what); and
- the optimal organizational (communication) structure among DMs (who should communicate what and with whom); in short, the optimal organizational design.

The concept of congruence can be extended to situations involving resource allocation and task execution, as the following example illustrates.

Example 5: A joint group of navy and marine forces is assigned to complete a military mission that includes capturing a seaport and airport to allow for the introduction of follow-on forces. There are two suitable landing beaches designated “North” and

"South," with a road leading from the North Beach to the seaport, and another road leading from the South Beach to the airport. From intelligence sources, the approximate concentration of the hostile forces is known, and counter-strikes are anticipated. The commander devises a plan for the mission that includes the completion of tasks shown in Figure 4. The following eight resource requirements/capabilities are needed to execute the mission: AAW (anti-air warfare), ASUW (anti-surface warfare), ASW (anti-submarine warfare), GASLT (ground assault), FIRE (artillery), ARM (armor), MINE (mine clearing), and DES (designation).

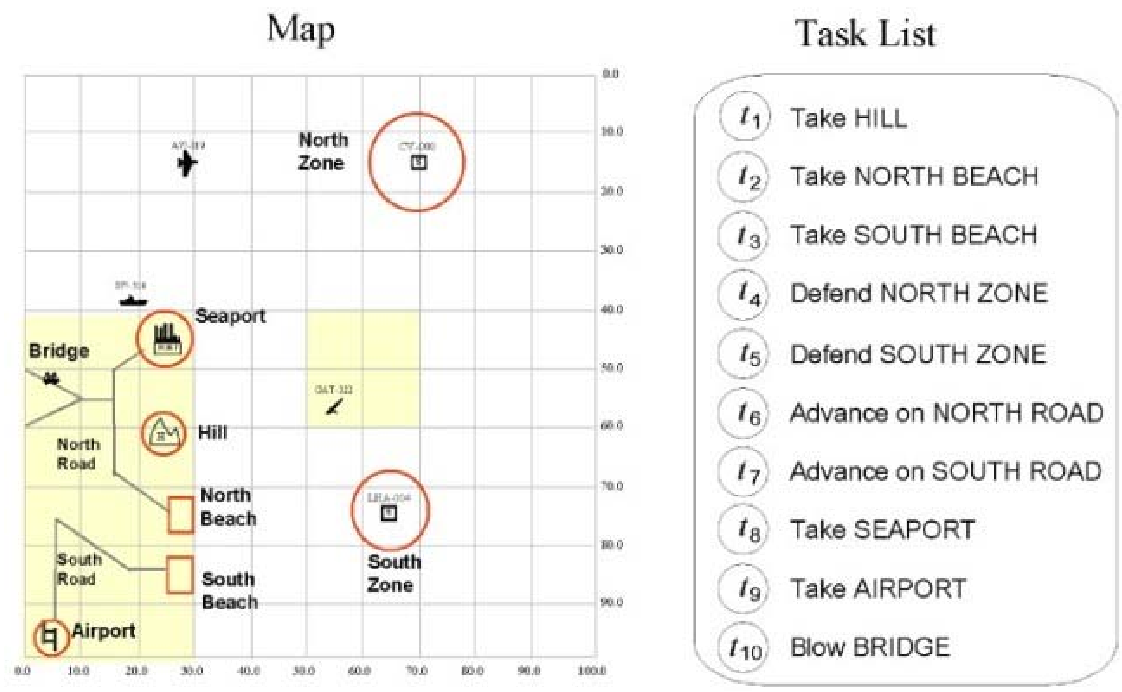

Figure 4. Geographical constraints and mission tasks for Example 5

The congruent organizational design problem in this context is one of finding the optimal organizational structure (e.g., decision hierarchy, allocation of resources and functions to humans, communication structure) and strategy (allocation of tasks to DMs, scheduling task execution, etc.) that allow the organization successfully to complete a specific mission in minimum time. We introduce a three-phase iterative optimization process that derives an optimized organizational design for a given mission structure and organizational constraints. In the first (mission-planning) phase of our design process, the optimal allocation of mission tasks to the organization's platforms (physical resources) is determined, to optimize the mission schedule. In the second phase, a three-way DM–platform–task allocation is derived, to minimize the coordination and workload overhead and its impact on the mission schedule. In the third phase, other dimensions of organizational structure (e.g., information acquisition and communication structures, decision hierarchy) are optimized, to fulfill the design objectives.

A 'finely-tuned' organization that is congruent to a specific mission may exhibit brittle performance when operating in dynamic and uncertain environments. Various strategies may be utilized to build organizations that account for dynamic and uncertain mission environments. At one extreme, one may construct an organization capable of processing a range of expected missions. At the other extreme, one may build a 'finely-tuned' organization for a specific mission, and allow online structural reconfiguration and/or strategy adaptation to cope with unforeseen changes in the mission and/or in the organization.

The former (multi-mission) organizations, termed *robust*, are able to sustain high levels of performance in dynamic environments without having to alter their structures. The latter organizations, termed adaptive, are able to generate new strategies and/or reconfigure their structures to potentially achieve even higher performance. The following example illustrates the motivation for building robust and adaptive organizations.

Example 6: Consider the same scenario as in Example 5, but the specifics of the mission scenario are assumed to have a great deal of uncertainty. In addition, throughout the course of the mission, various causes (e.g., operational resource failures, malfunctioning of a decision node, etc.) may trigger unexpected changes in either the mission environment or in organizational constraints. For concreteness, we consider the following mission uncertainties in the scenario of Example 5: 1) measurement errors; 2) task precedence errors; 3) unexpected tasks; and 4) DM failures and/or platform (resource) failures.

The rest of this article is organized as follows. In Section 2, we consider the problem of modeling a single DM in binary event detection tasks. We show that in many respects human decision problems are isomorphic to the paradigm of signal detection theory (SDT), where the alternatives are classified as *events* and *non-events*.

We characterize the expertise of an individual DM by an ROC curve. We then extend our discussion to a distributed detection model in Section 3. The impact of task structure on the performance of organizations with different designs is illustrated via Example 3, comparing the organizational expertise of different organizational designs for the two selected task environments.

We conclude that the architecture of an organization must be matched correctly to its task structure to achieve superior performance, leading to the concept of structural optimality (congruence). We elaborate on this concept in Section 4 in terms of a trade-off between decision performance and internal communication.

We discuss a method for determining congruent organizational structures by a successive decomposition of the task graph, combining results from probability theory and graph algorithms. Section 5 looks into a different aspect of the organizational design, namely the need to seek a proper balance of task scheduling, resource allocation, and decision hierarchy.

Via Example 5, we illustrate our methodology for modeling missions and for synthesizing the concomitant optimal organizations. Section 6 extends the organizational design methodology to synthesize robust and adaptive organizations. Finally, we conclude with a summary of current results in organizational design and future research directions.

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Bibliography

Aldrich H.E. (1979). *Organizations and Environments*. Engelwood Cliffs, NJ: Prentice Hall. [This study in contingency theory suggests that the decision performance is higher if there is a match between the task environment and the organizational design.]

Burton R.M. and Obel B. (1980). A computer simulation test of the M-form hypothesis. *Administrative Science Quarterly* **25**, 457–466. [Three typical hierarchical organizational designs.]

Burton R. M. and Obel B. (1998), “Strategic Organizational Diagnosis and Design: Developing Theory for Application”, (2nd Ed.). *Boston, MA: Kluwer Academic Publishers*, 1998.

Carley K.M. and Lin Z. (1995). Organizational design suited to high performance under stress. *IEEE Transactions on Systems, Man, and Cybernetics* **25**, 221–231. [Systematic evaluation of various organizational performance criteria.]

Condorcet N.C. (1785). *Essai sur l’application de l’analyse de Probabilite des Decisions Rendues a Pluralite des Voix. Paris*. [Assessment of an individual DM’s discrimination capability by a single competence value in the form of a probability value.]

Deb S., Pattipati K.R., and Shrestha R. (1997). QSI integrated diagnostic tool set. IEEE, *Autotestcon*, 408–421. [Mission monitoring and failure diagnosis with TEAMS software package.]

Desimone R.V. and DesJardin M.E. (1994). The application of uncertain reasoning during battle planning. *Proceeding of 1994 Symposium on Communication and Control Research*, 362–373, Monterey, CA. [Example 4 is taken from here.]

Emery F. E. and Trist E. L. (1965). *The causal texture of organizational environments*, Human Relations, vol. 18, pp. 21–32, 1965.

Gatsonis, C. and McNeil B.J. (1990). Collaborative evaluations of diagnostic tests: experience of the radiology–diagnostic–oncology group. *Radiology* **175**, 571–575. [Example 2 is extracted from here.]

Handley H.A.H. and Levis A.H. (2000). On organizational adaptation via dynamic process selection. *Proceeding of 7th International Command and Control Research and Technology Symposium*. Monterey, CA, USA, Track 1 – 23 pages. [Organizational performance: timeliness.]

Heimann C.L. (1993). Understanding the *Challenger* disaster: organizational structure and the design of reliable systems. *American Political Science Review* **87**(2), 421–435. [Example 1 is adapted from here.]

Hu T.C. (1982). *Combinatorial Algorithms*. Reading, MA: Addison-Wesley. [Gomory–Hu tree algorithm, viz., the optimal method to minimize the overall coordination cost in an organization.]

Kleinman D., Pattipati K.R., Luh P.B., and Serfaty D. (1992). Mathematical models of team performance: a distributed decision-making approach. *Teams: Their Training and Performance* (ed. R. Swezey and E. Salas), 177–218. Norwood, NJ: Ablex. [Review of team information processing and decision making.]

Kleinman, D. L., P. Young, and G. S. Higgins. (1996). ”The DDD-III: A Tool For Empirical research in Adaptive Organizations,” *Proceedings of the 1996 Command and Control Research and Technology Symposium*, Monterey, CA.

Kleinman, D. L., G. M. Levchuk, S. G. Hutchins, and W. G. Kemple. (2003), "Scenario Design for Empirical Testing of Organizational Congruence," *Proceedings of the 2003 Commandand Control Research and Technology Symposium*, 2003.

Krackhardt D. (1994). Graph theoretical dimensions of informal organizations. *Computational Organization Theory* (ed. K. Carley and M. Prietula). Hillsdale, NJ: Lawrence Erlbaum. [Krackhardt's measures of organizational design from a graph theoretical perspective and their relevance to organizational performance.]

Lee T.S. and Gosh S. (2000). The concept of stability in asynchronous distributed decision-making systems. *IEEE Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics* **30**(4), 549–560. [Robustness.]

Levchuk G. M., Meirina C., Levchuk, Y.N., Pattipati K.R., and Kleinman D.L. (2001). Design and analysis of robust and adaptive organizations. *Proceeding of 6th International Command and Control Research and Technology Symposium*. Annapolis, MD, USA, Track 6 – 34 pages. [Three-phase design methodology for constructing robust and adaptive organizations.]

Levchuk G.M., Levchuk, Y.N., Luo Jie, Pattipati K.R., and Kleinman D.L. (2002a). Normative design of organizations—part I: mission planning, *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans* **32(3)**, 346–359. [Recent developments in organizational design: mission modeling, platform–resource allocation, scheduling.]

Levchuk G.M., Levchuk, Y.N., Luo Jie, Pattipati K.R., and Kleinman D.L. (2002b). Normative design of organizations – part II: organizational structure, *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans* **32(3)**, 360–375. [Recent developments in organizational design: DM–resource allocation, organizational hierarchy.]

Levchuk G.M., Ruan S., Kleinman D. L., Pattipati K.R., and Kemple W.(2003a). "Congruence of Organizations and Missions: Theory versus Practice in Experiment," *8th International Command and Control Research and Technology Symposium*, TRACK 2: C^2 EXPERIMENTATION, Washington, DC, June 2003. [Experimental support for congruence concepts.]

Levchuk G.M., Yu F., Levchuk Y. N., and Pattipati K.R.(2003b). "From Hierarchies to Heterarchies: Application of Network Optimization to Design of Organizational Structures" *8th International Command and Control Research and Technology Symposium*, TRACK 3: MODELING & SIMULATION, Washington, DC, June 2003. [Initial work on design of Heterarchies.]

Levchuk G. M., Levchuk Y. N., Meirina C., and Pattipati K. R., and Kleinman D. L.(2003c), "Normative Design of Organizations - Part III: Modeling Congruent, Robust, and Adaptive Organizations", *IEEE Trans. on SMC, Part A: Systems and Humans*, Vol. 34, No. 3, pp. 337-350, 2004. [Design of robust and adaptive organizations.]

Levchuk G.M., Yu F., Levchuk Y., and Pattipati K. R. (2004), "Networks of Decision-Making and Communicating Agents: A New Methodology for Design and Evaluation of Organizational Strategies and Heterarchical Structures", *Proc. 2004 Command and Control Research and Technology Symposium*, San Diego CA, June, 2004. (Design of heterarchies.]

Leblebici H. and Salancik G. R.(1981). *Effects of environmental uncertainty on information and decision processes in banks,* Administrative Science Quarterly, vol. 26, no. 4, pp. 578 –596, 1981.

Mackenzie K.D. (1986). *Organizational Design: The Organizational Audit and Analysis Technology*. Norwood, NJ: Ablex. [Demonstrates that in certain cases a high degree of hierarchy will enhance the effectiveness and the efficiency of an organization.]

Meirina C., Levchuk G. M., and Pattipati. K.R.(2003). "A Multi-Agent Decision Framework for DDD-III Environment," *8th International Command and Control Research and Technology Symposium*, TRACK 3: MODELING & SIMULATION,Washington, DC, June 2003. [Agent-based simulation of project-based organizations.]

Meirina C., Yu F., Ruan S., Zhu L., Pattipati K. R., and Kleinman D. L.(2004), *Agent-based Decision Support System for the Third Generation Distributed Dynamic Decision-making (DDD-III) Simulator*, Proc. 2004 Command and Control Research and Technology Symposium, San Diego CA, June, 2004. . [Agent-based simulation of project-based organizations.]

Meirina C., Yu F., Ruan S., Levchuk G., Pattipati K.R., Kleinmna D.L. and Popp R. (2005b), *Optimization-based Agent Simulations for the SPEYES Systems*, 10th International Command and Control Research and Technology Symposium, Washington, DC, June 2005.

Meirina C., Levchuk G. M., Ruan S., Pattipati K. R. and R. L. Popp (2006), *Normative Framework and Computational Models for Simulating and Assessing Command and Control Processes*, Simulation Modeling Practice and Theory, Volume 14, Issue 4, May 2006, Pages 454-479. [Agent-based simulation of project-based organizations.]

Nadler D. A. and Tushman M. L. (1997). *Competing by Design*, New York Oxford, 1997.

Papastavrou J.D. and Athans M. (1992). On optimal distributed decision architectures in a hypothesis testing environment. *IEEE Transactions on Automatic Control* **37**(8), 1154–1169. [TROC curve to describe the aggregated expertise of a multiple level hierarchical team.]

Pattipati K.R., Pete A., and Tang Z.B. (1992). On the optimization of detection networks. *Journal of Science and Industrial Research* **51**, 593–611. [A review of algorithms for detection networks.]

Pete A., Pattipati K.R., and Kleinman D.L. (1993). Optimal team and individual decision rules in uncertain dichotomous situations. *Public Choice* **75**, 205–230. Netherlands: Kluwer Academic. [TROC to characterize the optimal team decision rules in uncertain binary choice situations.]

Pete A., Pattipati K.R., Kleinman D.L. and Levchuk Y.N. (1998). An overview of decision networks and organizations. *IEEE Transaction on Systems, Man, and Cybernetics—Part C: Applications and Reviews* **28**, 173–193. [Recent results in binary and M-ary distributed hypothesis testing problems in structured decision networks.]

Ruan S., Meirina C., Tu H., Yu F., and Pattipati K. R. (2004). *Effects-Based Design of Robust Organizations,* Proc. 2004 Command and Control Research and Technology Symposium, San Diego CA, June, 2004. [MDP and reinforcement learning approach to design of organizations.]

Swets J.A. (1986). Form of empirical ROCs in discrimination and diagnostic task: implication for theory and measurement performance. *Psychology Bulletin* **99**, 181–198. [Characterization of human decision strategy by an operating point on the DM's ROC curve.]

Tang Z.B., Pattipati K.R. and Kleinman D.L. (1993). Optimization of detection networks part II: generalized tree structures. *IEEE Transactions on Systems, Man, and Cybernetics—Part C: Applications and Reviews* **23**, 211–221. [Numerical algorithm to find optimal decision rules at DMs in a distributed system.]

Tarjan R.E. (1983). *Data Structures and Network Algorithm*. Philadelphia, USA: SIAM. [Graph algorithms.]

Tenney R.R. and Sandell N.R., Jr. (1981). Detection with distributed sensors. *IEEE Transactions on Aerospace Electronic Systems* AES–I **7**(4), 501–510. [First paper on distributed hypothesis testing problems with identical events at all DMs.]

Tsitsiklis J.N. (1993). Decentralized detection. *Advanced Statistical Signal Processing* (ed. H.V. Poor and J.B. Thomas), Vol. 2. Greenwich, CT: JAI Press. [Discusses decentralized detection problem: particular importance include computational difficulties associated with the general formulation of minimizing the decision cost.]

Tsourveloudis N.C. and Phillis Y.A. (1998). Manufacturing flexibility measurement: a fuzzy logic framework. *IEEE Transactions on Robotics and Automation* **14**(4), 513–524. [Flexibility measures in manufacturing.]

Tu H., Levchuk Y.N. and Pattipati K.R. (2004). *Robust Action Strategies to Induce Desired Effects*, IEEE Transactions on System, Man and Cybernetics, Part A: Systems and Humans. Vol.34, No.5, September 2004.

Varvatsoulakis M.N., Saridis G.N., and Paraskevopoulos P.N. (2000). Intelligent organization for flexible manufacturing. *IEEE Transactions on Robotics and Automation* **16**(2), 180–189. [Build flexible organizations by maintaining several alternatives for the optimal designs.]

Van Meter D. and Middleton D. (1954). Modern Statistical Approaches to Reception in Communication Theory. *Transactions of the IRE Professional Group Information Theory*, PGIT–4, 119–141. [First ROC analysis.]

Van Trees Harry L. (1968). *Detection, Estimation, and Modulation Theory*, Vol. I. New York: John Wiley [Likelihood ratio test, analytical ROC curves.]

Whittaker J. (1990). *Graphical Models in Applied Mathematical Multivariate Statistics*. Chichester, UK: Wiley. [A structured model of task environment: conditional independence graph.]

Williamson O.E. (1975). *Markets and Hierarchies: Analysis and Antitrust Implications*. New York: Free Press. [States a hypothesis that the organization and operation of an M-form organization is more favorable than a U-form.]

Yu F., Meirina C., Ruan S., Tu F. and Pattipati K.R.(2005), *Integration of Holarchy and Holonic Scheduling in C^2 Organizational Design*, 10th International Command and Control Research and Technology Symposium, Washington, DC, June 2005. [Holonic method for distributed scheduling.]

Yu F., Levchuk G. M., Meirina C., and Pattipati K.R.(2006). *A Novel Congruent Organizational Design Methodology Using Group Technology and a Nested Genetic Algorithm*, IEEE Transactions on Systems, Man, and Cybernetics, Part A, vol. 36, no. 1, pp. 5-18, January, 2006. [Group technology and genetic algorithms for organizational design.]

Biographical Sketches

Krishna R. Pattipati received the B.Tech degree in Electrical Engineering with highest honors from the Indian Institute of Technology, Kharagpur, in 1975, and the MS and Ph.D. degrees in Systems Engineering from the University of Connecticut in 1977 and 1980, respectively. From 1980-86 he was employed by ALPHATECH, Inc., Burlington, MA. Since 1986, he has been with the University of Connecticut, where he is a Professor of Electrical and Computer Engineering. His current research interests are in the areas of adaptive organizations for dynamic and uncertain environments, multi-user detection in wireless communications, signal processing and diagnosis techniques for power quality monitoring, multi-object tracking, and scheduling of parallelizable tasks on multi-processor systems. Dr. Pattipati has published over 300 articles, primarily in the application of systems theory and optimization (continuous and discrete) techniques to large-scale systems. He has served as a consultant to Alphatech, Inc. and IBM Research and Development, and is a cofounder of Qualtech Systems, Inc., a small business in Wethersfield, CT specializing in advanced integrated diagnostics and prognostics software tools.

Dr. Pattipati was selected by the IEEE Systems, Man, and Cybernetics Society as the Outstanding Young Engineer of 1984, and received the Centennial Key to the Future award. He was elected a Fellow of the IEEE in 1995 for his contributions to *discrete-optimization algorithms for large-scale systems and team decision making*. Dr. Pattipati has served as the Editor-in-Chief of the IEEE Transactions on SMC: Part B- Cybernetics during 1998-2001, Vice-President for Technical Activities of the IEEE SMC Society (1998-1999), and as Vice-President for Conferences and Meetings of the IEEE SMC Society (2000-2001). He was co-recipient of the Andrew P. Sage award for the Best SMC Transactions Paper for 1999, Barry Carlton award for the Best AES Transactions Paper for 2000, the 2002 NASA Space Act Award for "A Comprehensive Toolset for Model-based Health Monitoring and Diagnosis", the 2003 AAUP Research Excellence Award and the 2005 School of Engineering Teaching Excellence Award at the University of Connecticut. He also won the best technical paper awards at the 1985, 1990, 1994, 2002, 2004 and 2005 IEEE AUTOTEST Conferences, and at the 1997 and 2004 Command and Control Conferences.

Candra Meirina received the B.S. and M.S. degrees in electrical engineering from Purdue University, West Lafayette, Indiana, in 1995 and 1999, respectively. She is currently working toward the Ph. D. degree at the University of Connecticut, Storrs. From 1995 to 1997, she was a researcher with the Indonesia Institute of Sciences working in the Department of Calibration, Instrumentation, and Metrology. She was also a Lecturer at the Academy of Instrumentations and Metrology, Jakarta, from 1995 to 1997. Her recent and current research activities are in the area of organizational design, in particular in the application of agent-based decision making framework for modeling and designing adaptive organizations and team decision-support-systems.

Andras Pete received a B.Eng. in Electrical Machinery and Automation from the Technical University of Budapest, Hungary, in 1975, and a M.S. and Ph.D. in Control and Communication Systems from the

University of Connecticut, Storrs, in 1992 and 1996 respectively.

He worked as head of department with Alumatic Ltd. in Hungary, and later served as a consultant in K&F Research Development and Informatics Services Ltd., Hungary. Currently, he is a Plant Manager for Philips, Hungary. He won the Best Presentation award in the session “Modeling Human Performance” at the 1991 American Control Conference, Boston, MA, and Best Paper award at the 1995 Command and Control Symposium. His research interests include distributed detection, estimation theory, and coordination in human organizations.

Georgiy M. Levchuk is a Simulation and Optimization Engineer at Aptima, Inc.. He received his B.S./M.S. degrees in Mathematics with Highest Honors from the National Taras Shevchenko University, Kiev, Ukraine in 1995, and Ph.D. degree in Electrical Engineering from the University of Connecticut, Storrs, US, in 2003. His research interests include global, multi-objective optimization and its applications in the areas of organizational design and adaptation, and network optimization. Prior to joining Aptima, he held a Research Assistant Position at the Institute of Mathematics (Kiev, Ukraine), a Teaching Assistantship at Northeastern University, Boston, MA, and Research Assistantship at University of Connecticut (Storrs, CT) working on a projects sponsored by Office of Naval Research. Dr. G. Levchuk received best student paper awards at the 2002 and 2003 and best paper award at 2004 Command and Control Research and Technology Symposia.

Sui Ruan received the B.S and M.S. degrees in Electrical Engineering from Information and Electronic Systems department of Zhejiang University, Hangzhou, China, in 1996, 1999, respectively. From 1999 to 2002, she was with Bell Labs, Lucent Technologies, Beijing, China as a member of technical staff on system requirements analysis and software development for intelligent networking products. From 2002, she is a Ph.D. student in the Electrical and Computer Engineering department at the University of Connecticut. Her research interests include adaptive organizational design, and optimization algorithms for fault diagnosis.

David L. Kleinman received a BBE from Copper Union, New York, in 1962, and a M.S. and Ph.D. in Electrical Engineering from MIT in 1963 and 1967, respectively. From 1967 to 1971 he worked at Bolt Beranek and Newman, Inc., Cambridge, MA where he pioneered in the application of modern control and estimation theory to develop and validate an analytical model for describing human control and information processing performance in manned vehicle systems. From 1971–1973 he established and directed the Cambridge office of Systems Control, Inc., where he led applied research projects in both manual and automatic control. Since 1973, Dr. Kleinman has been a Professor in the Electrical and System Engineering Department at the University of Connecticut; he is the director of the CYBERLAB, a laboratory for empirical research in cybernetic systems. In addition, Dr. Kleinman holds a visiting appointment with the C2 Academic Group at the Naval Postgraduate School in Monterey, CA.

Dr. Kleinman’s efforts in human decision making have involved modeling human team performance and response characteristics in real-time multi-task sequencing and resource allocation environments. His current research, which is funded through grants from the Office of Naval Research, is in the area of team coordination in dynamic task environments, and structural adaptation processes in human organizations.

Dr. Kleinman was a Technical Committee Chair (Human Decision Making), and the Vice-President of Finance and Long-Range Planning, for the IEEE-SMC Society. He was the Program Chairman for the 1989 IEEE International Conference on Systems, Man, and Cybernetics, and for the 1990 JDL Symposium on Command and Control Research. In 1980 he was the Program Chairman for the 19th IEEE Conference on Decision and Control.

In 1993, Dr. Kleinman was elected Fellow of the IEEE. He is also a cofounder and director of Alphatech Inc., Burlington, MA, and of Qualtech Systems, Inc., in Wethersfield, CT.