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
Instructor: Prof. Om Prakash

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Presented by: Yash

Outline

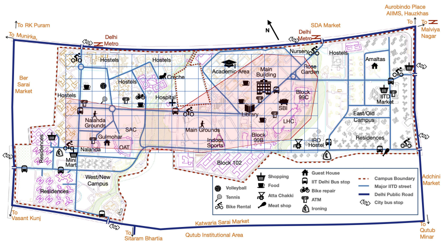
The Challenge: Greening Asia's Largest Fest

Context

- **Rendezvous (IIT Delhi)**: ∼160,000 attendees over 4 days.
- **Problem**: Massive environmental footprint (Waste, Energy, Carbon).
- **Goal**: Use Process Optimization to model and minimize this Environmental Load (E).

Scope: High-Intensity Zone

- **Area**: ∼82-90 Acres (26% of Campus).
- **Locations**: OAT, Nalanda, SAC, LHC, Red Square.
- **Footfall**: Captures 90% of event intensity.



Target ROI: 82 Acres, 137 Grid Cells

3.1 Problem Statement & Methodology

Problem: Develop a mathematical function to Quantify Total Environmental Load (E).

Key Variables

Sym	Description	Type	Value/Range
N	Number of Attendees	Demand	160,000 (Total)
S	Number of Stalls	Decision	$100 - 300$
A	Activity Hours	Decision	4 Days $\times$ 12 hrs

Assumed Constants (Ref: Literature/IITD Data):

- Base Impact α_1: 2.5 kg CO_2/person.
- Stall Impact α_2: 18 kg CO_2/stall (Embodied).
- Congestion Penalty γ_{NS}: 0.0005 (Waste leakage factor).

3.1 Formulation & Results

Objective Function: Minimize Load E

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

Preliminary Insight:

- The term N^2/S represents littering caused by overcrowding/queues.
- **Optimization**: $\frac{dE}{dS} = 0 \implies S^* = N\sqrt{\frac{\gamma_{NS}}{\alpha_2}}$
- For $N = 40,000$/day, $\alpha_2 = 18$, $\gamma_{NS} = 0.0005 \rightarrow S^* \approx 210$ **Stalls**.
- *Current scenario (∼100 stalls) is suboptimal due to high congestion penalty.*

3.2 Problem Statement & Variables

Problem: Optimal placement of dustbins to minimize user inconvenience (walking distance) and littering.

Variable Description

- i: Demand Zones (Grid Cells).
- j: Candidate Bin Locations.
- $y_{j,t} \in \{0, 1\}$: Binary decision to install bin type t at loc j.
- $a_{i,j,t} \in [0, 1]$: Fraction of demand from i assigned to j.

Constants:

- **Waste Rate (w)**: 0.15 kg/person/visit (Food fest norm).
- **Service Radius (R_t)**: 30m (High Intensity) to 50m (Pathways).
- **Bin Capacity (K_t)**: 20-30 kg (Dual FRP Bins).

3.2 Mathematical Formulation

Objective: Minimize Total Inconvenience Z

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

Subject to Constraints:

1. **Coverage**: $\sum_{j,t} a_{i,j,t} = 1$ (All waste must be collected).
2. **Capacity**: $\sum_i (F_i \cdot w \cdot a_{i,j,t}) \leq K_t \cdot y_{j,t}$ (Bins can't overflow).
3. **Radius (Accessibility)**: $a_{i,j,t} = 0$ if $D_{ij} > R_t$.
4. **Budget**: $\sum_{j,t} C_t \cdot y_{j,t} \leq B$.

3.3 Problem Statement & Hierarchy

Problem: Design a logicstics network to transport 6,000 kg/day of waste from zones to processing units.

System Components:

- **Sources (i)**: 90-acre ROI zones.
- **Sinks (j)**: Biogas (On-campus), Okhla Landfill, Recyclers.
- **Vehicles (k)**: Small Tippers (Tata Ace EV).

Parameters & Constants

- **Vehicle Capacity (V_{cap})**: 750 kg.
- **Fixed Cost (C_{fixed})**: Rs.800/vehicle/day.
- **Variable Cost**: Rs.20/km.

3.3 Formulation (Min Cost Flow)

Objective: Minimize Total Logistics Cost

$$\text{Min } Z = \underbrace{\sum_{i,j} x_{i,j}(C_{dist} D_{ij} + C_{proc,j})}_{\text{Variable Cost}} + \underbrace{C_{fixed} \cdot \left\lceil \frac{\sum x_{i,j}}{V_{cap}} \right\rceil}_{\text{Fixed Fleet Cost}}$$

Constraints:

1. **Supply**: $\sum_j x_{i,j} = \text{Waste Generated}_i$.
2. **Throughput**: $\sum_i x_{i,j} \leq \text{Capacity}_j$ (e.g., Biogas limit).
3. **Fleet**: Total volume $\leq$ Number of vehicles $\times V_{cap}$.

3.4 Problem Statement & Setup

Problem: Plan water refill stations to support reusable bottle policy (Zero Plastic).

Variables

- $y_j \in \{0, 1\}$: Install Station at location j?
- $x_{i,j} \in [0, 1]$: Fraction of demand satisfied by j.

Assumptions & Constants:

- **Demand (d_i)**: 0.25 L/hr/person $\rightarrow$ 10,000 LPH Peak.
- **Station Capacity**: 250 LPH (Cooling rate bottleneck).
- **Cost of Walking (C_{walk})**: Rs.0.02 per meter (Time value).
- **Install Cost (f_j)**: Rs.1,00,000 (RO + Cooling).

3.4 Formulation (Capacitated P-Median)

Objective: Min Generalized Cost

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

Key Constraints:

1. **Demand Met**: $\sum_j x_{i,j} = 1$.
2. **Capacity**: $\sum_i d_i x_{i,j} \leq \text{Cap}_j \cdot y_j$.
3. **Logical**: User can only go to j if $y_j = 1$.

Trade-off: More stations = Higher Install Cost vs. Less User Walking.

Conclusion

Integrated Sustainability Strategy

1. **Mod 3.1**: Optimize Scale ($S^* \approx 210$) to reduce congestion-led waste.
2. **Mod 3.2**: Place Bins within 30m radius to capture waste at source.
3. **Mod 3.3**: Efficient Logistics routing to minimize transport carbon.
4. **Mod 3.4**: Strategic Water Stations to eliminate plastic bottles.

Technological Optimism + Process Optimization
= Greener Rendezvous

Thank You

Open Loop: Optimizing "Rendezvous"
Dept of Chemical Engineering, IIT Delhi