# 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

February 18, 2026

# Outline

# The Genesis: From Biodiversity to Urban Chaos

## The Inspiration

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

- **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 urban un-sustainability.

## The Objective

Use **Systems Engineering & Optimization** to:

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

## 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**.

# Scope: The High-Intensity Zone

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

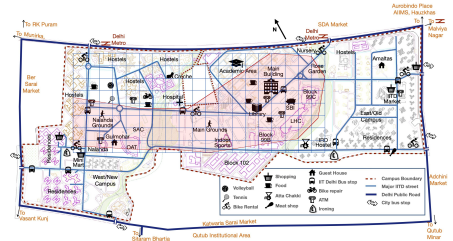| Parameter | Value |
|---|---|
| Total Campus | 320 Acres |
| **Target ROI** | **82 Acres** (26%) |
| Key Venues | OAT, Nalanda, SAC, LHC |
| Peak Footfall | $\sim$40,000/day |
| Grid System | 137 Cells ($\approx$0.6 ac) |
| Total (4 Days) | $\sim$160,000 attendees |



Figure: ROI with 137 Grid Cells overlaid on IITD Campus Map

# 3.1 Problem Statement

## Objective

Define an environmental impact function $E = f(N, S, A)$ that quantifies the **total ecological footprint** of the festival — incorporating energy use, waste generation, and emissions — and find the conditions that **minimize** $E$.

**Key Questions Addressed:**

- Can we capture non-linear phenomena like **crowding effects** and **diminishing returns**?
- What is the **ideal event scale** (stalls, hours) that minimizes footprint?
- Does the objective function need modification to better capture the sustainable festival design?

# 3.1 Variables & Assumed Constants

Table: Module 3.1 — Variables and Parameters

| Symbol | Description | Unit | Type |
|--------|-------------|------|------|
| $N$ | Number of attendees | Persons | **Decision Var** |
| $S$ | Number of food stalls | Stalls | **Decision Var** |
| $A$ | Activity duration (concerts, events) | Activity-hrs | **Decision Var** |
| $E$ | Total environmental load | kg $CO_2$-eq | Objective |
| $\alpha_1$ | Per-capita base impact | 2.5 kg/p | Constant |
| $\alpha_2$ | Per-stall embodied energy impact | 18 kg/stall | Constant |
| $\alpha_3$ | Per-activity base impact | 12 kg/act-hr | Constant |
| $\beta_N$ | Crowding nonlinearity coeff. (exp. 1.3) | 0.002 | Constant |
| $\beta_S$ | Stall scaling nonlinearity coeff. (exp. 1.2) | 0.5 | Constant |
| $\beta_A$ | Activity scaling coeff. (exp. 0.8) | 5.0 | Constant |
| $\gamma_{NS}$ | Congestion penalty coefficient | 0.0005 | Constant |

**Ref:** Bettencourt et al. (2007) for $N^{1.3}$ scaling; CPCB (2021) for waste norms; CEA (2024) for grid emission.

# 3.1 Mathematical Formulation

## Environmental Load Function

$$E = \underbrace{(\alpha_1 N + \alpha_2 S + \alpha_3 A)}_{\text{Base Load}} + \underbrace{(\beta_N N^{1.3} + \beta_S S^{1.2} + \beta_A A^{0.8})}_{\text{Non-linear Scaling}} + \underbrace{\left(\gamma_{NS} \frac{N^2}{S}\right)}_{\text{Congestion Penalty}}$$

**Component Interpretation:**

- **Base Load** $(\alpha_1 N + \alpha_2 S + \alpha_3 A)$: Direct consumption proportional to attendees, infrastructure, and activities.
- **Non-linear Scaling**:
    - $\beta_N N^{1.3}$: Super-linear crowding — more people $\Rightarrow$ disproportionately more littering (Urban Scaling Law).
    - $\beta_S S^{1.2}$: Supply-chain fragmentation with increasing stalls.
    - $\beta_A A^{0.8}$: Economies of scale in activities (Six-Tenths Rule).
- **Congestion Penalty** $(N^2/S)$: The critical "queue" term.
    - Too few stalls $(S \downarrow)$ $\Rightarrow$ Long queues $\Rightarrow$ Frustration & Littering $(E \uparrow\uparrow)$.
    - Too many stalls $(S \uparrow)$ $\Rightarrow$ Wasted embodied energy $(\alpha_2 S \uparrow)$.

## 3.1 Optimization & Insights

### Optimal Stall Count (Fixed $N$)

Differentiating $E$ w.r.t. $S$ and setting to zero:

$$\frac{\partial E}{\partial S} = \alpha_2 + 1.2\,\beta_S\,S^{0.2} - \gamma_{NS}\frac{N^2}{S^2} = 0$$

Approximating for small $\beta_S$ ($\beta_S \approx 0$):

$$\alpha_2 \approx \gamma_{NS}\frac{N^2}{S^2} \implies \boxed{S^* \approx N\sqrt{\frac{\gamma_{NS}}{\alpha_2}}}$$

**Numerical Result ($N = 40{,}000$/day):**

$$S^* \approx 40000\sqrt{\frac{0.0005}{18}} \approx \mathbf{210}$$

**Key Insights:**

- Current practice ($\sim$100 stalls) is **under-provisioned**.
- Congestion penalty **dominates** at low $S$.
- Increasing to $\sim$210 stalls paradoxically

# 3.2 Problem Statement

## Objective

Formulate a **Facility Location Problem (FLP)** to optimally place dustbins across the 82-acre festival zone, minimizing average walking distance weighted by footfall density.

**Key Considerations:**

- **Dual-compartment bins** (Wet + Dry) per SWM Rules 2016.
    - Green: Compostable / Organic (food waste).
    - Blue: Recyclable (paper, plastic, bottles).
- Each unit has a **cost** $C$, **service radius** $R$, and **capacity** $K$.
- **Greenery Protection**: Bins on hardscape edges only (no trampling of lawns).
- Designed for **peak surge** demand (Star Night: 40,000 in the zone).

# 3.2 Variables, Constants & Data

Table: Module 3.2 — Nomenclature

| Sym | Description | Unit | Type |
|-----|-------------|------|------|
| $y_j$ | Install dual-bin at location $j$? | $\{0,1\}$ | **Binary Decision** |
| $a_{i,j}$ | Fraction of zone $i$ demand $\rightarrow$ bin $j$ | $[0,1]$ | Continuous Decision |
| $F_i$ | Peak footfall at zone $i$ | Ppl/hr | Parameter |
| $D_{ij}$ | Walking distance $i \rightarrow j$ | m | Parameter |
| $w$ | Waste generation rate | 0.15 kg/p | Constant |
| $R$ | Service radius | 40 m | Constant |
| $K$ | Bin capacity (dual FRP unit) | 30 kg | Constant |
| $C$ | Bin procurement cost (per unit) | Rs. 12K | Constant |
| $B$ | Total budget | Rs. | Constraint |

**Ref:** SWM Rules 2016 (Wet+Dry segregation); Disney 30-ft rule; Glasdon norms (30–50 m).

## 3.2 Mathematical Formulation (MILP)

### Minimize Total User Inconvenience

$$\text{Min } Z = \sum_{i=1}^{m} \sum_{j=1}^{p} F_i \cdot a_{i,j} \cdot D_{ij}$$

**Subject to:**

1. **Coverage**: Every zone must be fully served. $\sum_{j} a_{i,j} = 1 \quad \forall i$

2. **Logical Link**: No assignment without installation. $a_{i,j} \leq y_j \quad \forall i,j$

3. **Capacity**: Bins must not overflow. $\sum_{i} F_i \cdot w \cdot a_{i,j} \leq K \cdot y_j \quad \forall j$

4. **Accessibility**: $a_{i,j} = 0$ if $D_{ij} > R$

5. **Budget**: $\sum_{j} C \cdot y_j \leq B$

# 3.2 Optimization Analysis & Insights

## Complexity

- **NP-hard** Facility Location.
- Discretize ROI into 137 cells ($50m \times 50m$).
- Solvable via Branch-and-Bound (Gurobi / CBC).

## Expected Outcomes

- **High density** near OAT/Amul (food zones, high $F_i$).
- **Sparse** along Main Road (low $F_i$, $R$ constraint).
- Relaxing binary $\rightarrow$ LP gives lower bound.

**Data Summary:**

- Total peak waste: $40,000 \times 0.15 = $ **6,000** kg/day.
- At $K = 30$ kg/bin $\Rightarrow$ minimum $\sim$200 dual-bins needed.
- Budget feasibility: 200 bins $\times$ Rs. 12K $\approx$ Rs. 24 Lakhs.

# 3.3 Problem Statement

## Objective

Design an efficient **waste collection and processing logistics** system that transports 6,000 kg/day of segregated waste from generation zones to processing facilities, minimizing total cost.

**System Architecture:**

- **Sources** ($i$): Demand zones within the 82-acre ROI.
- **Sinks** ($j$): 3 Processing Facilities:
    1. On-Campus Biogas/Compost ($\sim$1 km, Cap: 500 kg/day).
    2. Okhla Landfill/WTE ($\sim$12 km, Unconstrained capacity).
    3. Okhla Recycling Aggregator ($\sim$11 km, Net *revenue*).
- **Fleet**: Electric Tippers (Tata Ace EV).

# 3.3 Variables, Constants & Data

Table: Module 3.3 — Nomenclature

| Sym | Description | Unit | Type |
|---|---|---|---|
| $x_{i,j}$ | Waste flow from zone $i$ to facility $j$ | kg | **Continuous Decision** |
| $v_k$ | Deploy vehicle $k$? | $\{0, 1\}$ | Binary Decision |
| $W_i$ | Total waste at zone $i$ | kg | Parameter |
| $D_{ij}$ | Distance zone $i$ to facility $j$ | km | Parameter |
| $V_{cap}$ | Vehicle payload (Tata Ace EV) | 600–750 kg | Constant |
| $C_{dist}$ | Transport cost per km | Rs. 15–20/km | Constant |
| $C_{handling}$ | Handling cost per kg | Rs./kg | Constant |
| $C_{fixed}$ | Fixed cost per vehicle per day | Rs. 500–800 | Constant |
| $C_{proc,j}$ | Processing cost at facility $j$ | Rs./kg | Constant |

**Assumptions:** Direct transport (Star network); Homogeneous fleet; Linear costs.

# 3.3 Formulation (Minimum Cost Flow)

## Minimize Total Logistics Cost

$$Z = \underbrace{\sum_{i,j} x_{i,j} \left( C_{dist} D_{ij} + C_{handling} + C_{proc,j} \right)}_{\text{Variable Cost (Transport + Processing)}} + \underbrace{C_{fixed} \cdot \sum_{k} v_k}_{\text{Fixed Fleet Cost}}$$

**Subject to:**

1. **Waste Clearance** (all waste removed): $\sum_{j} x_{i,j} = W_i \quad \forall i$

2. **Facility Throughput**: $\sum_{i} x_{i,j} \leq Cap_j \quad \forall j$

3. **Fleet Capacity**: $\sum_{i,j} x_{i,j} \leq V_{cap} \cdot \sum_{k} v_k$

4. **Non-negativity**: $x_{i,j} \geq 0, \, v_k \in \{0, 1\}$

# 3.3 Sensitivity Analysis & Insights

## Complexity

- Core: LP Transportation Problem (Totally Unimodular $\Rightarrow$ Polynomial).
- Integer constraint on $v_k \Rightarrow$ MILP, but single scalar $\Rightarrow$ very low complexity.

## Sensitivity (+20% Waste)

If $W_i' = 1.2\, W_i$:

- Check: $\sum W_i' \leq \sum Cap_j$?
- Variable costs scale **linearly**.
- But vehicle fixed cost has a **step-function** jump if fleet is saturated.

**Key Insights:**

- **Waste Composition**: 40% Organic, 40% Recyclable, 20% Inert (CPCB norms).
- **Bottleneck**: On-campus biogas (500 kg) saturates first $\Rightarrow$ overflow to landfill.
- **Revenue Opportunity**: Recycling aggregator provides net *revenue* (Rs. 5–10/kg) for segregated waste.

# 3.4 Problem Statement

## Objective

Plan **water refill station** locations using a **Capacitated P-Median** formulation. Minimize total cost (installation $+$ user walking inconvenience) to support a reusable water bottle policy and **eliminate single-use plastic**.

**Key Considerations:**

- Each participant receives a metallic bottle (cost recovered via festival pass).
- Stations can only be installed at **pre-designated feasible locations** (near existing plumbing).
- Demand is **splittable**: aggregate probability of users visiting nearby stations.
- Delhi climate $\Rightarrow$ high hydration need ($\sim$250 ml/hr/person).

# 3.4 Variables, Constants & Data

Table: Module 3.4 — Nomenclature

| Sym | Description | Unit | Type |
|-----|-------------|------|------|
| $y_j$ | Install station at location $j$? | $\{0, 1\}$ | **Binary Decision** |
| $x_{i,j}$ | Fraction of zone $i$ served by $j$ | $[0, 1]$ | Continuous Decision |
| $d_i$ | Water demand at zone $i$ | Ppl/hr | Parameter |
| $D_{ij}$ | Walking distance $i \rightarrow j$ | m | Parameter |
| $f_j$ | Installation + operation cost | Rs. 1 Lakh | Constant |
| $cap_j$ | Station dispensing capacity | 250 LPH | Constant |
| $C_{walk}$ | Monetary value of walking | Rs. 0.02/m | Constant |

**Ref:** Blue Star/Voltas 150–300 LPH specs; WHO hydration norms; Market pricing (Indiamart).

**Peak Water Demand**: $40{,}000 \times 0.25$ L/hr = **10,000 LPH**. At 250 LPH/station $\Rightarrow$ Min. $\sim$40 stations.

# 3.4 Formulation (Capacitated P-Median)

## Minimize Generalized Cost

$$Z = \underbrace{\sum_{j=1}^{p} f_j\, y_j}_{\text{Installation (CAPEX)}} + \underbrace{\sum_{i=1}^{m} \sum_{j=1}^{p} \alpha_{ij}\, x_{i,j}}_{\text{User Inconvenience}}$$

where $\alpha_{ij} = d_i \cdot D_{ij} \cdot C_{walk}$ is the weighted walking cost coefficient.

**Subject to:**

**1 Demand Satisfaction**: $\displaystyle\sum_j x_{i,j} = 1 \quad \forall\, i$

**2 Station Capacity**: $\displaystyle\sum_i d_i\, x_{i,j} \leq cap_j \cdot y_j \quad \forall\, j$

(Also acts as logical link: if $y_j = 0$, capacity is 0.)

**3 Integrality**: $y_j \in \{0,1\}, \quad 0 \leq x_{i,j} \leq 1$

# 3.4 Solution Strategy & Insights

## Algorithmic Approach

1. **Greedy**: Iteratively add the station yielding max cost reduction.
2. **Lagrangian Relaxation**: Relax demand constraints; decompose into knapsack sub-problems.
3. **Exact**: Branch-and-Bound (Gurobi/CBC). With $m \approx 50$, $p \approx 20$: converges in seconds.

## Key Trade-offs

- High $f_j \Rightarrow$ Fewer, centralized stations (long walks).
- Low $f_j \Rightarrow$ Distributed topology (short walks).
- **Shadow Price** of capacity constraint reveals bottleneck stations to upgrade.

**Fairness Note:** Current objective minimizes *average* distance. A **Minimax** secondary constraint could ensure no zone walks more than a threshold.

# Integrated Blueprint & Next Steps

## System-Level Summary

1. **Mod 3.1**: Right-size infrastructure ($S^* \approx 210$ stalls) to cut congestion-led waste.
2. **Mod 3.2**: Place $\sim$200 dual-bins (Wet+Dry) within 40 m radius to capture waste at source.
3. **Mod 3.3**: Route 6,000 kg/day via optimized fleet (minimize cost, maximize recycling revenue).
4. **Mod 3.4**: Deploy $\sim$40 refill stations to eliminate single-use plastic.

## Module 3.5 (Next): System Integration

Combine all modules into a **multi-objective optimization**: minimize total cost *and* environmental impact *and* user inconvenience, subject to combined constraints from Modules 3.1–3.4.

# Thank You

*"Just like Mother Nature, we optimize continuously —
learning, adapting, and improving."*

Sustainable Rendezvous Project
Dept. of Chemical Engineering, IIT Delhi