sustainability

Supplementary Material

Corporate Social Responsibility Practices in USA: Using Reverse Supply Chain Network Design and Optimization Considering Carbon Cost

Content

Part I: Methods

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Part I: Method

Table S1. Orthogonal Arrays of 27 experiments to satisfy 13 factors, each with three different levels used to quantitative evaluation and performance of the mixed-integer linear programming model.

Experiments	**Factors**												
	Transportation Cost	**Energy Cost - fix**	**Energy Cost - variable**	**Rent Cost**	**Labor Cost**	**Social Cost of Carbon**	**Shortage Cost**	**Remanufacturing Cost**	**Mean demand rate**	**Retrieval Cost**	**Inventory Cost**	**Inventory level**	**Supply rate**
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3

26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Part II: Experiments Results

Table S2. Optimal number of units transported for experiment 1.

From \ To	Taunton	Hingham
Melrose	5	58
Canton	78	5
Natick	5	92
Revere	54	5
Boston	30	64
Somerville	5	88

Table S- 1. Optimal number of units transported for experiment 2.

From \ To	Taunton	Hingham
Melrose	5	112
Canton	151	5
Natick	5	180
Revere	102	5
Boston	54	122
Somerville	5	170

Table S- 2: Optimal number of units transported for experiment 3.

From \ To	Taunton	Hingham
Melrose	5	166
Canton	218	5
Natick	5	145
Revere	121	5
Boston	102	107
Somerville	5	203

Table S- 3: Optimal number of units transported for experiment 4.

From \ To	Taunton	Hingham
Melrose	76	95
Canton	10	5
Natick	268	180
Revere	81	26
Boston	5	171
Somerville	5	170

Table S- 4: Optimal number of units transported for experiment 5.

From \ To	Taunton	Hingham
Melrose	59	5
Canton	23	5
Natick	5	92
Revere	54	5

Boston	28	42
Somerville	5	55

Table S- 5: Optimal number of units transported for experiment 6.

To / From	Taunton	Hingham
Melrose	5	112
Canton	5	5
Natick	5	112
Revere	5	54
Boston	5	88
Somerville	5	87

Table S- 6: Optimal number of units transported for experiment 7.

To / From	Taunton	Hingham
Melrose	62	55
Canton	162	5
Natick	5	255
Revere	121	5
Boston	103	107
Somerville	5	203

Table S- 7: Optimal number of units transported for experiment 8.

To / From	Taunton	Hingham
Melrose	5	165
Canton	5	5
Natick	5	58
Revere	5	53
Boston	5	88
Somerville	5	87

Table S- 8: Optimal number of units transported for experiment 9.

To / From	Taunton	Hingham
Melrose	56	52
Canton	168	5
Natick	5	172
Revere	102	5
Boston	122	54
Somerville	5	170

Table S- 9: Optimal number of units transported for experiment 10.

To / From	Taunton	Hingham
Melrose	5	166
Canton	96	5
Natick	5	267
Revere	96	31

Boston	5	204
Somerville	5	203

Table S- 10: Optimal number of units transported for experiment 11.

To / From	Taunton	Hingham
Melrose	121	5
Canton	205	5
Natick	5	203
Revere	121	5
Boston	204	5
Somerville	5	203

Table S- 11: Optimal number of units transported for experiment 12

To / From	Taunton	Hingham
Melrose	5	112
Canton	171	5
Natick	5	180
Revere	122	5
Boston	54	122
Somerville	5	170

Table S- 12: Optimal number of units transported for experiment 13.

To / From	Taunton	Hingham
Melrose	137	34
Canton	5	5
Natick	5	59
Revere	102	5
Boston	54	122
Somerville	5	170

Table S- 13: Optimal number of units transported for experiment 14

To / From	Taunton	Hingham
Melrose	5	166
Canton	10	5
Natick	5	268
Revere	10	97
Boston	5	171
Somerville	5	170

Table S- 14: Optimal number of units transported for experiment 15

To / From	Taunton	Hingham
Melrose	91	91
Canton	176	5

Natick	5	176
Revere	121	5
Boston	145	64
Somerville	5	203

Table S- 15: Optimal number of units transported for experiment 16

From \ To	**Taunton**	**Hingham**
Melrose	74	32
Canton	151	5
Natick	5	193
Revere	102	5
Boston	122	54
Somerville	5	170

Table S- 16: Optimal number of units transported for experiment 17

From \ To	**Taunton**	**Hingham**
Melrose	5	122
Canton	197	5
Natick	5	210
Revere	121	5
Boston	80	129
Somerville	5	203

Table S- 17: Optimal number of units transported for experiment 18

From \ To	**Taunton**	**Hingham**
Melrose	165	5
Canton	5	5
Natick	5	58
Revere	53	5
Boston	88	5
Somerville	34	58

Table S- 18: Optimal number of units transported for experiment 19

From \ To	**Taunton**	**Hingham**
Melrose	112	5
Canton	161	5
Natick	5	170
Revere	102	5
Boston	171	5
Somerville	5	170

Table S- 19: Optimal number of units transported for experiment 20

To / From	Taunton	Hingham
Melrose	5	166
Canton	96	5
Natick	5	267
Revere	96	31
Boston	5	204
Somerville	5	203

Table S- 20: Optimal number of units transported for experiment 21

To / From	Taunton	Hingham
Melrose	5	112
Canton	5	5
Natick	5	112
Revere	5	54
Boston	5	88
Somerville	5	87

Table S- 21: Optimal number of units transported for experiment 22

To / From	Taunton	Hingham
Melrose	5	122
Canton	202	5
Natick	5	204
Revere	121	5
Boston	86	123
Somerville	5	203

Table S- 22: Optimal number of units transported for experiment 23

To / From	Taunton	Hingham
Melrose	5	165
Canton	5	5
Natick	5	59
Revere	5	54
Boston	5	88
Somerville	5	87

Table S- 23: Optimal number of units transported for experiment 24

To / From	Taunton	Hingham
Melrose	112	5
Canton	151	5

Natick	5	180
Revere	102	5
Boston	161	15
Somerville	5	170

Table S- 24: Optimal number of units transported for experiment 25

From \ To	Taunton	Hingham
Melrose	43	74
Canton	5	5
Natick	5	112
Revere	43	16
Boston	5	88
Somerville	5	87

Table S- 25: Optimal number of units transported for experiment 26

From \ To	Taunton	Hingham
Melrose	73	44
Canton	151	5
Natick	5	180
Revere	102	5
Boston	122	54
Somerville	5	170

Table S- 26: Optimal number of units transported for experiment 27

From \ To	Taunton	Hingham
Melrose	5	166
Canton	96	5
Natick	5	267
Revere	96	30
Boston	5	205
Somerville	5	203

Part III: Data

In this section two different survey databases were used, Commercial Buildings Energy Consumption Survey (CBECS) was for collection centers and reselling centers energy data. Manufacturing Energy Consumption Survey (MECS) was used for remanufacturing facilities energy data.

Commercial Buildings Energy Consumption Survey (CBECS)

CBECS is a national sample survey that collects information on commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenses). Commercial buildings include all buildings in which at least half of the floor space is used for a purpose that is not residential, industrial, or agricultural. The latest survey was conducted in 2012, and the microdate file contains 6,720 records for building characteristics in the USA (EIA, U.S., 2012b)

Our model used the following criteria from the survey for the collection and resellers centers, as shown in Figure 1 and 2:

Principal building activity: Retail (other than mall)

Census region and division: New England

Establishment counts, total floor-space per establishment, space-heating, cooling, ventilation, water-heating, lighting, cooking, refrigeration, office equipment, computers, and others. This helps in classify our commercial buildings fixed and variable cost and usage. Most of their usages are: electricity and natural gas. CBECS data were used in identify the collection centers and the reselling centers in our numerical example.

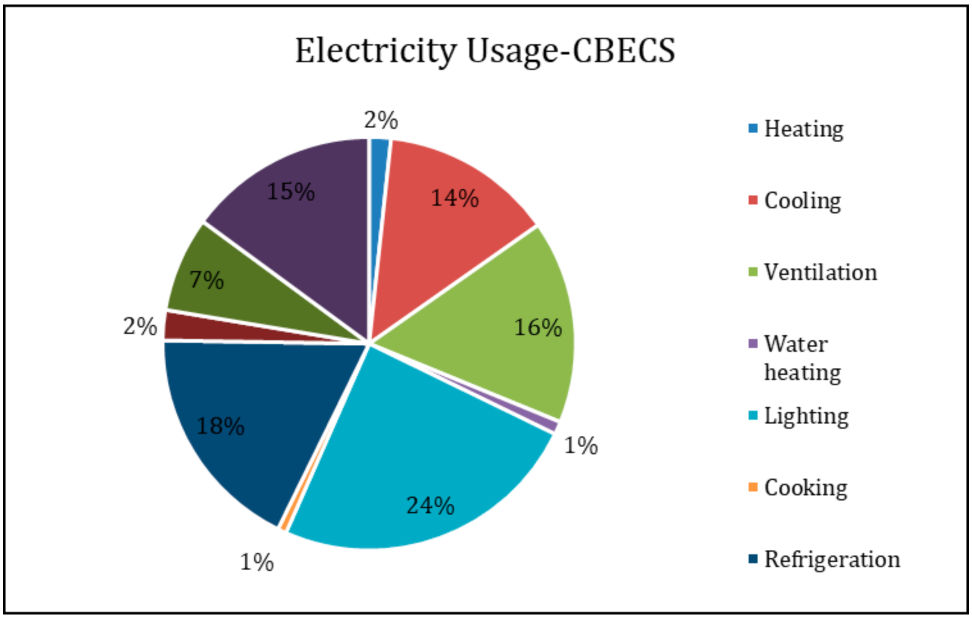

Figure S- 1: Electricity usage data derived from Commercial Buildings Energy Consumption Survey (CBECS) for electrical equipment, appliances, and components industry of New England region.

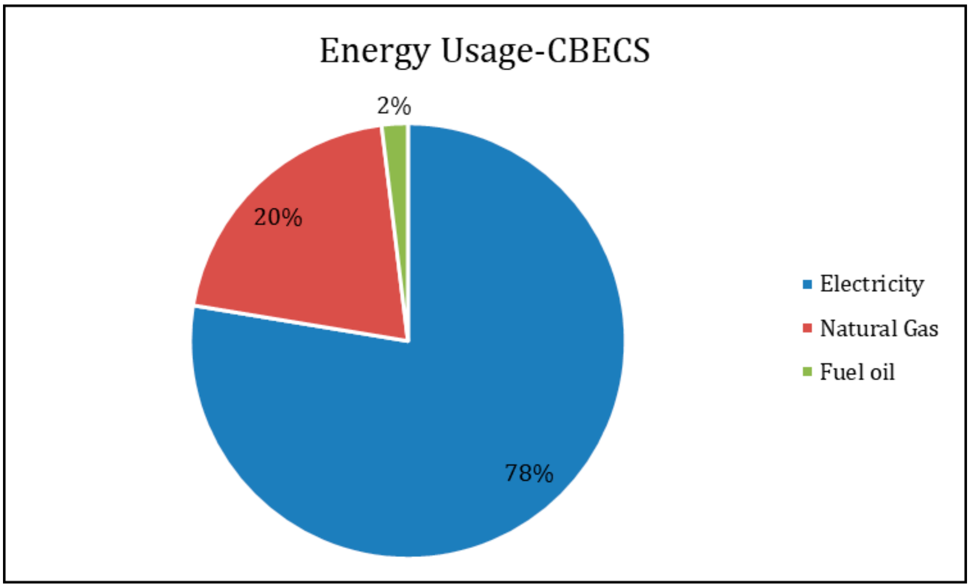

Figure S- 2: Energy usage data derived from Commercial Buildings Energy Consumption Survey (CBECS) for retail sector of New England region.

Manufacturing Energy Consumption Survey (MECS)

MECS is a national sample survey that collects information on manufacturing establishments, their energy-related building characteristics and their energy consumption and expenses. The MECS was first conducted in 1985, the most recent survey was in 2010; the first data set was made available in February, 2013. MECS is currently conducted on a quadrennial basis, and uses the North American Industry Classification System (NAICS) to classify business establishments according to the type of economic activity (process of production) in Canada, Mexico and the USA (EIA, U.S., 2010a).

Our model used the following criteria from this survey for the remanufacturing facilities, as shown in Figure 3 and 4:

NAICS Code: 335

Subsector and Industry: Electrical Equip., Appliances, and Components

Census region and division: New England

Establishments counts, total floor-space per establishment, process heating, process cooling and refrigeration, machine drive, facility HVAC, and facility lighting.

Most of their usages are: electricity and natural gas. Distillate fuel oil and diesel, and residual fuel oil are less than 0.5 million bbl. MECS data were used in identify the remanufacturing facilities in our numerical example.

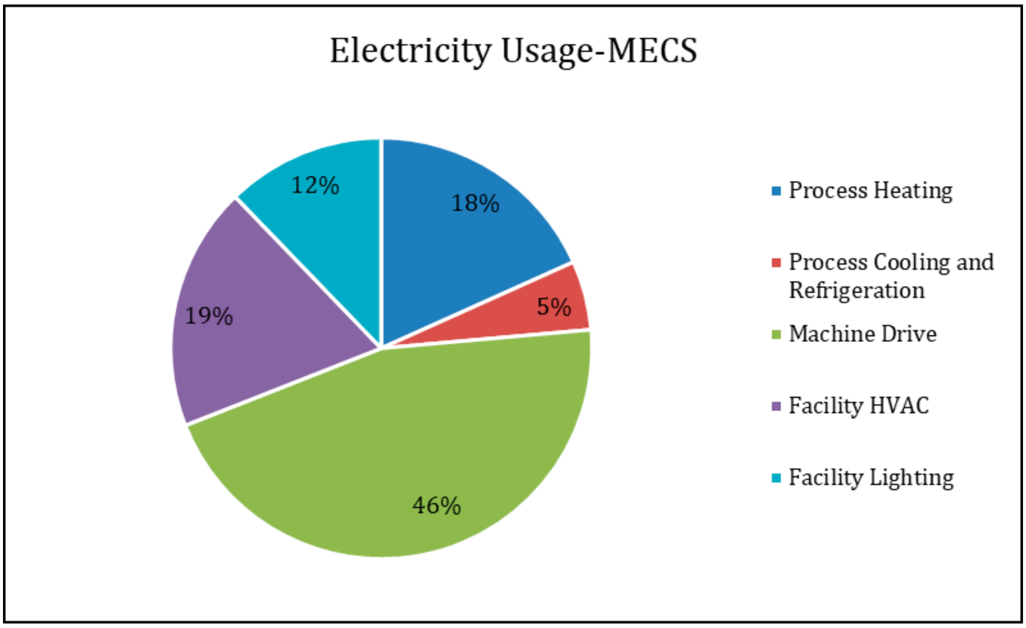

Figure S- 3: Electricity usage data derived from Manufacturing Energy Consumption Survey (MECS) for electrical equipment, appliances, and components industry of New England region.

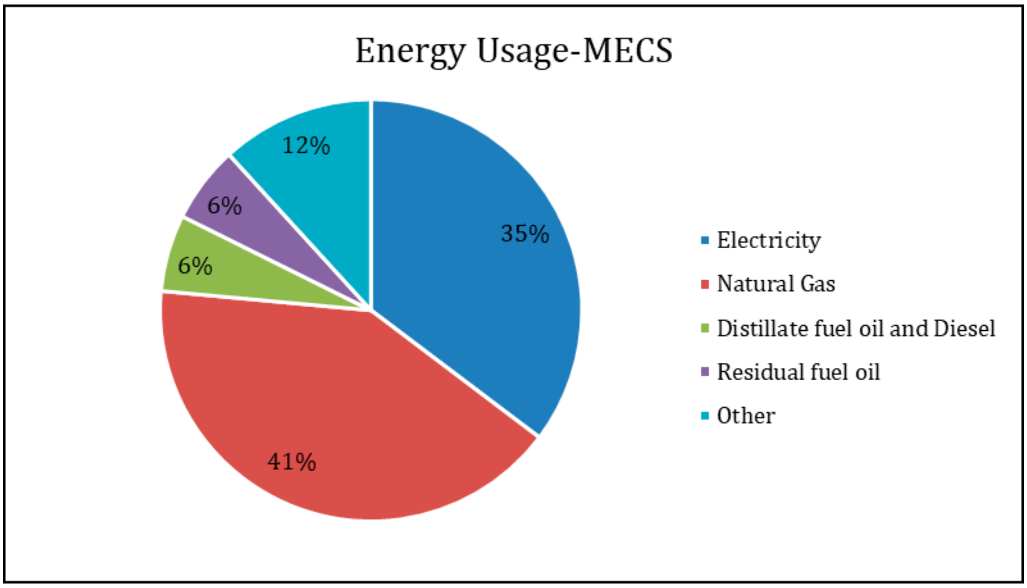

Figure S- 4: Energy usage data derived from Manufacturing Energy Consumption Survey (MECS) for electrical equipment, appliances, and components industry of New England region.

Table S29. Actual rent cost for collection centers (Melrose, Canton, and Natick), two remanufacturing facilities (Taunton and Hingham), and three reselling centers (Revere, Boston, and Somerville) used in the deterministic model

Table S30. Actual **n**umber of laborers and their cost per year for collection centers (Melrose, Canton, and Natick), two remanufacturing facilities (Taunton and Hingham), and three reselling centers (Revere, Boston, and Somerville) used in the deterministic model

Table S31. Actual **t**rip distances between locations in miles

Table S- 27: Actual rent cost for collection centers (Melrose, Canton, and Natick), two remanufacturing facilities (Taunton and Hingham), and three reselling centers (Revere, Boston, and Somerville) used in the deterministic model.

Cities	Space (Sq ft)	Rent per Sq ft/year	Total rent per year
Canton	1000	$14.4	$4,220
Natick	3000	$10.5	$10,575
Melrose	1500	$15.0	$7,460
Taunton	10000	$11.0	$110,000
Hingham	9801	$8.0	$78,408
Revere	2700	$10.0	$27,000
Boston	5100	$25.0	$127,500
Somerville	4000	$17.0	$68,000

Table S- 28: Actual number of laborers and their cost per year for collection centers (Melrose, Canton, and Natick), two remanufacturing facilities (Taunton and Hingham), and three reselling centers (Revere, Boston, and Somerville) used in the deterministic model.

Cities	Number of laborers	Labor cost per year
Canton	5	$93,600
Natick	3	$56,160
Melrose	4	$74,880
Taunton	15	$280,800
Hingham	17	$318,240
Revere	4	$74,880
Boston	3	$56,160
Somerville	6	$112,320

Table S- 29: Actual trip distances between locations in miles.

From \ To	Taunton	Hingham
Melrose	52.8	28.1
Canton	17.2	19.3
Natick	37.0	30.5
Revere	45.0	24.0
Boston	40.0	19.0
Somerville	43.0	22.0

Part IV: Statistical Analysis Results

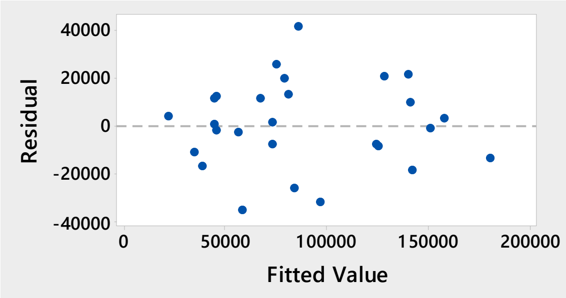

Figure S- 5: The residuals plotted against the predicted values, to test homogeneousness of the residual.

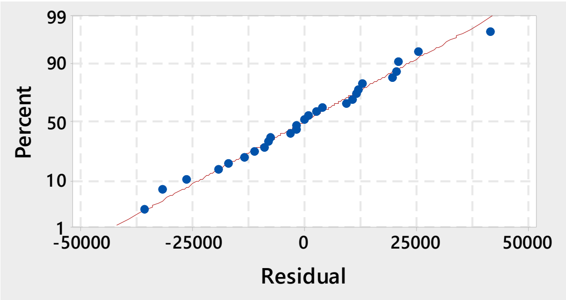

Figure S- 6: Normal probability plot of residuals to test normality assumption.