Experiment-1:

Study of Optimization in Engineering Problems

Aim: To study optimization problems in different engineering fields and identify objective functions, decision variables, and constraints.

Theoretical Background

Optimization is the process of finding the **best possible solution** to a problem under given conditions.
An optimization problem generally consists of:

1. **Decision Variables**
   Variables whose values are to be determined (e.g., dimensions, quantities, time).
2. **Objective Function**
   A mathematical function representing the goal of optimization (minimization or maximization).
3. **Constraints**
   Restrictions or limitations on decision variables (equality or inequality constraints).

General Mathematical Form

General Mathematical Form

$$\text{Optimize } f(x_1, x_2, \ldots, x_n)$$

subject to

$$g_i(x_1, x_2, \ldots, x_n) \leq / = / \geq b_i$$

Engineering optimization problems arise in:

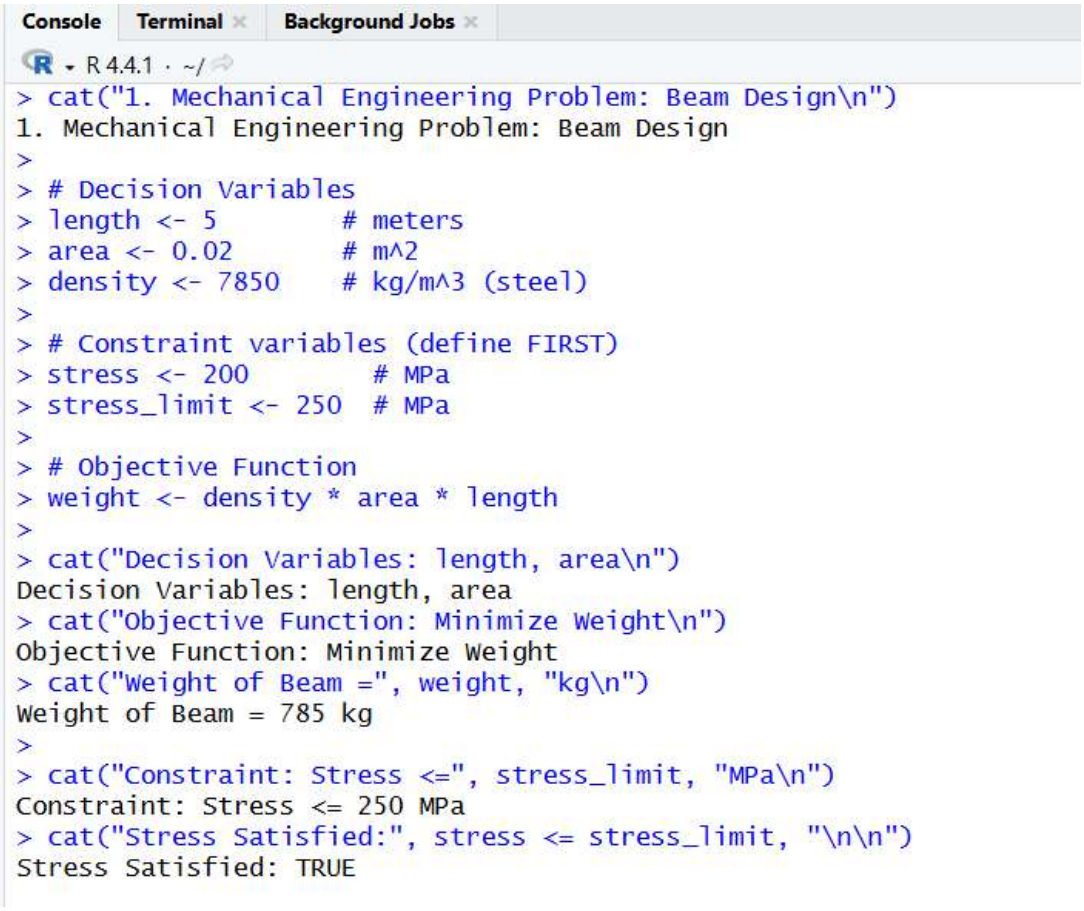
- Mechanical engineering (minimum weight design)
- Electrical engineering (minimum power loss)
- Civil engineering (minimum construction cost)
- Production engineering (maximum profit)

Example 1: Mechanical Engineering

R Code

```r
############################################################
# Experiment 1: Study of Optimization Problems in Engineering
# Identification of decision variables, objective function
# and constraints for real-life engineering problems
############################################################

cat("EXPERIMENT 1: STUDY OF OPTIMIZATION PROBLEMS IN ENGINEERING\n\n")

############################################################
# 1. Mechanical Engineering Problem
# Minimize weight of a beam
############################################################

cat("1. Mechanical Engineering Problem: Beam Design\n")

# Decision Variables
length <- 5         # meters
area <- 0.02        # m^2
density <- 7850     # kg/m^3 (steel)

# Constraint variables (define FIRST)
stress <- 200         # MPa
stress_limit <- 250   # MPa

# Objective Function
weight <- density * area * length

cat("Decision Variables: length, area\n")
cat("Objective Function: Minimize Weight\n")
cat("Weight of Beam =", weight, "kg\n")

cat("Constraint: Stress <=", stress_limit, "MPa\n")
cat("Stress Satisfied:", stress <= stress_limit, "\n\n")

```

Output


Console
Terminal
Background Jobs
R 4.4.1 · ~/
> cat("1. Mechanical Engineering Problem: Beam Design\n")
1. Mechanical Engineering Problem: Beam Design
>
> # Decision Variables
> length <- 5 # meters
> area <- 0.02 # m^2
> density <- 7850 # kg/m^3 (steel)
>
> # Constraint variables (define FIRST)
> stress <- 200 # MPa
> stress_limit <- 250 # MPa
>
> # Objective Function
> weight <- density * area * length
>
> cat("Decision Variables: length, area\n")
Decision Variables: length, area
> cat("Objective Function: Minimize Weight\n")
Objective Function: Minimize Weight
> cat("Weight of Beam =", weight, "kg\n")
Weight of Beam = 785 kg
>
> cat("Constraint: Stress <=", stress_limit, "MPa\n")
Constraint: Stress <= 250 MPa
> cat("Stress Satisfied:", stress <= stress_limit, "\n\n")
Stress Satisfied: TRUE

Example 2: Electrical Engineering

R Code

```
#########################################################
# 2. Electrical Engineering Problem
# Minimize power loss in transmission line
#########################################################

cat("2. Electrical Engineering Problem: Power Loss Minimization\n")

# Decision Variables
current <- 10     # Amperes
resistance <- 5   # Ohms

# Objective Function: Power Loss = I^2 * R
power_loss <- current^2 * resistance

cat("Decision Variables: current\n")
cat("Objective Function: Minimize Power Loss\n")
cat("Power Loss =", power_loss, "Watts\n")

# Constraints
max_current <- 15
cat("Constraint: Current <=", max_current, "A\n")
cat("Constraint Satisfied:", current <= max_current, "\n\n")
```

Output

```
Console   Terminal   Background Jobs

R 4.4.1 · ~/

> cat("2. Electrical Engineering Problem: Power Loss Minimization\n")
2. Electrical Engineering Problem: Power Loss Minimization
>
> # Decision Variables
> current <- 10     # Amperes
> resistance <- 5   # Ohms
>
> # Objective Function: Power Loss = I^2 * R
> power_loss <- current^2 * resistance
>
> cat("Decision Variables: current\n")
Decision Variables: current
> cat("Objective Function: Minimize Power Loss\n")
Objective Function: Minimize Power Loss
> cat("Power Loss =", power_loss, "Watts\n")
Power Loss = 500 Watts
>
> # Constraints
> max_current <- 15
> cat("Constraint: Current <=", max_current, "A\n")
Constraint: Current <= 15 A
> cat("Constraint Satisfied:", current <= max_current, "\n\n")
Constraint Satisfied: TRUE
```

Example 3: Civil Engineering

R Code

```r
############################################################
# 3. Civil Engineering Problem
# Minimize construction cost
############################################################

cat("3. Civil Engineering Problem: Construction Cost Minimization\n")

# Decision Variables
cement <- 300   # kg
steel  <- 100   # kg

# Objective Function: Total Cost
cost <- 7 * cement + 60 * steel

cat("Decision Variables: cement, steel\n")
cat("Objective Function: Minimize Construction Cost\n")
cat("Total Cost = Rs.", cost, "\n")

# Constraints
min_strength <- 400
strength <- 450

cat("Constraint: Strength >=", min_strength, "\n")
cat("Strength Satisfied:", strength >= min_strength, "\n\n")

```

Output

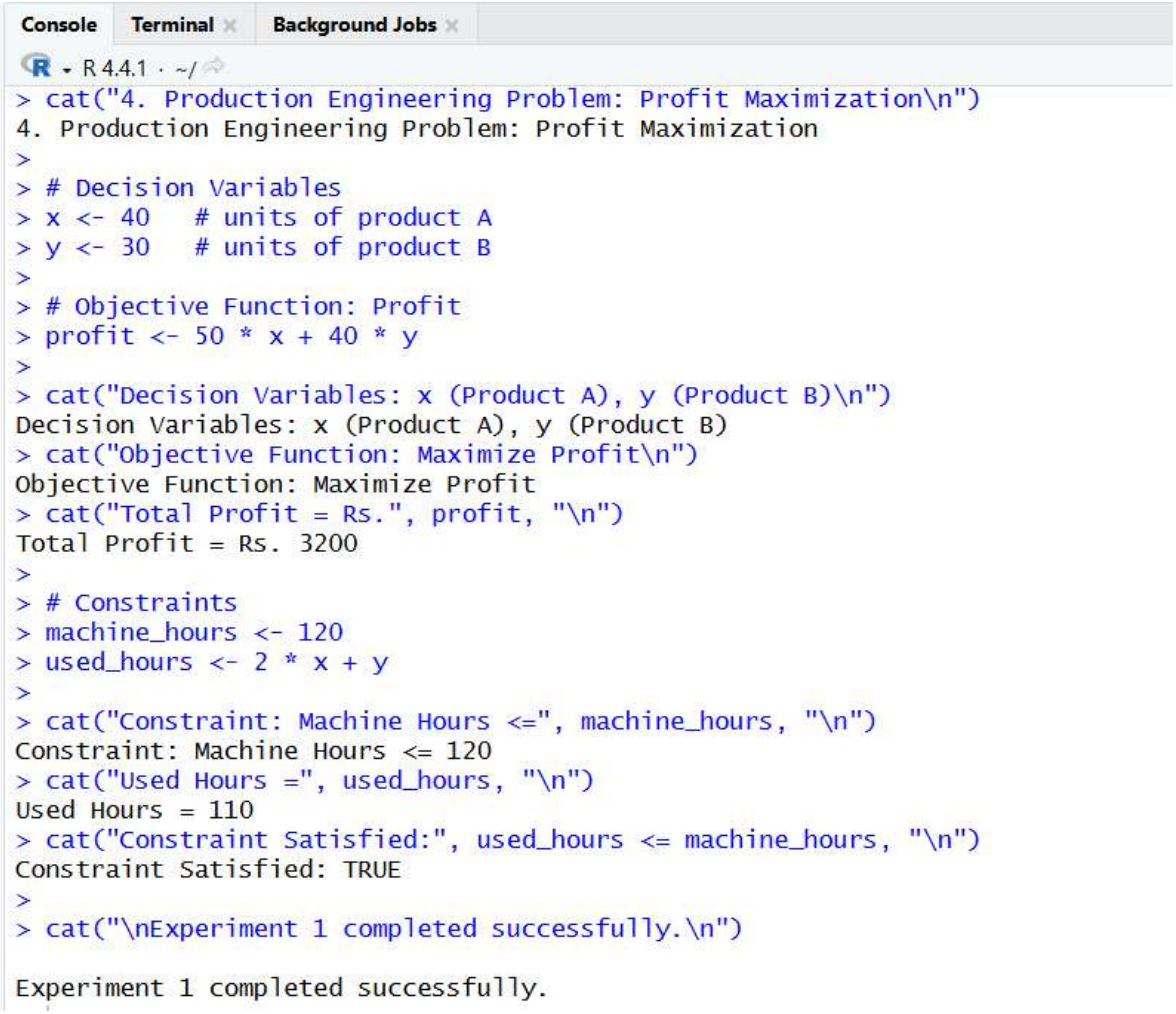
```
Console   Terminal   Background Jobs
R 4.4.1 · ~/
> cat("3. Civil Engineering Problem: Construction Cost Minimization\n")
3. Civil Engineering Problem: Construction Cost Minimization
>
> # Decision Variables
> cement <- 300   # kg
> steel  <- 100   # kg
>
> # Objective Function: Total Cost
> cost <- 7 * cement + 60 * steel
>
> cat("Decision Variables: cement, steel\n")
Decision Variables: cement, steel
> cat("Objective Function: Minimize Construction Cost\n")
Objective Function: Minimize Construction Cost
> cat("Total Cost = Rs.", cost, "\n")
Total Cost = Rs. 8100
>
> # Constraints
> min_strength <- 400
> strength <- 450
>
> cat("Constraint: Strength >=", min_strength, "\n")
Constraint: Strength >= 400
> cat("Strength Satisfied:", strength >= min_strength, "\n\n")
Strength Satisfied: TRUE
```

Example 4: Industrial Engineering

R Code

```r
############################################################
# 4. Production / Industrial Engineering Problem
# Maximize profit
############################################################

cat("4. Production Engineering Problem: Profit Maximization\n")

# Decision Variables
x <- 40   # units of product A
y <- 30   # units of product B

# Objective Function: Profit
profit <- 50 * x + 40 * y

cat("Decision Variables: x (Product A), y (Product B)\n")
cat("Objective Function: Maximize Profit\n")
cat("Total Profit = Rs.", profit, "\n")

# Constraints
machine_hours <- 120
used_hours <- 2 * x + y

cat("Constraint: Machine Hours <=", machine_hours, "\n")
cat("Used Hours =", used_hours, "\n")
cat("Constraint Satisfied:", used_hours <= machine_hours, "\n")

cat("\nExperiment 1 completed successfully.\n")
```

Output



Practice Questions

1. Modify the beam design code to include an additional constraint on the maximum length.

   R Code

```r
############################################################
# Practical Q1: Beam Design with Maximum Length Constraint
############################################################

cat("Practical 1: Beam Design with Maximum Length Constraint\n")

# Decision Variables
length <- 5          # meters
area <- 0.02         # m^2
density <- 7850      # kg/m^3

# Constraints
stress <- 200        # MPa
stress_limit <- 250  # MPa
max_length <- 6      # meters

# Objective Function
weight <- density * area * length

# Output
cat("Objective Function: Minimize Weight\n")
cat("Weight of Beam =", weight, "kg\n")

cat("Constraint 1: Stress <=", stress_limit, "MPa\n")
cat("Stress Satisfied:", stress <= stress_limit, "\n")

cat("Constraint 2: Length <=", max_length, "m\n")
cat("Length Satisfied:", length <= max_length, "\n")
```

Output

```
> ############################################################
> # Practical Q1: Beam Design with Maximum Length Constraint
> ############################################################
>
> cat("Practical 1: Beam Design with Maximum Length Constraint\n")
Practical 1: Beam Design with Maximum Length Constraint
>
> # Decision Variables
> length <- 5          # meters
> area <- 0.02         # m^2
> density <- 7850      # kg/m^3
>
> # Constraints
> stress <- 200        # MPa
> stress_limit <- 250  # MPa
> max_length <- 6      # meters
>
> # Objective Function
> weight <- density * area * length
>
> # Output
> cat("Objective Function: Minimize Weight\n")
Objective Function: Minimize Weight
> cat("Weight of Beam =", weight, "kg\n")
Weight of Beam = 785 kg
>
> cat("Constraint 1: Stress <=", stress_limit, "MPa\n")
Constraint 1: Stress <= 250 MPa
> cat("Stress Satisfied:", stress <= stress_limit, "\n")
Stress Satisfied: TRUE
```

```
>
> cat("Constraint 2: Length <=", max_length, "m\n")
Constraint 2: Length <= 6 m
> cat("Length Satisfied:", length <= max_length, "\n")
Length Satisfied: TRUE
>
```

2. Change the objective from minimizing weight to minimizing cost by including material cost per kg.

R Code

```r
############################################################
# Practical Q2: Beam Cost Minimization
############################################################

cat("Practical 2: Beam Cost Minimization\n")

# Decision Variables
length <- 5          # meters
area <- 0.02         # m^2
density <- 7850      # kg/m^3
cost_per_kg <- 60    # Rs per kg

# Objective Function
weight <- density * area * length
cost <- weight * cost_per_kg

# Constraint
stress <- 200
stress_limit <- 250

# Output
cat("Objective Function: Minimize Cost\n")
cat("Total Weight =", weight, "kg\n")
cat("Total Cost = Rs.", cost, "\n")

cat("Stress Constraint Satisfied:", stress <= stress_limit, "\n")
```

Output

```
> # Practical Q2: Beam Cost Minimization
> ############################################################
>
> cat("Practical 2: Beam Cost Minimization\n")
Practical 2: Beam Cost Minimization
>
> # Decision Variables
> length <- 5          # meters
> area <- 0.02         # m^2
> density <- 7850      # kg/m^3
> cost_per_kg <- 60    # Rs per kg
>
> # Objective Function
> weight <- density * area * length
> cost <- weight * cost_per_kg
>
> # Constraint
> stress <- 200
> stress_limit <- 250
>
> # Output
> cat("Objective Function: Minimize Cost\n")
Objective Function: Minimize Cost
> cat("Total Weight =", weight, "kg\n")
Total Weight = 785 kg
> cat("Total Cost = Rs.", cost, "\n")
Total Cost = Rs. 47100
>
> cat("Stress Constraint Satisfied:", stress <= stress_limit, "\n")
Stress Constraint Satisfied: TRUE
```

3. Create an R program that models an electrical power loss minimization problem.

R Code

```r
############################################################
# Practical Q3: Electrical Power Loss Minimization
############################################################

cat("Practical 3: Electrical Power Loss Minimization\n")

# Decision Variables
current <- 10        # Amperes
resistance <- 5      # Ohms

# Objective Function
power_loss <- current^2 * resistance

# Constraint
max_current <- 15

# Output
cat("Objective Function: Minimize Power Loss\n")
cat("Power Loss =", power_loss, "Watts\n")

cat("Constraint: Current <=", max_current, "A\n")
cat("Constraint Satisfied:", current <= max_current, "\n")

```

Output

```
> ############################################################
> # Practical Q3: Electrical Power Loss Minimization
> ############################################################
>
> cat("Practical 3: Electrical Power Loss Minimization\n")
Practical 3: Electrical Power Loss Minimization
>
> # Decision Variables
> current <- 10        # Amperes
> resistance <- 5      # Ohms
>
> # Objective Function
> power_loss <- current^2 * resistance
>
> # Constraint
> max_current <- 15
>
> # Output
> cat("Objective Function: Minimize Power Loss\n")
Objective Function: Minimize Power Loss
> cat("Power Loss =", power_loss, "Watts\n")
Power Loss = 500 Watts
>
> cat("Constraint: Current <=", max_current, "A\n")
Constraint: Current <= 15 A
> cat("Constraint Satisfied:", current <= max_current, "\n")
Constraint Satisfied: TRUE
```