RECYCLING CONCRETE CONSTRUCTION AND DEMOLITION WASTES SYSTEMS: A CONSTRUCTION MANAGEMENT FRAMEWORK

Hassnein, Omar (Msc). Ezeldin A. Samer (Phd), Department of Construction and Architectural Engineering, The American University in Cairo, New Cairo, Egypt (phone: 20.2.2615.4220; fax: 20.2.2795.7565; e-mail: onfarahat@aucegypt.edu, aezeldin@aucegypt.edu)

Abstract: This paper examines the recycling of concrete construction and demolition waste (CDW) to reuse it as aggregates in other structural applications for projects in the Middle East. This study focuses on the technical and financial components of concrete recycling plants. The study emphasizes on three main types of concrete recycling plants; namely, stationary, mobile and traditional plant settings according to capacity, production rate and country of origin. The data extracted are gathered and grouped to obtain a comprehensive cost-benefit financial model and to demonstrate the feasibility of constructing a concrete recycling plant in the Middle East. The results of the developed model show that the mobile type has generated the most profits due to the transportation costs savings. Furthermore, a sensitivity analysis is conducted to verify the model. The sensitivity analysis addresses the parameters with most contribution based on a 80/20 approach. The sensitivity analysis showed that administrative, salaries and cost of goods sold expenses had the most impact on the model. Moreover, a user-friendly platform is developed to help the user to take decisions related to investments.

1 Introduction

Concrete is the second most consumed material after water. Concrete is also one of the most durable materials used in construction and pavement activities for many decades. It is estimated that 25 billion tons of concrete are manufactured globally each year. About 1,300 million tons of waste is generated in Europe each year, of which about 40% (510 million tons) is in the Construction and Demolition Waste (CDW). The US produces about 325 million tons of CDW and Japan produces 77 million tons. In addition, China and India are now producing and using over 50% of the world’s concrete, therefore their waste generation will also be as significantly high as the developing countries (Haggar, 2007).

This paper presents the development of a financial feasibility model for recycling Construction Demolition Waste (CDW) using traditional, mobile or stationary plants specialized in recycling concrete aggregates. The study also presents a sensitivity analysis that addresses the components with most contribution on the production process.

2 Background

This section focuses on three main factors that constitute the basis for the development of the financial feasibility model. The three factors are:
1) The Cradle to Cradle recycling approach
2) Sources of concrete wastes and its uses after recycling
3) The technical properties of recycled concrete.

As the resources of the world are getting scarcer and more expensive, researchers are focusing of ways and techniques to re-use resources. The concrete average annual consumption for each human is estimated to be 1 cubic meter (Marie and Quiasrawi, 2012) leading to a rapid increase in the aggregate consumption. Cradle to cradle is a useful and important concept in introducing sustainability into the concrete production. Cradle to cradle is basically designing the materials to acquire many life cycles and reused over and over again (Haggar, 2007) as illustrated in Figure 1.

Many countries have recycling schemes for the concrete CDW and have achieved high levels of recovery. These countries include Netherlands, Japan, Belgium and Germany, and France (Haggar, 2007). However, in developing countries, the CDW remains a major problem because it is disposed in landfills (The Cement Sustainability Initiative, 2009). In Egypt, the estimated concrete CDW is 50.3 million cubic meter, in addition to the waste generate from other construction material, like wood, plastic and steel (Haggar, 2007)

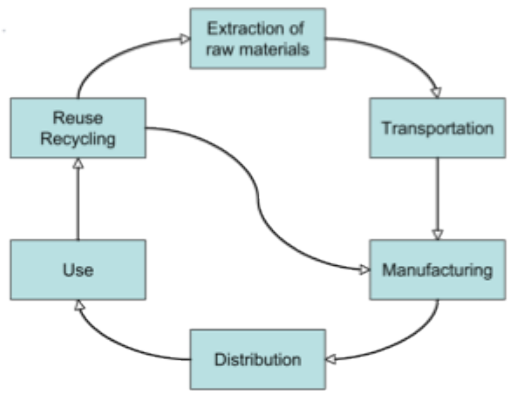

Figure 1: Cradle to Cradle approach (Haggar, 2007)

There are two sources of CDW, the wet and dry sources. The dry source includes all waste from construction or demolition site and the rejected or damaged precast elements. The wet source includes the returned wet concrete leftovers from the ready mix trucks (approximately 2-3% of each truck) and the leftovers in a precast elements factory. Recovered concrete from CDW can be used as aggregates for the road sub base and non-critical structural elements like fences and sidewalks (Hassanein, 2013)

To study the mechanical properties of concrete containing recycled aggregate, a comprehensive and comparative experimental study was conducted on four sets of mixes. The mixes were made of conventional, type I Portland cement, dolomite coarse aggregates, and river sand. The first mixture used conventional aggregates, made with dolomite and river sand. In the second mixture, the coarse aggregates were crushed as “old” recycled concrete. The third used “new” crushed recycled concrete, returned from the job site. The final mixture had both coarse and fine aggregates crushed as “old” recycled concrete. The slump, slump retention, compressive and flexural strength, water and rapid chloride permeability, abrasion resistance, and resistance to elevated temperature were tested and recorded. The concrete containing recycled aggregates demonstrated properties comparable to conventional aggregates concrete (Abou-Zeid, 2005). Malesev (2010) indicated in another study that the concrete strength slightly differed between the recycled and virgin aggregates concrete, as it depends on the quality of the crushed concrete. Concrete compressive strength mainly depends on the quality of recycled aggregate. The same conclusion is valid for concrete tensile strength (splitting and flexural) (Malesev, 2010)

3 Methodology

In order to develop a financial feasibility model, the data gathered and its sources become very crucial. The data includes the prices of machinery, production rates of equipment, and the prices of raw and recycled aggregates. Moreover, the feasibility model is using additional financial parameters:

- Labor wages and working hours
- Number of labor in each process
- Average work efficiency
- Depreciation of equipment
- Production rates of machinery and heavy hauling equipment
- Inflation rates

To obtain this information, 15 experts are interviewed. The numbers of experts and their qualifications are as follows:

- 4 Academic Researchers with experience in sustainability and construction waste recycling
- 2 Recycling aggregates' directors in international companies
- 3 Site managers of recycling plants
- 2 Owners and entrepreneurs in the field of recycling
- 2 Researchers in research centers working for governments, companies and consultants.
- 2 Representatives and engineers in equipment production companies

This combination of well-selected experts provides solid information to develop the proposed financial model using Microsoft Excel software. The model forecasts, in an income statement format, a 10 year financial evaluation for all plant types. The man-hours are extracted from a sheet which includes all the allocated man-hours in each stage in the recycling process.

The experts were selected based on the experience they gained from their current and previous positions. In addition, the diversity and years of experience are important factors when choosing the interviewees. The selection is as follows:

- The academic researchers are faculty from the following;
  - Technical University of Madrid, Spain
  - CEDEX Research center Madrid, Spain
  - The American University in Cairo, Egypt
  - Cairo University, Cairo Egypt
- Recycling aggregates' directors in international companies;
  - Lafarge, Paris, France
  - Lafarge, Cairo, Egypt
- Site managers and Owners of recycling plants;
  - Stationary Recycling plant in Madrid, Spain
  - Traditional recycling plant in Giza, Egypt
  - Mobile recycling plant in Paris, France.
- 2 Representatives and engineers in equipment production companies ;
  - The enhancement Recycling company, Giza, Egypt
  - Kleeman recycling equipment producer, Stuttgart, Germany

4 Model development

4.1 Production Process

This section presents the process of recycling the concrete waste to be used as aggregates in mixing concrete, Figure 2. The first step of the process is to insert the material using a dosing equipment in a 40mm screen then the unscreened material goes into the primary crusher then through a 40mm screen. If it passes through the screen then it is the final product, if else, it goes through secondary crusher. The main difference between closed and open systems is the re-crushing at the last phase (indicated by the letter B). The 40mm screen passes only 0-40mm size aggregates and the rest is returned to the crusher to be re-crushed.

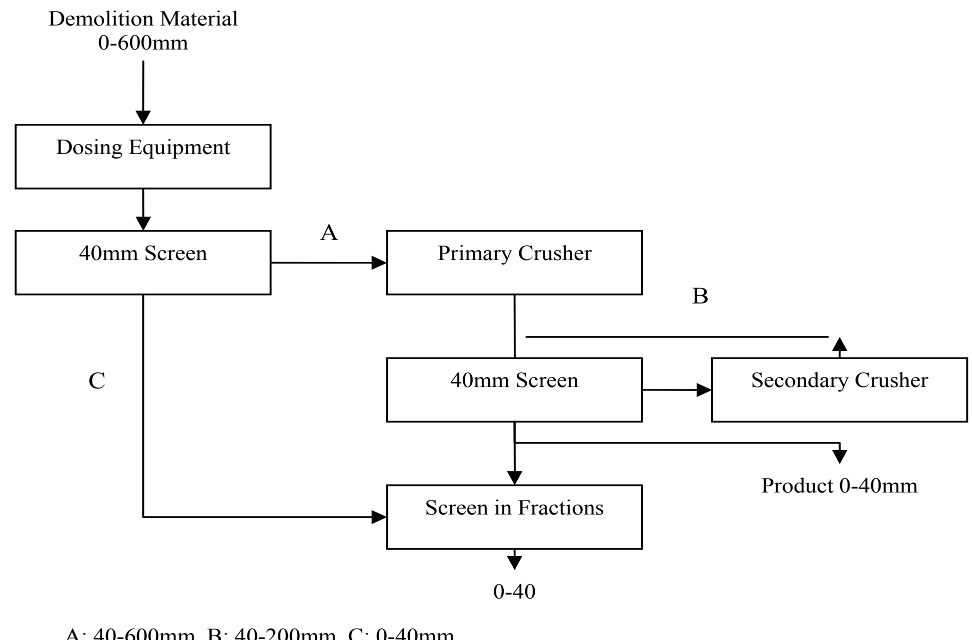

Figure 2: Flow-chart of typical plant for production of recycled aggregate from cornet debris which is free from foreign matter (closed system), (Boesman, 1985)

4.2 Plant operation process

Table 1 is a tabulated format simplifying the recycling of concrete aggregates. It shows the processes in order of crushing, the descriptions of the process and the machine used in each phase.

Table 1: Ideal recycling Plant Processes

Process	Description of process	Machine
Broken down to smaller pieces (0.4-0.7m)	Large pieces of debris arriving from demolition sites are typically reduced to 0.4-0.7 m maximum size	Means of a wrecking ball and hydraulic shears to cut reinforcement
Manual or mechanical pre-separation	Large pieces of steel, wood, plastics, and paper are removed by hand when going through the conveyor belt	By hand
Primary screening	Removing particles of 10mm<d<40mm. Remove all minus 10mm particles such as sand, gypsum, etc.	Straight or swing conveyor with screen.
Primary crushing	Incoming material is then crushed in a primary crusher.	Crusher is usually of the jaw or impact type
Magnetic separation	All iron and steel is removed by self-cleaning	Self-cleaning

	magnets, which are placed at one or more critical locations above conveyor belts.	magnets/permanent magnetic separator
Secondary screening	Products from the primary crusher are screened on a deck typically consisting of a 10mm scalping screen. Minus 10mm material is wasted in order to eliminate fine contaminants such as dirt and gypsum.	Straight or swing conveyor with screen.
Secondary crushing	Plus 40mm material is passed through a secondary crusher in order to reduce all products to 40mm maximum size.	Jaw, cone, hammer or impact crusher
Washing, screening or air-sifting	All materials are then washed or air-sifted in order to remove remaining lightweight matter such as wood, paper, and plastics, and the clean product is screened into various size fractions according to customer specifications.	Straight or swing conveyor with screen.

4.3 Assumptions and Capabilities

The model has several assumptions that should be considered by the user. The assumption affects the results directly. The model assumptions are indicated in Table 2.

Table 2: Model Assumptions

Title	Assumption	Editable by user
All equipment are purchased		
Number of Plant increase in year 5	From 1 to 2 plants	
Percentage of final product sold	100%	
Rent increase percentage	15%	√
Salaries increase percentage	10%	√
Inflation rate	10%	√
Number and skill of Labor assigned	As assigned in the model for each type and capacity	
Salvage Value of equipment	50% of original price	√
Interest rates on installments	Not available	
Income taxes deduction	Not available	

Furthermore the model features consists of the following:

- The model is covering the three types of plants mentioned earlier, mobile, stationary and traditional.
- The model generates graphs indicating revenues, expenses and net profits.
- The model can compare revenues, expenses and net profits for one type with all three capacities , 200, 400 and 800 TPH on bar charts
- The model can compare revenues, expenses and net profits for one capacity (200, 400 or 800 TPH) with all three plant types mobile, traditional and stationary on line graphs

4.4 Expenses

All the monetary values used in the model are displayed in a dual currency format. The expenses are divided into two categories, initial investment and operational expenses. The expenses are analyzed based on Table 3 Prices Initial Investment Equipment. The prices in the table are subjected to 25% shipping costs and 30% customs and taxes of the original price.

Table 3 Prices Initial Investment Equipment

Equipment	800 TPH (EGP, USD)	400 TPH (EGP, USD)	200TPH (EGP, USD)
Wheel Loader.	1,200,000/171,500	1,200,000/171,500	1,200,000/171,500

Trucks	1,500,000/215,000	1,500,000/215,000	850,000,121,500
Jaw crusher or Impact crusher, as primary crushers and Vibratory feeder	14,218,750.00/2,312,000	8,531,250.00/1,218,000	2,843,750.00/407,000
Straight or swing conveyor with screen. Permanent magnetic separator. Sand Washer	200,000/28,570	200,000/28,570	150,000/21,420

4.5 Variables of the model

After interviewing the experts, the variable of the model are chosen based on the experts' opinions. The variables included in the model are selected as they are common in all types of plants. Furthermore, the variables, including productivity rates, labor, equipment and material costs, are extracted base on the recycling process requirements, after in-depth analysis of the process. All the variables in the model can be edited by the user. The variables are as follows:

- Labor salaries for all skills
- Labor man-hours for all skills
- Operation Equipment costs for different capacities (200TPH, 400TPH and 800TPH)
- Hauling vehicles for different capacities
- Depreciation rates
- Inflation rates
- Prices for selling recycling aggregates
- Price for buying construction waste (high quality waste; containing 80% or more of concrete waste).

5 Sensitivity analysis

This section addresses the capability of the proposed model to handle the variations of the model parameters and to generate acceptable corresponding results. It also relates the parameters' sensitivity and effectiveness to expenses, revenues and profits. The methodology that is used consists of the following:

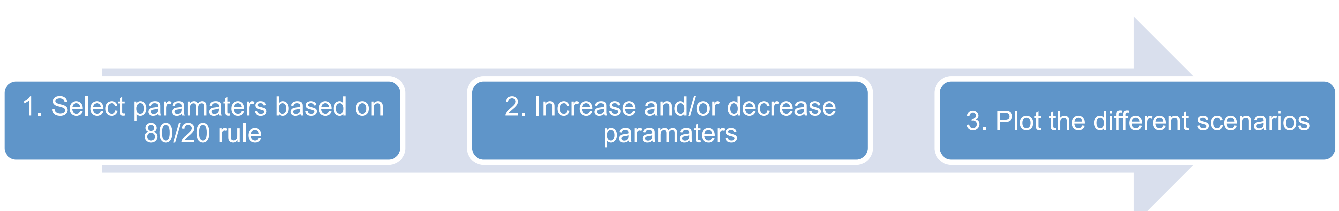

Figure 3: Steps followed for sensitivity analysis

5.1 Step 1:

The first step is selecting the parameters based on the 80/20 rule. Basically, according to this rule, 20% of the parameters are targeted and should be contributing to 80% of the total expenses. The model used for the sensitivity analysis is in the 800 TPH mobile plant sheets.
According to Figure 4, the expenses that had a contribution of 80% of the total expenses are

1. Cost of Goods Sold,
2. Administrative expense and

3. Total salaries expense.

5.2 Step 2:

The second step is to increase and decrease the selected parameters by increments of 10% from -20% to +20%, i.e., -20%, -10%, **0% (original),** 10%, and 20%.

5.3 Step 3:

The third step is to plot all scenarios and observe the effect on the different results, such as expenses, profits and profit margin, in Figure 6 and 7. .

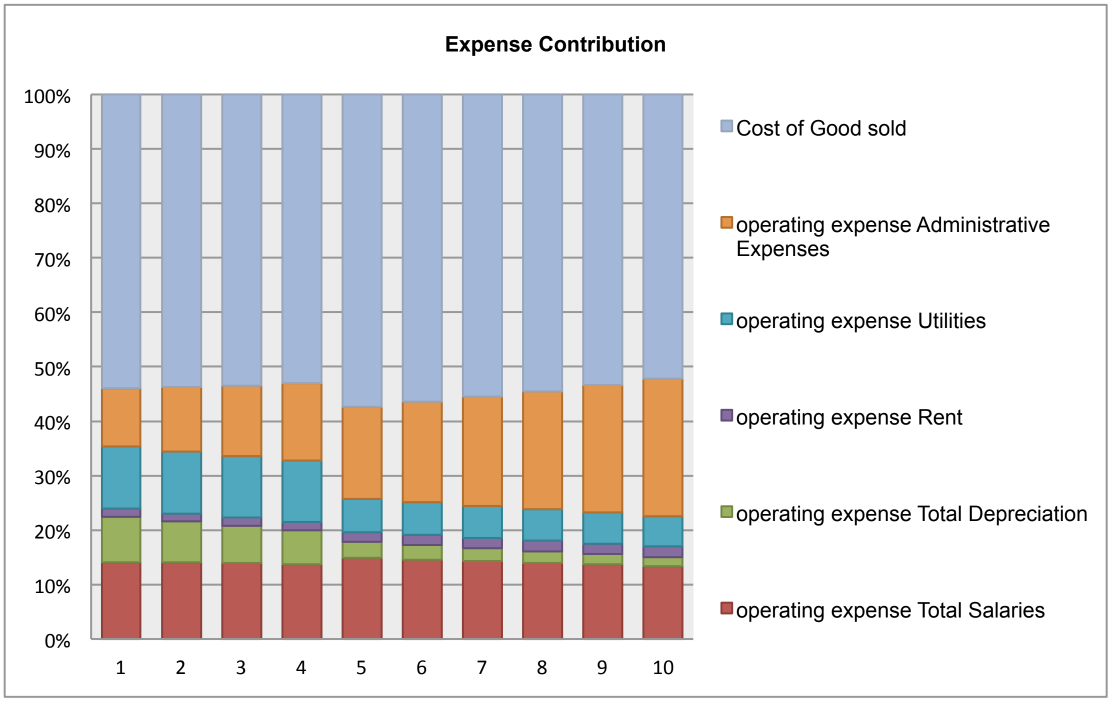

Figure 4: Expense Contribution according to the 80/20 rule

6 Analysis of Results:

As shown in figures 5, the profit margin has decreased dramatically when increasing the major items by 20%, to reach 60% compared to the original which is 50% in year 10. This verifies the calculations of the model and shows that the selected expenses have a great impact on the model when magnified. In figure 6, the percentage change in profit margin is illustrated, showing the positive and negative effects when maneuvering the sensitive items by +/- 10% and 20%. In Figure 6, the variation is indicated in percentage from the original profit margin. According to Figure 7 and 8 the highest net profits are mobile 800 TPH and 400 TPH, and traditional 800 TPH and 400 TPH plants. The profit margin is highest in mobile 800 TPH, mobile 400 TPH, mobile 200 TPH, then the traditional and stationary from highest to lowest respectively.

The results show clearly the net profits and profit margin for all types with the capacities of 800 TPH, 400TPH, 200TPH in Figure 7 and 8. It can be noticed that the mobile type has the highest net profit and profit margin among all types, followed by the traditional. This can be explained by the high transportation cost assigned per cubic meter for the stationary equipment. In addition, the high initial investment installments associated with the stationary type decreases the net profit to negative.

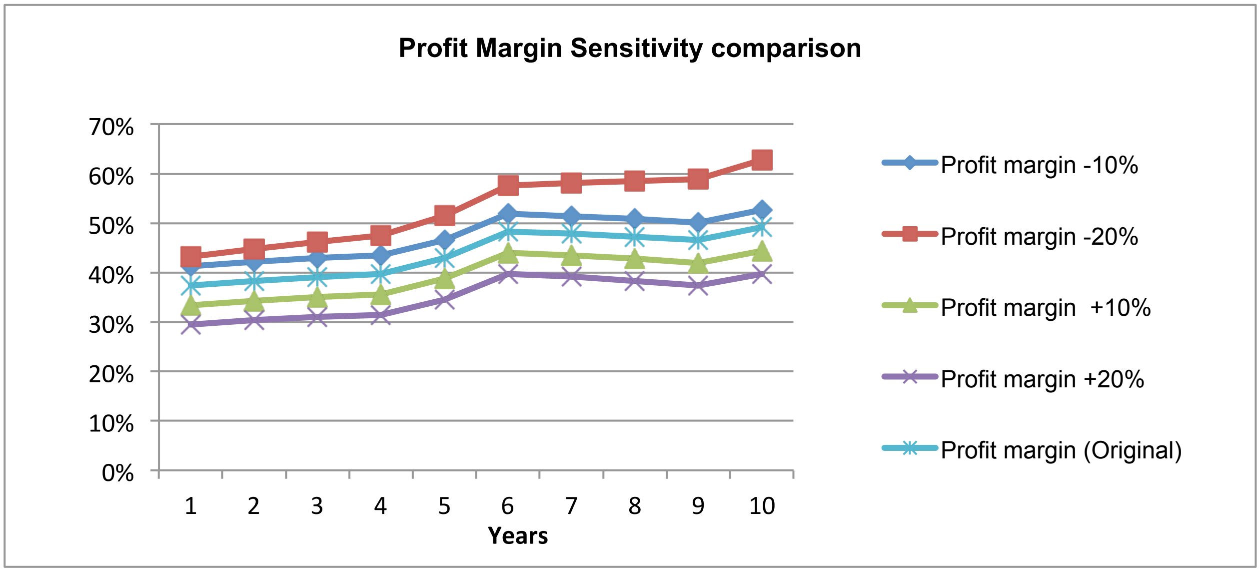

Figure 6 Profit Margin Sensitivity comparison

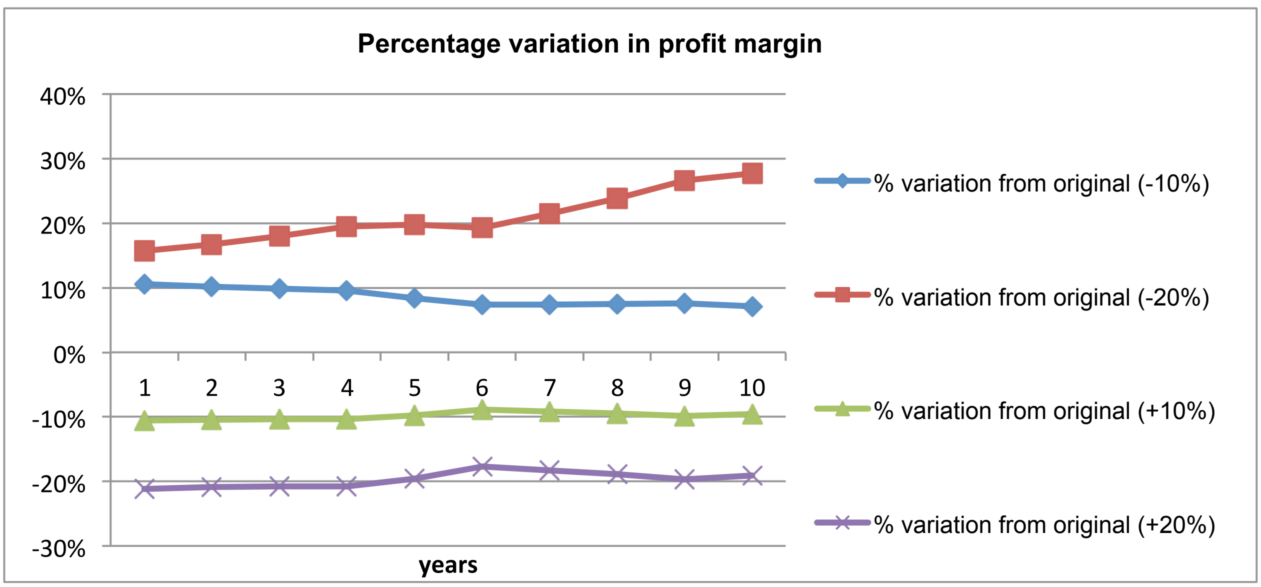

Figure 5: Percentage variation in profit margin

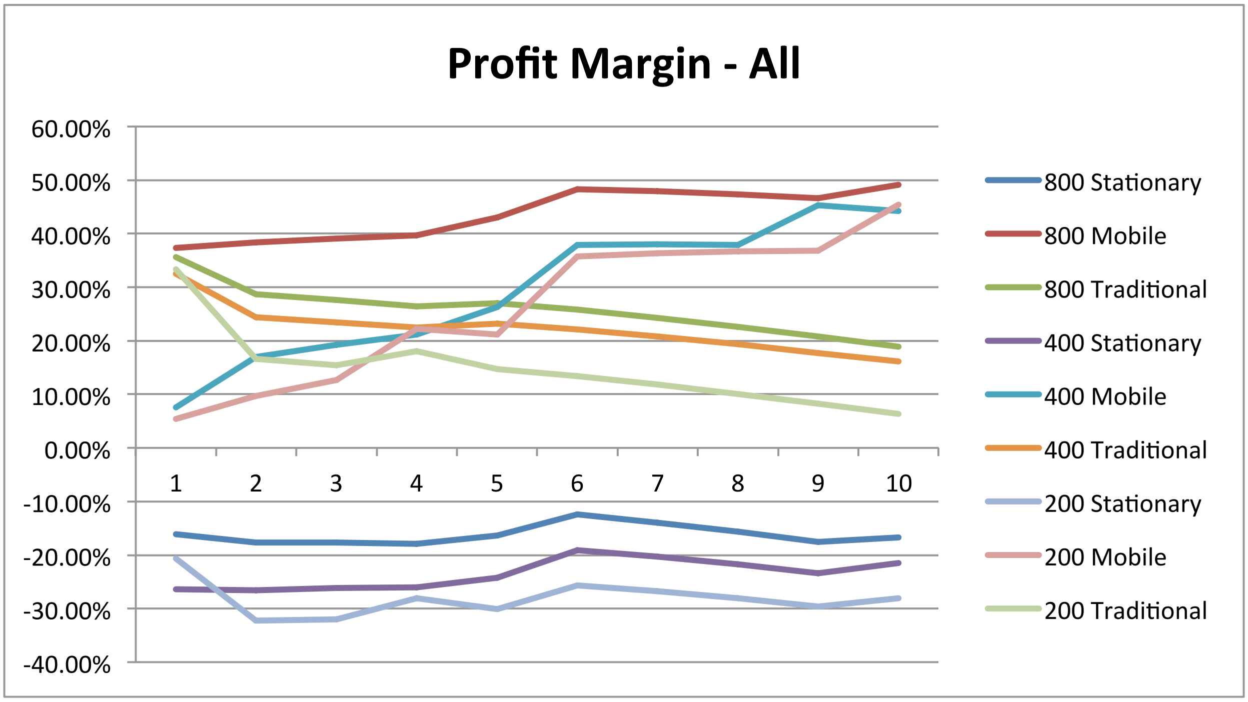

Figure 7: Profit margin all plant types all capacities

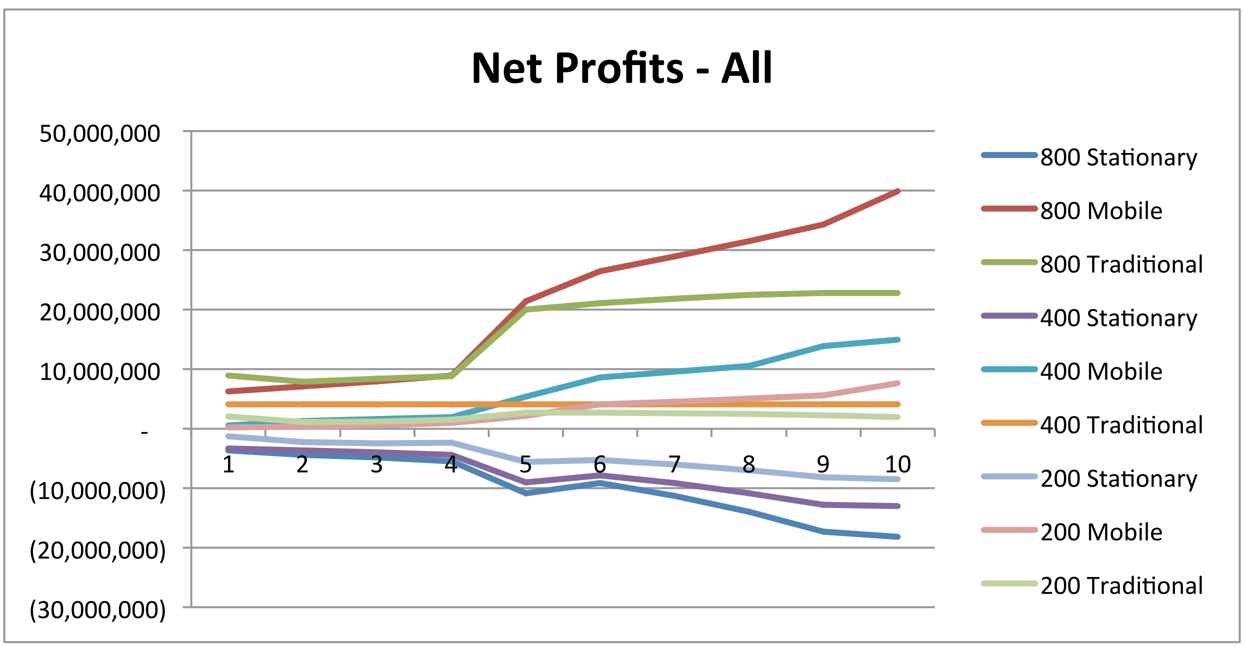

Figure 8: Net profits all plant types all capacities

7 Conclusion

Engineers and researchers are looking for new ways to reduce, reuse and recycle concrete wastes as aggregates. The concept of cradle to cradle started trending. Many experiments have been conducted to validate and compare the use of recycled material in new structures versus the use of virgin materials. Therefore, the financial model in this paper is created to assist the decision makers in taking the most cost effective decisions to recycle concrete.

The proposed model is developed through stages. The first one is the layout and calculation design to produce the required output. The next stage is data input and duplicating the model for several types and capacities and then entering the data for all models. The model is created to compare the revenues, expenses and net profits for stationary, mobile and traditional types with capacities 200, 400, 800 TPH each. The sensitivity analysis stated, from high to low, that the cost of goods sold (the price for buying high quality CDW), the administrative and salaries expenses has the highest impact on the model. As such, it is recommended to reduce these expenses, if possible without degrading the quality of the recycling process. Moreover, the profit margin and net profit extracted graphs showed that the mobile plant, followed by the stationary, produced the highest profit margins and net profits. This is due to the low transportation costs needed to transport the materials for the mobile type and the low machinery costs and operating expenses in the traditional type. The investigation reveals that even that the market in the Middle East is currently not utilizing stationary plants to produce a very high volume of recycled aggregates daily, the financial model demonstrates a positive and promising trend in this application.

8 References

Abou-Zeid, M.N.A., 2005. Reincarnation of Concrete. Jounral Concrete International, 7: 20-31.

Kamel, A.M.K.. 2007. Guidelines of recycled concrete aggregates in the Egyptian construction industry, Thesis paper, The American University in Cairo, Cairo, Egypt.

Haggar, S.E.H. 2007. Sustainable Industrial Design and Waste Management: Cradle-to-Cradle for Sustainable Development. 1st edition, Academic Press, CA, USA.

Hansen, T.C.H. 19992. Recycling of demolished concrete and masonary, 1st edition, Taylor & Francis, Oxon, United Kindom.

Hassanein, O.H.; Ezeldin, A.E. , 2013. Concrete Recycling in Egypt for Construction Applications: A technical and Financial Feasibility Model. World academy of science, engineering and technology, International Science Index 84, 7:621-626

Lu, W. L. and Yuan, H.Y.2007. A framework for understanding waste management. Jounral of Waste Mangement, 124: 1252-1260.

Malesev, M.M., 2010. Recycled Concrete as Aggregate for Structural Concrete Production. Sustainability, 2: 1204-1225

Marie, M.R. and Quiasrawi H.Q. 2012. Closed-loop recycling of recycled concrete aggregates. Journal of Cleaner Production 37: 225-235 (2012).

The Cement Sustainability Iniative. Recycling Concrete . Industry Report. Geneva: World Business Council for Sustainable Development , 2009.