



# Self Configuring Digital Twin for Optimizing E-Waste Recycling

March 2022

*Changing the World's Energy Future*

Md Mamunur Rahman, Damon S Hartley, Ruby Thuy Nguyen



*INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC*

#### **DISCLAIMER**

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

# **Self Configuring Digital Twin for Optimizing E-Waste Recycling**

**Md Mamunur Rahman, Damon S Hartley, Ruby Thuy Nguyen**

**March 2022**

**Idaho National Laboratory  
Idaho Falls, Idaho 83415**

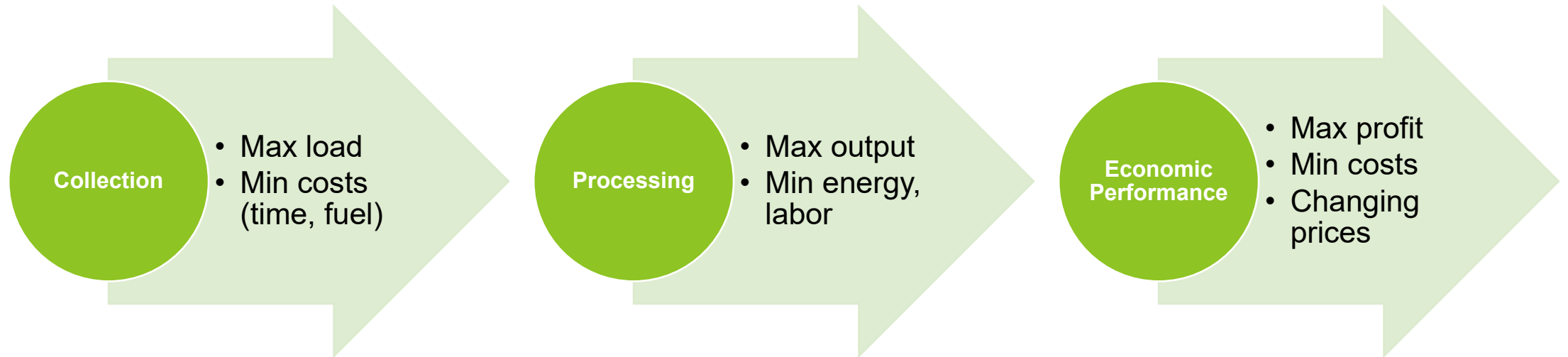
**<http://www.inl.gov>**

**Prepared for the  
U.S. Department of Energy  
Under DOE Idaho Operations Office  
Contract DE-AC07-05ID14517**

# Self Configuring Digital Twin for Optimizing E-Waste Recycling Using CMAT

Industrial Engineering and Operations Management (IEOM)  
Annual Conference 2022, Istanbul, Turkey.  
Industry Solutions and Industry 4.0

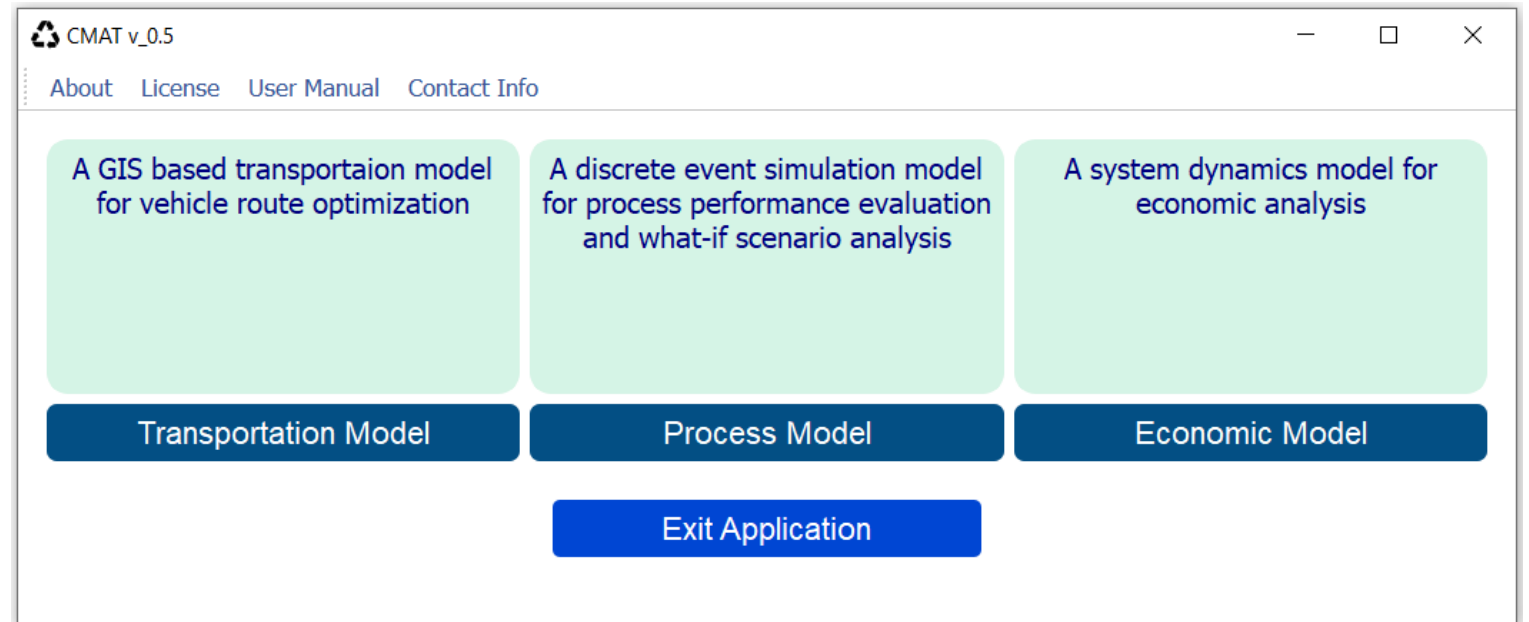
# Electronic Waste Recycling



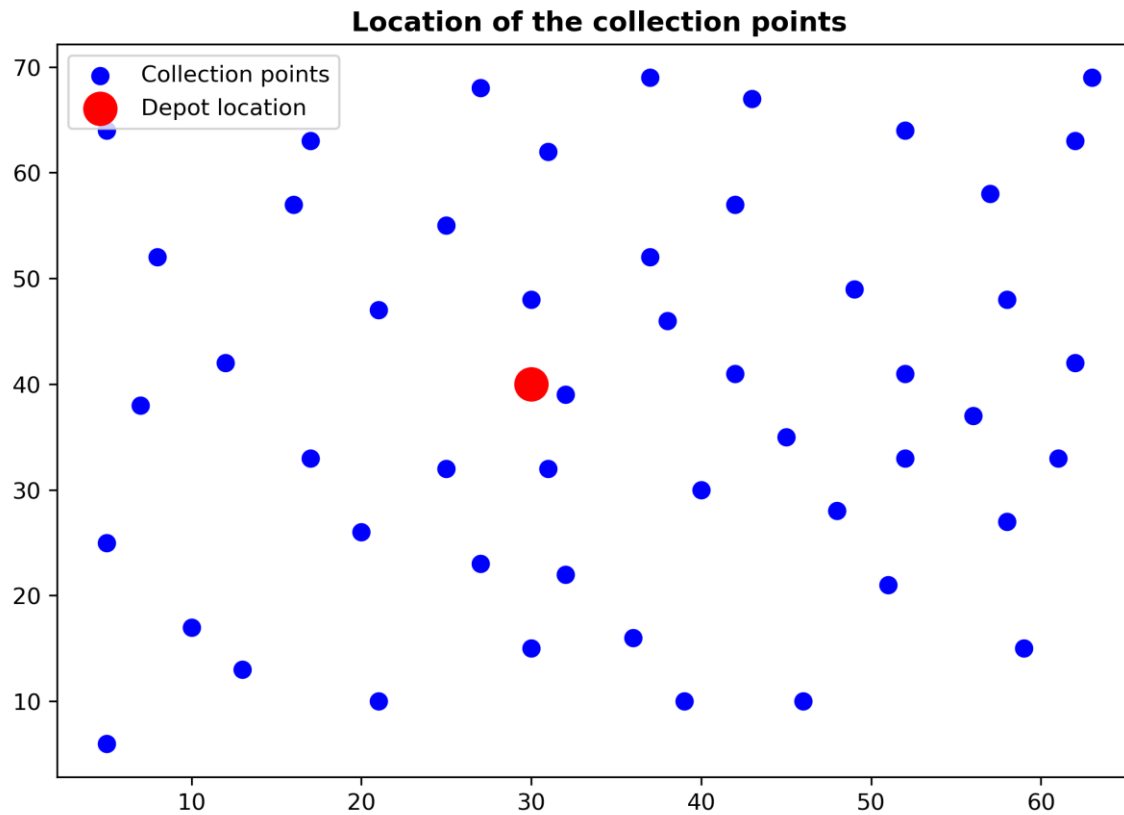
Funded by  **REMADE**  
INSTITUTE

Partnered with  **SUNN KING**  
*We Rule Electronics Recycling*

# Comprehensive Manufacturing Assessment Tool (CMAT)



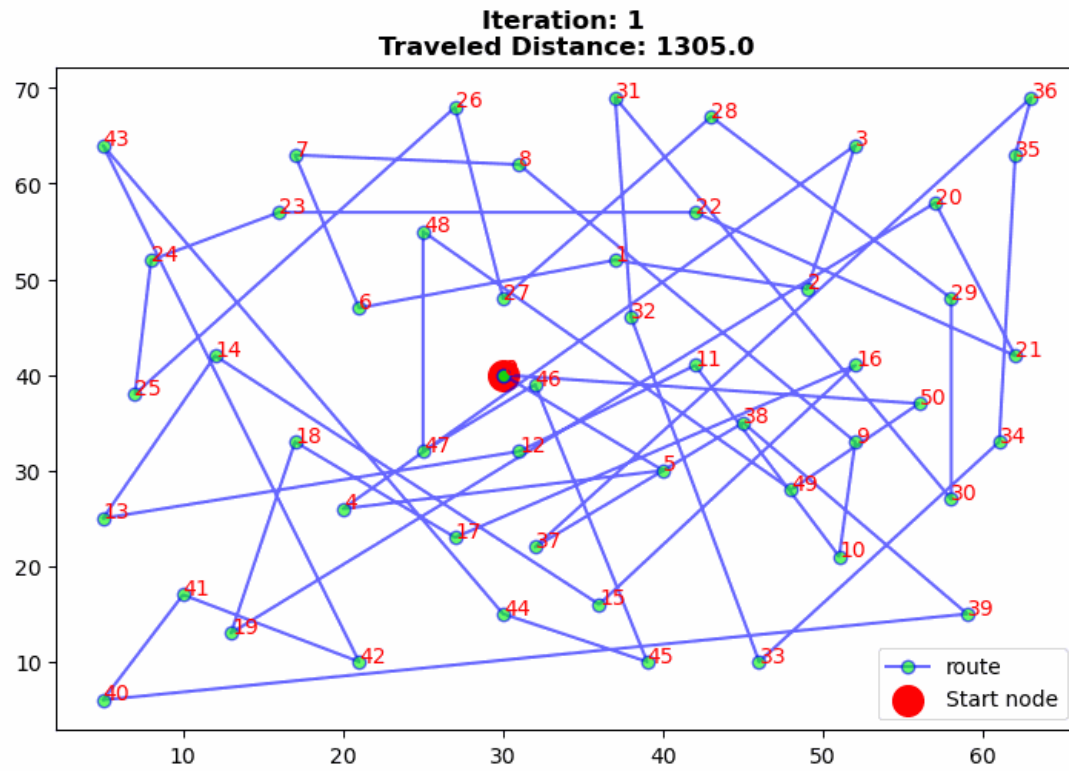
# 01. Transportation Module



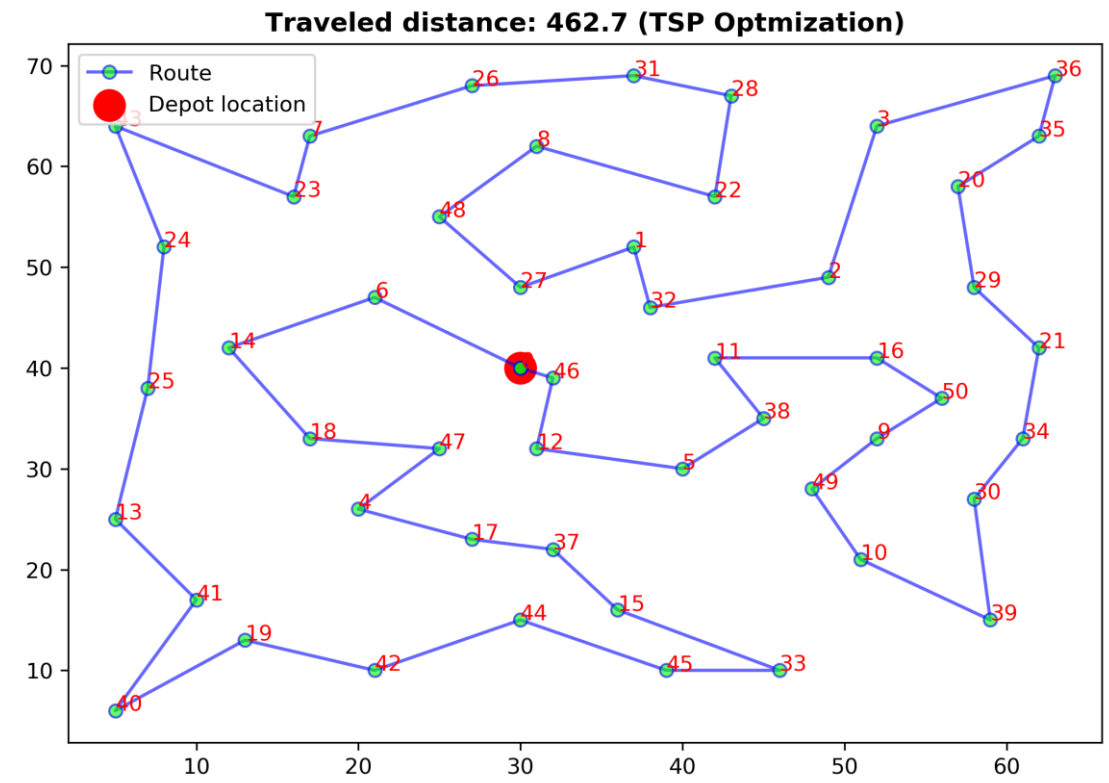
Traveling  
Salesman  
Problem

# 01. Transportation Module

## Optimization of TSP Problem

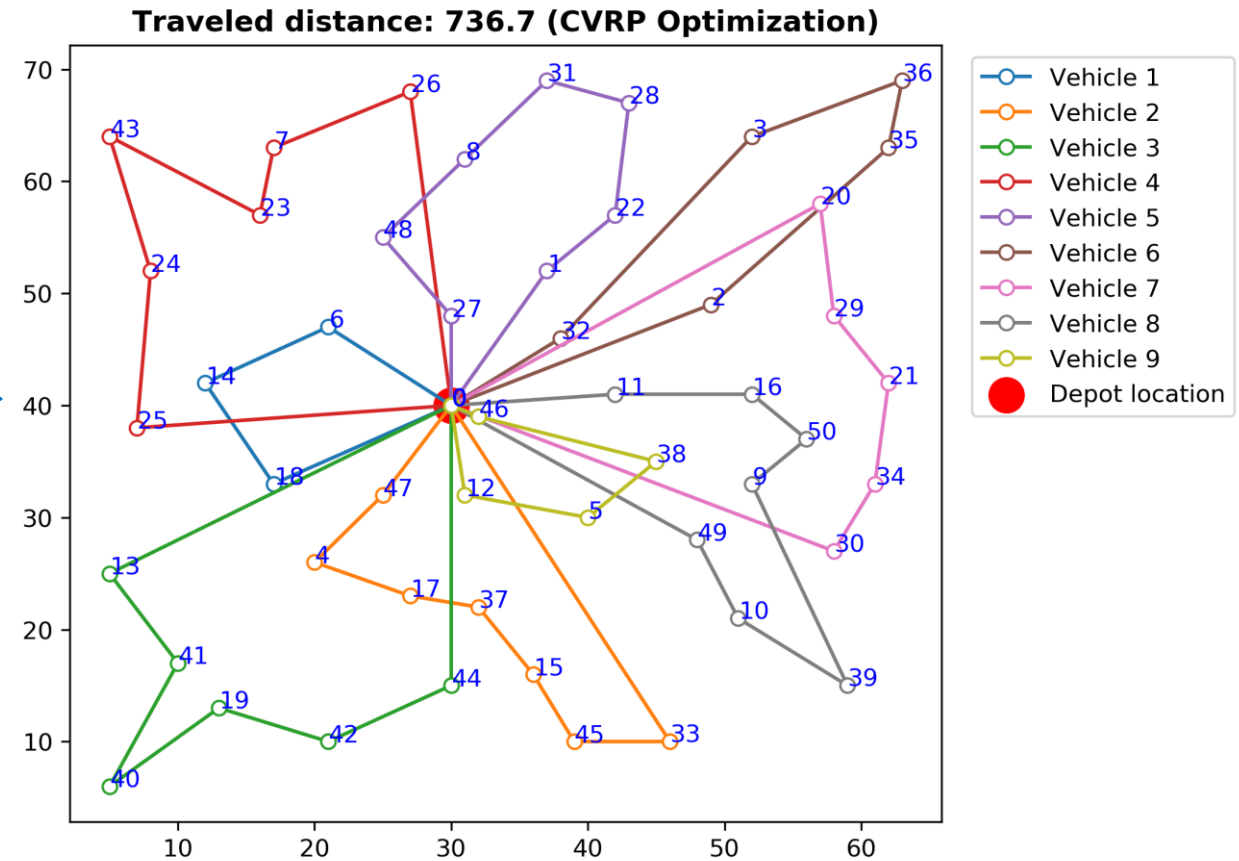
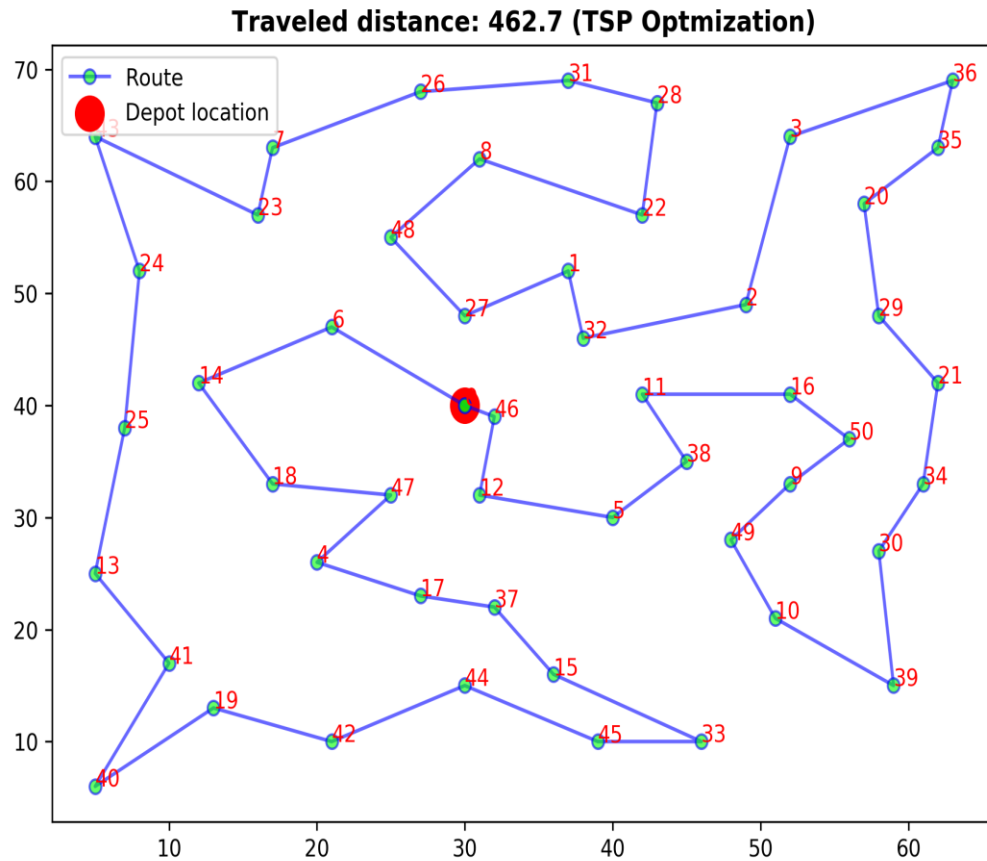


## Optimized Route





# 01. Transportation Module



# 01. Transportation Module

## Input Window

Transportation Modeling

Average weight per pallet (lbs)

Collection points data (excel file)

Selected file: No file selected yet

Unique address data (csv file)

Selected file: No file selected yet

OD matrix data (csv file)

Selected file: No file selected yet

Objective to minimize

## Sample Excel File

	A	B	C	D	E	F	G	H
1	Name	Capacity (pallets)	Vehicle Weight (lbs)	Engine Size (Liter)	Engine Efficiency	Idle Engine RPM	Max Engine RPM	Frontal Area (square meter)
2	vehicle_1	20	15000	8	40%	600	2200	5.5
3	vehicle_2	50	16000	9	30%	600	2200	5.5
4	vehicle_3	35	20000	10	35%	600	2200	5.5
5								
6								
7								

Collection Addresses Vehicle List

	A	B	C	D	E	F	G
1	Account Name	Amount (pallets)					
2	Company-XYZ	0					
3	Account 1	3					
4	Account 2	5					
5	Account 3	4					
6	Account 4	4					
7	Account 5	3					

Collection Addresses Vehicle List

# 01. Transportation Module

## Output Window

```
Transportation Model Output

vehicle_1
=====
Route: ['Company-XYZ', 'Account 27', 'Account 16', 'Account 5', 'Account 22', 'Account 11', 'Company-XYZ']
Travel distance : 151.6 miles
Travel time : 3.8 hours
Fuel burnt : 15.9 gallons
CO2 emission : 352.2 lbs
Miles per gallon : 9.5
Collected amount : 19 pallets
Capacity utilization : 95%

vehicle_2
=====
Route: ['Company-XYZ', 'Account 12', 'Account 23', 'Account 14', 'Account 18', 'Account 20', 'Account 13', 'Account 4', 'Account 26', 'Account 17', 'Account 15', 'Account 3', 'Account 25', 'Account 21', 'Company-XYZ']
Travel distance : 478.8 miles
Travel time : 10.3 hours
Fuel burnt : 55.3 gallons
CO2 emission : 1,223.0 lbs
Miles per gallon : 8.7
Collected amount : 50 pallets
Capacity utilization : 100%

vehicle_3
=====
Route: ['Company-XYZ', 'Account 24', 'Account 19', 'Account 6', 'Account 7', 'Account 8', 'Account 1', 'Account 10', 'Account 2', 'Account 9', 'Company-XYZ']
Travel distance : 1,049.7 miles
Travel time : 22.9 hours
Fuel burnt : 128.9 gallons
CO2 emission : 2,849.7 lbs
Miles per gallon : 8.1
Collected amount : 34 pallets
Capacity utilization : 97%

Overall Summary
=====
Total collected amount : 103 pallets
Unvisited account names : None
Uncollected amount : 0 pallets
```

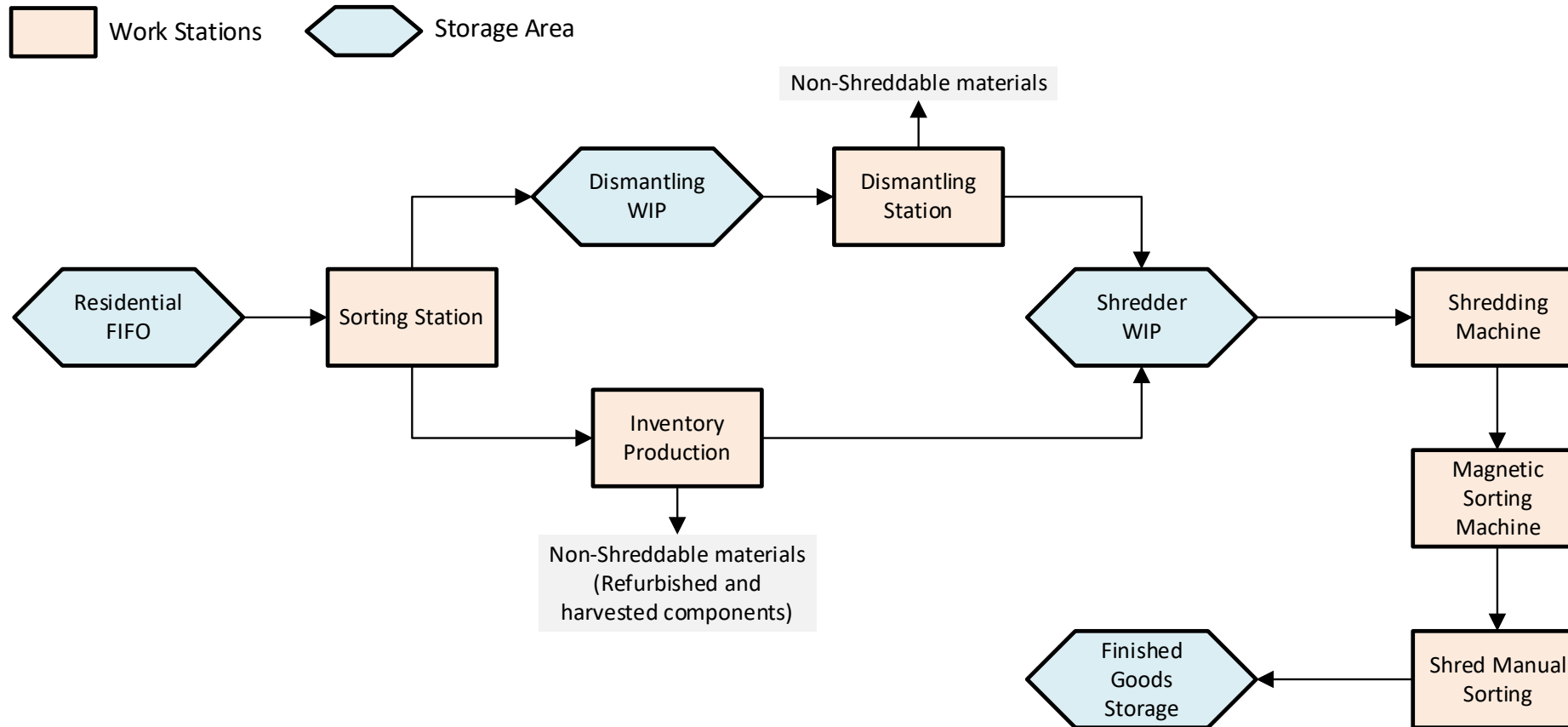
Interactive Route Map

Close



## 02. Process Module

### Sample Shopfloor Layout



## 02. Process Module

### User Input Excel File

	A	B	C	D	E	F	G	H	I	J
1	TYPE	Manual Work Station								
2	NAME	Sorting Station								
3	NO OF OPERATORS	5								
4	OPERATOR WAGE RATE	10								
5	INPUT QUEUE CAPACITY	5000								
6	PRODUCT CATEGORIES	crt_tv	crt_monitor	lcd_tv	lcd_monitor	desktop	laptop	printer	small_kee	peripherals
7	PROCESSING TIME	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1
8	NON SHREDDABLE OUTPUT PROBABILITY	0%	0%	0%	0%	0%	0%	0%	0%	0%
9	NON SHREDDABLE OUTPUT PERCENTAGE	0%	0%	0%	0%	0%	0%	0%	0%	0%
10	OUTPUT QUEUE NAMES	inventory production items dismantling wip items								
11	OUTPUT QUEUE CAPACITIES	6000	5000							

General Data

Product source1

Work station1

Work station2

Dismantling1

Shredding Work Stations

Storage Areas

Material Movement

## 02. Process Module

### Input Window

**Process Modeling**

**User Input**

**File location**

**Selected file:** C:\..\TEMPLATE\_process\_model\_data\_sample.xlsx

**Electricity cost (\$/kWh)**

**How long do you want to run the simulation?**

weeks

working days/week

shifts/day

hours/shift

### Output Window

**Output**

**Finished Goods Storage (storage area)**

=====

Current amount : 81,286 lbs  
Current capacity utilization : 0.8 %  
Average capacity utilization : 0.4 %  
Entered material amount : 81,286 lbs  
Labor cost : 0 USD

**Shredding Machine**

=====

Primary output : 113,112 lbs  
Capacity utilization : 23.6 %  
Idle time : 0.5 %  
Energy consumption : 15,993.3 kWh  
Labor cost : 400 USD

**Magnetic Sorting Machine**

=====

Primary output : 101,705 lbs  
Sorted materials : 11,301 lbs  
Capacity utilization : 23.6 %  
Idle time : 0.7 %  
Energy consumption : 11,995.0 kWh  
Labor cost : 0 USD

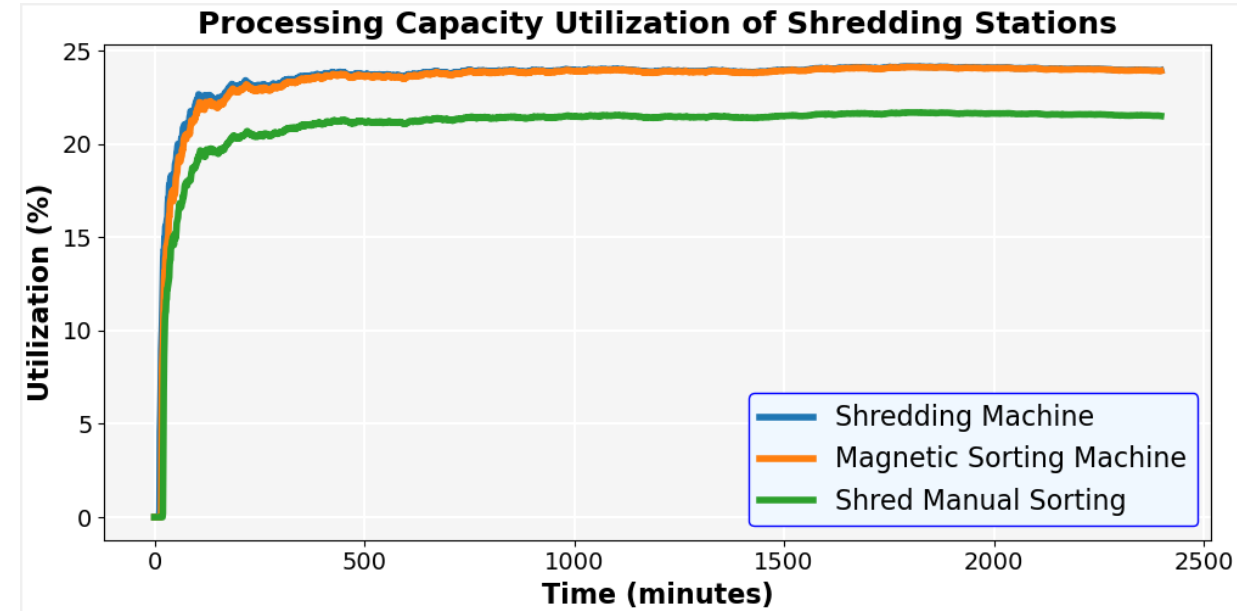
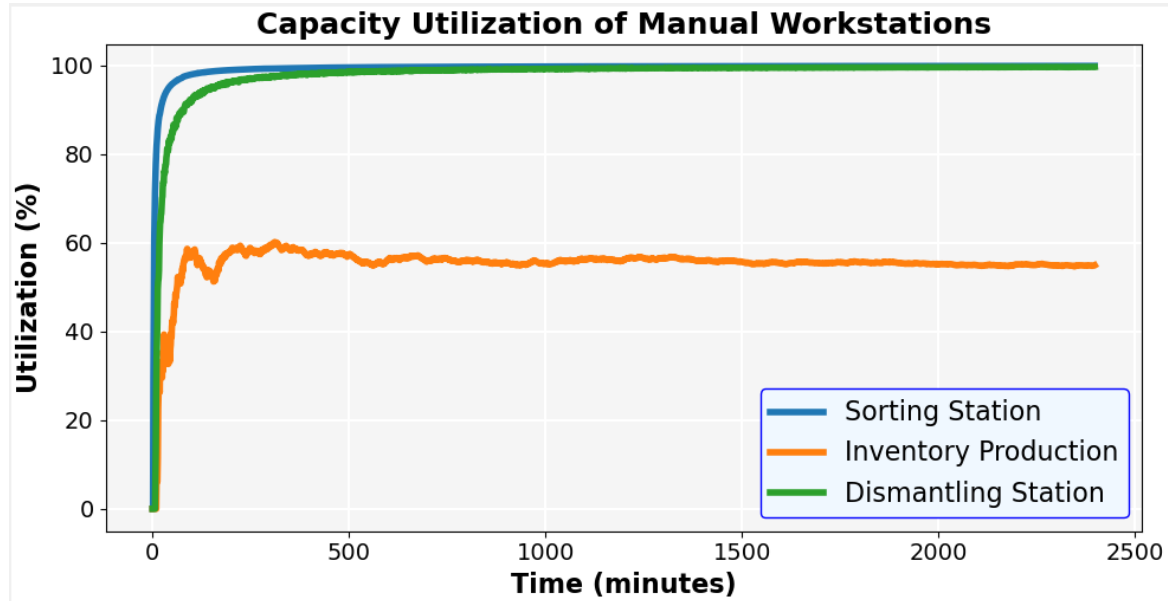
**Shred Manual Sorting**

=====

Primary output : 81,297 lbs

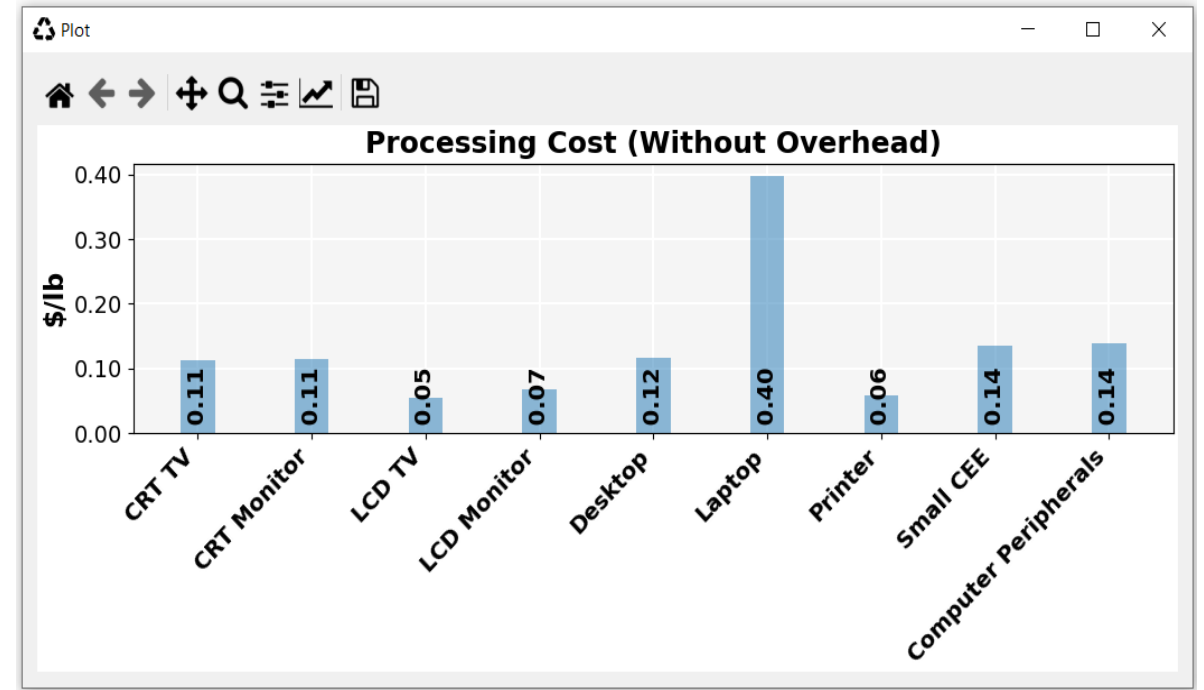
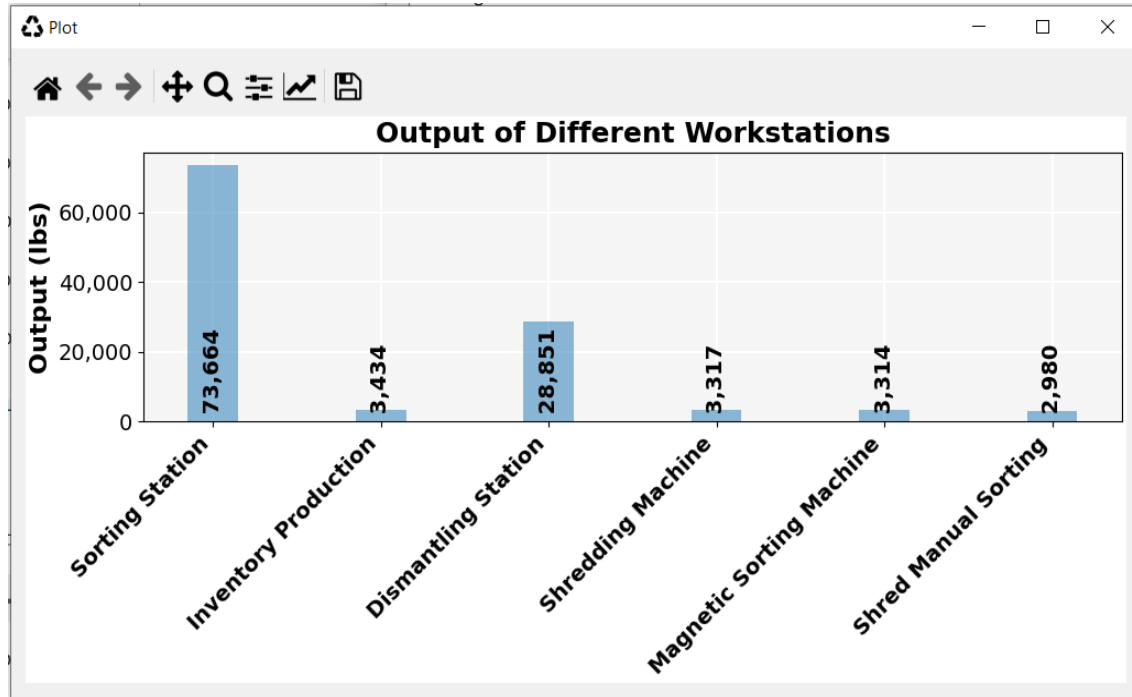
**Create Plots**

## 02. Process Module



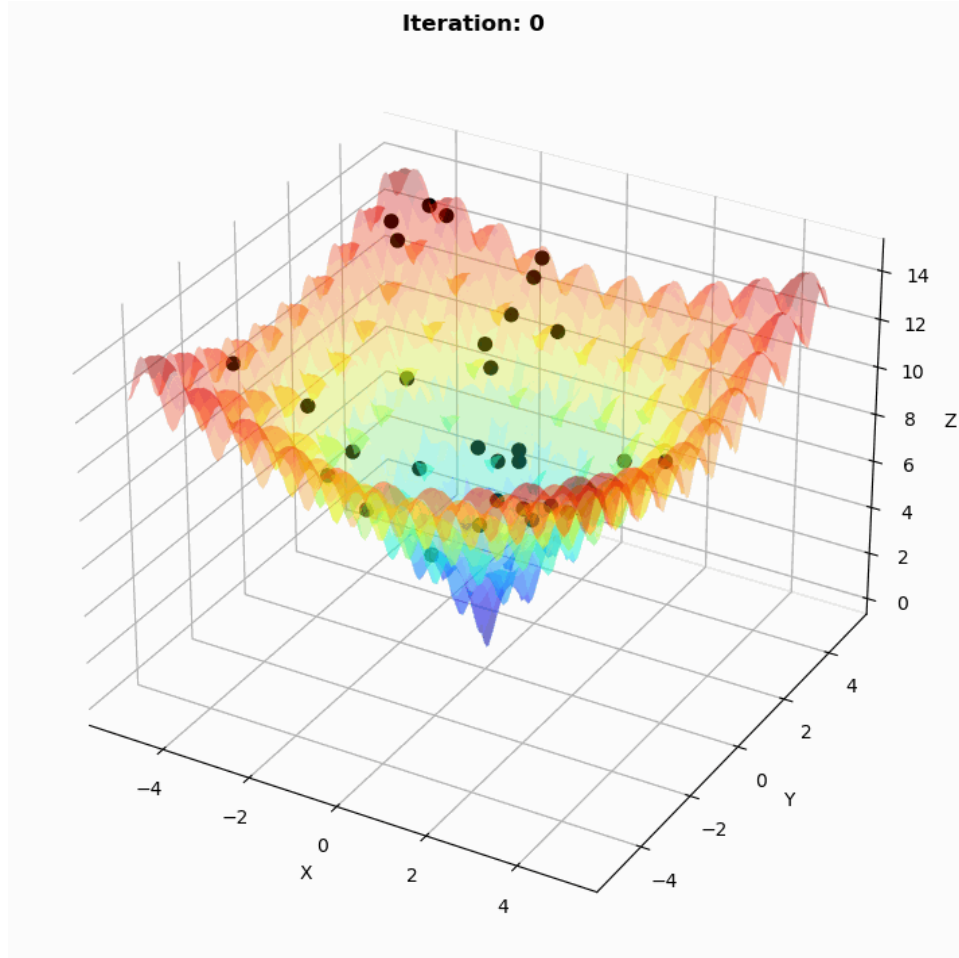


## 02. Process Module



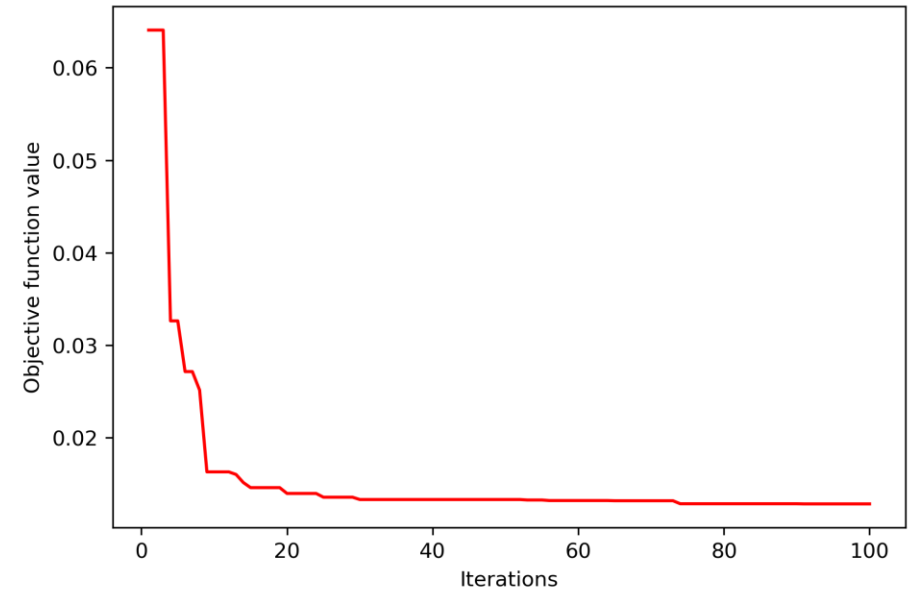
## 02. Process Module

### HACO Algorithm Searching for Optimum Solution



**Ackley Test Function** 
$$f(\mathbf{x}) = -a \exp \left( -b \sqrt{\frac{1}{d} \sum_{i=1}^d x_i^2} \right) - \exp \left( \frac{1}{d} \sum_{i=1}^d \cos(cx_i) \right) + a + \exp(1)$$

### Optimization of Manpower



### Optimum Allocation of Manpower

Sorting Station	: 05
Dismantling Station	: 12
Inventory Production	: 11
Shredding Machine	: 02
Optimized processing cost	: 0.013 \$/lb

## 03. Economic Module

Economic Modeling

### Monthly Cost Data

Fixed manufacturing overhead

Repair and maintenance

Transportation

Warehouse misc operating costs

Utility cost

Fraction of utility cost from shop floor machines

Fraction of overhead cost from top ewaste categories

### Material Price Per Ib (Revenue)

Aluminum	<input type="text" value="0.45"/>
Iron	<input type="text" value="0.05"/>
Copper	<input type="text" value="2.25"/>
Copper yoke	<input type="text" value="0.71"/>
Plastic	<input type="text" value="0.08"/>
Silver	<input type="text" value="317"/>
Gold	<input type="text" value="10570"/>
Palladium	<input type="text" value="23848"/>
Degaussing wire	<input type="text" value="1.08"/>
Mixed PC wire	<input type="text" value="0.69"/>
Computer CPU	<input type="text" value="8.33"/>
Computer RAM	<input type="text" value="14.34"/>
CD ROM	<input type="text" value="0.24"/>
Power supply	<input type="text" value="0.32"/>
CRT tube environmental fee	<input type="text" value="0.12"/>

### Freight & Fees Per Ib Charged By Smelters

Motherboard shred	<input type="text" value="0.50"/>
TV shred	<input type="text" value="0.50"/>
HDD shred	<input type="text" value="0.50"/>
CEE shred	<input type="text" value="0.50"/>

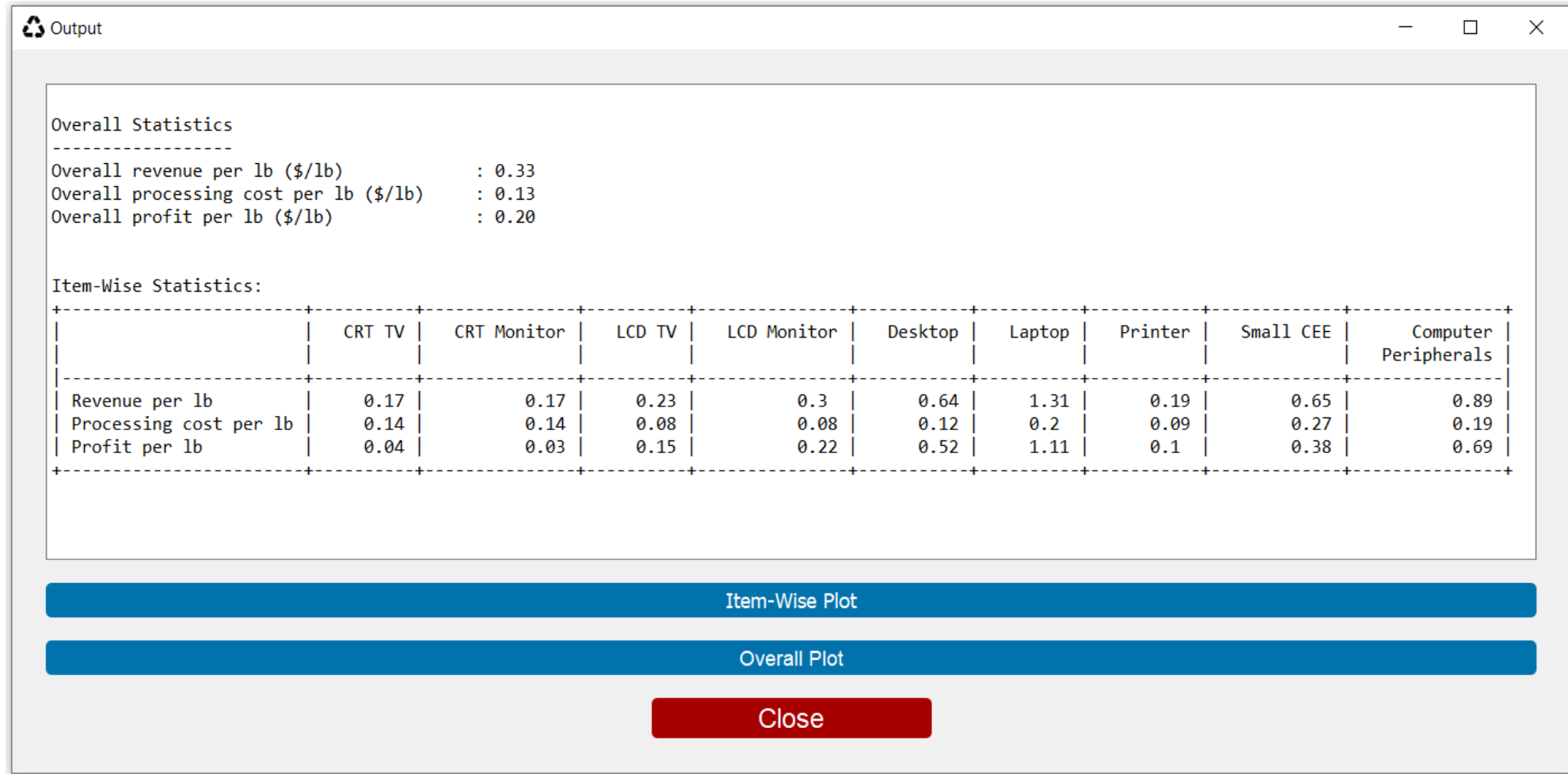
### Material Processing Data

File location

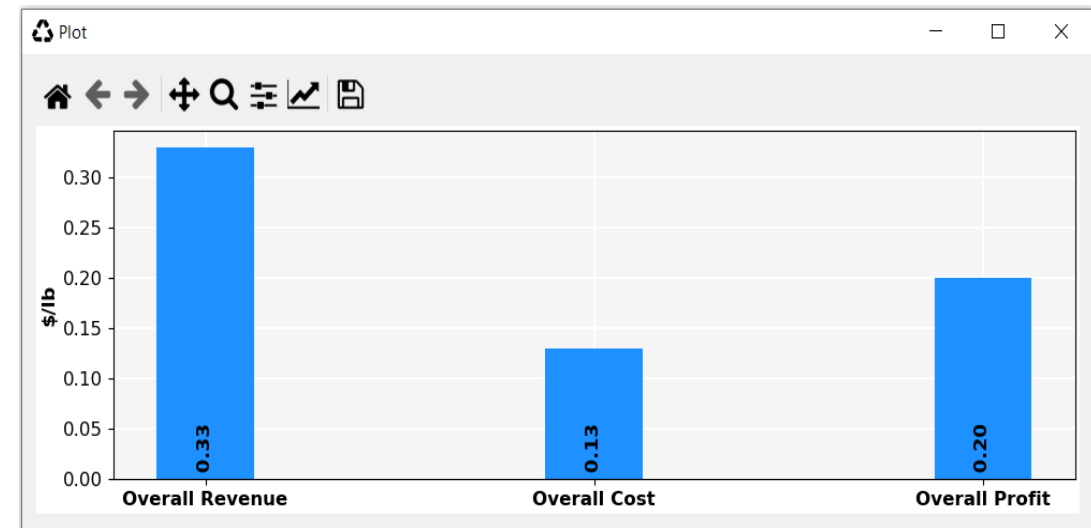
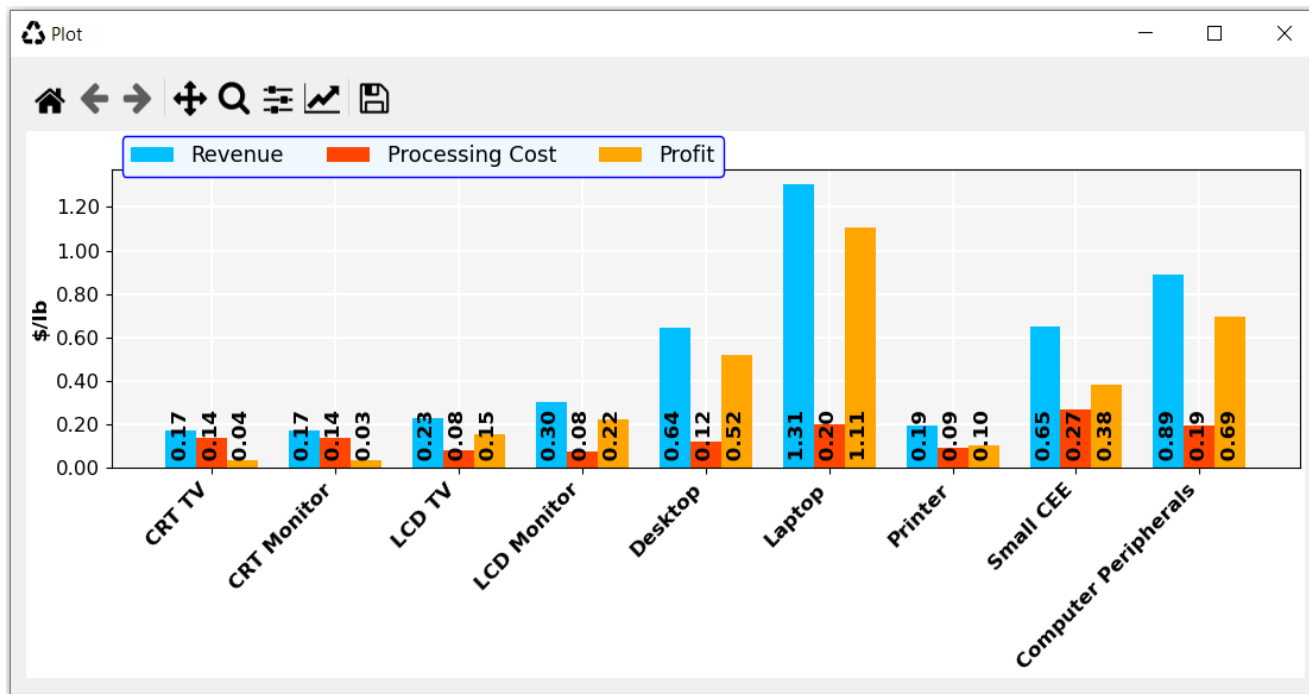
Selected file No file selected yet

Input Window

## 03. Economic Module



# 03. Economic Module



# Concluding Remarks

- Very easy to use
- Zero simulation/coding experience
- Source code in Python
- Plan to release as open source under Apache License
- Customizable for other industries
- Our other software and scientific offerings at:

<https://dynamicmodel.inl.gov/SitePages/Home.aspx>

<https://github.com/IdahoLabResearch/>

# THANK YOU!

**Md Mamunur Rahman**  
[mdmamunur.rahman@inl.gov](mailto:mdmamunur.rahman@inl.gov)