Sustainable "Rendezvous": A Festival Systems Challenge

Comprehensive Process Optimization (Modules 3.1 - 3.4)

Sustainability Task Force

Department of Chemical Engineering

Course: CLL782 - Process Optimization
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Outline

The Genesis: From Biodiversity to Urban Chaos

The Inspiration

Sanskruti, General Secretary (Cultural Affairs), hails from the biodiverse landscapes of West Champaran.

- **Observation**: Urban life offers convenience but at a massive, silent environmental cost.
- **The Trigger**: "Rendezvous" (Asia's Largest Fest) generates tons of waste, acting as a microcosm of this urban un-sustainability.

The Vision

"Sustainability is not about restriction, but about acting responsibly and optimizing resources."

Transform Rendezvous from a logistical challenge into a **Model of Sustainability**.

The Objective

Use **Systems Engineering & Optimization** to:

1. Quantify Impact.
2. Optimize Infrastructure.
3. Minimize Waste.

Scope: The High-Intensity Zone

To ensure impact, we focus on the festival's core activity hub.

Parameter	Value
Total Campus	320 Acres
Target ROI Area	**82 Acres** (26%)
Key Venues	OAT, Nalanda, SAC, LHC
Peak Footfall	∼40,000 / day
Grid System	137 Cells (0.6 acres each)

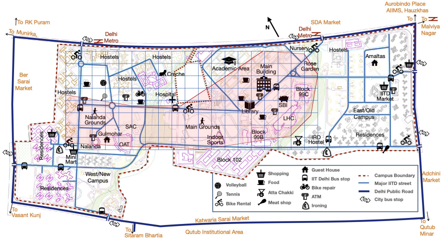

Figure: ROI with 137 Grid Cells

3.1 Problem Statement & Variables

Problem: Develop a mathematical function $E(N, S, A)$ to quantify total environmental load, capturing non-linear "crowding" and "congestion" effects.

Table: Module 3.1 Variable Definitions

Sym	Description	Unit	Type
N	Number of Attendees	Persons	Parameter (Demand)
S	Number of Food Stalls	Stalls	**Decision Variable**
A	Activity Duration	Hours	Decision Variable
α_2	Stall Embodied Impact	kg CO_2/stall	Constant (18.0)
γ_{NS}	Congestion Penalty	-	Constant (0.0005)
E	**Total Env Load**	kg CO_2-eq	**Objective**

3.1 Formulation & Insights

Objective Function

$$E = \underbrace{(\alpha_1 N + \alpha_2 S)}_{\text{Base Load}} + \underbrace{(\beta_N N^{1.3})}_{\text{Non-linear Scale}} + \underbrace{\left(\gamma_{NS}\frac{N^2}{S}\right)}_{\text{Congestion Penalty}}$$

- **Trade-off**:
  - Too few stalls ($S \downarrow$) $\rightarrow$ High Congestion ($N^2/S \uparrow$) $\rightarrow$ Littering.
  - Too many stalls ($S \uparrow$) $\rightarrow$ High Embodied Energy ($\alpha_2 S \uparrow$).
- **Analytical Solution**:

$$\frac{dE}{dS} = \alpha_2 - \gamma_{NS}\frac{N^2}{S^2} = 0 \implies S^* = N\sqrt{\frac{\gamma_{NS}}{\alpha_2}}$$

- **Result**: For $N = 40,000$, $S^* \approx$ **210 Stalls**. (Current practice is suboptimal).

3.2 Problem Statement & Variables

Problem: Optimally place dustbins (j) to cover demand zones (i) such that walking distance is minimized, subject to service radius (R_t).

Sym	Description	Unit	Type
i	Index of Demand Zone	-	Index $(1 \dots 137)$
j	Candidate Location	-	Index
$y_{j,t}$	Install Bin type t at j?	$\{0, 1\}$	**Binary Decision**
$a_{i,j,t}$	Fraction demand $i \to j$	$[0, 1]$	Continuous Decision
F_i	Footfall at Zone i	Ppl/hr	Parameter
R_t	Service Radius	m	Const (30-50m)
K_t	Bin Capacity	kg	Const (30kg)

3.2 Mathematical Formulation

Minimize User Inconvenience (Weighted Distance)

$$\text{Min } Z = \sum_i \sum_j \sum_t (F_i \cdot a_{i,j,t} \cdot D_{ij})$$

Subject to Constraints:

1. **Coverage Requirement**: $\sum_{j,t} a_{i,j,t} = 1 \quad \forall i$
2. **Capacity Limit**: $\sum_i (F_i \cdot w \cdot a_{i,j,t}) \leq K_t \cdot y_{j,t} \quad \forall j, t$
3. **Service Radius**: $a_{i,j,t} = 0 \quad \text{if } D_{ij} > R_t$
4. **Logical Link**: $a_{i,j,t} \leq y_{j,t}$

3.3 Problem Statement & Variables

Problem: Design a logistics network to clear 6 tons of waste/day using a fleet of vehicle (k) from zones (i) to facilities (j).

Sym	Description	Unit	Type
$x_{i,j}$	Waste Flow $i \to j$	kg	**Continuous Decision**
v_k	Vehicle k Deployed?	$\{0, 1\}$	Binary Decision
V_{cap}	Vehicle Payload	kg	Const (750 kg)
C_{dist}	Transport Cost	Rs/km	Const (Rs. 20)
C_{proc}	Processing Cost	Rs/kg	Const (Facility dep.)
C_{fix}	Vehicle Fixed Cost	Rs/day	Const (Rs. 800)

3.3 Formulation (Min Cost Flow)

Minimize Total System Cost

$$\text{Min } Z = \underbrace{\sum_{i,j} x_{i,j}(C_{dist} D_{ij} + C_{proc,j})}_{\text{Var Cost}} + \underbrace{C_{fix} \cdot \sum_{k} v_k}_{\text{Fixed Fleet Cost}}$$

Subject to Constraints:

1. **Waste Clearance**: $\sum_j x_{i,j} = \text{Total Waste}_i \quad \forall i$
2. **Processing Limit**: $\sum_i x_{i,j} \leq \text{Capacity}_j \quad \forall j$
3. **Fleet Capacity**: $\sum_{i,j} x_{i,j} \leq V_{cap} \cdot \sum_k v_k$

3.4 Problem Statement & Variables

Problem: Locate water stations (Capacitated P-Median) to minimize total cost (Installation + Walking), enabling value recovery via reusable bottles.

Sym	Description	Unit	Type
y_j	Install Station at j?	$\{0, 1\}$	**Binary Decision**
$x_{i,j}$	Assign $i \rightarrow j$	$[0, 1]$	Decision Variable
d_i	Water Demand	L/hr	Parameter
f_j	Install Cost	Rs.	Const (Rs. 1 Lakh)
C_{walk}	Walking Cost	Rs/m	Const (Rs. 0.02)
Cap_j	Station Capacity	L/hr	Const (250 LPH)

3.4 Formulation (P-Median Variant)

Minimize Generalized Cost

$$\text{Min } Z = \underbrace{\sum_j f_j y_j}_{\text{CAPEX}} + \underbrace{\sum_{i,j} (d_i x_{i,j}) D_{ij} C_{walk}}_{\text{User Inconvenience}}$$

Subject to Constraints:

1. **Service Guarantee**: $\sum_j x_{i,j} = 1 \quad \forall i$
2. **Capacity**: $\sum_i d_i x_{i,j} \leq Cap_j \cdot y_j \quad \forall j$
3. **Integrality**: $y_j \in \{0, 1\}$

Conclusion: The Sustainable Blueprint

Integrated Design

Our system-level optimization transforms Rendezvous:

1. **Right-Sizing**: $S \to 210$ to cut congestion waste.
2. **Precision**: 30m bin grid ensures zero littering.
3. **Efficiency**: Optimized fleet routing cuts transport emissions.
4. **Innovation**: Water stations replace plastic bottles.

Technological Optimism + Optimization
= A Greener Future

Thank You

"Just like Mother Nature, we optimize continuously."