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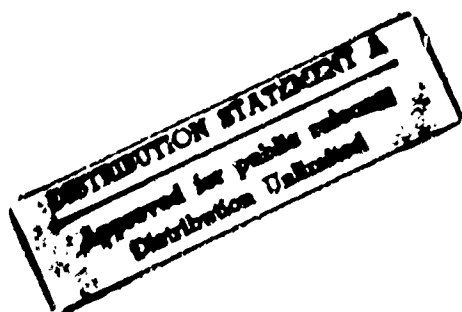


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COMPUTER-AIDED SYSTEMS ENGINEERING

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COMPUTER-AIDED SYSTEMS ENGINEERING

Dr. S. Andriole

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This document accompanies a videotape of the same presentation recorded live at the Software Productivity Consortium in March 1994. It is recommended that the videotape be viewed with these viewgraphs at hand.

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Computer-Aided Systems Engineering

Dr. Stephen J. Andriole
Drexel University

This presentation includes information concerning toolset requirements, current and projected tools, tool capabilities assessment and perceived critical deficiencies. Dr. Andriole presents a tools assessment matrix that demonstrates a mapping between toolset requirements and currently available systems engineering tools. He discusses the benefits and problems that organizations experience with tools. The timing and costs of investments in tools, how tools can be expected to perform and future expectations are presented.

Dr. Andriole explains why companies choose tools, identifies the most favorable environments and discusses common obstacles to successful CASE use. This video is intended for systems and software engineering development lead engineers, project managers and division managers working in the area of system and software engineering. Viewers will benefit by gaining information about systems engineering tools and automation, especially the value and capability of commercial off-the-shelf (COTS) tools. Dr. Andriole emphasizes the use of lower cost PC based (DOS or MAC) tools to support systems engineering activities including requirements modeling, simulation and prototyping, evaluation and trade-off analysis, testing and reliability, technology forecasting and risk analysis.

Dr. Andriole presents an overall framework for evaluating systems engineering tools based on how effectively the tools support the systems engineering process, followed by an overview of selected tools that are currently available.

Dr. Andriole is the Director of Information Systems Technology Laboratory at Drexel University. Prior to this he worked for several years at the Defense Advanced Research Projects Agency and was a professor at George Mason University. Dr. Andriole has broad expertise in the area of systems analysis and systems engineering of software intensive systems. He has published several articles related to systems engineering tools.

Computer-Aided Systems Engineering

An Assessment of Current Practices, Tools & Trends

Stephen J. Andriole

The Assessment Framework

- **Systems Engineering**
- **The State-of-the-Practice of Computer-Aided Systems Engineering**
- **The Generic Systems Engineering Framework**
- **Phase-by-Phase Organization & Categorization**
- **Criteria-Based Evaluation & Assessment ----> The Matrix**
- **COTS/CASE Tools Sampler**
- **SPC COTS/CASE "Products" & Services ...**

The State-of-the-Practice of Computer-Aided Systems Engineering

- "Practiced" for Years by Systems Engineers
- Opportunistic -- Not Characterized by the Same Zeal or Investments that Characterize the Computer-Aided Software Engineering Movement
- In Many Respects -- Further Integrated into the Other-Than-Software-Intensive Design & Development Process Than in the Software-Intensive Systems Design & Development

The State-of-the-Practice of Computer-Aided Systems Engineering (Continued)

- Practiced as Pieces of a Greater Whole:
 - Cost-Benefit Modeling
 - Technology Forecasting
 - Project Management
 - Resource Allocation
 - Cost Estimation
 - Trade-Off Analysis ...
 - No "I-CASE" ... Yet ...
- "Attached" to Life Cycle Phases

The "Generic" Systems Engineering Framework

- May Be Described -- Like the Software (Systems) Engineering Life Cycle -- as a "Conversion Process"
-- From Fuzzy & Ill-Understood Requirements to Detailed Design & Measurable Performance
- Well-Supported by "Standards", Such as Blanchard's Framework & 499A/B
- Characterized by:
 - Objectives (by Phase & Overall)
 - Methods
 - Tools

Systems Engineering

- The Process by Which we Convert Complex Requirements into Working, Maintainable Systems is Part of the Discipline and Structure Known as ***Systems Engineering***
- While there are All Sorts of Variations on this Theme, Systems Engineering Refers to Those Processes and Activities that Together Define a Life Cycle that Follows a System Through Crude Concept Development, Testing and Evaluation, and Eventual Retirement

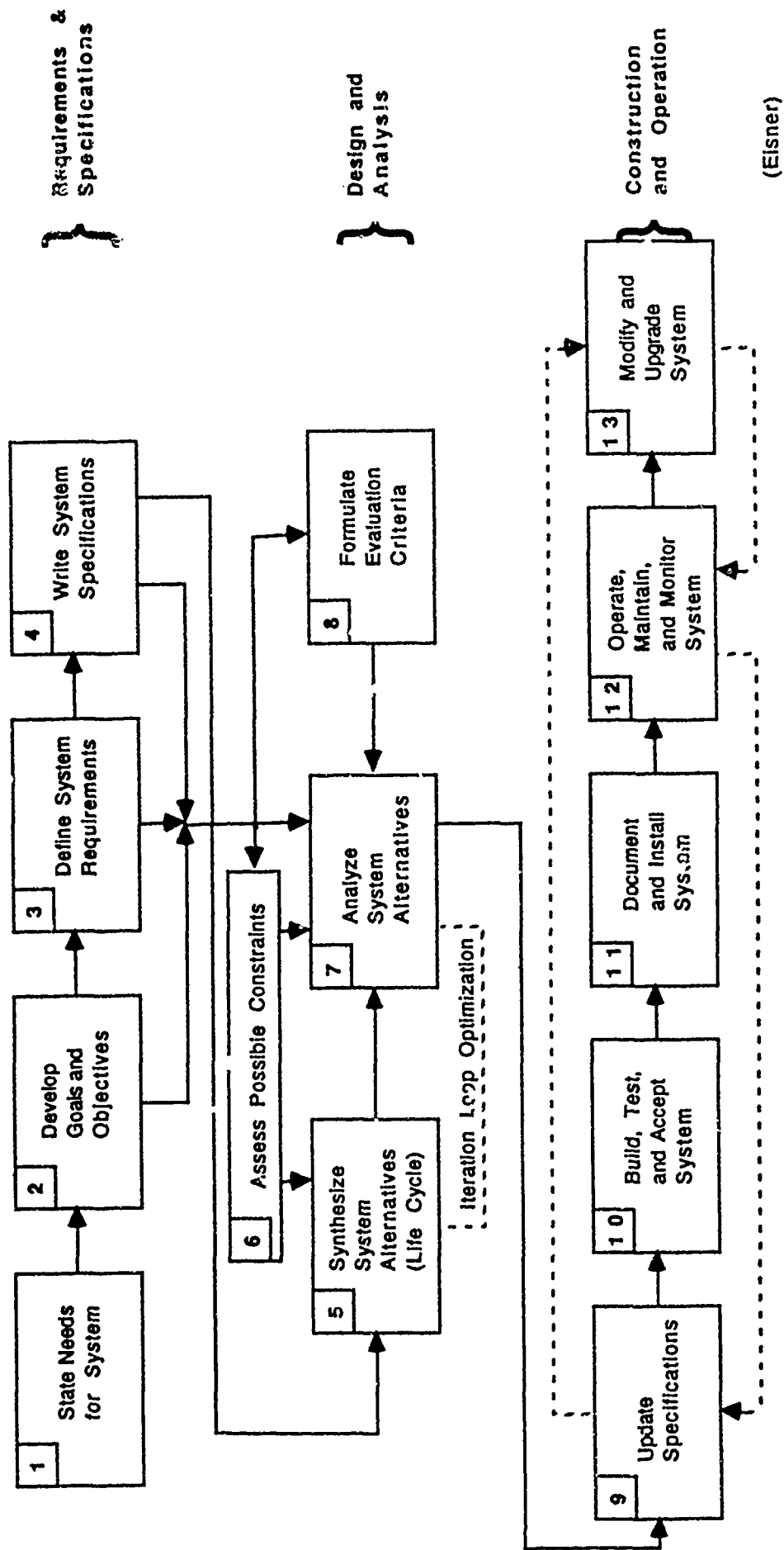
Systems Engineering

- Systems Engineering Traces its Origins to the Work of Hall (1962), Chestnut (1965; 1967), Chase (1974), Sage (1977; 1983), and Blanchard and Fabrycky (1981; 1990)
- More Recently, Sage (1992), Blanchard (1991), Eisner (1988), and Chapman, Bayhill and Wymore (1992) have Refined the Methods, Tools Techniques, Activities, Functions and Purpose of Systems Engineering
- Along the Way an Overarching Department of Defense Standard Evolved

Systems Engineering

- The Essence of the Systems Engineering Process is Requirements ---> Design ---> Development Efficiency
- The Primacy of Requirements is Well Documented (Andriole, 1989, 1990; Sage, 1992; Sage & Palmer, 1990; Davis, 1990, 1992)

Generic Systems Engineering Process



Systems Engineering

- Eisner defines systems engineering as *"an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system."* Eisner describes the systems engineering process as consisting of 25 "elements"

Systems Engineering

1. Requirements Analysis
2. Requirements Allocation
3. Functional Analysis
4. Functional Allocation
5. Specification Analysis
6. Specification Development
7. Preliminary Design
8. Interface Definition
9. Schedule Development
10. Preliminary Cost-Analysis
11. Technical Performance Measurement
12. Trade-Off/Alternative Analysis
13. Pre-Planned Product Improvement
14. Final Design
15. Schedule Update
16. Cost Update

Systems Engineering

- 17. Fabrication
- 18. Coding
- 19. Preliminary Testing
- 20. Debugging & Reconfiguration
- 21. Testing & Integration
- 22. Updates

A. Schedule

B. Cost

C. Technical Performance Measurement

23. Documentation

24. Training

25. Production

Systems Engineering

- 499A
- "Systems engineering is the ... logical sequence of activities and decisions transforming an operational need into a description of system performance parameters and a preferred system configuration ... systems engineering is the application of scientific and engineering efforts to (a) transform operational need into a description of system performance parameters and a system configuration through the use of an iterating process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; (c) integrate reliability, maintainability, safety, survivability, human, and other such factors into the total engineering effort to meet cost, schedule, and technical performance objectives"

Systems Engineering

- The Revised (Draft) Standard (DOD, 1992) -- 499B -- Describes the Systems Engineering Process as Follows:

"A comprehensive, iterative problem solving process that is used to: (a) transform validated customer needs and requirements into a life-cycle balanced solution set of system product and process designs, (b) generate information for decision-makers, and (c) provide information for the next acquisition phase"

Systems Engineering Goals (After Sage)

- All (Life Cycle) Encompassing
- Problem Understanding
- Communication
- Early Capture of Design & Implementation Needs
- Bottom-Up & Top-Down Design & Development
- Alternative Systems Management Approaches
- Process & Product Quality Assurance
- Product Evolution
- Support for Configuration Management Standards
- Support for Automated Design & Development Aids
- Teachable & Transferable Methodology
- All phase Definition & Documentation
- Product Functionality, Revisability & Transitioning
- Support System Product Development & System User Organizations

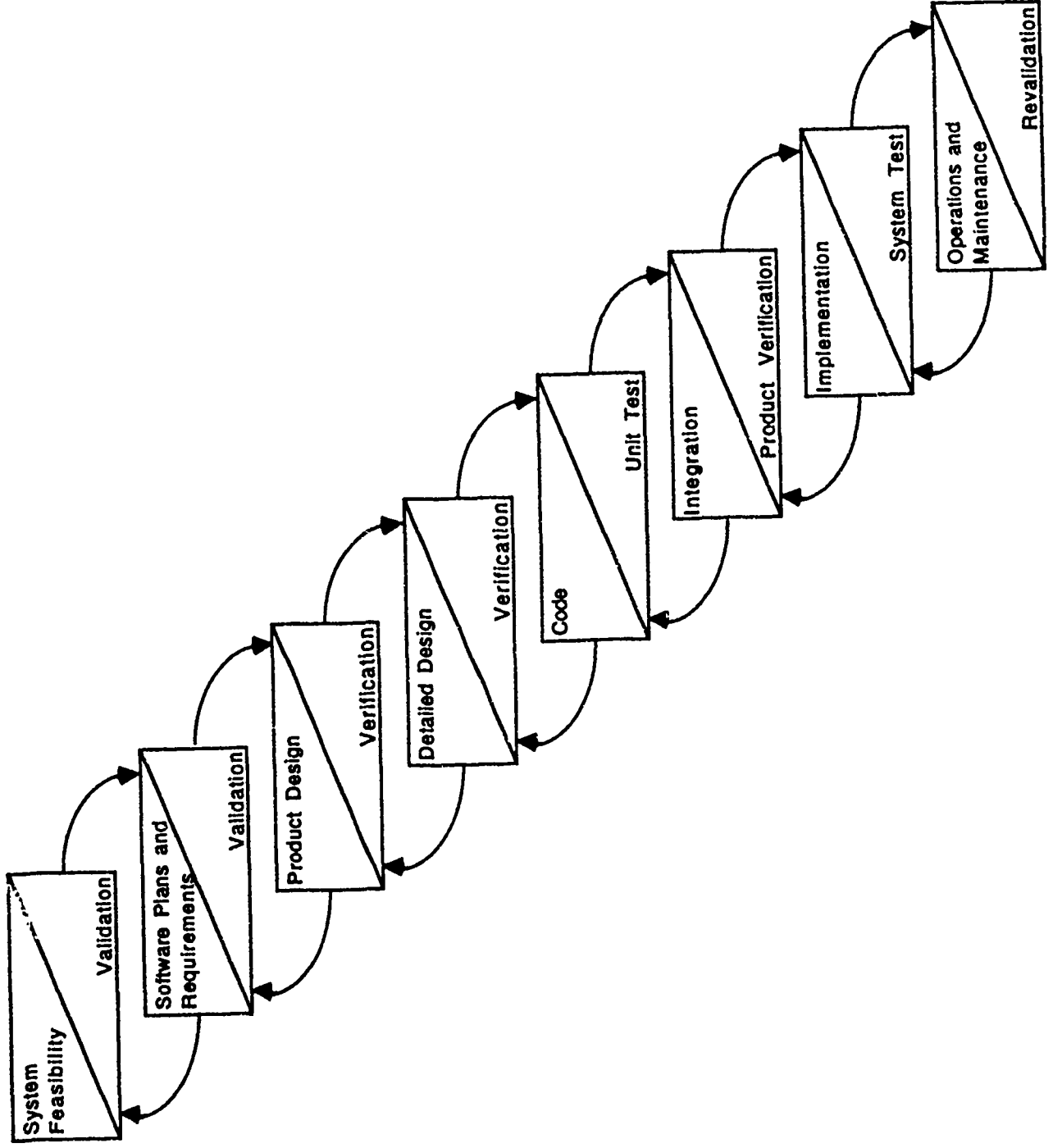
Systems Engineering Management Plan (SEMP)

- At the Core of the Planning and Management Process lies the SEMP that Requires the Production of Documentation that can be Reviewed and Assessed. This Documentation Includes at Least the Following:
 - Project Management Schedules
 - Product Cost Estimation
 - Timeline Analysis Sheets
 - Requirements Allocation Sheets
 - Work Breakdown Structures
 - Technical Performance Measures
 - Human Factors Engineering Plan
 - Risk Management Plan
 - Data/knowledge Management Plan
 - Maintainability Plan
 - User Manuals

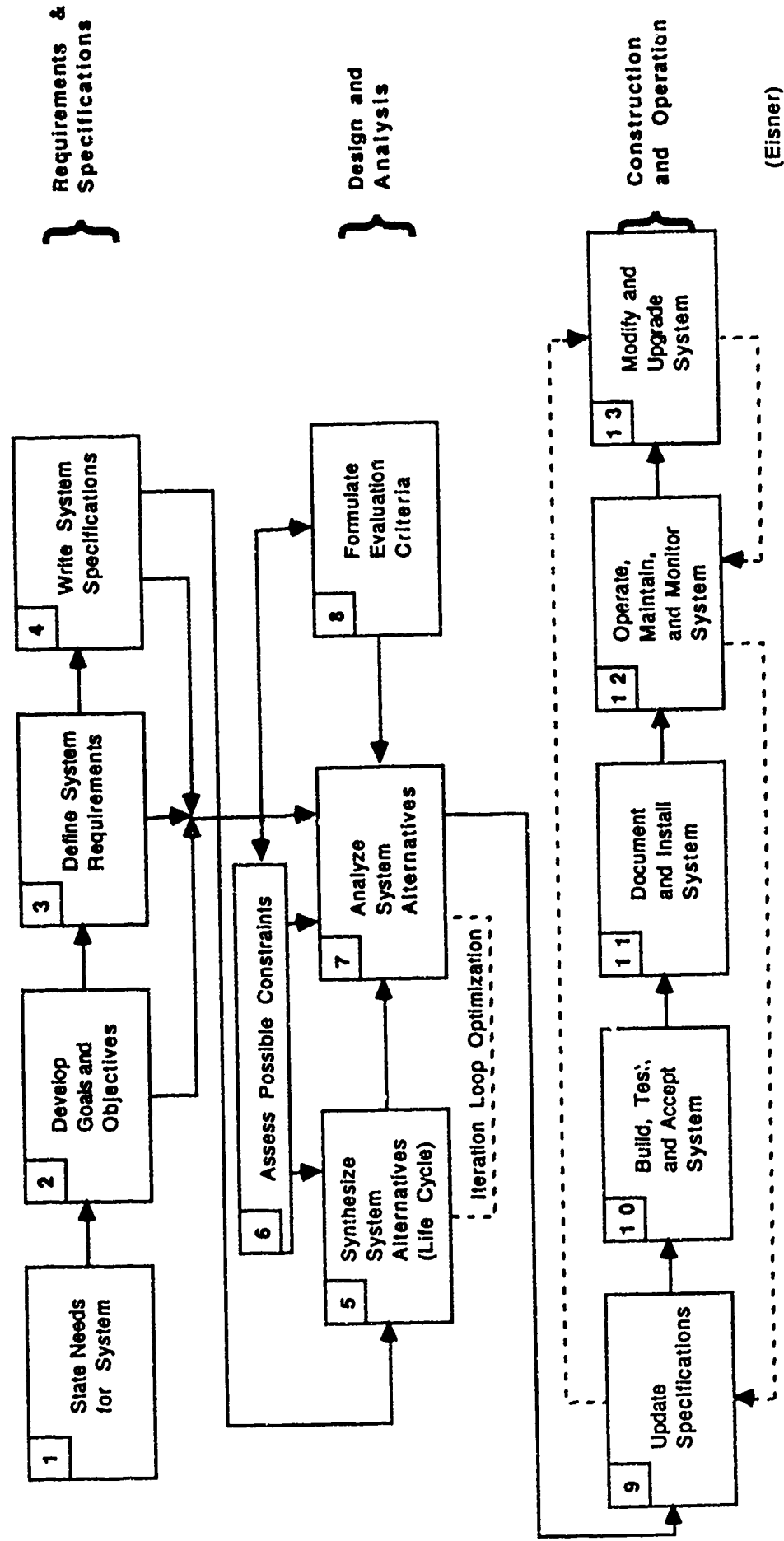
Systems Engineering Management Plan (Continued)

- Software Requirements Specifications (Preliminary & Detailed)
- Software Design Specifications
- Test & Evaluation Master Plan
- Configuration Management Plan
- Production/Manufacturing Plan
- Total Quality Management Plan ...

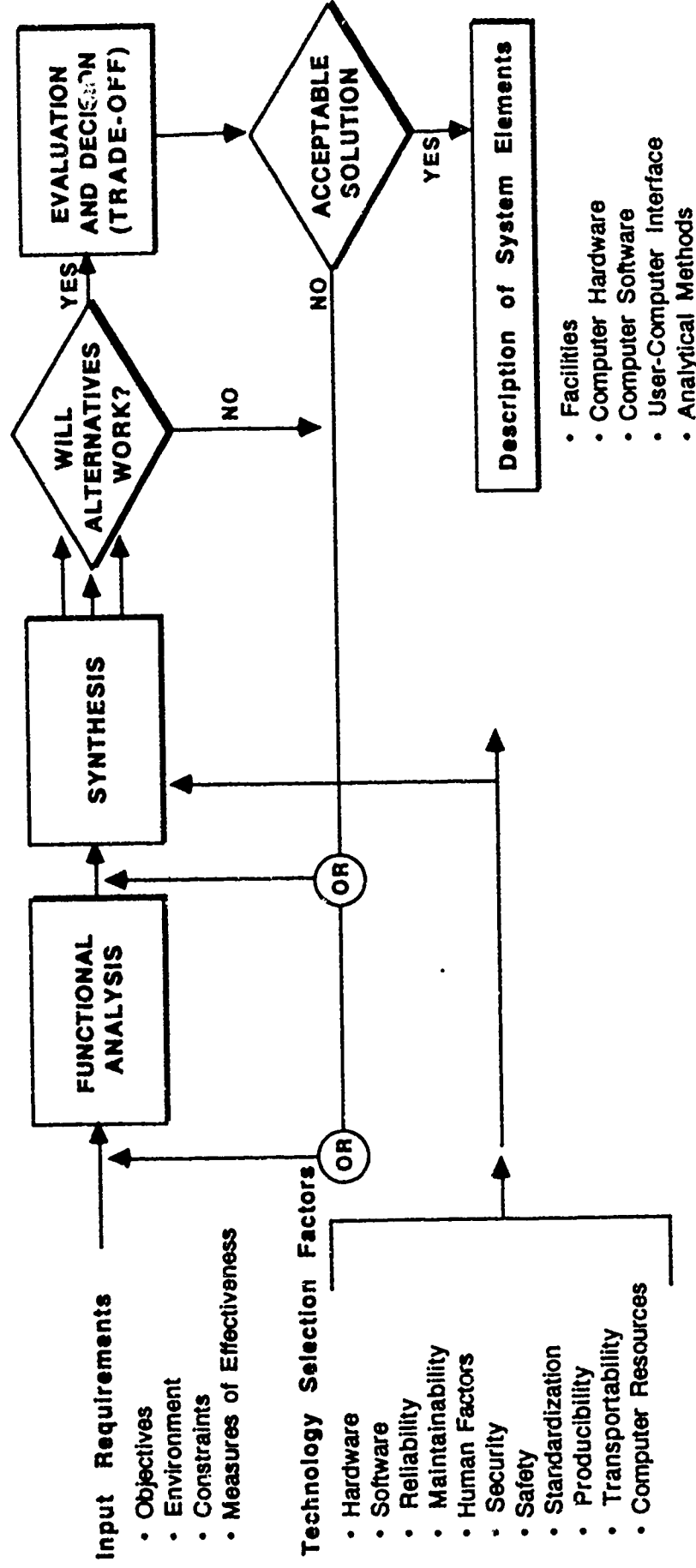
The Waterfall Model Of The Software Life Cycle



Generic Systems Engineering Process

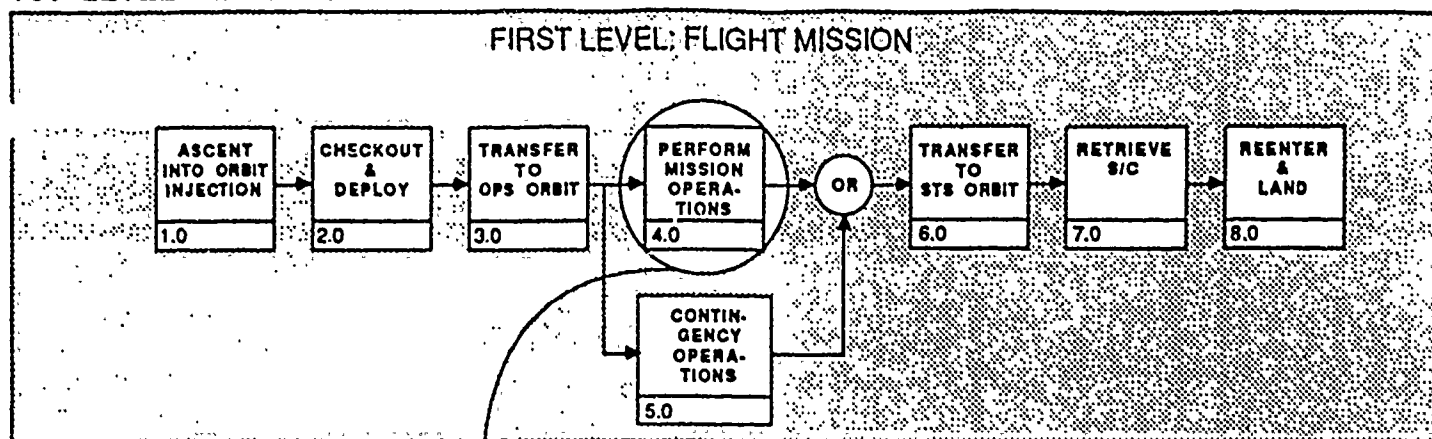


Generic Systems Engineering Process

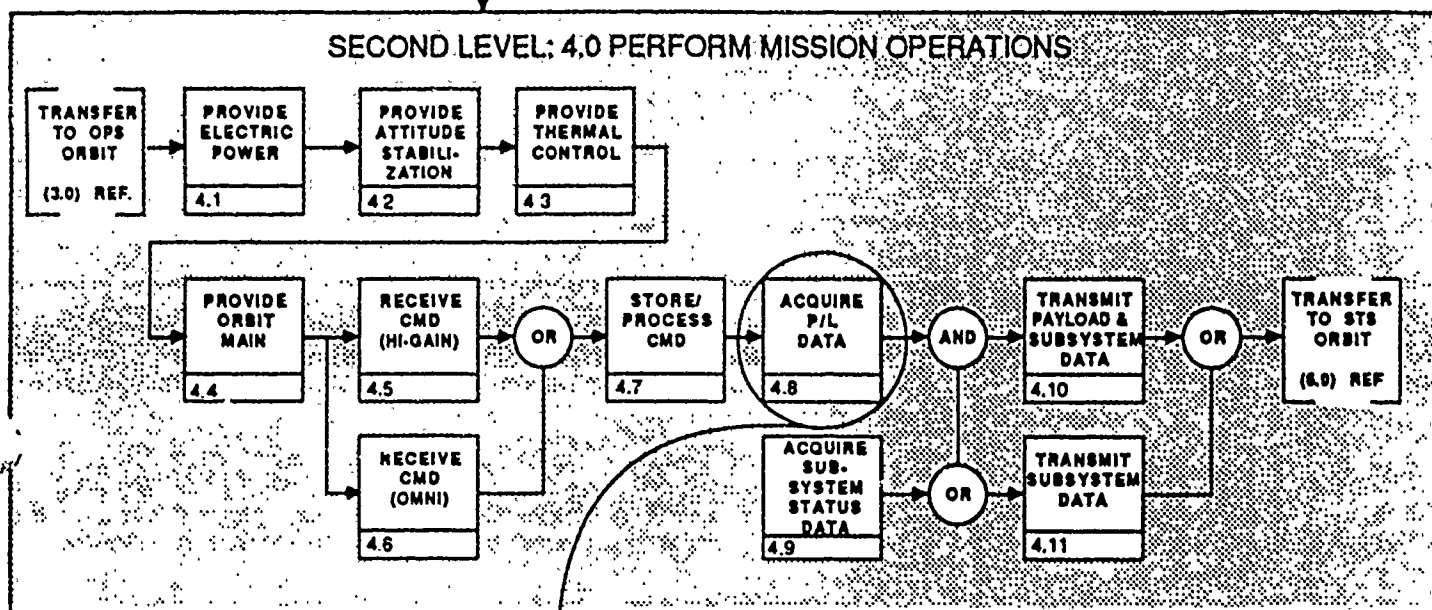


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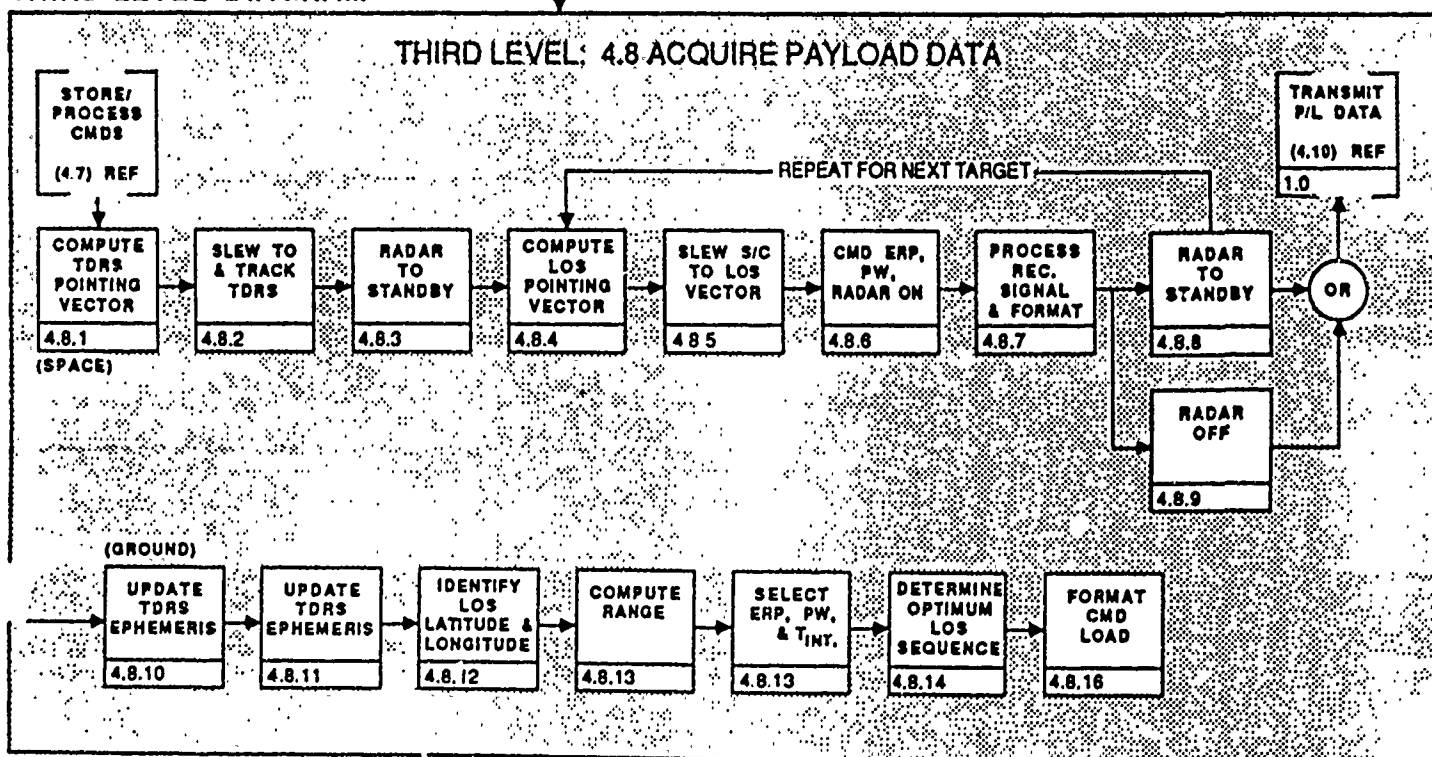
TOP-LEVEL DIAGRAM



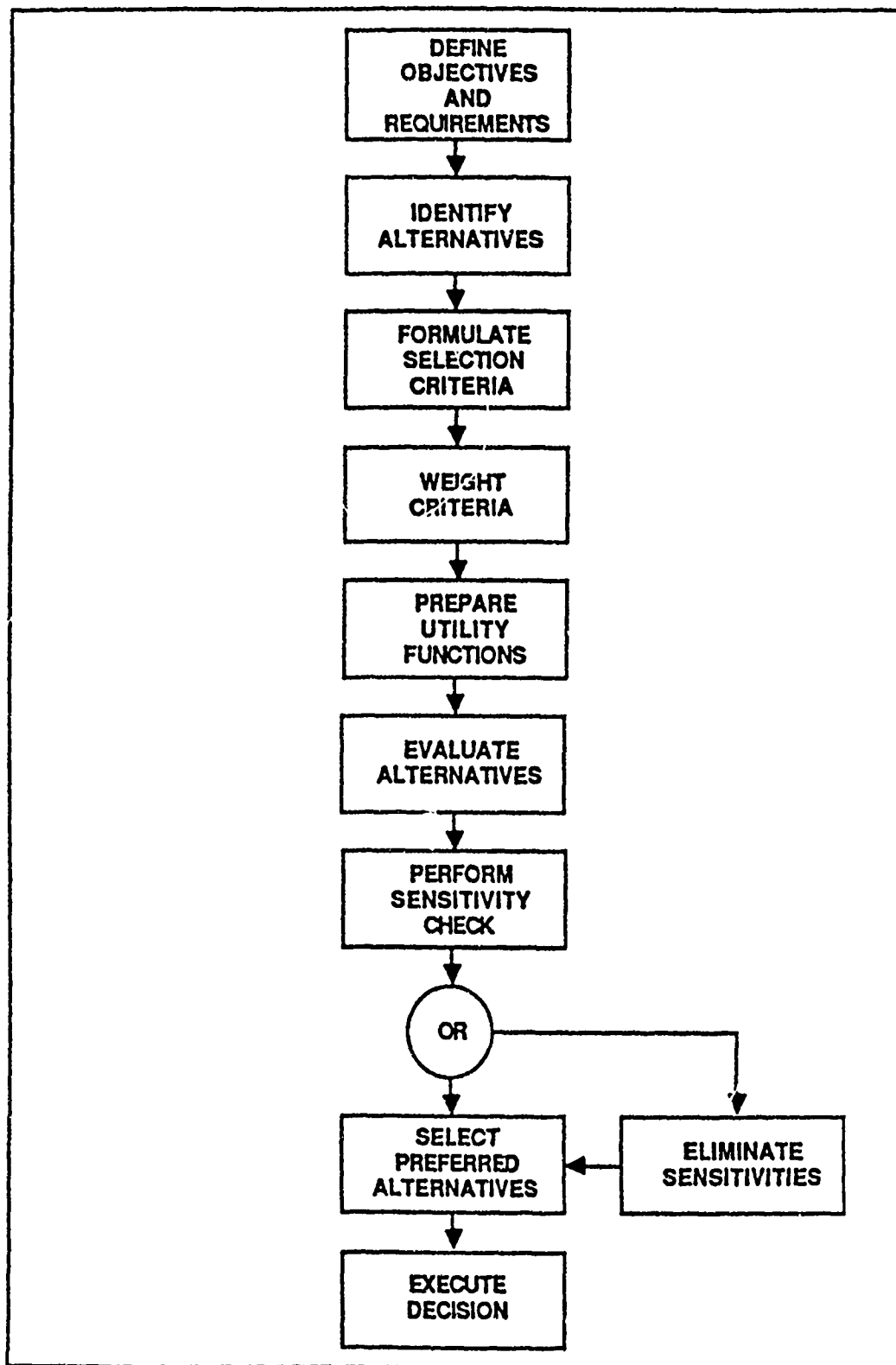
SECOND-LEVEL DIAGRAM



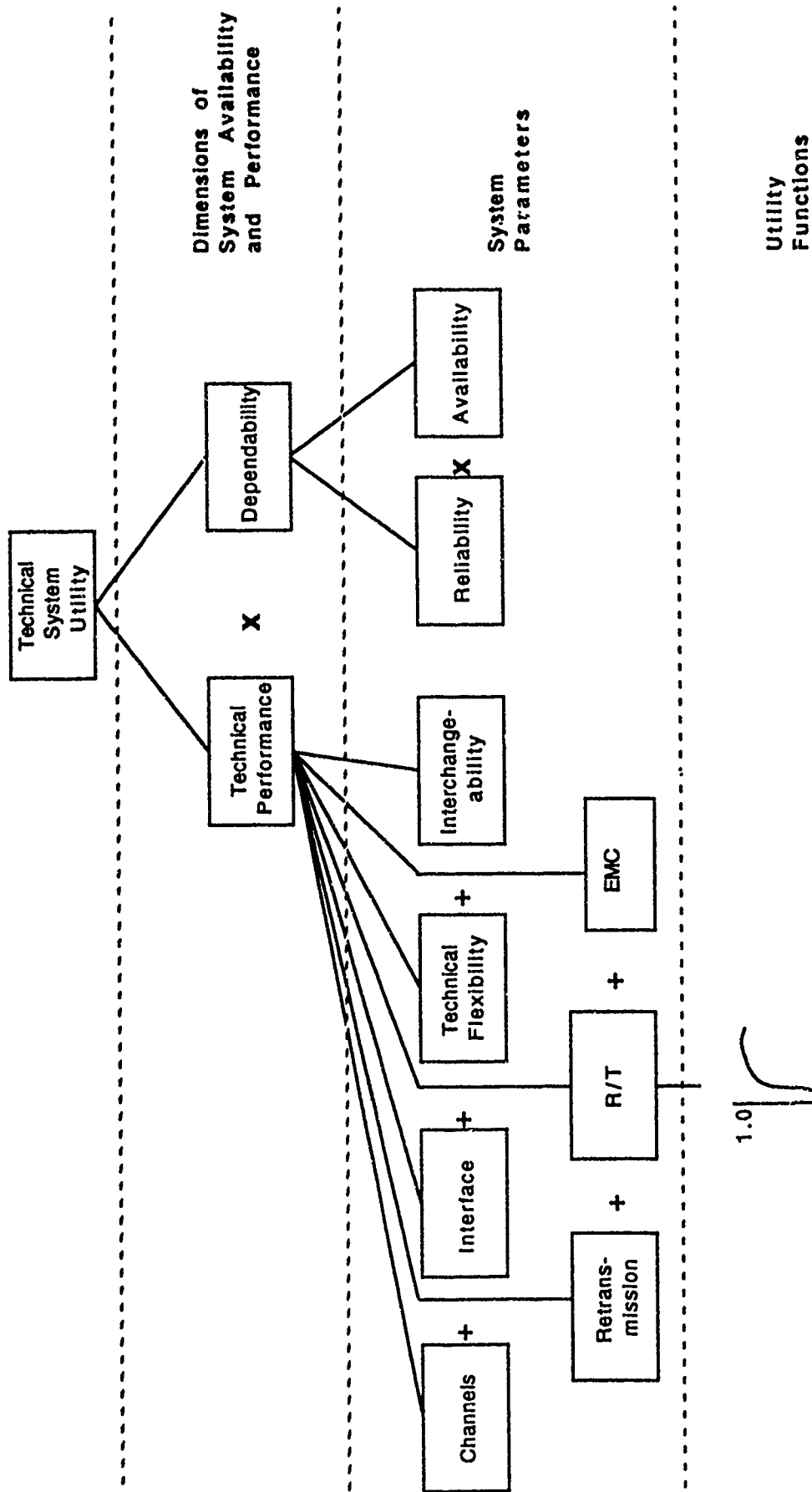
THIRD-LEVEL DIAGRAM



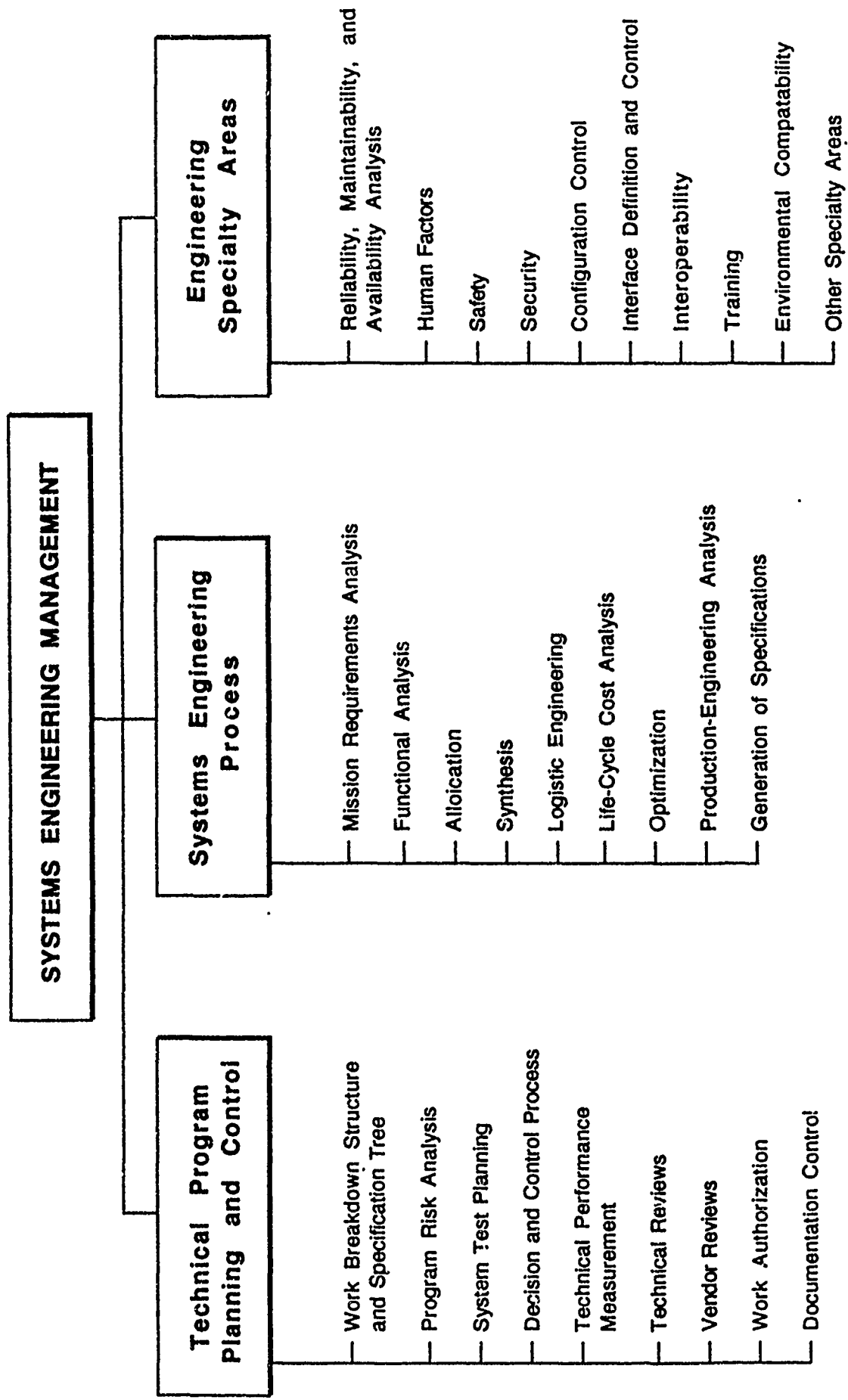
Trade-Off Analysis Methodology



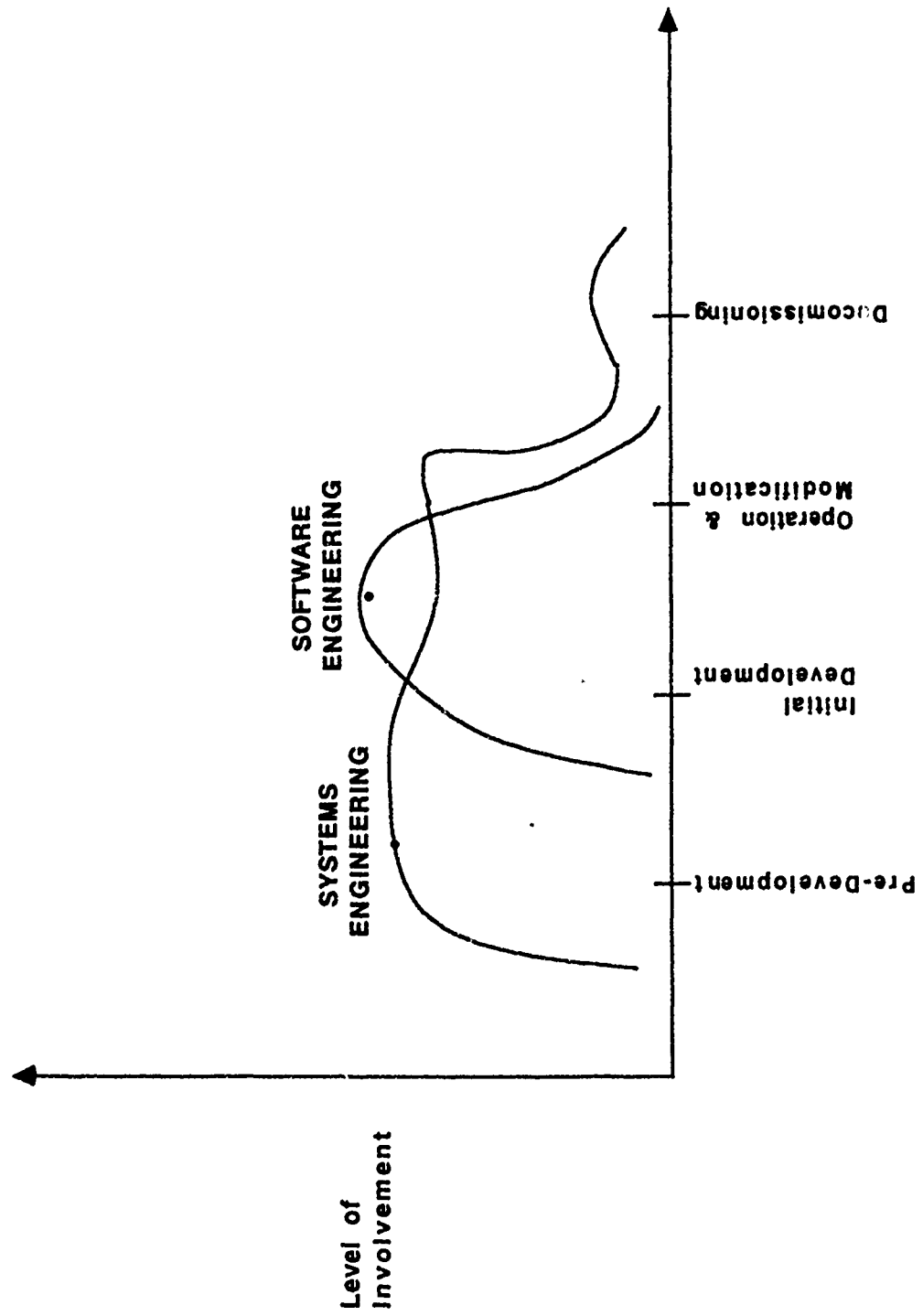
A Simplified Structure Of A Radio Evaluation Model



==A Systems Engineering Management Structure==



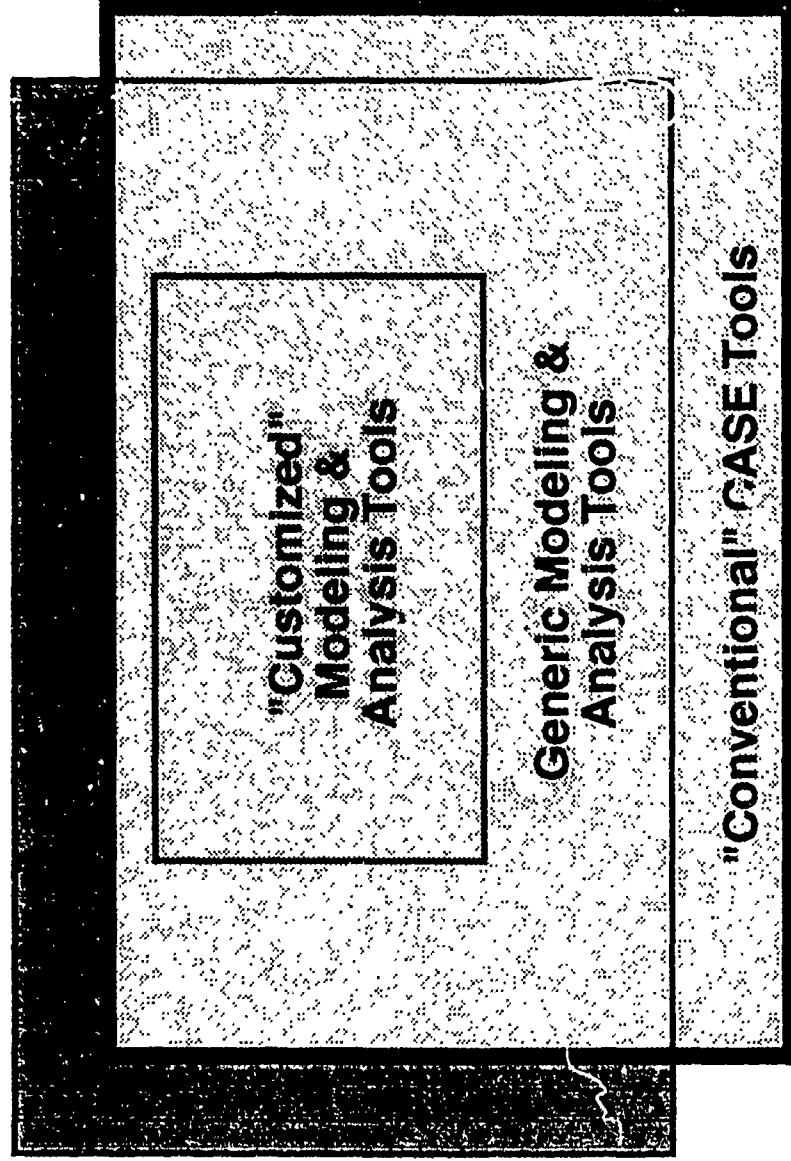
Time Scope



Systems Engineering "Versus" Software Engineering

	Systems Engineering		Software Engineering
Alternative Design Methods	H		M
Multidisciplinary Orientation	H		L
Requirements Analysis & Prototyping	H		M
Criteria-Based Trade-Off Analysis	H		L
Detailed Software Specifications	M		H
Optimal Software Production	M		H
Methods Integration (Re-) Planning	M		L
Education & Training Curricula	M		M
Artifact Profiling	M		M
Applications Range Assessment	M		M
Measures & Standards	M		M
Processes/Metrics Introspection	M		M

Computer-Aided Systems Engineering



Criteria-Based Evaluation & Assessment --> The Tools Matrix

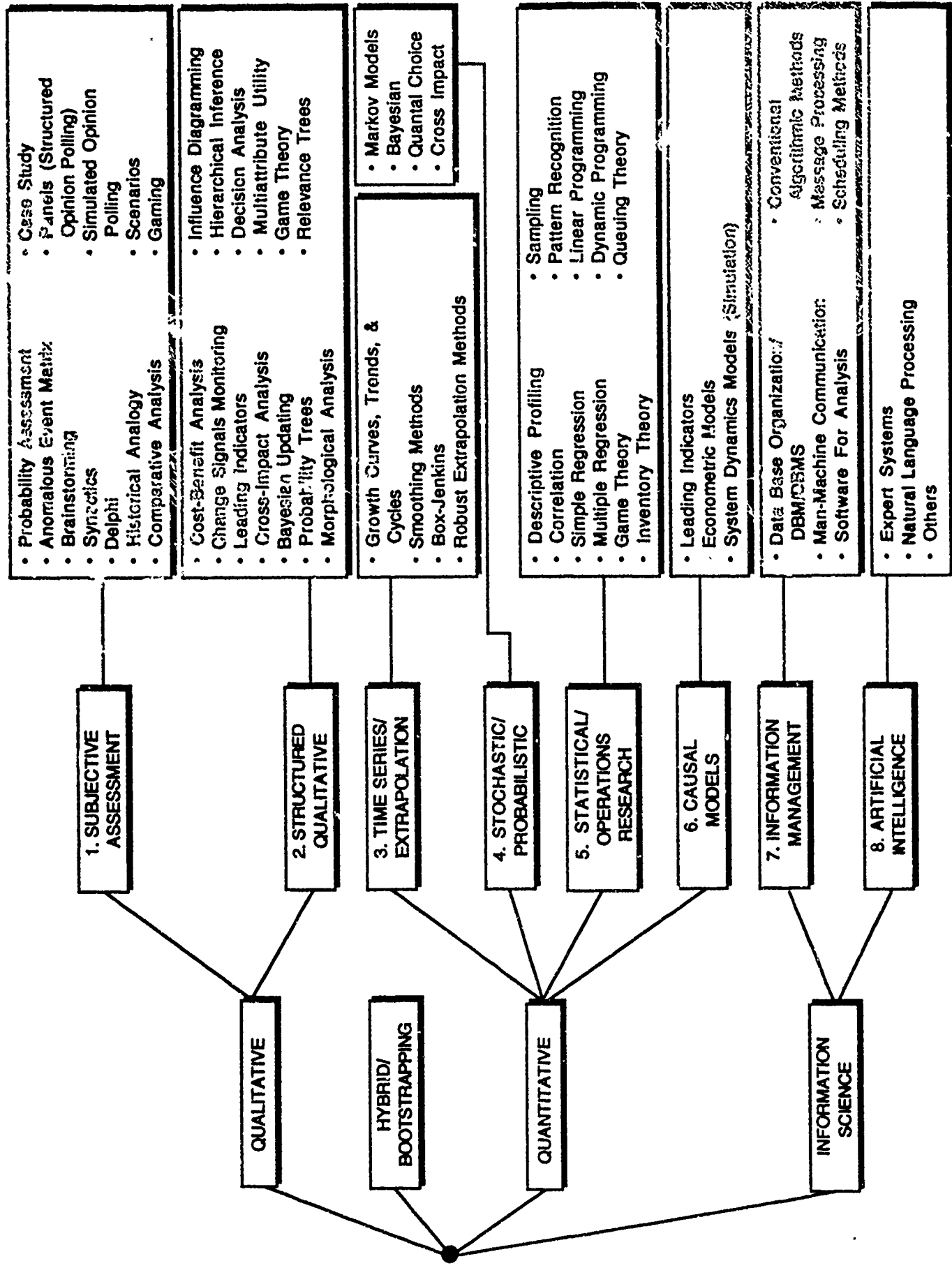
- Tools Can Be Assessed According to Their:
 - "Fit" (with a Systems Engineering Phase, Method, or Objective
 - Cost (to Include Acquisition, Training & Use)
 - Quality of Output
 - Ease of Use
 - Robustness
 - Support ...

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COTS/CASE Tools Sampler

- **Tools Not Usually Associated with Software Engineering + Some of Those That Are!!!**
- **Tools That Support Methods & Objectives of the Systems Engineering Life Cycle Phases**
- **Tools That Support:**
 - **Modeling, Charting & Diagramming**
 - **Analysis (eg, Cost-Benefit, Estimation)**
 - **Documentation & "Auditing"**
 - **Management**
 - **Technology Assessment**
 - **Testing & Evaluation ...**

A Taxonomy Of Analytical Methods & Sub-Methods



Life Cycle Phase-by-Phase Organization & Categorization

- **Pre-Phases**
 - **Project Management Tools**
 - **Simple Graphics Tools**
 - **Modeling & Analysis Tools**
 - **"Visualization" As A Way of Life**
- **Early Phases & Activities**
 - **Requirements, Requirements, Requirements**
 - **Requirements Models, Tools & "Environments"**
 - **Trade-Off Analyses**
 - **Constraint Analysis ...**

Life Cycle Phase-by-Phase Organization & Categorization (Continued)

- **Mid-Phases & Activities**
 - **Specification (from Multiple Perspectives)**
 - **On-Going Requirements Traceability**
 - **Design (from Multiple Perspectives)**
 - **Development (Often Evolutionary)**
- **Later Phases & Activity**
 - **T&E; V&V**
 - **On-Going Requirements Traceability**
 - **Documentation (Throughout)**
 - **Configuration Management**

Exemplar CAS(ystems)E Tools

- **Requirements Modeling**
 - **QFD Capture**
 - **RDD**
 - **DOOR**
 - **TopDown**
 - **DATA**
 - **IDEF0**
 - **Inspiration**
 - **Systems Engineering Design Software (SEDSO)**
 - **Conventional CASE Tools**
 - **Many CAD/CAM/CALS Tools**
 - **Some Evaluation & Trade-Off Analysis Tools**

Exemplar CAS(ystems)E Tools

- **Simulation & Prototyping**
 - **Extend**
 - **iThink**
 - **MicroSaint**
 - **MetaDesign**
 - **Skylights**
 - **ToolBook**
 - **Show Partner**
 - **TAE+**
 - **Access**
 - **LabView**
 - **Design/IDEF/IDEF0**
 - **Visual Basic**
 - **Prograph**

Exemplar CAS(ystems)E Tools

- **Evaluation & Trade-Off Analysis**
 - **Logical Decision**
 - **Expert Choice**
 - **DecisionMap**
 - **Decision Analyst**
 - **Lightyear**
 - **ADAM 2**
 - **Arborist**
 - **COMPARE!**
 - **Best Choice 3**
 - **Criterion**
 - **Crystal Ball**
 - **David**
 - **Decision Pad**
 - **Equity**

Exemplar CAS(ystems)E Tools

- Expression Tree
- HIVIEW
- SuperTree

Exemplar CAS(ystems)E Tools

- **Testing & Reliability**
 - **RPP**
 - **PC Availability**
 - **PC Predictor**
 - **Tiger Computer Program(s)**
 - **Machanical Reliability Prediction Program (MRP)**
 - **Maintainability Effectiveness Analysis Program (MEAP)**
 - **Optimum Repair Level Analysis (ORLA) Model**
 - **Equipment Designer's Cost Analysis System (EDCAS)**
 - **Network Repair Level Analysis (NRLA)**
 - **OPUS Model**
 - **VMETRIC**

Exemplar CAS(ytems)E Tools

- **Systems & Logistics Integration Capability (SLIC)**
- **Life Cycle Cost Calculator (LCCC)**
- **Cost Analysis Strategy Assessment (CASE)**
- **Life-Cycle Model for Defense Material Systems**

Exemplar CAS(ystems)E Tools

- **Technology Forecasting**

- **4CAST/2**
- **Autocast**
- **Forecast!**
- **GLIM**
- **MTS**
- **NCSS**
- **SAS**
- **SIBYL/Runner**
- **STORM**

Exemplar CAS(ytems)E Tools

- Risk Analysis
 - @Risk
 - RiskWatch
 - Automated Risk Evaluation System (ARES)
 - Bayesian Decision Support System (BDSS)
 - The Buddy System
 - Continuous Risk
 - Los Alamos Vulnerability & Risk Assessment (LAVA)

Exemplar CAS(ystems)E Tools

- Prototyping Tools for Software Systems Engineering
- Tool "Requirements"
- Exemplar Tool Types
- Specific Tools ...

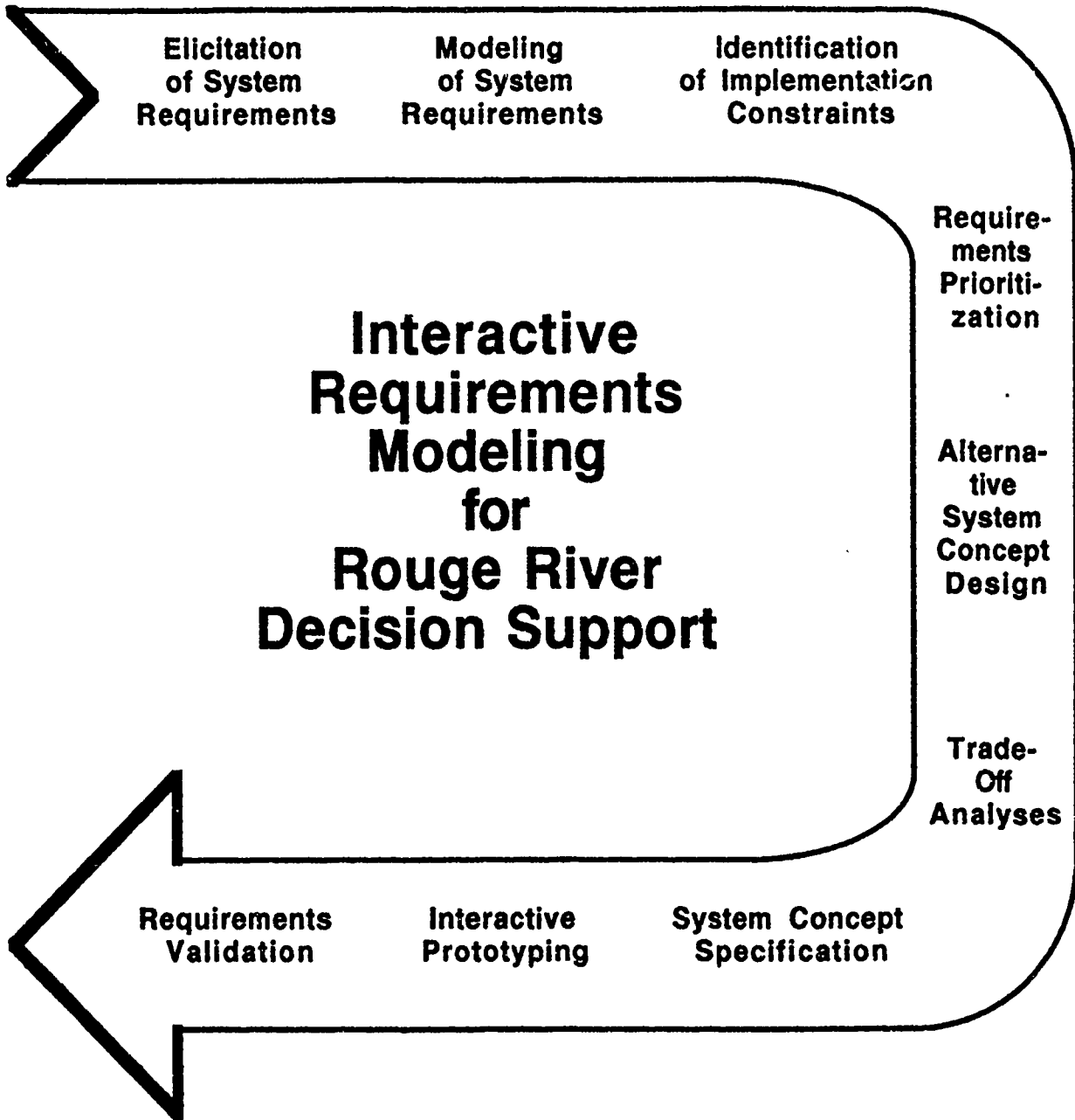
Impact

- **Software Support For All Phases of Life Cycle**
- **Capability to Store & Model Requirements Data ---> Prototypes ---> Specifications Designs**
- **"Audit Trail" of Design/Development Process**
- **Capability to Store Designs, Models, Prototypes & Modules & Reuse the Concepts, Data, Models & Software**

***Interactive Requirements
Modeling & Prioritization & System
Concept Design***

for

Rouge River Decision Support



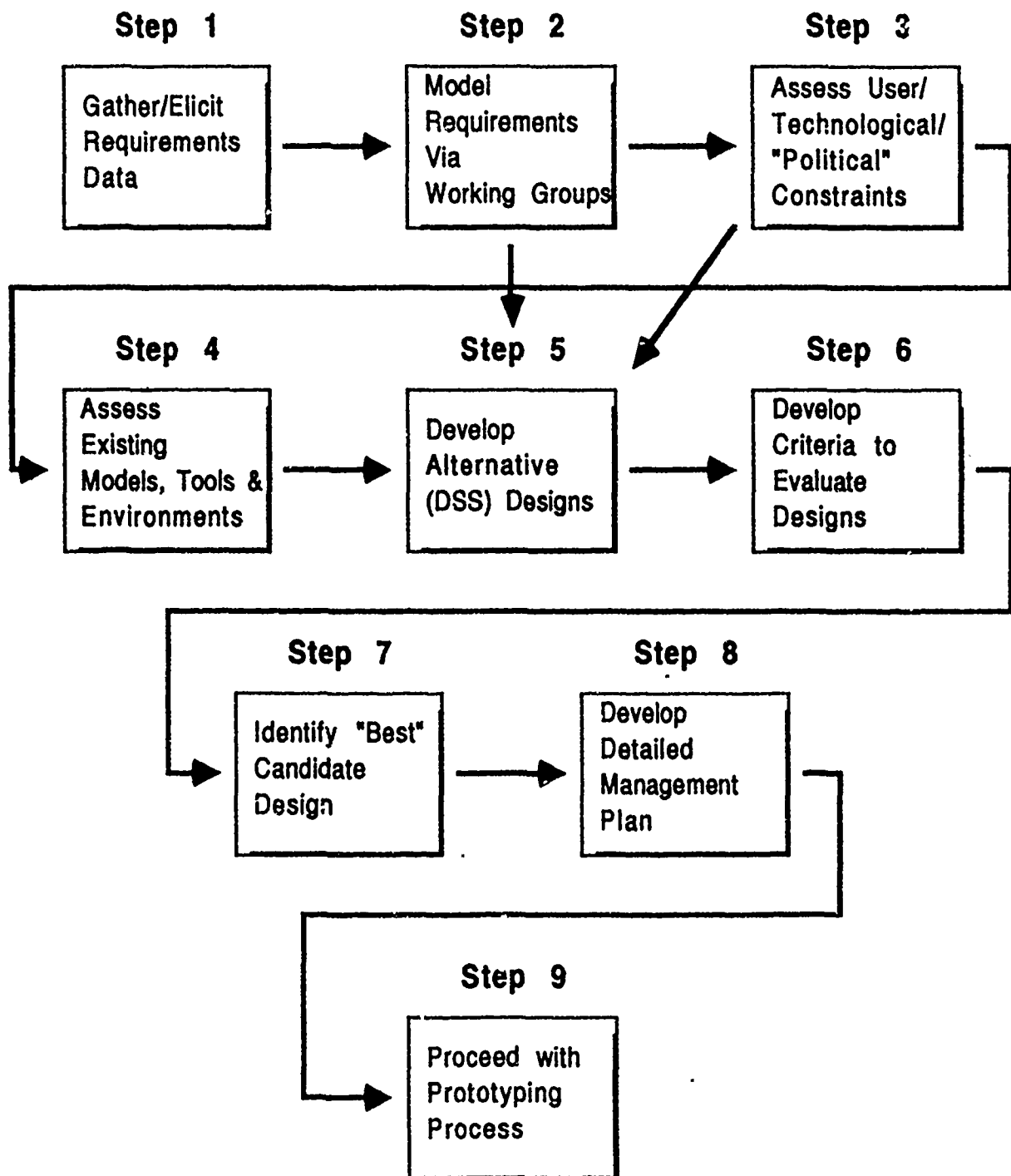
The Process

- **Collect Requirements Data Via Individual & Group Discussions & Via Codified Requirements Data**
- **Document Requirements Data -- Not in Elaborate "Specs" -- But in a Form that Lends Itself to Analysis & Modification**
- **Organize the Requirements Data in Alternative Forms for Iteration -- Such as in Simple Outline Form & in a Hierarchical Form**
- **Assess, Rank-Order, Trade-Off -- "Reconcile" Requirements**
- **Identify Off-the-Shelf & Existing Special Purpose Applications Programs & Implementation Environments**
- **Match the Requirements to the Existing Systems**
- **Develop a System Requirements Specification that Lies at the Intersection of Requirements, Existing Systems & Constraints**

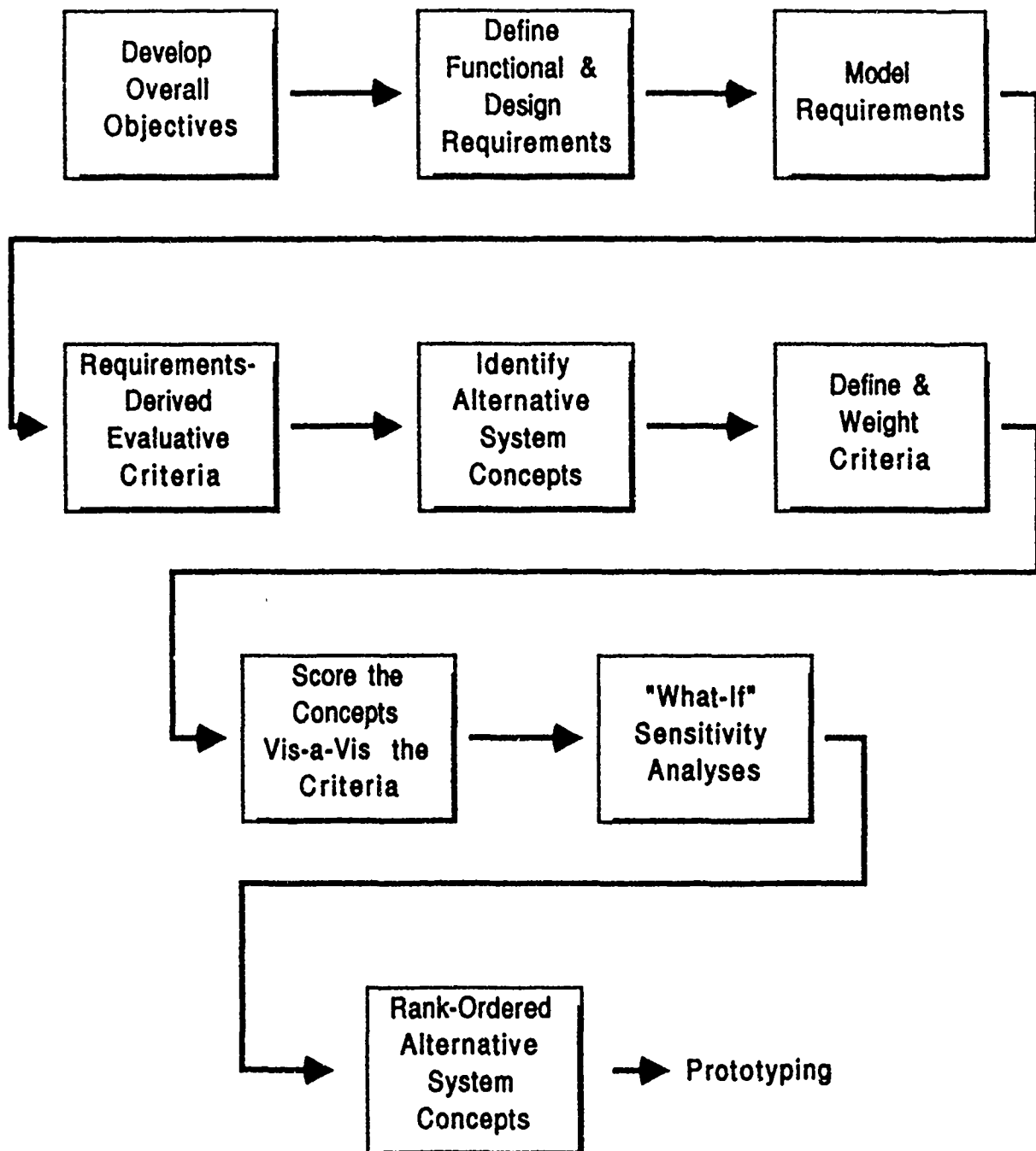
Some Special Assumptions & Features of the Process

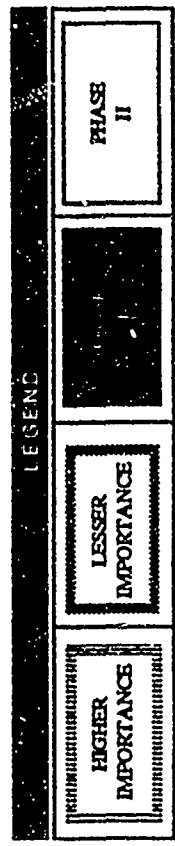
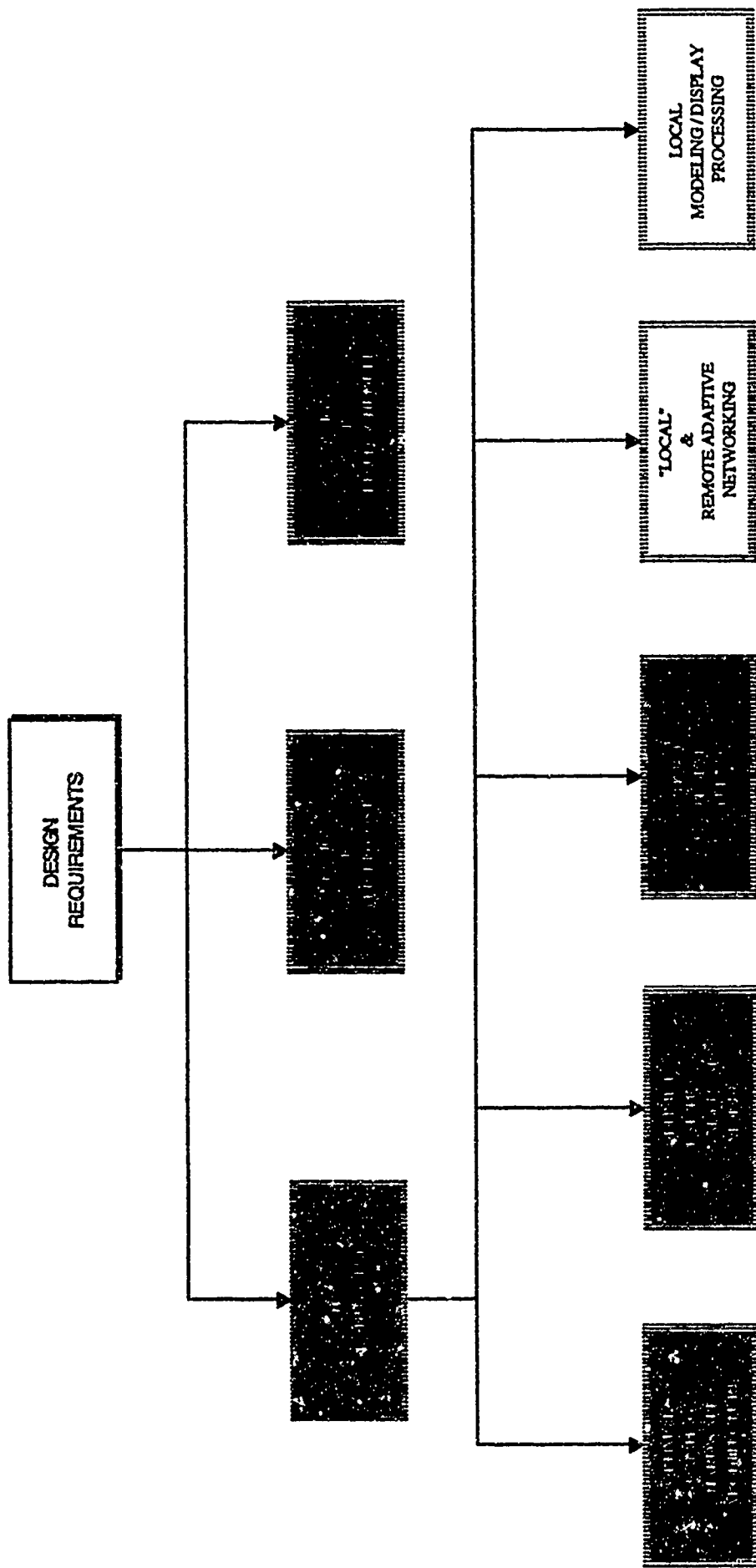
- The Process Assumes the Value of "Participatory Design"
- The Process Assumes the Value of Iterative Design & Prototyping -- to a Point!
- The Process Assumes the Value of a Life Cycle-Driven System Development Methodology
- The Process Assumes the Need to Make Requirements Explicit & to "Model" Requirements to Determine What are the "Most," "Moderately," and "Not Quite as" Important Requirements
- The Process Assumes the Stupidity of Re-Inventing the Wheel
- Requirements will Be Captured, Modeled & Communicated to All "Stakeholders" During the Process

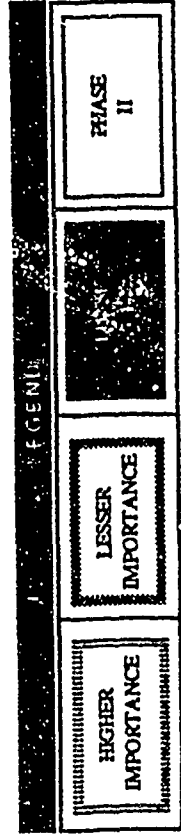
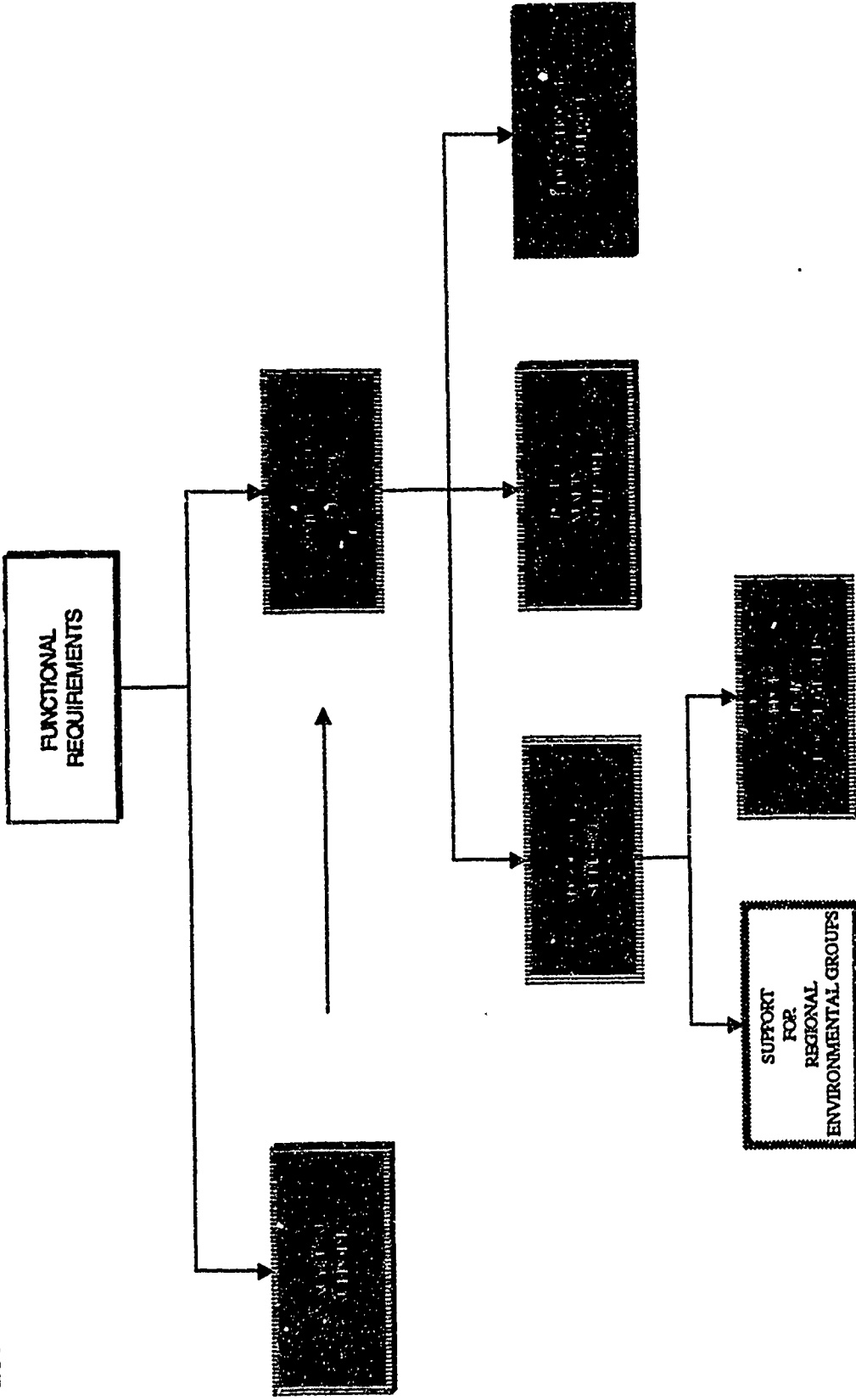
Requirements Modeling --> Prototyping Process --> Management Plan



System Concept Evaluation Process







Decision Outline on DSS H/S Architecture

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Alternatives:

- System Concept #1
- System Concept #2
- System Concept #3

Factors:

R DSS H/S Architecture

1 Funct'l Requirements

2 Analyt'l Requirements

3 Flow Analysis

4 Whole River Simulation

4 Threshold Analysis

4 Quasi-RT Analysis

4 Realtime Analysis

3 Map Partitioning

4 Scenario-Driven

4 Clutter/De-clutter

3 Querying

4 Cost-Result Analyses

4 Comparative Analyses

4 Sensitivity Analyses

2 Communicat'n's Requirements

3 Advocacy Requirements

4 Reg'n'l Group Support

4 Local Support

3 Policymkg Requirm'ts

4 Remote PMKG Support

4 Local Support

5 Investment Strategy

5 In-Stream Analysis

3 Educatn'l Requirm'ts

4 Water Polut'n Educat

4 General Pollution

4 RR Basin Pollution

1 Design Requirements

2 H/S Architecture

3 Optimize Hardware

3 Optimize Models

3 Optimize OS Trends

2 Local Modeling

3 Local/Remote Network

2 Design to Cost

2 Design to Schedule

Decision Results on DSS H/S Architecture

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Alternative	Score	Comments
System Concept #3	98.55	Concept for PC/NT-based DSS with full networking
System Concept #2	75.84	Concept for UNIX-based system w modest networking
System Concept #1	57.84	Concept that calls for UNIX workstation-based DSS

Comments: "Optimal" hardware/software architecture

SYSTEM CONCEPT I

- **SUN / UNIX**
- **ARC / INFO**
- **SPATIAL / TEMPORAL INFORMATION**
- **INTERACTIVE VISUALIZATION**

SYSTEM CONCEPT II

- SUN / UNIX
- ARC / INFO
- SPATIAL / TEMPORAL INFORMATION
- INTERACTIVE VISUALIZATION

PC's

UNIX
WORKSTATIONS

PC's

SYSTEM CONCEPT III

MODELING

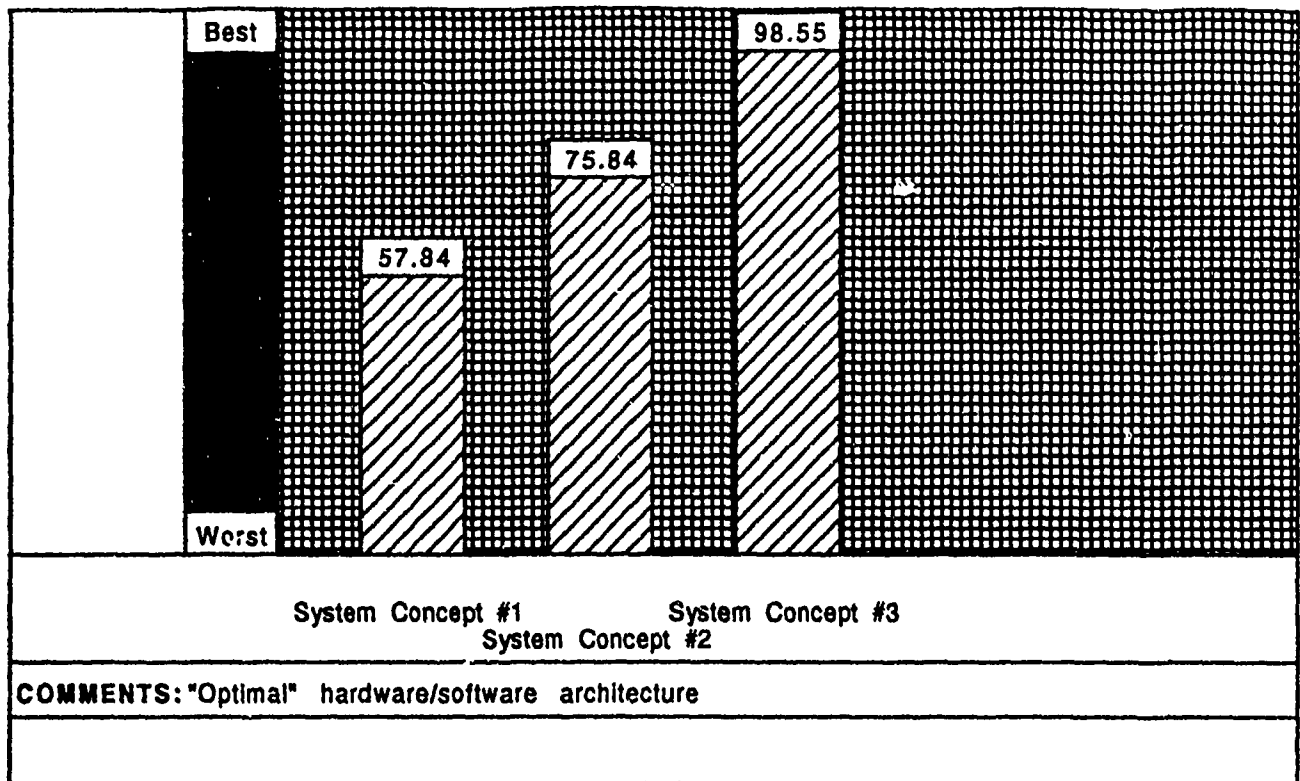
- PC
- WINDOWS NT
- GUT FOR PRE / POST PROCESSING
(& ANIMATION)

NOVELL
CLIENT / SERVER

- SUN / UNIX
- ARC / INFO
- ORACLE
- SPATIAL / TEMPORAL INFORMATION

SERVER

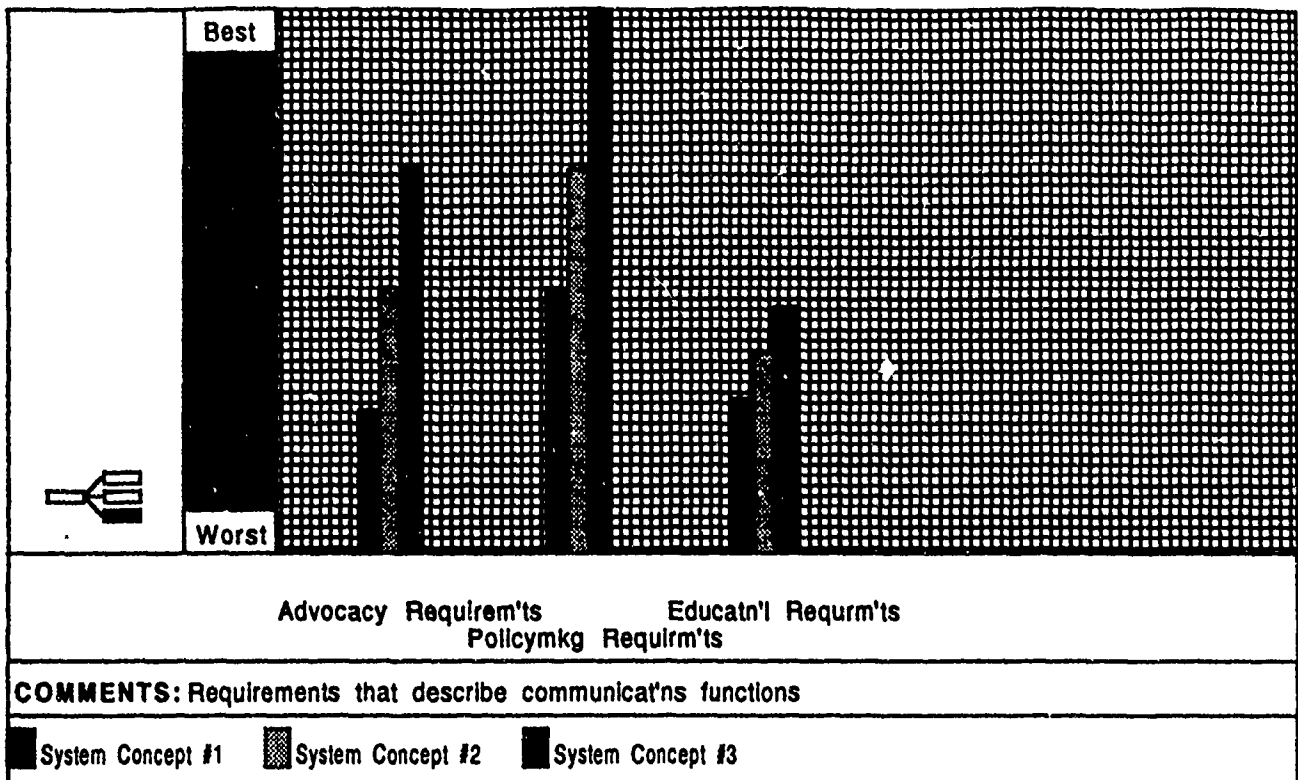
Decision Results on DSS H/S Architecture



5

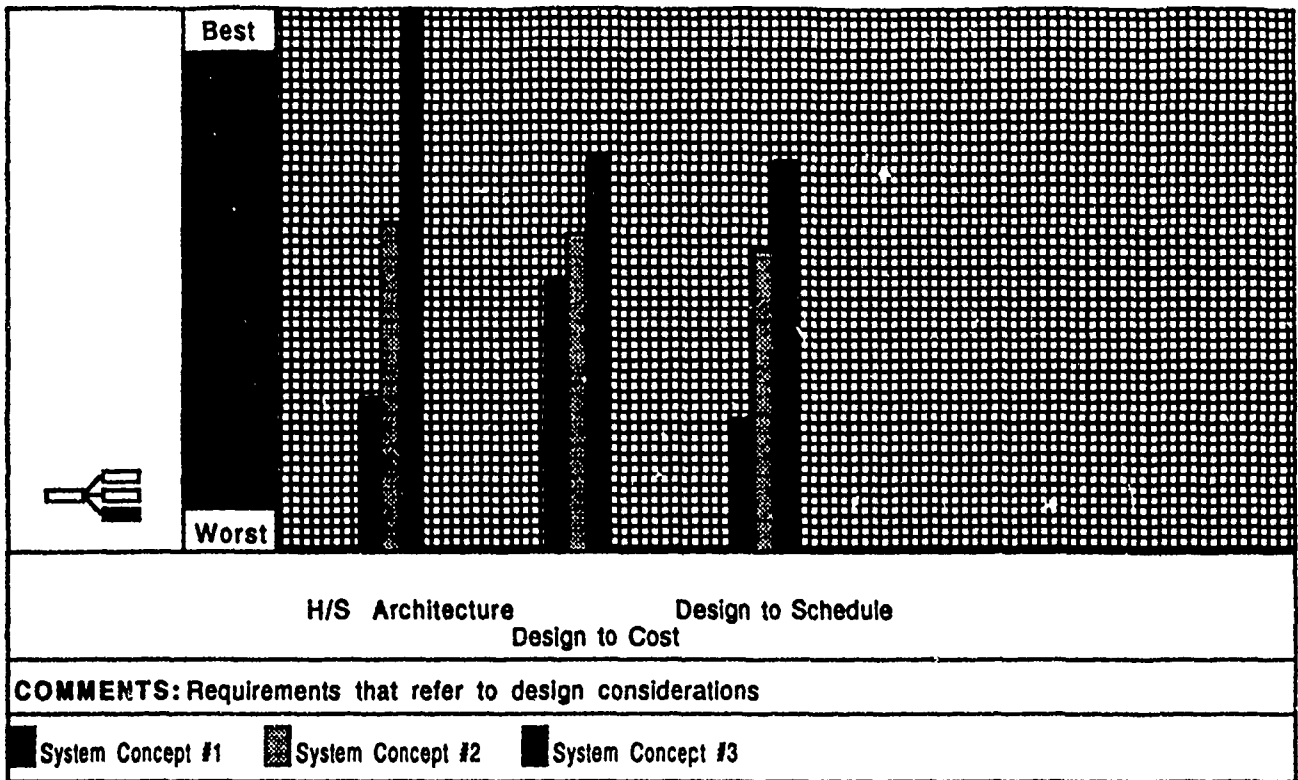
Decision Comparison on Communicatn's Req'm'ts

5



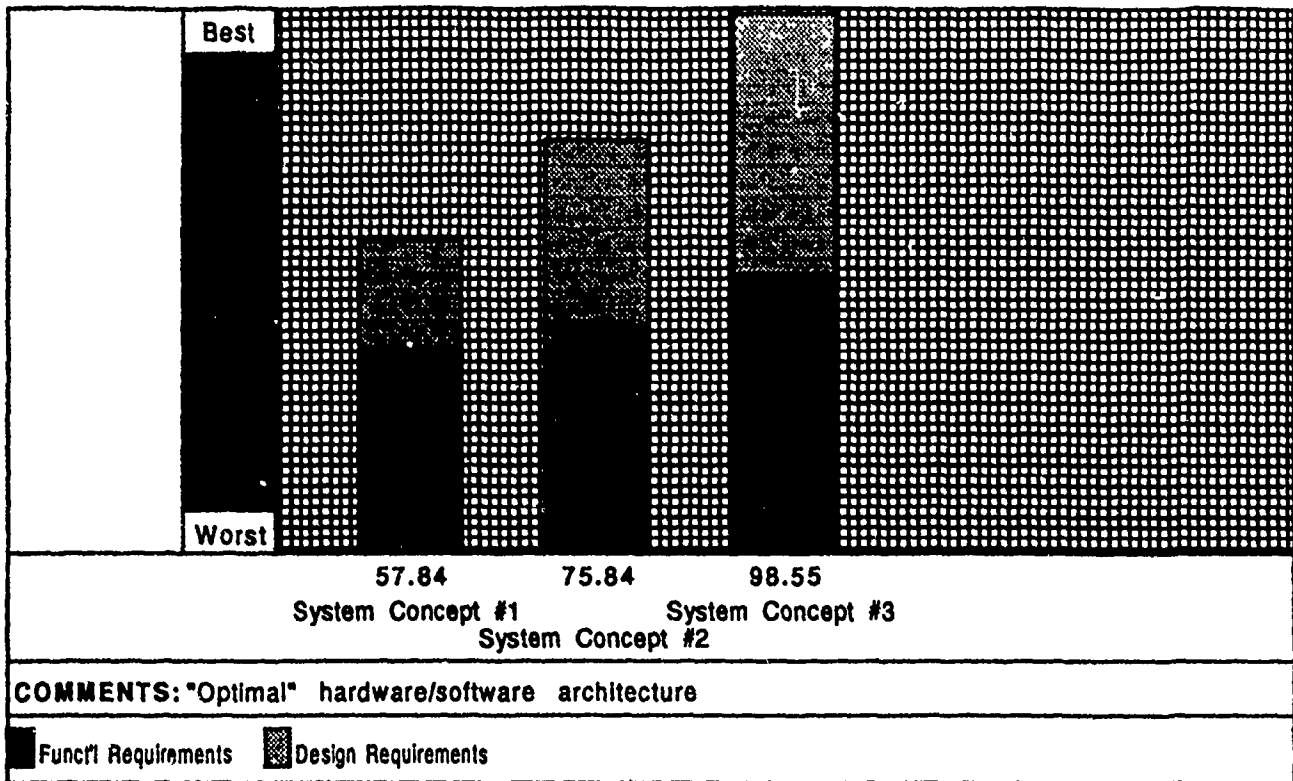
Decision Comparison on Design Requirements

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Decision Comparison on DSS H/S Architecture

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Trends

- **Toward I-CASE**
- **Toward Greater Distribution**
- **Toward Automation ...**

Key References

- **Howard Eisner, *Computer-Aided Systems Engineering*, Prentice-Hall, 1988**
- **Benjamin S. Blanchard, *System Engineering Management*, Wiley-Interscience, 1992**
- **William L. Chapman, A. Terry Bahill & A. Wayne Wymore, *Engineering Modeling & Design*, CRC Press, 1992**
- **Andrew P. Sage, *Systems Engineering*, Wiley-Interscience, 1992**
- **Benjamin S. Blanchard & William J. Fabrycky, *Systems Engineering & Analysis*, Prentice-Hall, 1990**
- **Odean Bowler, et al., *Requirements Analysis & Design Tools Report*, Software Technology Support Center, 1992**
- **Chris Sittenauer, et al., *Re-Engineering Tools Report*, Software Technology Support Center, 1992**

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