Lecture L9

Budget Planning & optimal Programming for Pavement Management

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Part A

Multi-Objective Optimal Programming

Multi-Objective Problem

- High level of service
- Safe traffic operations
- Minimal socio-environmental impacts
- Sound condition of network facilities
- Reasonably low budget
- Efficient use of resources

Many are conflicting requirements !

Single- vs Multi-Objective Optimization

- Single objective with other requirements imposed as constraints

  -- Solutions are non-optimal due to interference of optimization process by setting limits to requirements

- Pseudo multi-objective formulation through combined representation of requirements by one numerical parameter

  -- physical meaning of combined parameter unclear

Multi-Objective optimization for Pavement Management programming

- Single-agency network level PMS problem
- Multi-year maintenance /rehab activities programming
- Genetic-algorithm multi-objective optimization

Multiple Objectives in PMS

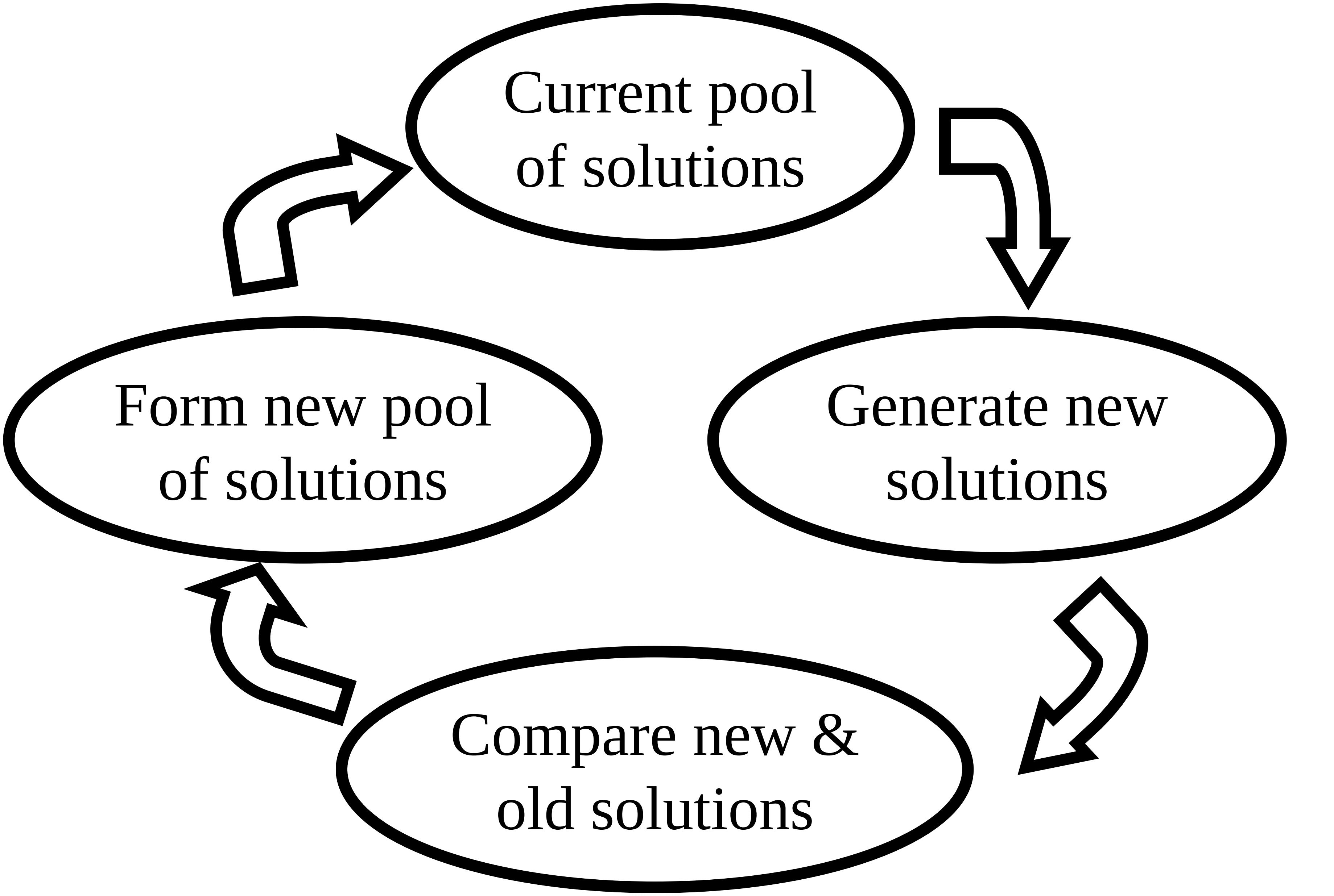
- Minimize maintenance costs
- Maximize road performance
  (road condition, safety, speed, etc)
- Maximize maintenance work production
- Minimize socio-environmental impacts
- Maximize utilization of resources
- Minimize road user costs

Genetic Algorithms

- Darwin evolution concept to search the “fittest’ solution
- Mechanics of natural selection
- Represent solutions in coded strings of “genes”
- Search population of points at a time
- Use probabilistic search mechanisms
- May not produce the ‘best’ solution, but ‘good’ solutions

Genetic Algorithms

- Flexibility in formulation
- Dislocated solution space
- Discrete optimization
- Robust search ability
- Family of “good” solutions


Current pool of solutions
Generate new solutions
Compare new & old solutions
Form new pool of solutions

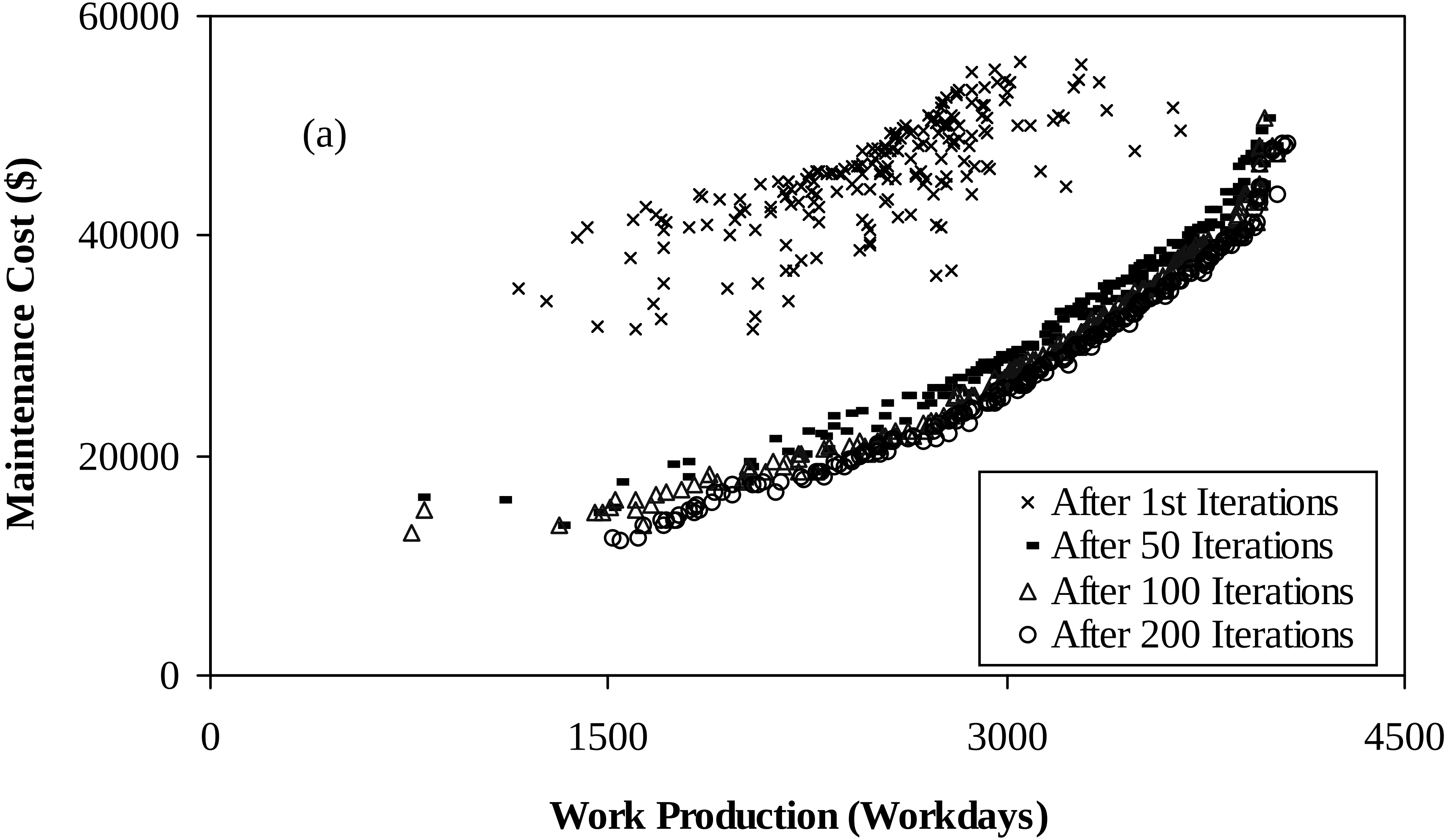
Example: Multi-Objective Optimization for Pavement Management programming

- Single-agency network level PMS problem
- Multi-year maintenance /rehab activities programming

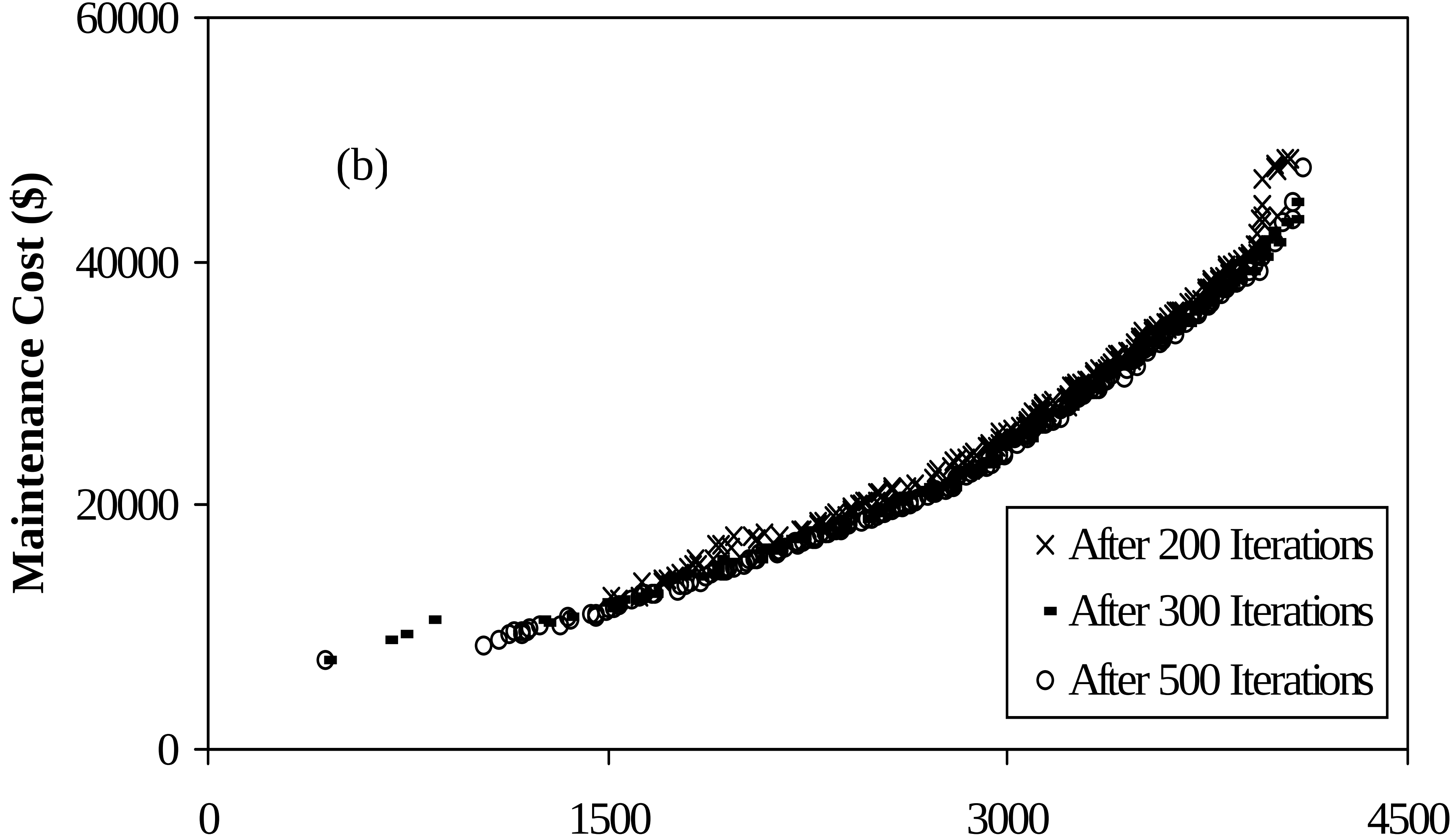
Concept of Pareto Optimality

- A curve or surface can be defined for all non-dominated solutions
- Known as the Pareto frontier
- Globally non-dominated solutions, called the Pareto optimal set, define the Pareto optimal frontier

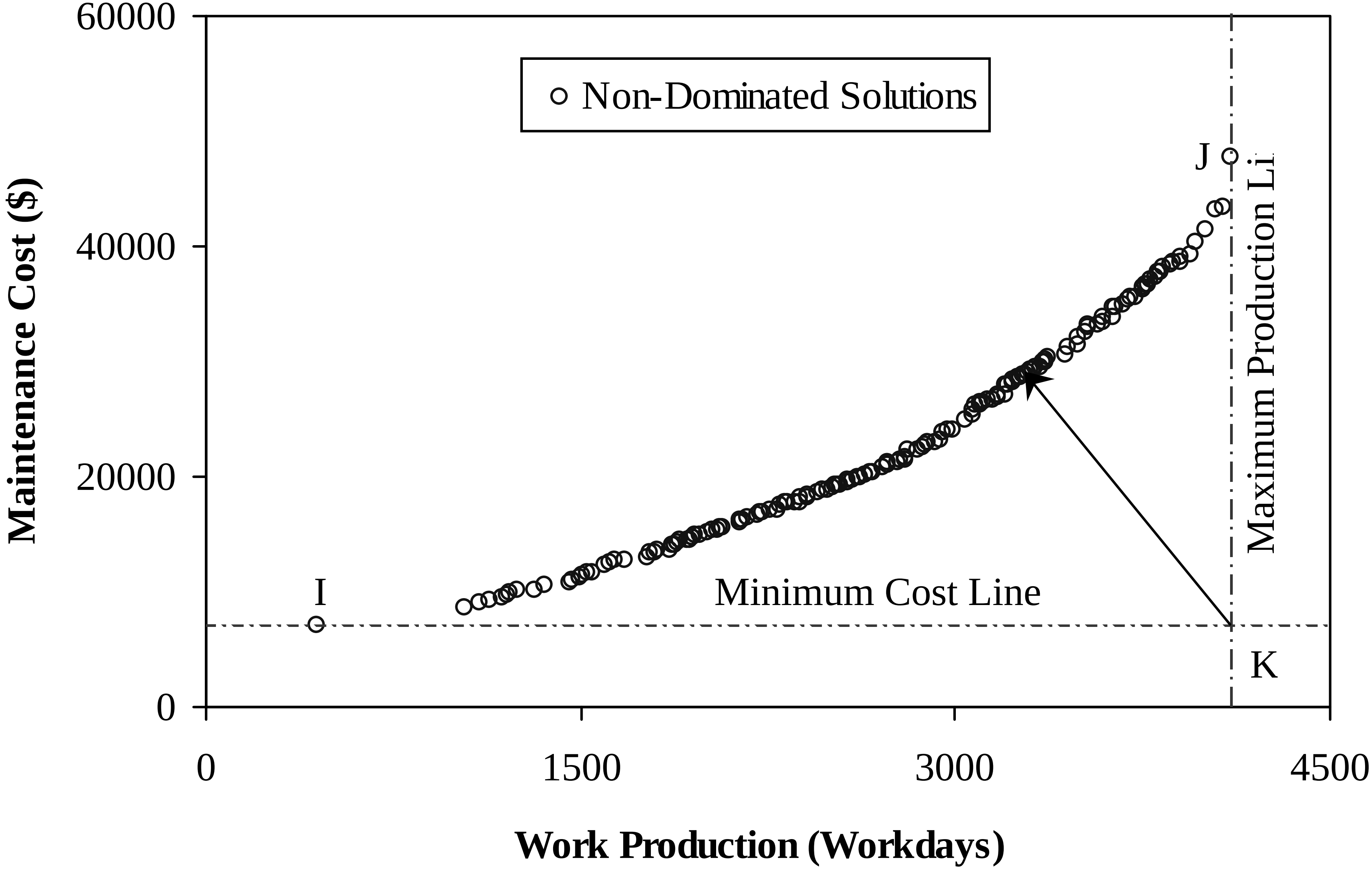
Convergence of GA Solutions



Convergence of GA Solutions



“Best” Choice of Solution



Conclusions for Part A

- GA based on Pareto frontier concept offers optimal set of non-dominated solutions for multi-objective problems

- Trade-off assessment can be made to choose the most desired solution. Otherwise, solution nearest to peak could be picked.

Part B

Budget Allocation
in Multi-Level
Decision-Making Environment

Different Levels of Budgeting Decisions

- Central Authority
- Regional Agencies
- Project Level

Current Practice in Budget Allocation

- Formula-based Allocation System
- Needs-based Allocation System

Formula-based Allocation System

Step 1: Select road network parameter(s) or characteristics as basic allocation variables

Step 2: Determine criteria, rules or formulas as basis of budget allocation

Formula-based Allocation System

Example

Allocation variables:

Road classification	R
Road length	L

Allocation criteria:

Allocation ~ w_1(L of R_1) + w_2(L of R_2) + ……

Needs-based Allocation System

- **Assessment of network pavement maintenance / rehabilitation needs by road functional class**
- **Estimation of maintenance / rehabilitation costs required for all roads of each sub-unit**
- **Compute total budget needs of each sub-unit and allocate budget accordingly**

  (may adjust for climatic effects, relative importance of distress types and severity levels, road class, etc.)

Sub-Optimality of Common Funds Allocation Methods

Formula-Based Methods

- Implicit assumption of budget needs being proportional to allocation parameters is not valid
- Funds allocated do not match maintenance / rehabilitation needs
- Objective of allocation is unclear and not defined
- The allocation procedure does not seek to optimize

Sub-Optimality of Common Funds Allocation Methods

Needs-Based Methods

- Needs and emphases at different management levels and agencies may not be the same
- Objectives of different management levels and agencies may be different
- The allocation procedure is not an optimization process

Sub-Optimality of Common Funds Allocation Methods

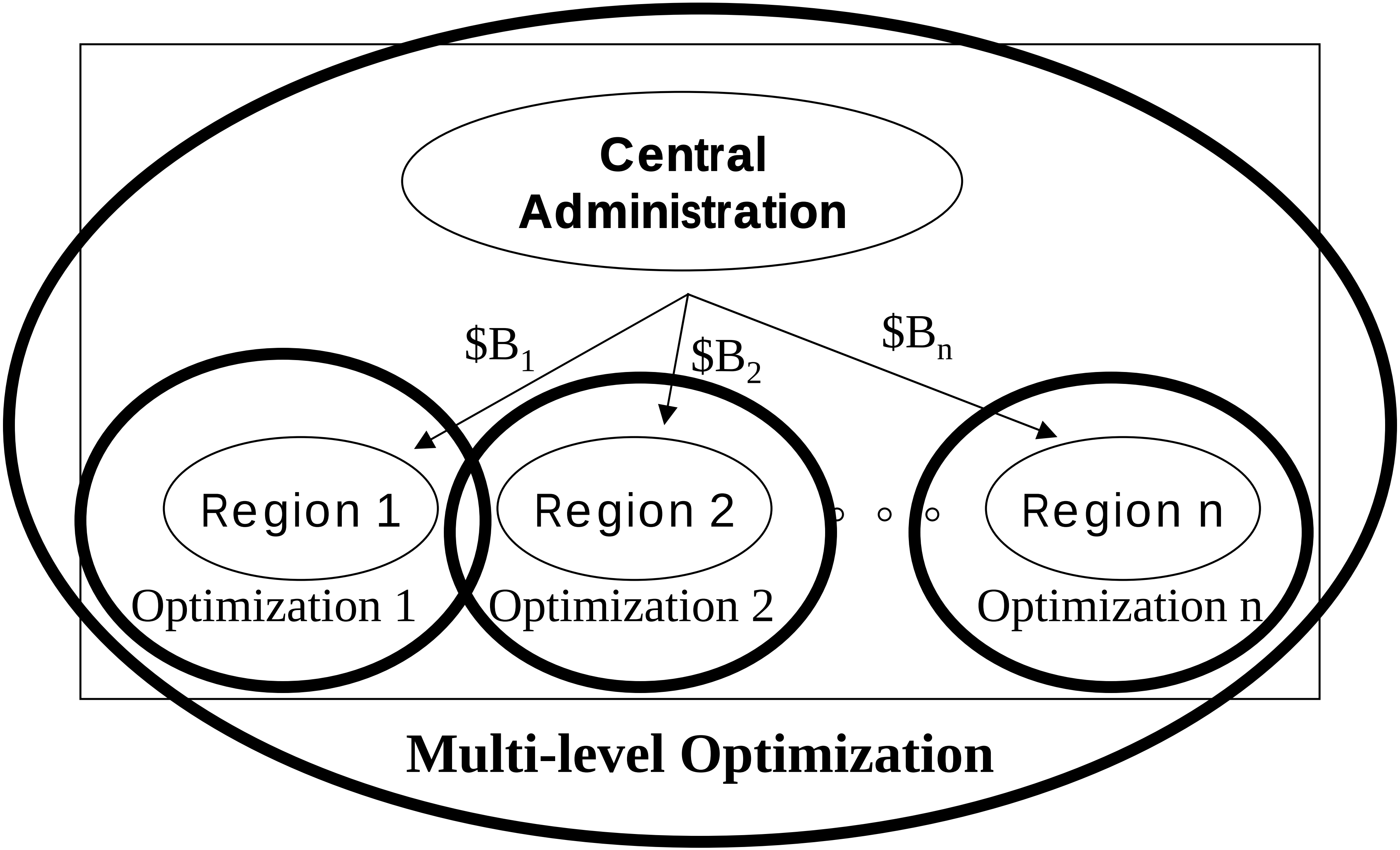
A single allocation basis/criterion is undesirable

- **Different budget needs of regional agencies**
  - **Different states of development among regions**
  - **Different operational and road network characteristics**
  - **Different available resource and capability**
  - **Different management and development strategies**

Approach for Two-Level Integrated Optimization Analysis

- Level 1: Optimization at regional level
- Level 2: Overall optimization by central authority

Two-Level Integrated Optimization



Level 1 Optimization

- Regional-level optimization by individual regional agencies
  - Based on needs and funds requirements of regional agencies
  - Identify regional objective functions
  - Consider constraints – budget, manpower, and equipment availability, etc.
  - Creates database for all possible budget levels

Level 2 Optimization

- Integrated optimization by central authority
  - Examine different fund allocation strategies
  - Apply input from database of regional optimal strategies
  - Assess merits of different allocation strategies

Problem description:

- 1 Central authority and 3 Regions
- 1 year planning period
- Multiple objective functions
  - Region 1: Maximize number of roads repaired
  - Region 2: Maximize performance level
  - Region 3: Maximize use of manpower
  - Central level: Maximize overall network road condition

Objective Functions and Constraints

- Region 1:

Maximize (Number of roads repaired)

subject to:

1. Manpower constraints
2. Equipment availability
3. Allocated budget

Objective Functions and Constraints (cont'd)

- Region 2:

Minimize (Regional network PDI)

subject to:

1. Manpower constraints
2. Equipment availability
3. Allocated budget

Objective Functions and Constraints (cont'd)

- Region 3:

Maximize (Total man-days committed)

subject to:

1. Manpower constraints
2. Equipment availability
3. Allocated budget

Objective Functions and Constraints (cont'd)

- **Central Authority:**

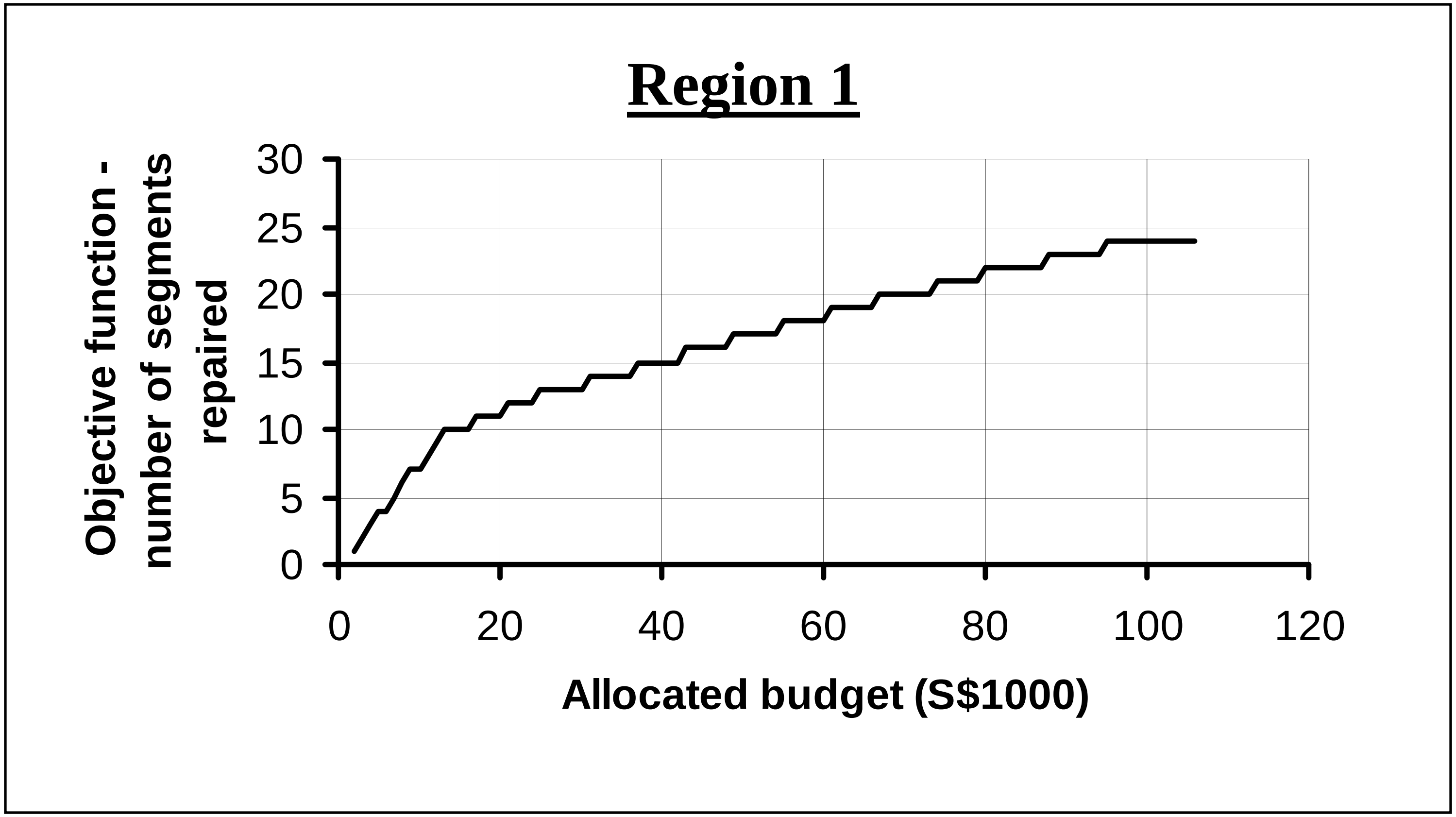
  Minimize (Regional network PDI)

  subject to:

  1. Total available budget

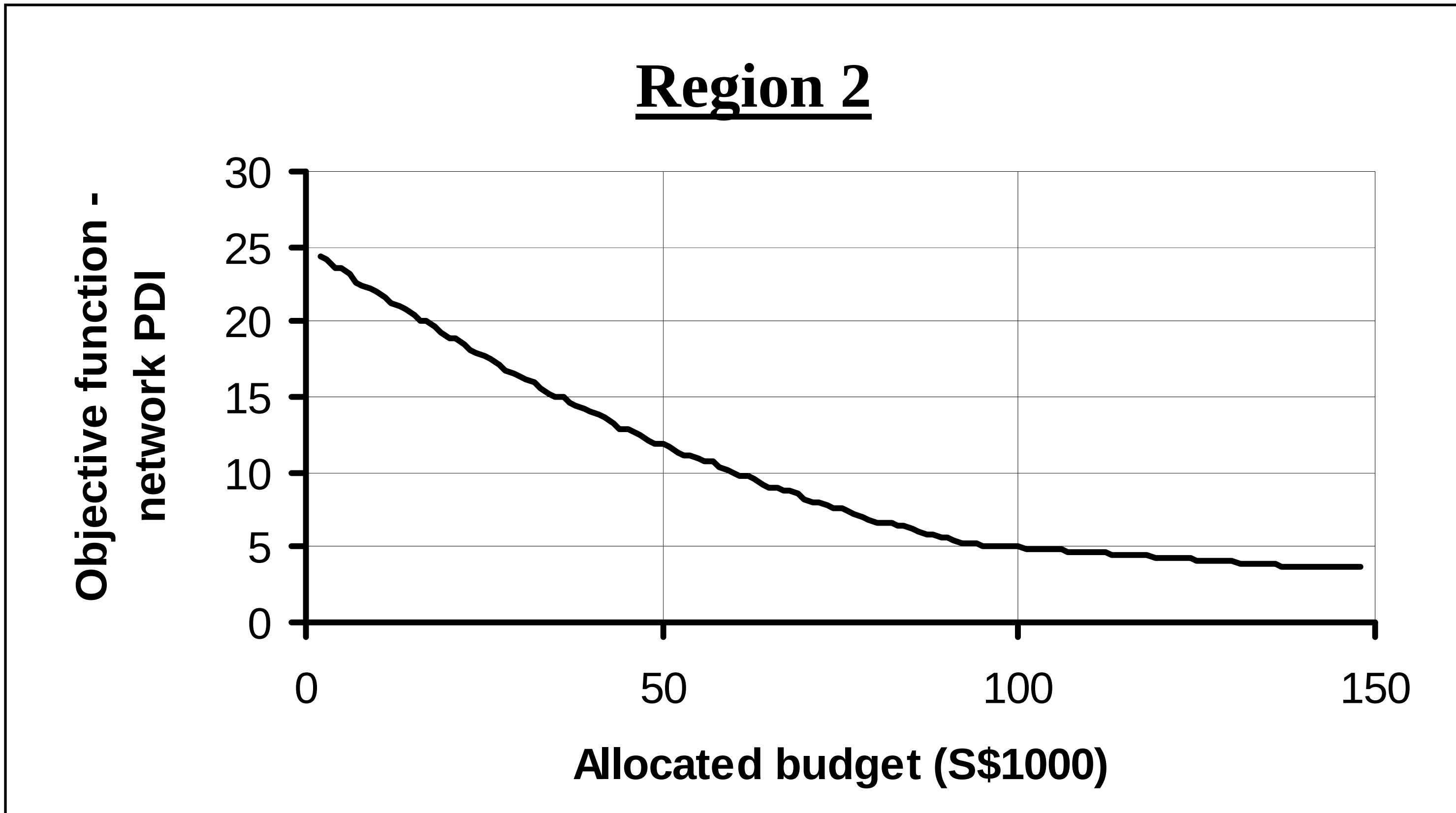
Hypothetical Example

Results: Optimal solutions for regional networks



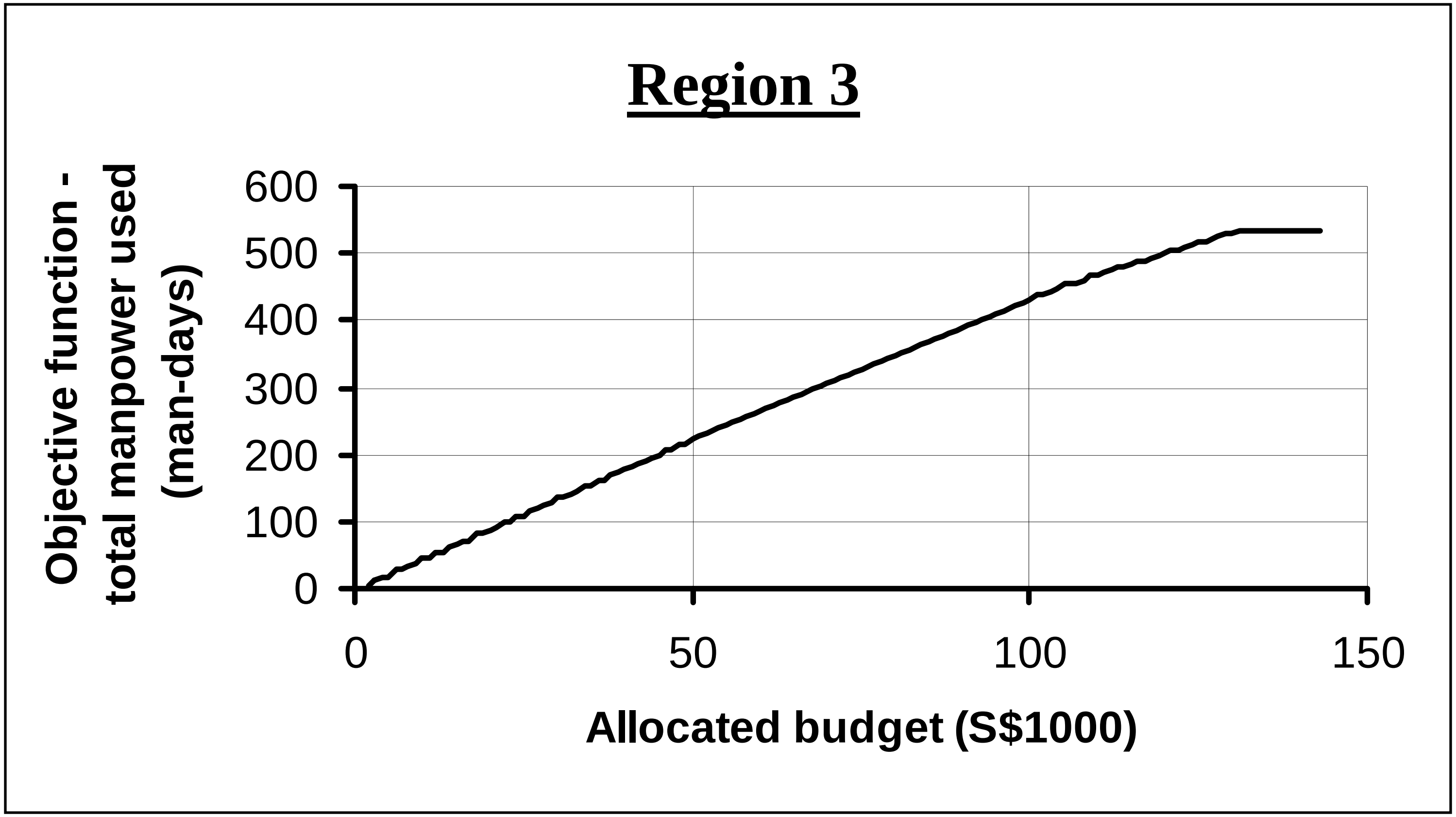
Hypothetical Example

Results: Optimal solutions for regional networks



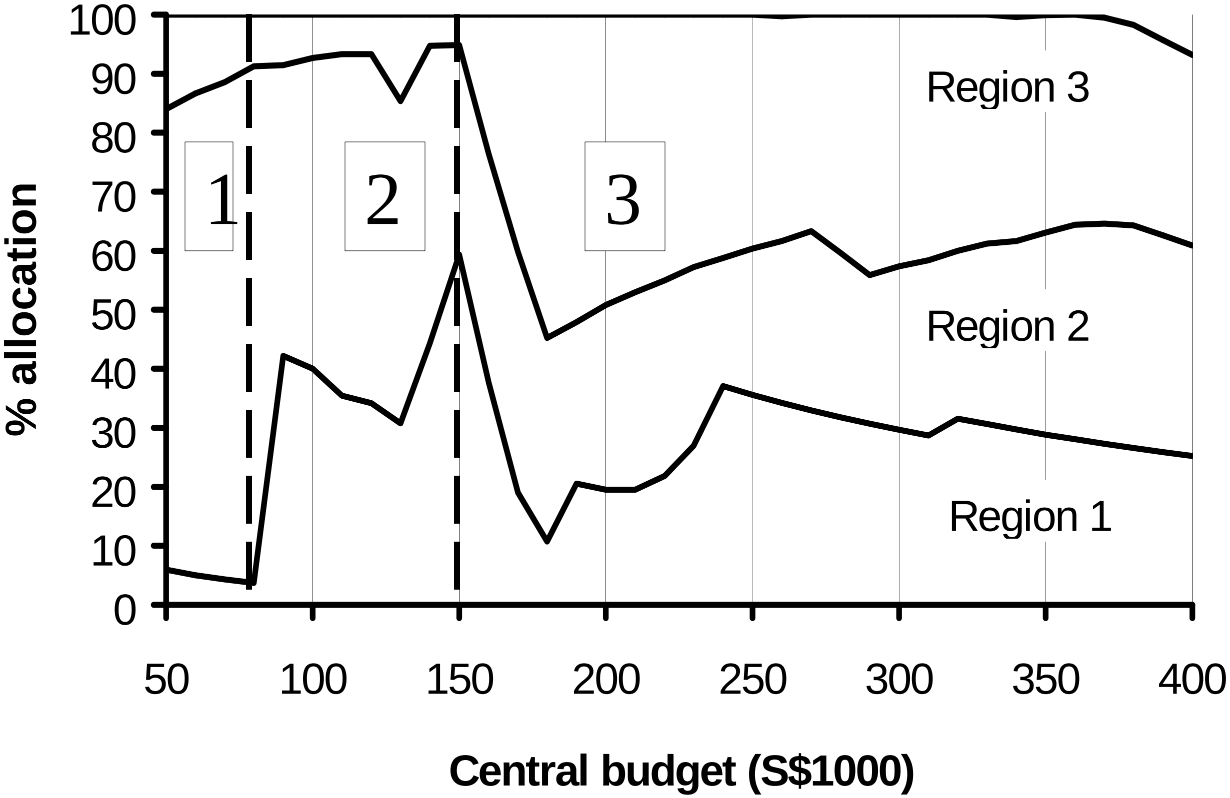
Hypothetical Example

Results: Optimal solutions for regional networks



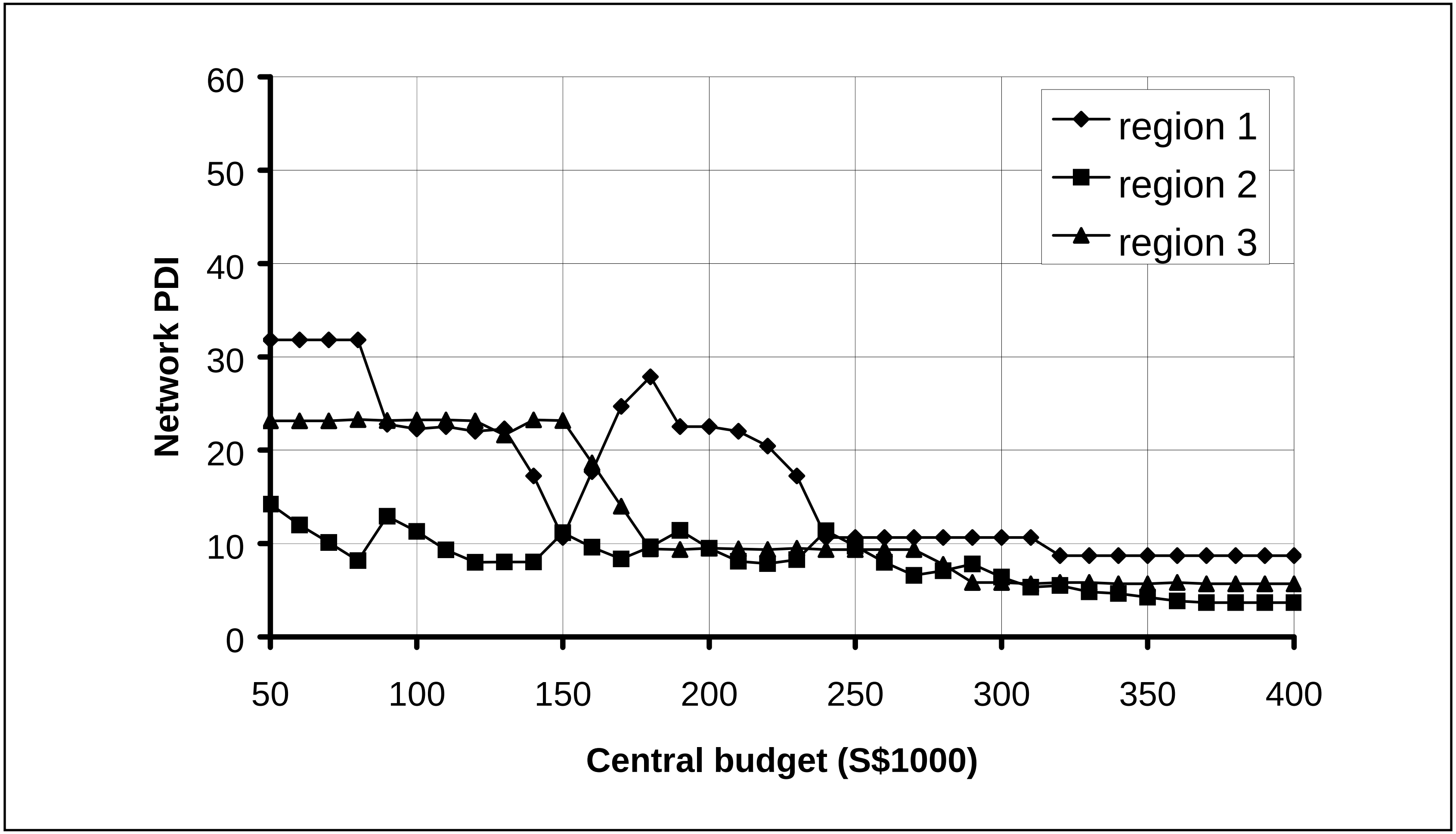
Hypothetical Example

Results: Optimal Solutions for Central Authority



Hypothetical Example

Results: Regional network PDI distributions



Conclusions

- Fixed-criteria or formula-based budget allocation approaches in pavement management does not lead to optimal usage of available funds.
- An integrated two-level optimization approach has been presented to overcome the problem.
  - Level 1: Regional optimization
  - Level 2: Integrated central optimization
- Solution procedure has been demonstrated with a hypothetical example problem.
- Practical applications?

References

- Chapter 18 “Pavement management Systems” in The Handbook of Highway Engineering, edited by T. F. Fwa. (2006)
- Chan W. T., Fwa T. F. and Tan J. Y. (2003) Optimal Fund-Allocation Analysis for Multidistrict Highway Agencies. ASCE Journal of Infrastructure Systems, Vol. 9, No. 4, pp. 167-175.
- Chan, W T, T F Fwa and J. Y. Tan (2004) "Benefits of Information Integration in Budget Planning for Pavement Management". Transportation Research Record, No. 1889, pp. 3-12.

Thank You

THE END