Computing and Network Systems Administration, Operations Research, and System Dynamics Modeling: A Proposed Research Framework

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ABSTRACT

Information and computing infrastructures (ICT) involve levels of complexity that are highly dynamic in nature. This is due in no small measure to the proliferation of technologies, such as: cloud computing and distributed systems architectures, data mining and multidimensional analysis, and large scale enterprise systems, to name a few. Effective computing and network systems administration is integral to the stability and scalability of these complex software, hardware and communication systems. Systems administration involves the design, analysis, and continuous improvement of the performance or operation of information and computing systems. Additionally, social and administrative responsibilities have become nearly as integral for the systems administrator as are the technical demands that have been imposed for decades. The areas of operations research (OR) and system dynamics (SD) modeling offer system administrators a rich array of analytical and optimization tools that have been developed from diverse disciplines, which include: industrial, scientific, engineering, economic and financial, to name a few. This paper proposes a research framework by which OR and SD modeling techniques may prove useful to computing and network systems administration, which include: linear programming, network analysis, integer programming, nonlinear optimization, Markov processes, queueing modeling, simulation, decision analysis, heuristic techniques, and system dynamics modeling.

Keywords: Systems Administration, Operations Research, System Dynamics, Information and Computing Systems, Performance, Optimization.

1. INTRODUCTION

The role of the systems administrator, or sysadmin, continues to evolve dramatically, due mostly to rapid growth areas, such as: distributed cloud computing, infrastructure-as-a-service (IaaS), software-as-a-service (SaaS), and other related service-oriented information and computing technologies (ICT). The sysadmin engages primarily in the design, analysis, and continuous improvement of the performance or operation of information and computing systems, which also includes user support. In sum, the sysadmin is expected to ensure the ongoing stability of complex and mission-critical technical and human-computer systems. Failure of such complex infrastructures may be both disruptive and costly [1]. Stability of the software, hardware, network, database, and human-computer interface (HCI) “ensemble” by sysadmins necessitates proper planning and management of complex IT infrastructures. To accommodate such demands, recent research efforts examine more closely particular technical and non-technical (i.e., “soft”) needs of sysadmins, such that a broader and richer array of models and tools may offer greater support of their workspace [2-5].

The areas of operations research (OR) and system dynamics (SD) modeling have been used successfully in diverse disciplines and in a variety of ways, objectives of which are to understand and optimize the performance of systems, such as: industrial, scientific, engineering, economic and financial, to name a few. In fact, OR has been used effectively to solve computational and algorithmic problems in computing and network infrastructures. The same, however, cannot be said for the field of systems administration. Still, development and maintenance of ICT systems, along with network and cloud computing infrastructures, can leverage: (1) the application of the scientific method, the basis upon which operations research (OR) exists; and (2) systems thinking, as exemplified in systems dynamics (SD) modeling.

In this paper, I propose a research framework by which both operations research and system dynamics modeling techniques may prove useful to computing and network systems administration. Such techniques include: linear programming, network analysis, integer programming, nonlinear optimization, Markov processes, queueing modeling, simulation, decision analysis, heuristic techniques, and system dynamics modeling.

The remainder of this paper is as follows. In Section 2 of this paper, we shall explore briefly the literature as it pertains to: (1) systems administration and its concomitant technical and social systems; (2) the field of operations research (OR), the various kinds of problems to which OR has successfully been applied, and the variety of quantitative and scientific modeling approaches used; and (3) systems dynamics, the essence of which involves systems thinking, which views the world as a system of complex systems that involve both technical and human behavioral subsystems. In Section 3 we present our proposed research framework, by which both OR and SD modeling techniques may prove useful to computing and network systems administration. Finally, Section 4 discusses limitations and constraints, future work, and conclusions.

2. LITERATURE

Systems Administration

The history of systems administration begins some 60 years ago, with the development in 1952 of the IBM 701, the first commercial computer [6]. At that time, system operators, who were themselves employed by customers’ organizations, were encouraged to coordinate with IBM the sharing of information, experiences, solutions, and the like. Subsequent stages in the evolution of computing led to a reshaping and further refinements to systems management, all of which have led to the current computing environment that now involves cloud computing, distributed systems, and a myriad of complex hardware, software, and networking architectures. A contemporary definition for systems administration is proposed in [7], which states: “Network and system administration is a branch of engineering that concerns the operational management of human-computer systems.” Reference [7] further states that “we are now forced to think systems not just computers,” due mostly to the level of complexity found with modern computing and behavioral systems.

Practically speaking, the duties of a system and network administrator span operational (day-to-day), tactical (planning and process changes), services provisioning, and management practices, all of which entail technical and non-technical (or socio-technical) requirements and demands [8]. Such duties range from issues associated with fundamentals, such as workstations, servers, networks, security, and helpdesk, to management practices, such as organizational structures, users’ perceptions of infrastructure, technical and non-technical management, and hiring and firing of systems administration personnel [6, 8]. In addition to an impressive array of “how-to” resources for today’s systems administrator, there also exist professional groups—most notably, USENIX: The Advanced Computing Systems Association (https://www.usenix.org/)—meetings, workshops, and conferences, all of which accommodate sharing of information and experiences, tools and techniques, etc., among professional systems administrators.

A paradigm shift appears to be underway, which expands the scope of study in the area of systems administration. This is evidenced by the recent development of a formal theory of system administration, using a mathematical framework [9], the objective of which is to make possible a dynamical stability of the system as a whole. Reference [9] makes the point that the complexity of interaction between humans and computers presents an interesting challenge toward the formulation of any mathematical theory of system administration. Interestingly, this complexity of human-computer interaction brings us to a second aspect of this paradigm shift. Specifically, there recently has been a notable increase in the number of studies that explore aspects of systems administration that are: (1) managerial-administrative; (2) services-oriented; (3) socio-behavioral; and (4) performance-driven; all of which explore collectively the human-computer interaction (HCI) aspect of systems administration [10-14]. It is specifically this collective HCI aspect around which we develop our proposed research framework. The dynamic nature of computing and network infrastructures necessitates the availability of “toolsets” that would further support systems administrators’ operational and planning needs [15, 16]. The fields of operations research (OR) and system dynamics (SD) offer researchers great potential for the study of applying viable methods that support systems administrators.

Operations Research

The field of operations research (OR) began sometime early in World War II, with the express purpose of determining ways to allocate scarce resources efficiently and effectively to military operations and activities. Following the war, scientists and business consultants who were engaged directly with application of OR to military problems discovered ways by which OR might also be applied to problems in business, industry, and government. In effect, OR applies the scientific method to discover a problem of interest or concern, construct scientific (mathematical) models to address the abstract nature of the problem, and then apply suitable experiments to validate the model(s) [17]. Operations research has been applied successfully in a variety of fields, including computer science and engineering. Interestingly, but not surprisingly, applications of OR in the field of computing have focused quite heavily on solving algorithmic and computational problems that require allocation of scarce resources (e.g., queueing models in operating systems, network design and Internet packet routing, and so on), and with considerable success. Operations research deals mainly with decision-making by human beings, who may quite often rely on intuition as well as facts [18]. Intuition may prove helpful, but only to a certain extent. Table I identifies some of the more widely-used OR modeling approaches and their application types [18]. As shown in Table I, the different methodologies fall into one of the following categories: mathematical programming, probabilistic (stochastic), or (in the case of heuristic techniques) a methodology whereby a good or near-optimal solution is identified. As stated earlier, the real power of operations research is the development of mathematical models for decision makers. In addition to applications of OR in manufacturing and production [17-18], there also have been a number of successes in the application of OR in service industries [19]. Reference [19] offers an excellent (and recent) review on how OR has been applied in the service sector in five active sectors, which include: transportation and warehousing, information and communication, human health and social assistance, retails and wholesales, and financial and insurance services. (It is worth noting that [19] contains an extensive and useful set of references.)

As suggested earlier, system administrators are themselves service providers, both to end-users and organizations. Thus, the diverse service industries to which OR has been applied successfully suggests that OR may also prove useful to services and support provided by systems administrators.

TABLE I. OPERATIONS RESEARCH METHODOLOGIES

	OR Modeling Approaches		
	Methodology	***Application Type***	***Mathematical Programming (MP) or Probabilistic (P)***
1.	Linear Programming	Optimization through allocating limited resources among competing activities	**MP**
2.	Network Analysis	Production, distribution, project planning, facilities location, resource management	**MP**

	OR Modeling Approaches		
	Methodology	***Application Type***	***Mathematical Programming (MP) or Probabilistic (P)***
3.	Integer Programming	Optimization for which the variables are integer only	**MP**
4.	Nonlinear Optimization	Finding the best solution in which the objective function and constraints are not necessarily linear	**MP**
5.	Markov Processes	Decision making for which phenomena exhibit uncertainty	**P**
6.	Queueing Models	Involves waiting lines, or queues, such as servicing customer requests by one or more servers	**P**
7.	Simulation	Studies behavior of existing or proposed systems through modeling of such systems	**P**
8.	Decision Analysis	Selecting among a set of possible alternatives for which considerable uncertainty exists	**P**
9.	Heuristic Techniques	Search through a reasonable number of possible solutions, as opposed to all possible solutions, to find a good, or near-optimal, solution	**MP** or **P**

System Dynamics

As discussed in the previous subsection, operations research emphasizes the development of mathematical models, in order to understand one or more problems and make decisions, based upon objective facts. We have seen, however, that human decision making, though well-intentioned, is far from perfect. Indeed, a resolution to some particular problem may in fact be realized, but may lead to other problems, not considered by the decision maker. Such problems may result from the dynamic complexity of the world, which exhibit characteristics, such as feedback, time delays, accumulations, and nonlinearity [20]. These characteristics are quite often unexpected, due mainly to our applying a “situation-problem-decision-results” approach, which does not consider the fact that decisions may themselves alter our environment and trigger undesirable side effects. What is required, therefore, is an approach that is system-oriented and which involves systems thinking. The field of system dynamics was developed over fifty years ago by Jay Forrester [21, 22]. Simulation is integral to effective application of system dynamics, and the primary tool necessary to such simulations is the causal loop diagrams, which includes, among other things, feedback processes. As with operations research, system dynamics has been used successfully in a variety of problem spaces and disciplines, the literature of which is quite extensive. Areas to which system dynamics have been applied successfully include project management, public health, economics, and waste management, to name a few [23-26]. Similar to OR, however, application of SD to needs and requirements of systems administrators appears to be minimal.

We next propose a research framework, by which both OR and SD modeling techniques, may prove useful to computing and network systems administration.

3. PROPOSED RESEARCH FRAMEWORK

A proposed research framework should have a theoretical basis to which multiple problem spaces should be linked. As such, our proposed research framework employs the key aspects of the theory of system administration described in Reference [9]. Additionally, we adopt the definition for systems administration from [7], which states: “Network and system administration is a branch of engineering that concerns the operational management of human-computer systems.”

As shown in Table II below, problem space elements are indicated for each of the seven theoretical aspects [9]. Associated with each theory-problem space combination is a set of recommended OR-SD methodologies, the rationale of which shall be discussed shortly. Other methodologies (not indicated in Table II) may also be applicable.

TABLE II. PROPOSED RESEARCH FRAMEWORK

	Theory-Problem Space-Methodology		
	Theory	***Problem Space***	***Methodology***
1.	Policy determination and evaluation	A description of what is intended and allowed of a system and its behavior	Markov Processes Decision Analysis
2.	Strategic decisions about resource usage	CPU utilization, memory and storage, network and gateway access	Linear Programming Integer Programming Nonlinear Optimization
3.	Interaction between users and systems for resources	Arrangement of workstations, printing devices, and any other physical resources needed by users	Linear Programming Simulation System Dynamics
4.	Productivity considerations (system economics)	Planning: hardware, software, networking, databases Process management	Network Analysis Decision Analysis Heuristic Techniques
5.	Empirical verification of strategies and policies	Measuring effectiveness of strategies and policies	Simulation System Dynamics
6.	Efficiency of policy and implementation	Measuring efficiency	Simulation
7.	Efficiency of the system in doing its job	Measuring efficiency	Simulation System Dynamics

The rationale for selection of OR-SD methodologies for each of the seven theory-problem space combinations in Table II is as follows:

1. **Policy determination and evaluation.** Computing and network systems infrastructures are designed and implemented based upon specific needs and requirements. The operational dynamics of contemporary organizations exhibit considerable uncertainty, especially due to external social and political-economic forces. Moreover, there are quite often a variety of possible courses or paths through which organizations may follow. Markov processes and decision analysis methodologies are appropriate for this problem space.
2. **Strategic decisions about resource usage.** A common objective for CPU utilization, memory and storage, network and gateway access, is optimization. Such resources are limited, and there usually exist one or more constraints. Mathematical programming methodologies such as linear programming, integer programming, and nonlinear optimization should prove useful to the systems and network administrator for such optimizations.
3. **Interaction between users and systems for resources.** Objectives of this particular theory-problem space combination include: optimization, efficient operations, and feedback loop dynamics. As such, the appropriate methodologies to address these objectives are: linear programming, simulation, and system dynamics.
4. **Productivity considerations (system economics).** This theory-problem space combination emphasizes the efficient allocation of scarce resources. Hence, network analysis, decision analysis, and heuristic techniques (the latter applied mostly to user training) are applicable.
5. **Empirical verification of strategies and policies.** The first and second theory-problem space combinations prescribe policies and strategies, respectively; however, an important attribute is the measure of effectiveness of these policies and strategies. Both simulation and system dynamics are necessary for empirical verification.
6. **Efficiency of policy and implementation.** Whereas policy effectiveness is measured in item 5 above, the *efficiency* also must be measured. In this case, simulation is best suited for this task.
7. **Efficiency of the system in doing its job.** Similar to item 6 above, efficiency of the system in doing what it has been designed to do is critical. Both simulation and system dynamics are the recommended methodologies.

It is worth noting that the preceding rationale is subject to refinement, depending upon empirical results from potential future studies that focus on one or more of the various the theory-problem space combinations shown in Table II.

4. CONCLUSIONS AND FUTURE WORK

As discussed earlier, the systems administrator is expected to maintain stability of complex computing and network infrastructures. Failure to do so may result in costly disruption to users and organizations. Despite such a critical role, studies that focus on the sysadmin are few in number; however, interest in this role is on the rise. Thus, building upon a theoretical foundation [9], a proposed research framework is described, by which both operations research (OR) and system dynamics (SD) may be applied to seven theory-problem space combinations. A limitation of this proposed framework is that there may be other equally viable combinations of methodologies, not considered in this work. Future work would include, among other things, studies of the degree of alignment between the OR and SD methodologies proposed in this framework and what is actually the case in applied and industry settings. Analyses of results from such studies may lead to further refinements to the application of methodologies indicated in the proposed framework. It may be that systems administrators currently employ one or more of the methodologies included in the proposed framework. If so, the literature appears not to reflect the use of such methods. A preliminary means by which this might be determined is by way of a survey of practitioners (i.e., sysadmins) in industry. Results of such a survey may accommodate a baseline against which results of future studies may be compared. Our proposed research framework should contribute to a systematic understanding about the overall efficiency and effectiveness of the systems administrators' primary objective, which is the continuous improvement of computing and network systems' performance.

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