SYSTEMS ENGINEERING AND TRAFFIC ENGINEERING

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Telecommunications networks are undergoing major changes in technologies, architectures, services, and environments. Traffic engineering should be able to cope with the complexity, large-scale, and uncertainty accompanying these changes. Systems engineering could deal with ill-defined problems including the complexity of system architectures and uncertainty concerning the future and human behavior. This paper briefly describes the systems engineering procedure for telecommunications networks, and traffic engineering process from the viewpoint of systems engineering. It then surveys the need and possibility of cooperation between traffic engineering and systems engineering.

1. INTRODUCTION

The goal of traffic engineering is to resolve every problem relevant to teletraffic in telecommunications networks. Traffic engineering must freely use the concepts and methodologies of other disciplines including problem-solving and decision-aiding methodologies. Telecommunications networks are now undergoing major changes in technologies, architectures, services, and environments. Hence, traffic engineering must further extend its sphere of activities to the interdisciplinary and ill-defined problems including societal, economic, human, and environmental factors. In this context, systems engineering or systemic approach could deal with ill-defined problems including the complexity of system architectures and uncertainty concerning the future and human behavior. ISDN challenges teletraffic disciplines, requiring in particular higher involvement in systems engineering and design activities [1] [2] [3] [4].

Systems engineering is a way of thinking and a sequential and logical approach for developing large-scale complex systems [5] [6]. The essence of systems engineering is in its emphasis on the whole-system and whole-life concepts [7]. The whole-system concept is that a system has many components and many complicated interactions, and that systems engineering is the design of the whole rather than the design of the components. The whole-life concept is that system has its life-cycle from inception to retirement, and that systems engineering balances the various technical, economic, human, and performance criteria and operational requirements evaluated over the whole life of system.

2. SYSTEMS ENGINEERING FOR TELECOMMUNICATIONS SYSTEMS

Telecommunications systems are real-time, man-machine systems, composed of closely-interrelated functional components, physical equipment, human beings, and
operations. They are affected by their environments such as customers' behavior, tariffs, laws, other telecommunications networks, economic and social activities.

Telecommunications networks, whether public or dedicated, involve many technologies such as switching, transmission, signaling, computers. Systems engineering for telecommunications networks incorporates these technologies that must cohere in the final design.

Systems engineering accomplishes its many purposes by a structured process consisting a number of phases corresponding to the life-cycle of a system. The systems engineering process would start with a policy and program planning phase, and proceed through such phases as project planning, system development, operation, and finally modification or retirement and phase out. The phases of the systems engineering process are the time dimension of system engineering. In Hall's three dimensional morphology[8], seven steps of a problem-solving procedure may be carried out at each phase: problem definition, value system design, system synthesis, system analysis, optimization of alternatives, decision making and planning for the next phase.

Focusing on the main activities at each phase, the systems engineering procedure for telecommunications networks would be arranged as follows, with the policy and program planning phase, and the project planning phase merged into one 'planning' phase.

I. Planning phase :-market studies of services/ forecasting traffic volume and characteristics/ sociological studies of prices or tariffs/ specification of customer requirements for QOS/ survey of trends in telecommunications technologies/ identification of value systems including objectives.

II. Design phase :-identification of design alternatives for network configuration, functional architecture, routing and traffic control algorithm, and measurements method/ evaluation of design alternatives/ optimization of design parameters/ implementation of the selected architecture.

III. Production phase :-production design of network components/ quality assurance of produced network and components.

IV. Insertion phase :-realization of network/ field test and hand-over.

V. Operation phase :-operation of network/ monitoring of functions and performance/ measurements and data analysis of operational information.

VI. Modification phase :-modification of network and system architectures.

The modification phase leads back to the planning phase in the next cycle of systems engineering procedure. Although subsystems, such as switching systems or transmission systems, may retire in their life-cycles and be renewed, telecommunication networks evolve iterating the above engineering cycles without retirement as their missions change with time depending on the changes of environments and objectives.

Systems engineering activities for developing a telecommunications network could be freely carried out by general systems engineering methodology. Emphasis should be placed on definition of objectives, multiobjective evaluation, analysis of human behavioral factors, and balancing the whole-system and whole-life.

3. TELETRAFFIC ENGINEERING FROM THE VIEWPOINT OF SYSTEMS ENGINEERING
Since the concepts of systems engineering appear to be universally applicable in every domain of engineerings, it is appropriate to use these concepts in the context of proposed framework for traffic engineering.

Like systems engineering process, traffic engineering process itself iterates activity steps of the time dimension as a telecommunications network emerges. The traffic engineering activities may be summarized as follows.

I. Planning phase
   —traffic forecasting/ specification of QOS.
II. Design phase
   —performance analysis/ parameter optimization/ synthesis or evaluation.
III. Operation phase
   —dimensioning/ measurements/ traffic control.

In this case, the insertion phase is combined into the operation phase for simplicity. Synthesis means the integration of the results of performance analyses and the selection of good alternatives from the viewpoint of performance.

From the viewpoint of systems engineering, traffic engineering process should have the following characteristics.

1) Traffic engineering must involve many feedback loops which occur between two activities. In the design phase, feedback loops should occur in the design of system performance, in cooperation with feedback loops in the design of system functions.
2) The activities of traffic engineering should be balanced over all activity phases based on the whole-life concept of systems engineering. For example, too detailed performance evaluation in the design phase will not be adequate when environments and design assumptions such as traffic forecasts, system architectures, customer's behavior, component capacity, are uncertain or changing.
3) It will be more important to evaluate the entire telecommunications network or system rather than investigate in detail isolated parts of the entire system. For example, in the performance evaluation of a network, end-to-end or overall performance must be obtained from well-balanced performance evaluation of network components or parts.
4) Value system design in the planning phase, for which systems engineers or system designers are responsible, is important, because optimization and synthesis in the design phase are based on the value or decision criteria set up in the value system design. There is the need for the methods to quantitatively evaluate other criteria besides cost-performance.

4. TRENDS OF TELECOMMUNICATIONS NETWORKS

The evolution of telecommunications technologies and services challenges traffic engineering to dealing with the large-scale, complexity, and economics of the network to provide cost-effective, reliable services to customers. The following is the trends of telecommunications networks which affects traffic engineering issues.

1) Private or dedicated networks: The deployment of private or dedicated telecommunications networks like CATV, LAN, MAN will prevail and bring about a variety of new traffic problems such as imbalanced directional traffic, multimodal distribution of holding times, multiaddress calling, and exclusive use by the hour.
2) Multiservices: ISDN will provide multiservices in which voice, data, video, and graphic telecommunications services are integrated with common resources. This will include a number of issues such as uncertainty of service demands, dynamic bandwidth allocation, a variety of QOS requirements, and user-to-user signaling.
3) Systems architectures: Hierarchical architectures have been adopted to decouple the system software architecture from the underlying hardware technology. The need to support system extensions and reusability of software results in modular architectures for software and hardware. Tradeoffs in cost and performance have enabled the evolution of telecommunications systems with distributed processing and databases that allow for choice in partitioning software architecture.

4) Network intelligence: Operations support systems are needed to manage a new flexible and dynamic network, to meet changing competitive and regulating environments, to reduce existing network operations costs, and to meet changing organizational needs. Trends in operations systems and technologies are giving customers the ability to control and manage their own telecommunications needs using the resources of service providers.

5) Computer technologies: There are several specific computer technologies which could be applied to telecommunications systems: super computer, database machine, knowledge processing machine, and dataflow mechanism compared with the traditional control-flow mechanism.

6) Multi-vendor environment: The dual effects of new technology and competition have created a multi-vendor environment in telecommunications equipment. The development of universal standards and protocols for future products and technologies is crucial for constructing the network of the future, to permit hardware and software from different vendors to interact.

Traffic problems brought about by these trends have been pointed out at the 5th ITC seminar [12]. From the viewpoint of systems, future telecommunications networks will probably have the following characteristics:

- large-scale, complex systems composed of many interrelated components.
- offer of multiservices using common resources.
- uncertainty of customer's requirements.
- shorter system life-cycle.
- distributed intelligence (database and processing units).
- modular architectures for hardware, software, and services.
- multi-vendor systems (open system architecture).

5. PROSPECTS OF TRAFFIC ENGINEERING

To cope with the changes and future trends of telecommunications networks, traffic engineering should search for the applicability of systems engineering methodology, including system theory, to the interdisciplinary and ill-defined problems which strongly influence traffic issues.

From the viewpoints of both systems engineering and the trends in telecommunications networks, problems in traffic engineering process and possibilities for applying of systems engineering methodology are summarized as follows.

1) Planning phase
   a) Problem definition: Traffic problems and their weights should be identified beforehand to be arranged as the major problems, subproblems, and causal problem factors. Traffic engineering activities should also be planned over the whole procedure of developing a telecommunications network. This problem definition could be accomplished with systematic and structural approaches like 'relevance tree', 'objective tree', and 'ISM (Interpretive Structural Modeling)' [13] [14] [15] [16].
   b) Forecasting: Forecasting methods are required for taking account of uncertainty and volatility of environments and customer behavior. In addition to the
traditional methods like multiple regression model, time series analysis, Kalman filter and econometric model, systemic methods such as 'scenario method', 'systems dynamics', 'multivariate analysis', and 'MDS(multidimensional scaling)' may be applicable to these problems with uncertainty and without measurement data [17] [18] [19] [20] [21]. Especially, human and behavioral factors must be involved in forecasting new services or customer's reaction under overload conditions [22].

(2) Design phase

a) Structural modeling: Performance evaluation and synthesis must be carried out on the basis of profound comprehension of network or system structures, which include system architectures of components and interactions among network components. Standard reference models such as OSI and network architecture reference models will be useful to develop an understanding of the network structures [23] [24]. For this, systemic approaches using graphical methods such as 'ISM', 'cross-impact analysis', 'interaction matrix', and so on, may be applicable [6] [13].

b) Analysis and synthesis for large-scale complex systems: A more efficient and systematic analytical approach is required for performance analysis and synthesis of large-scale systems with distributed intelligence as a whole. System theory, particularly 'decomposition or aggregation method' for the control or optimization problems of large-scale systems, appears to be applicable to these evaluation problems [25] [26] [27].

c) Robust design: To cope with uncertainty and volatility of environmental conditions, telecommunications networks should be designed to be able to absorb a large amount of temporal and spatial traffic variations, and volatility of service requirements. This robust network design could be accomplished with a flexible architecture design or dimensioning with an accommodation margin [28] [29]. An evaluation method for accommodation margin based on reasonable formulation is need.

d) Control algorithm: The opening of network protocols to the end user or the introduction of new terminal equipment will bring new traffic problems. There must be some controls implemented to prevent one customer's demands or behavior affecting other customers. In designing control algorithms, some criteria are needed for the performance fairness among customers. For control parameters determined from corresponding measured data, 'learning theory' and 'fuzzy set theory' may be applicable [230] [31] [32].

e) Evaluation: Evaluation includes determining preferences among alternatives. The existence of multiple objectives poses difficult problems to weight all alternatives considering the numerous effects of each alternative. Methods in systems engineering such as 'decision theory', 'multi-attribute utility theory' and 'AHP (Analytic Hierarchy Process)' may be applicable [33] [34] [35] [36].

(3) Operation phase

a) Quick feedback: Measurement methods and traffic control algorithms should be designed in the design phase. After processing measurement data and forecasting short term trends, resources will be balanced and provided if necessary. To quickly respond to forecasting errors and traffic variations needs some method of generating a feedback loop from measurement to planning and dimensioning. 'Extreme engineering' may be one example of this kind of traffic engineering with a quick feedback loop [37].

Over the entire phase of traffic engineering procedure, the following directions are pointed out:
a) Structured traffic engineering: For the problems defined in the planning phase, traffic engineering should adopt a structured procedure whereby traffic engineering activities such as forecasting, requirements specification, design, evaluation, dimensioning, measurement, and control, could be carried out in a systematic and balanced way [38] [39].

b) Computer-Aided Traffic Engineering (CATE): At any point in the traffic engineering process, enhanced computer technology will contribute to traffic engineering activities which should cope with shortening of the system life-cycle and uncertainty of the future. Computer-aided planning, design, analysis of telecommunications systems constitutes an important part of structured traffic engineering. Some analytical tools or software packages for performance evaluation, network planning and dimensioning have been used [40] [41] [42] [43]. Design automation of optimization using repeated analysis and high-speed simulation for congestion phenomena will be available via super computer. Recent advancements in artificial intelligence will contribute to the development of computer-aided traffic engineering that is flexible, comprehensive, user-friendly and cost-effective.

6. CONCLUSION

Systems engineering for telecommunications networks and trends of telecommunications networks were summarized and requirements for the cooperation of systems engineering and traffic engineering were discussed. Although emphasis was placed on the applications of systems engineering methodologies and systems theory to traffic engineering, the concepts or philosophy of systems engineering are also important and useful. Already some applications of systems engineering methodology or cooperation with systems engineering have been carried out and some substantial results have appeared at former ITC congresses and ITC seminars.

So far, traffic engineering has made rapid progress with introduction of new services, new systems, and new operational strategies like alternate routing, multi-link switching networks, electronic call processors, multiprogramming computer system, packet switched networks, and multiple access control in LAN. Traffic engineering is now challenging the new problems like multiservices in ISDN, burst traffic handling in Asynchronous Transfer Mode (ATM), and modular architectures in intelligent networks. Combined with systems engineering, traffic engineering should make rapid progress and also be useful for evolving telecommunications networks.

REFERENCES