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Supply Chain Design Network Model for Biofuels and Chemicals from Waste Cooking Oil

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Supply chain is an effective coordination and integration of all activities performed by several business lines with the aid of their infrastructures. Supply chain managing and designing teams should adopt the latest most effective scientific methods to locate facilities.
Waste cooking oil (WCO) is dumped in swears and municipal drainages, causing a lot of problems. One of the most important uses of WCO is converting it to biodiesel. In Egypt case, a lot of barriers were found to initiate a plant producing biodiesel from WCO, as there is no collection supply chain system designed. Lack of public awareness led to the drawback of dumping WCO in municipal drains, causing sewer damage and water pollution. Only 35 % of wastewater in Egypt is purified before being dumped into the Nile River. This research generates a supply chain design model of three layered medium mixed integer linear programme for an application of biodiesel production from WCO. MATLAB Software with a Graphical User Interface programmed by the C SHARP C# programming software and EXCEL solver tools were used. CAPCOST tool was used to generate economic feasibility study. Scenarios are examined to price out and compare trade-offs potential solutions. Optimizing the operations are focused on chemical engineering unit operations, production process facilities as well as the entire supply chain.

1. Introduction

Biodiesel is used in many applications, including heating oil used in urban housing sustainable buildings and blended fuel used in vehicles. Biodiesel fuel can be used in any mixture with petroleum diesel fuel due to similar characteristics, producing more clean energy, having lower emissions as well as being eco-friendly. The most worldwide efficient blend used in cars is B-20 biodiesel blend, which is 20 % biodiesel and 80 % petroleum diesel.
Biodiesel produced from waste cooking oil (WCO) is renewable, non-toxic, free of Sulphur, biodegradable, and can be blended with petroleum-based fuels. Neat biodiesel and its blends with diesel fuel reduces carbon monoxide and hydrocarbons emissions (Karmee et al., 2015). A study by US Department of Energy showed that 78.5 % reduction in the carbon dioxide emissions is noted when using biodiesel instead of petroleum diesel. Biodiesel has 10 % higher nitrogen oxide emissions (NOx) as compared with petroleum diesel (Ayhan D., 2005), which if not treated forms smog, resulting in acid rains. Disadvantage of B100 biodiesel is that it may clog car filters and gels in cold weather, so it is used as a blend mixed with petroleum diesel.
Compared to petroleum diesel, the cost of biodiesel is the major barrier for its widespread use and its commercialization. Vegetable oil as a raw material costs 70 – 95 % of the total biodiesel production cost (Mariano et al., 2013). Biodiesel from vegetable oil is 1.75 - 2.5 times more expensive than biodiesel from waste cooking oil (Fischer et al., 1998).
Egypt imports monthly 500,000 t of petroleum diesel, 160,000 t of gasoline, and 220,000 t of fuel oil, in addition to Liquefied Natural Gas (LNG) (El-Shimi et al., 2006). In Egypt, there is no process for blending produced biodiesel with the daily consumption of petroleum diesel 37,000 t/d (Mariano et al., 2013). In addition, there are no measurements for peoples Willingness to Accept (WTA) for participation in safe WCO disposal for recycling with different incentive levels as well as opportunity cost. This paper focuses on the development of decision

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supporting tool for solving supply chain design issue, using analytical algorithm to solve the mixed integer linear problem (MILP).
MATLAB Software with a GUI (graphical user input interface) programmed by the C# (C SHARP) programming software and EXCEL solver tools are used (Emara et al., 2016). A three-layered supply chain network model, raw materials collecting areas, distribution centre and plant locations, is constructed with the aid of surveys to detect optimum locations and capacities for collecting WCO with its suggested possible routes including loading capacities. Economic feasibility study is generated addressing the opportunities for WCO re-usage.

2. Problem statement

The cost of biodiesel fuels varies depending on plant production cost, which is discussed in details and supply chain cost with all its costing items, including stock availability, raw material fixed and variable costs, traveling distance, geographic area, distribution centre handling cost, inbound as well as outbound transportation cost. Plant data are retrieved from a previous study (Mariano et al., 2013) and used in the economic feasibility study with cash flow analysis for the whole project, adding flexibility of changing some input data in the economic feasibility study for Egypt case.
The aim of the study is to construct a feasible supply chain system model to minimize the total raw material, logistics and utilities costs. WCO is generated from 4 main locations: a) Residential areas, b) Restaurants, c) Food industrial factories, and d) Hotels. Restaurants, food industrial factories and hotels used to pay collectors to dispose their waste including WCO. Implementing this model, WCO is no more waste, and it is a valuable feed stock for biodiesel production.

3. Motive of research

Determine optimum location for 70 % Capacity Plant. Develop supply chain model to address and mitigate the environmental problem of WCO dumping and disposal. Reuse of WCO producing a sustainable source of energy by production of biodiesel. Construct database for WCO collecting locations and capacities.
The model is flexible, robust, user friendly, and applicable to other applications for different commodities. As shown in Figure 1, the algorithm consists of mainly five pillars to construct the MILP model. The five pillars are: objective function, constrains, decision variables, data inputs and the optimization solving methods.

4. Solution approach

A MILP programming model is developed for determining the optimal distribution centre locations and plant facility locations, possible routes as well as activity costs within the supply chain designed model network. All the data used in the model including but not limited to WCO locations, collecting capacity, traveling distances, traveling time and weight of different industrial activities were collected in a database based on analytical survey. A comprehensive open loop cycle is followed. This system is designed for industrial factories, hotels and restaurant activities as well as for people participating from the residential areas. Locations for waste cooking oil disposal bins are determined to decrease collecting trucks average transportation distance. An example for a route in Giza government design is mentioned in Figure 2, the three districts (Dokki, Agoza, Mohandseen) restaurant routes are of 15.76 km gathering 120 resultants with a total waste cooking oil disposal of 2,400 kg/d. The red line, in the Figure 2, shows the route followed by trucks.

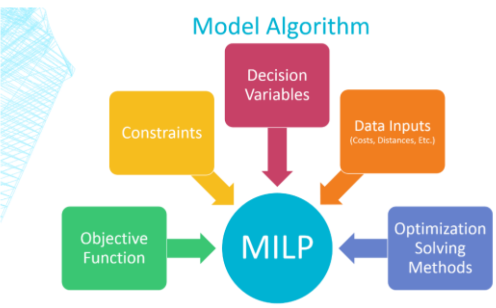

Figure 1: Model Solution Algorithm

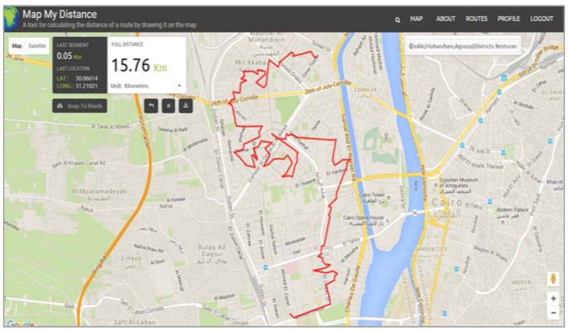

Figure 2: Districts Restaurants Route

5. Mathematical model

The supply chain design is a MILP programming method, considering the uncertainty associated with the objective model function. The model links objective function, decision variables and constrains in a cohesive equation-based model. First objective is selecting the best locations for (a) WCO raw materials suppliers, (b) WCO distribution centres, and (c) biodiesel production plant, from predetermined candidate locations, to minimize the total transit cost between these three points by constructing MILP network. Second objective is to minimize the total cost (Z) used to calculate cost per unit weight for the WCO at the feed plant inlet after designing the supply chain.

The objective is minimizing the total cost composed of raw material transportation cost, distribution center fixed cost, distribution center storage variable cost, inbound transportation cost, outbound transportation cost, raw material cost.

The more constrains the narrower the solution window range is. The model can order waste cooking oil amount less than or equal to the total available amount from the collecting point, it can only deliver amount less than or equal the storage capacity of distribution centers and if there is no inflow to any of the distribution centers, the center is closed to minimize the fixed capital cost. The binary variable (*Y)*condition states that the number of distribution centers opened is constrained by the minimum and maximum available and allowed number by the user. For scaling up or down cost per kg of WCO is calculated using the total cost (Z) and the plant capacity of 8.186×10^{6} kg/y.

5.1 Objective function

$$Z = \sum_i\sum_j C_{ij} X_{ij} + \sum_i f_i Y_i + \sum_i Cs\ X\ Y_i + \sum_i CIB\ X_i\ Kn_i + \sum_j COB\ X_j\ Ko_j + Cr \tag{1}$$

5.2 Subjected to constrains

$$\sum_j X_{ij} \leq S_i \ \forall\ i \in S \tag{2}$$

$$\sum_i X_{ij} \geq D_j \ \forall\ j \in D \tag{3}$$

$$X_{ij} - M_{ij} Y_i \leq 0 \ \forall\ i, j \tag{4}$$

$$\sum_i Y_i \geq P^{Min} \tag{5}$$

$$\sum_i Y_i \leq P^{Max} \tag{6}$$

$$X_{ij} \geq 0 \ \forall\ i, j \tag{7}$$

$$Y_i = \{0,1\} \ \forall i \tag{8}$$

a. Decision variables
- *X*: WCO commodities amount.
- *Y*: D.Cs whether to open or close binary variable.

b. Indices:
- *i*: Inbound Transportation Index. First phase: WCO Raw material areas. Second phase: WCO D.Cs.
- *j*: Outbound Transportation Index. First phase: WCO Distribution centers. Second phase: Plant.

c. Input Data:
- C_{ij}: Transportation cost for WCO D.C j from WCO raw material area *i*, biofuel plant j from D.C *i*.
- COB: Outbound transportation cost per distance per amount of WCO.
- CIB: Inbound transportation cost per distance per amount of WCO.
- Cs: Storage cost per amount of WCO.
- Cr: Raw material cost.
- D_j: WCO demand by D.C *j* from raw material area *i*, Biofuel plant j from WCO D.C *i*.
- Kn: Inbound transportation distance.
- Ko: Outbound transportation distance.
- F_i: Fixed cost for opening WCO D.C *i*.
- M: Total WCO D.Cs capacities.
- P^{Max}: Maximum WCO D.Cs available to open.
- P^{Min}: Minimum WCO D.Cs available to open.
- S_i: WCO raw material available supply at raw material areas and D.Cs.
- Z: Total cost.

6. Case study in Egypt

6.1 Suggested locations

Egypt consists of 27 governments, Giza Government was the core of the case study, which is generalized and applied for the other two governments Cairo and Alexandria. Number of participants per category for the three collecting locations are mentioned in Table 1 with 270,000 residents participated in each government during the project initial phase.

Table 1: Proposed model WCO disposal comparison percentages.

Distribution Clusters	Restaurants	Club Restaurants	Hotels	Chips factories	Residents
Dokki District	120	42	0	0	90,000
Al Haram District	70	0	11	0	90,000
6 October Village District	152	45	0	2	90,000
Total (3 Districts)	342	87	11	2	270,000
Collected WCO [kg/y]	2,322,870	560,340	79,850	70,000	1,071,900
WCO share percentages	57 %	14 %	2 %	2 %	26 %

The three governments WCO production is 11.7×10^6 kg/y, WCO plant capacity is 8.19×10^6 kg/y, model is operating with 70 % capacity of the proposed available collected WCO amount. Disposal percentage of Giza 35 %, Cairo 43 %, Alexandria 22 %. Supply chain Mixed integer linear problem model is of 108 routes, 150 user inputs, 99 variable, 54 main equation, solved using 2 different methods one using MATLAB and C sharp and the other using Excel solver tools as shown in Figure 3a.

Since biodiesel is blended with petroleum diesel, therefore the best plant location is to be near a petroleum refinery. In Egypt, there are 8 refineries of production capacity greater than 11,130 m^3/d. Four of these plants are in Alexandria government, one in Egypt capital Cairo government, Two in Suez government and one in Assiut Government. SOPC (Suez Oil Processing Company). NPC (Nasr Petroleum Company). CORC (Cairo Oil Refining Company). APC (Alexandria Petroleum Company). APRC (Amreya Petroleum Refining Company). ASORC (Assiut Oil Refining). MIDOR (Middle East Oil Refinery Company). ANRPC (Alexandria National Refining & Petrochemicals Company). In this proposed model, trade-offs are carried between the three predetermined different plant locations.

These trade-offs are function in transportation distance for the following three plant locations: NPC (Nasr Petroleum Company) in Suez. CORC (Cairo Oil Refining Company) in Great Cairo. APC (Alexandria Petroleum Company) in Alexandria.

A proposed model is designed shown in Figure 3b, of 9 collecting areas, 9 distributions centres and 3 plant areas. Trade-offs are carried using the model to choose the optimum location.

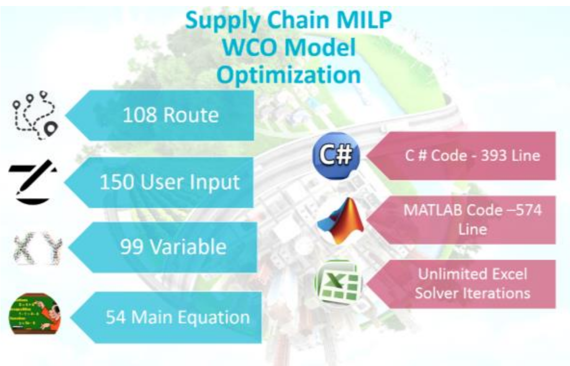

Figure 3a: Supply Chain MILP Model Optimization

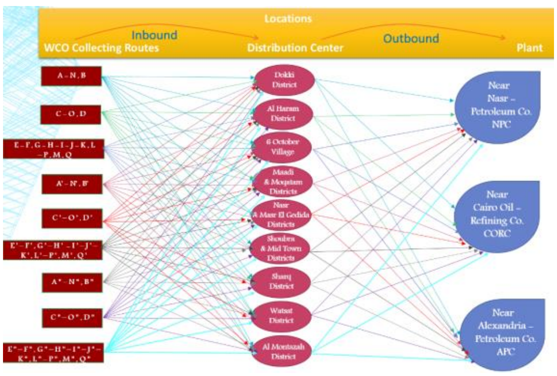

Figure 3b: Supply chain possible route solutions

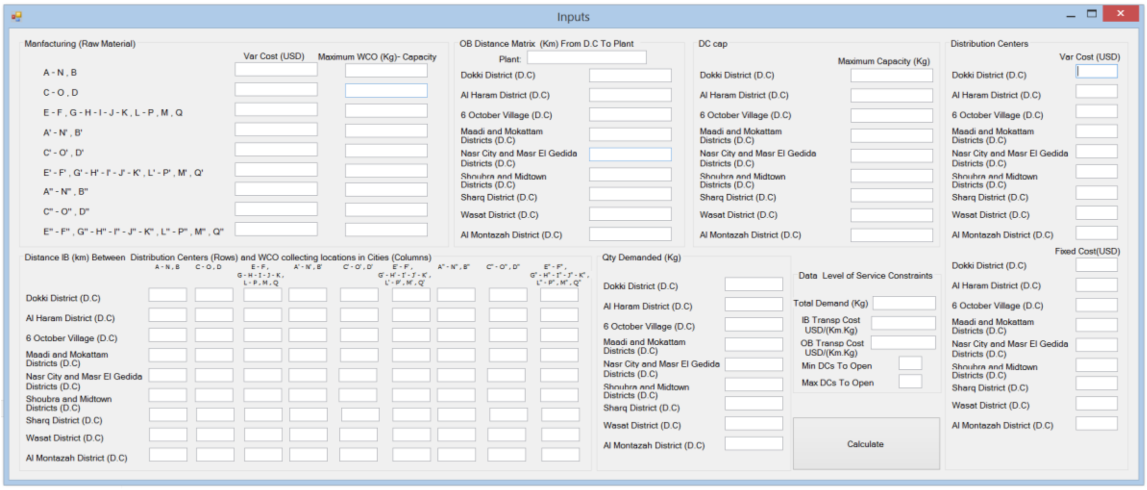

Figure 4: C# GUI for WCO Supply Chain Mode

6.2 Results

The model calculations are generated for the three plant locations in Alexandria, Cairo and Suez. Figure 4 shows the GUI window for user inputs. Figure 5 shows the results for MATLAB output. In conclusion location in Great Cairo near Cairo Oil Refining Company CORC is the best location for the plant as shown in Figure 6a, based on the supply chain MILP model for 70% basis with a total WCO annual cost of $3.38×10^6$ and annual production of $8.19×10^6$ kg Cost of WCO would be $0.413/kg.

The MILP model for CORC case is solved by EXCEL solver tool, MATLAB and C#. Model Results are shown in Figure 6b. CAPCOST Cash Flow analysis shown in Figure 7 is based on 2 y construction period and plant life time of 15 y. Plant is producing Biodiesel and Glycerol with an annual revenue of $8.61×10^6$. Fixed capital investment cost is $4.61×10^6$ and WCO annual cost is $3.36×10^6$.Resulting in a payback period of 2.9 y, using discounted cash flow with 20 % income tax rate and 10 % interest rate.

Total =

TotalCost	DCFixedCost	OB_Transport	IB_Transport	Mfg_Costs	DC_Hnadling
3.3834e+06	6588.2	6551.8	1.9202e+05	3.1271e+06	51179

Distribution_Centers_Table =

DistributionCenter	VarCost_USD	FixedCost_USD	DC_Open	MAN_1	MAN_2	MAN_3	MAN_4
'Dokki District (D.C)'	0.006252	941.18	1	1.4126e+06	0	-2.92e-10	0
'Al Haram District (D.C)'	0.006252	941.18	1	0	8.2986e+05	2.92e-10	0
'6 October Village (D.C)'	0.006252	941.18	0	0	0	0	0
'Maadi and Mokattam Districts (D.C)'	0.006252	941.18	1	0	0	0	1.7382e+06
' Nasr City and Masr El Gedida Districts (D.C)'	0.006252	941.18	1	0	0	0	0
'Shoubra and Midtown Districts (D.C)'	0.006252	941.18	1	0	0	0	0
'Sharq District (D.C)'	0.006252	941.18	1	0	0	0	0
'Wasat District (D.C)'	0.006252	941.18	1	0	0	0	0
'Al Montazah District (D.C)'	0.006252	941.18	0	0	0	0	0

MAN_5	MAN_6	MAN_7	MAN_8	MAN_9
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	5.8399e-10	0	0	0
1.0211e+06	1.46e-10	0	0	0
0	1.7546e+06	0	0	0
0	0	9.0058e+05	0	1.46e-10
0	0	0	5.2905e+05	7.2999e-11
0	0	0	0	0

Figure 5: Supply chain results near CORC Plant

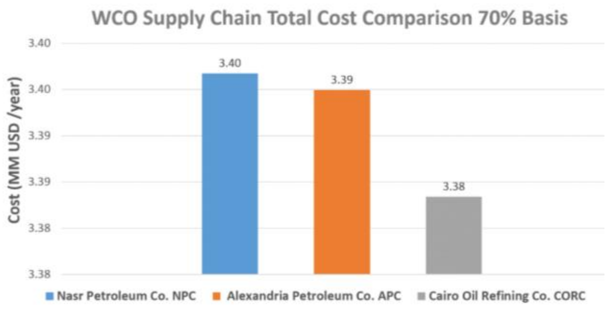

Figure 6a: Total cost comparison

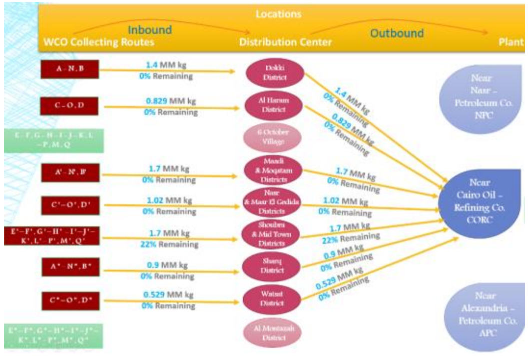

Figure 6b: CORC solution results

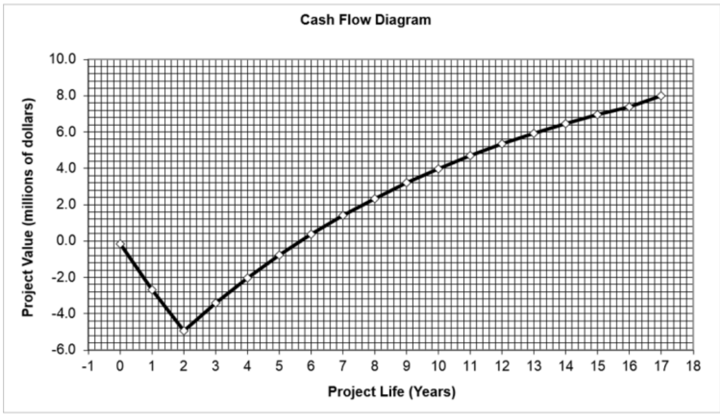

Figure7: Cash flow diagram of the biodiesel from WCO plant Egypt case

7. Conclusions

The potential of renewable fuel energy sources in Egypt is very big, but it needs more concern from the government and investors. WCO is a strategic recycled raw material used for producing biofuel and chemicals such as biodiesel and glycerol rather than dumping it. Each supply chain model is unique and has its own parameters, the goal is to link all the parameters effectively. WCO is considered a cleaner production source of fuel such as biodiesel.

Supply chain cost for WCO is of a big share of the total investment cost. As a result, the supply chain designed parameters and variables are sensitive. Biodiesel reduces 78.5 % of CO_2 emissions when using petroleum diesel as a fuel source. Supply chain network designed is a decision supporting tool, which can be solved by many programming languages. MATLAB SOFTWARE with the aid of C# (C Sharp) programming language, EXECL SOLVER TOOL, were used to create the MILP model. This decision supporting tool is used to construct a strategic decision based on an economic feasibility study of plant data.

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