Department of Systems Engineering

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SYST 302: Systems Methodology and Design II #11

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Design for Economic Feasibility

- Concepts and Introduction
- Cost Emphasis in the System Life-Cycle
- Life-Cycle Cost Analysis
- Evaluating Economic Alternatives

Introduction

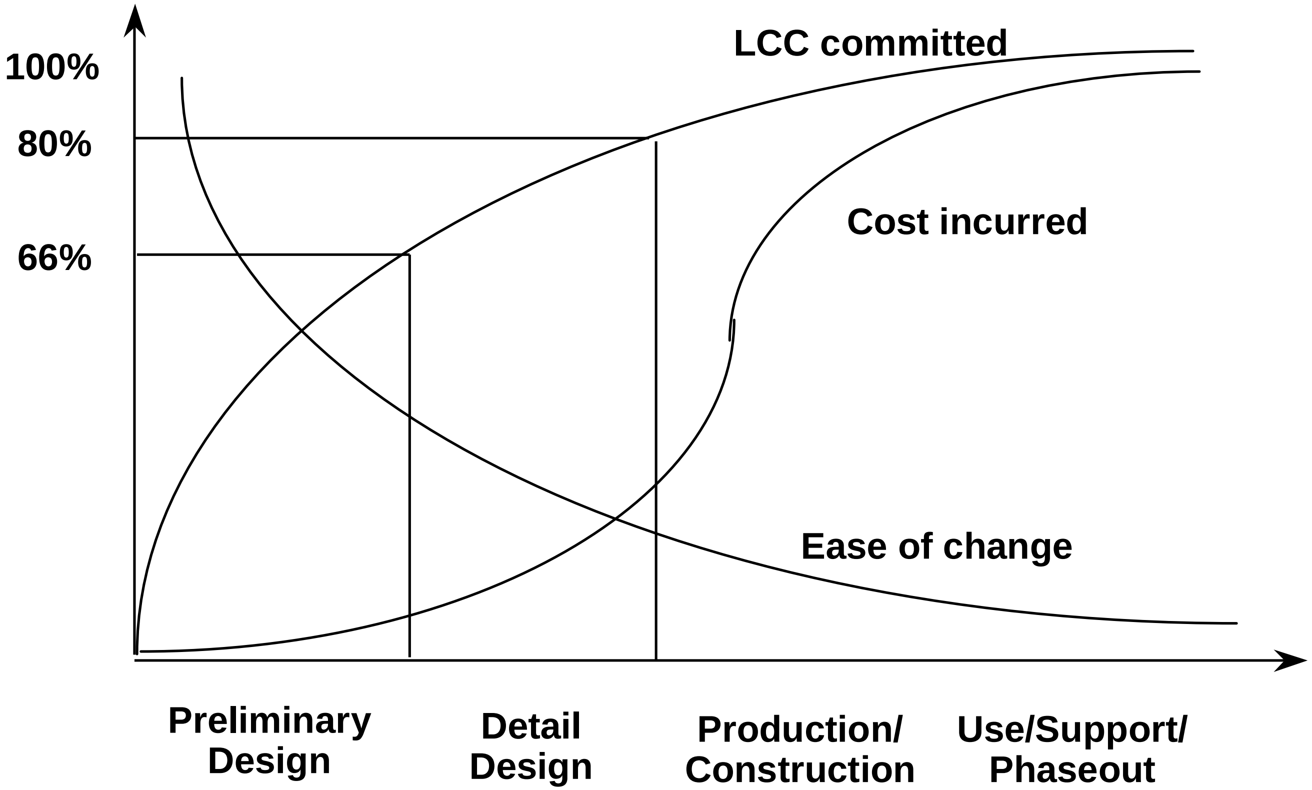
- **Life-Cycle Cost (LCC): The cost associated with the entire system life cycle such as research, design, testing, production or construction, operations, consumer use and support.**
  - **The cost of different phases of system life-cycle are interrelated**
  - **They must be viewed on an integrated basis**
  - **LCC is critical to design for economic feasibility**
- **LCC includes:**
  - **Research and development cost**
  - **Production and construction cost**
  - **Operation and support cost**
  - **Retirement and disposal cost**
- **LCC analysis: To evaluate alternative system design and arrive at a most cost-effective solution**

Consumer-to-Consumer Process
- Generic life-cycle activities

- **Consumer:** **Identification of need (desires)**
- **Producer:**
  - **System planning function (marketing analysis, feasibility study, etc.)**
  - **System research function (basic and applied research)**
  - **System design function (requirement, preliminary design, detailed design, prototype, test, etc.)**
  - **Production and/or construction function (plant and manufacturing engineering, quality control, etc.)**
- **Consumer:**
  - **System evaluation function (T&E)**
  - **System use and logistic support function (maintenance, modification, phase out, disposal, etc.)**

Cost Commitment

- Large portion of total cost is in operation and support
- Commitment of these cost is made in early stages
- LCC economic analysis should therefore originate early in the product life cycle

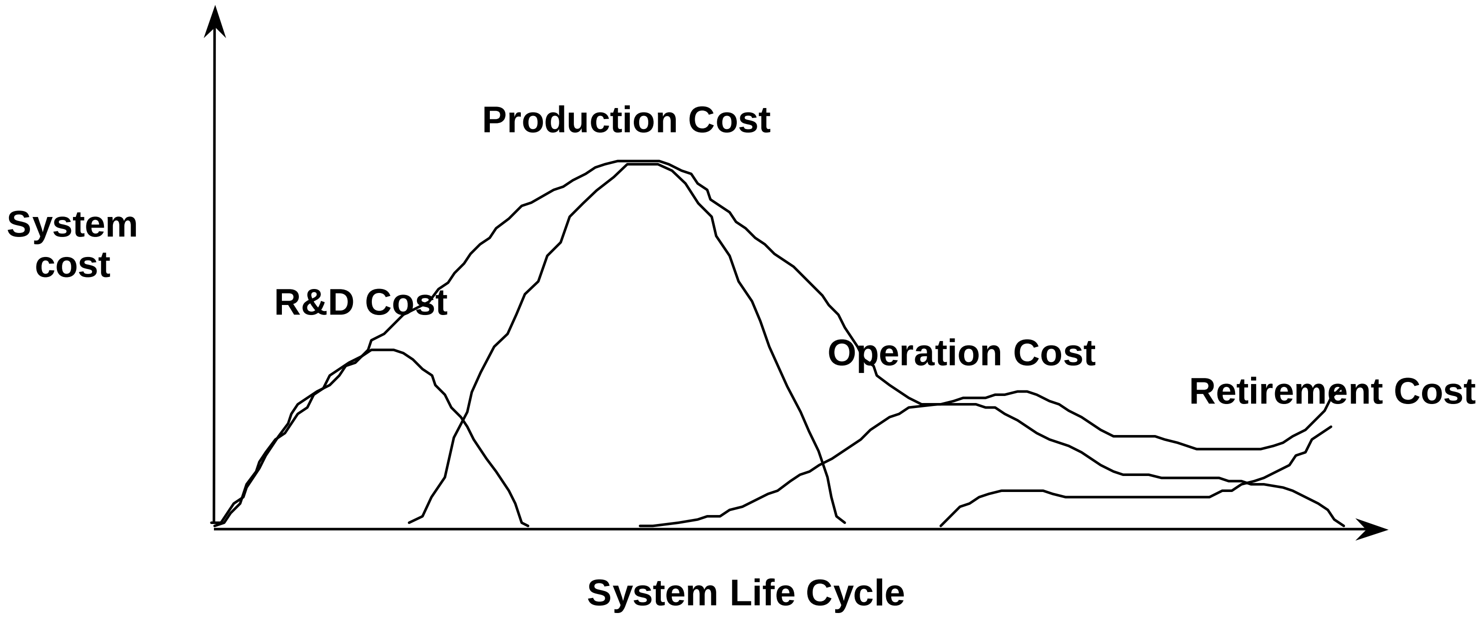


Life-Cycle Economic Analysis

- **Define the needs:** **Identify cost analysis goal**
  - **Evaluate different alternatives based on LCC?**
  - **Determine feasibility with a budgetary constraint?**
- **Define guidelines and constraints:** **Maximum weight, minimum reliability, minimum capacity, etc.**
- **Identify alternatives:** **It is better to consider many alternatives than to overlook one that may be very good.**
- **Develop the Cost Breakdown Structure(CBS):**
  - **Link objectives and activities with resources**
  - **Provide a mechanism for cost allocation, categorization, monitoring and control**
- **Select cost model for evaluation:** **Market analysis, system operation, personnel requirements, support equipment, product distribution, maintenance, inventory policy, etc.**

Cost Treatment over the Life Cycle

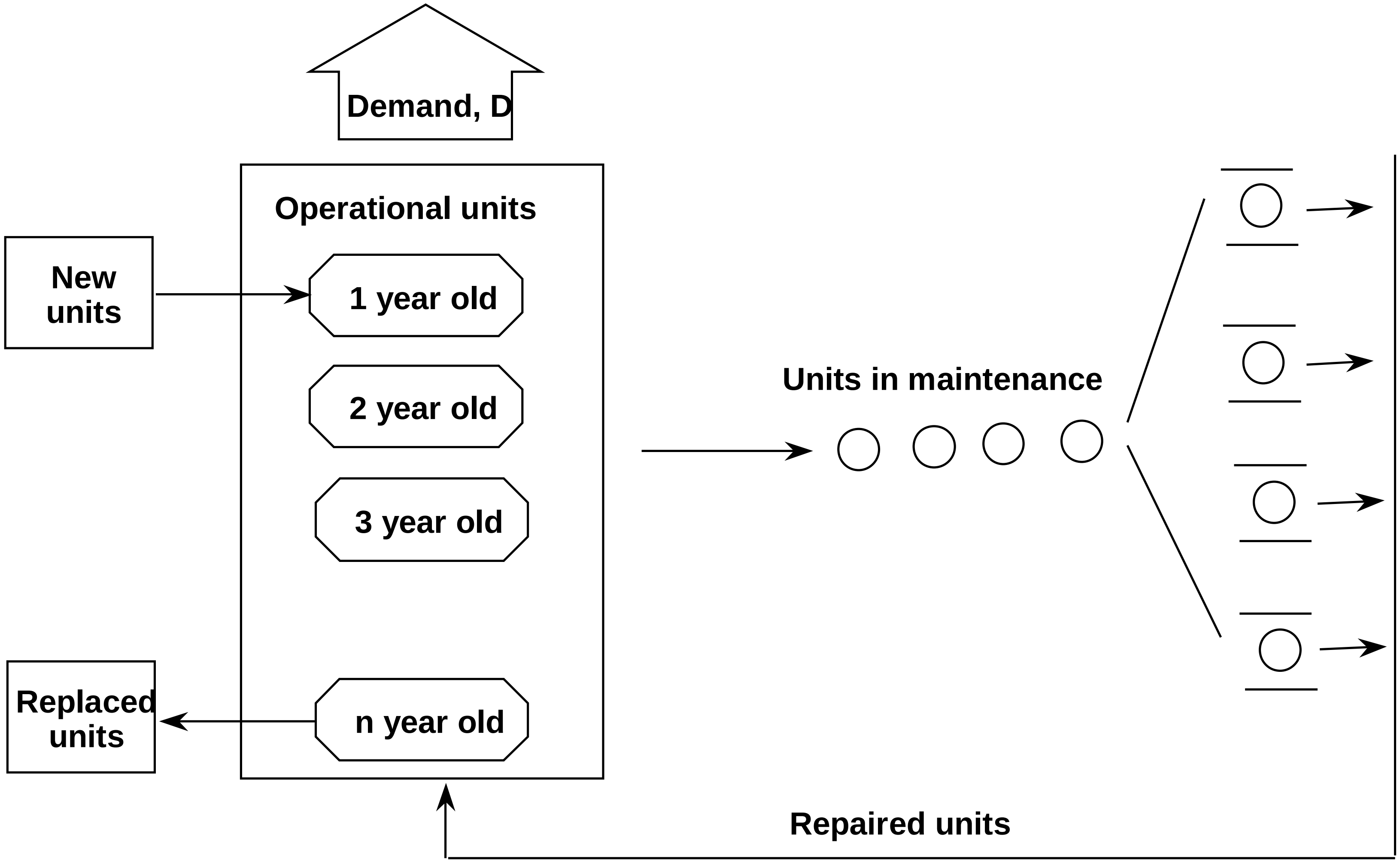
- **Develop the Cost Profile:**
  - Identify cost category in CBS and project individual cost into future over the life cycle
  - Introduce appropriate inflationary factors, learning curves effects, etc.
  - Consider time value of money



Case Study
Repairable Equipment System Design

- **System Description:**
  - The repairable equipment population system (REPS) is designed and deployed to meet a demand D
  - Units are repaired when fail
  - As units age, they become less reliable and more expensive to maintain
  - New units are procured each year in a constant rate
  - Ex: Airlines, Auto rental companies, Equipment rental, etc.
- **Design Problem:**
  - To determine the population size, the replacement age of units, the number of repair channels
  - Minimize the sum of all costs associated with the system

Repairable Equipment Population System



Assumptions and Scope

- **System Operation:**
  - Steady state mode with exponentially distributed interarrival times and repair times
  - Finite population multi-channel queuing formulation is used
  - Units completing repair have same operational characteristics as their age group
- **Design Variables:**
  - Controllables: number of units to deploy, the replacement age of units, and the number of repair channels
  - Focus on optimizing design variables as the only controllable factors
- **System Parameters:**
  - Demand: the primary stimulus of the system
  - Shortage penalty cost, cost of providing repair capability, time value of money, etc.

Evaluation Function

Annual Equivalent Life Cycle Cost: (AELCC)

AELCC = PC + OC + RC + SC

PC: annual equivalent population cost

OC: annual operating cost

RC: annual repair facility cost

SC: annual shortage penalty cost

Annual Equivalent Population Cost: (PC)

PC = $NC_i = N[P*(A|P,i,n) - B*(A|F,i,n)]$

where N = number of units, P = acquisition cost of a unit

$B = P - n\frac{P-F}{L}$ = book value of a unit at the end of year n

Annual Equivalent Costs

Annual Operating Cost : (OC)

$\text{PC} = N(\text{EC} + \text{LC} + \text{PMC} + \text{Other})$

EC = annual cost of energy consumed, LC = annual labor cost

PMC = annual preventive maintenence cost

Other : insurance premiums, taxes, etc.

Annual Repair Facility Cost: (RC)

$\text{RC} = M\text{C}_r$

M = number of repair channels

C_r = annual fixed and variable cost per repair channel

Annual Shortage Penalty Cost

Annual Shortage Penalty Cost: (SC)

SC = [E(S)]C_s

E(S) = expected number of units short

C_r = shortage cost per unit short per year

$$E(S) = \sum_{j=1}^{D} jP_{(N-D+j)}$$

where P_i is the probability of i failed units and

$$P_i = P_0 C_i \text{ for } i = 0,1,2,\ldots,N;\; P_0 = \left(\sum_{i=0}^{N} C_i\right)^{-1}$$

$$C_i = \begin{cases} \dfrac{N!}{(N-i)!i!}\left(\dfrac{\lambda}{\mu}\right)^i & \text{if } i = 0,1,2,\ldots,M \\ \dfrac{N!}{(N-i)!M!M^{i-M}}\left(\dfrac{\lambda}{\mu}\right)^i & \text{if } i = M+1, M+2,\ldots,N \end{cases}$$

System Parameters

Parameter	*value*	
Unit Acquiaition cost	$52,000	
Unit design life	6 years	
Unit savage value	$7,000	
Unit operation cost		
Energy and fuel	$500	
Operating labor	$450	
Preventive maintenance	$400	
Other operating cost	$400	
Annual repair channel cost	$45,000	
Annual shortage cost	$73,000	
Annual interest rate	10%	
Age groups	MTBF	MTTR
0 - 1	0.20	0.03
1 - 2	0.24	0.04
2 - 3	0.29	0.05
3 - 4	0.29	0.05
4 - 5	0.26	0.04
5 - 6	0.22	0.07

Assuming

Demand, D = 15

Population, N=19

Repair Channels, M=3

Retirement Age, n=4

Total System Annual Equivalent Cost

Annual Equivalent Population Cost: (PC)

$$\text{PC} = NC_i = 19\left[52{,}000\left(\frac{0.10(1.10)^4}{(1.10)^4-1}\right) - \left(52{,}000 - 4\left(\frac{52{,}000-7{,}000}{6}\right)\right)\left(\frac{0.10}{(1.10)^4-1}\right)\right]$$

$$= 19(11{,}664) = 221{,}616$$

Annual Operating Cost: (OC)

$$\text{PC} = 19(500+450+400+400) = 33{,}250$$

Annual Repair Facility Cost: (RC)

$$\text{RC} = M\text{C}_r = 3(45{,}000) = 135{,}000$$

Annual Shortage Penalty Cost: (SC)

$$\lambda = \frac{1}{MTBF} = \frac{1}{\frac{1}{4}\left(0.20+0.24+0.29+0.29\right)} = 3.9215;\ \mu = \frac{1}{MTTR} = \frac{1}{\frac{1}{4}\left(0.03+0.04+0.05+0.05\right)} = 23.5294$$

$$E(S) = \sum_{j=1}^{D} jP_{(N-D+j)} = \sum_{j=1}^{15} jP_{(4+j)} = 1(0.1189) + 2(0.0925) + \cdots + 15(0.0000) = 1.0063$$

$$\text{SC} = [\text{E(S)}]\text{C}_s = (1.0063)(73{,}000) = 73{,}484$$

$$TC = PC + OC + RC + SC = 463{,}350$$

Optimal Solution

Retirement Age	Number of Units	Number	of	Channels, *M*
n	*N*	2	3	4
3	19	598,395	465,985	469,130
4	18	592,920	464,770	465,755
4	19	600,720	463,350*	464,295
4	20	610775	466,610	468,755
5	19	643,050	480,375	467,735

*** Optimal configuration**

Considering Design Requirements

- **Design Dependent Parameters:**
  - Baseline system may not be acceptable
  - Decision making over a set of design dependent parameters
- **Design Requirements:**
  - Limit to initial cost (< 50k)
  - Bound on probability of no units short of demand (> 0.7)
  - Lower bound on average MTBF (> 0.2 years)
  - Upper bound on service years (< 5 years)
- **Optimization:**
  - Generate candidate systems
  - Optimization over design variables

Candidate Systems

Parameter	*value*	
Unit Acquisition cost	$45,000	
Unit design life	6 years	
Unit salvage value	$6,000	
Unit operation cost		
Energy and fuel	$500	
Operating labor	$500	
Preventive maintenance	$400	
Other operating cost	$400	
Annual repair channel cost	$45,000	
Annual shortage cost	$73,000	
Annual interest rate	10%	
Age groups	MTBF	MTTR
0 - 1	0.16	0.04
1 - 2	0.21	0.04
2 - 3	0.26	0.05
3 - 4	0.26	0.06
4 - 5	0.26	0.06
5 - 6	0.24	0.06

Parameter	*value*	
Unit Acquisition cost	$43,000	
Unit design life	6 years	
Unit salvage value	$5,000	
Unit operation cost		
Energy and fuel	$800	
Operating labor	$700	
Preventive maintenance	$400	
Other operating cost	$400	
Annual repair channel cost	$45,000	
Annual shortage cost	$73,000	
Annual interest rate	10%	
Age groups	MTBF	MTTR
0 - 1	0.18	0.04
1 - 2	0.21	0.04
2 - 3	0.25	0.05
3 - 4	0.25	0.05
4 - 5	0.23	0.06
5 - 6	0.20	0.06

Evaluation Summary

	Baseline	*System I*	*System II*
N	19	20	20
M	3	4	4
n	4	5	4
P	$52,000	$45,000	$43,000
Avg. MTBF	***0.26***	***0.23***	***0.22***
Prob(no units short)	***0.622***	***0.663***	***0.730***
Annual Equi. LCC	***$463,350***	***$478,470***	***$468,825***