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Recycling of construction and demolition waste via a mechanical sorting process☆

Wen-Ling Huang [b], Dung-Hung Lin [b], Ni-Bin Chang [a,*], Kuen-Song Lin [c]

[a] *Department of Environmental Engineering, National Cheng-Kung University, 1 University Road, 70101 Tainan, Taiwan, ROC*

[b] *Department of Civil Engineering, National University of Applied Science and Technology, Kaohsiung, Taiwan, ROC*

[c] *Department of Chemical Engineering, Yuan-Ze University, Chun-Li, Taiwan, ROC*

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Abstract

This paper assesses a construction and demonstration (C&D) waste recycling program in relation to technical, institutional, and economic considerations. The focus is primarily placed on a feasibility study for a new mechanical sorting process that was installed with several unit operations, including bar screening, trommel screening, air classifier, disk screening, and final manual sorting. Lab analyses, consisting of sieve analysis, LA abrasion test, friability test, organic content test, and fineness test, with respect to three types of product streams (A, B, and C) were conducted in accordance with selected physical and chemical properties. Findings clearly indicate that the reuse of fine particle generated in product stream A as construction materials in roadbed is highly recommended if the impurities can be removed beforehand. The product stream B could be suitable for reusing as the covering materials in daily operation of sanitary landfills. Yet it could also be used as backfill materials in the construction projects if the impurities can be removed in advance. Only does the LA abrasion test support the reuse of product stream C as coarse aggregate or pavement subbase for those new structures. Once the secondary materials market is stable and the institution settings are sufficient, it is worthwhile addressing that the associated

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* Corresponding author. Tel./fax: +886-6-234-2357

E-mail address: nibin@giga.net.tw (N.-B. Chang).

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cost-benefit analysis does confirm the economic potential for such a management practice.

Keywords: Construction and demolition waste; Sorting; Resource recovery; Cost benefit analysis; Mass balance; Separation; Solid waste management

1. Introduction

Wastes from the construction, remodeling, and repairing of individual residences, commercial buildings, and other civil engineering structures are classified as construction wastes. Wastes from razed buildings are normally defined as demolition wastes (Wood, 1992; Gavilan and Bernold, 1994; Apotheker, 1990; Kalin, 1991; Oglesby et al., 1989; Spencer, 1989, 1990; Spivey, 1974). Construction and demolition (C&D) wastes may be also produced significantly from environmental disasters, such as earthquakes, hurricanes, tornadoes, and floodwater (Tansel et al., 1994). Construction and demolition wastes frequently constitutes between 15 and 20% of municipal solid wastes (MSW) in Taiwan (EPA, 1999). Some studies in the United States reported that the rates could be as high as 23% (Apotheker, 1990). A study by Bossink and Brouwers (1996) further pointed out that these amounts vary world wide from 13 to 29%. The composition of C&D wastes normally includes but is not limited to dirt, stones, bricks, blocks, gypsum wallboard, concrete, steel, glass, plaster, lumber, shingles, plumbing, asphalt roofing, heating, and electrical parts (Stein, 1987; Gavilan and Bernold, 1994; Seo and Hwang, 1999). Yet these materials frequently vary constantly due to the changing nature of construction materials over time. In particular, during the past century, the type of materials used for urban infrastructure has changed significantly (Brunner and Staempfli, 1993). The fraction of metals (steel, aluminum, copper), glass, and in particular synthetic organic compounds (plastics, insulation materials, chemical additives, and finishing agents) has increased since the 1940s (Brunner and Staempfli, 1993). This would result in a significant impact to the composition of C&D wastes.

Both the public and the construction industry are concerned about raw material shortages and the environmental impacts due to illegal dumping of C&D wastes (Lauritzen, 1994; Perez, 1994; Traenkler and Walker, 1994; Ravindrarajah, 1987). Proper disposal of C&D wastes has received wide attention recently because significantly larger quantities of C&D waste streams, collected from damaged buildings in a disastrous earthquake which occurred in 1999 in Taiwan, require need of immediate disposal. The shaded area in Fig. 1 illustrates the region affected by this earthquake. This environmental disaster caused severe structural damage to 100 000 dwellings that need extensive repair or a complete building overhaul. The statistics of the damage and loss in this environmental disaster is reported in Table 2. Except for the 30 million tons of C&D wastes appearing around the earthquake epicenter, it is predicted that an additional several million tons of C&D wastes are going to generate during structure rebuilding and repair in the future. Without proper reuse, recycling, and recovery, these C&D wastes would quickly fill all the remaining landfill space, which has already been growing in scarce around this region. Therefore, the concept of 'sustainable construction' must be much emphasized in the future (Kibert, 1994).

The profitability of recycling C&D wastes critically depends on the regulatory policy, contract specifications, economics, selected technology, and project management practice (Tansel et al., 1994). Suggestions for conducting a profitable recycling program for C&D wastes were discussed by Brooks et al. (1995). Extensive studies have been conducted to evaluate various waste management technologies for reducing the volume of C&D wastes destined for landfill operations (Lauritzen, 1994; Gavilan and Bernold, 1994; Brooks et al., 1995; Seo and Hwang, 1999). Yet the rising cost for landfilling C&D wastes diminishes the acceptance potential from a long-term perspective (Ferguson, 1994; Freeman, 1994; Gavilan and Bernold, 1994; Hendriks, 1994; Townsend et al., 1999; Johnson et al., 1999). Except for the impact due to improper disposal of C&D wastes in landfills that might cause a remarkable increase in environmental costs, the depletion of raw materials suitable for

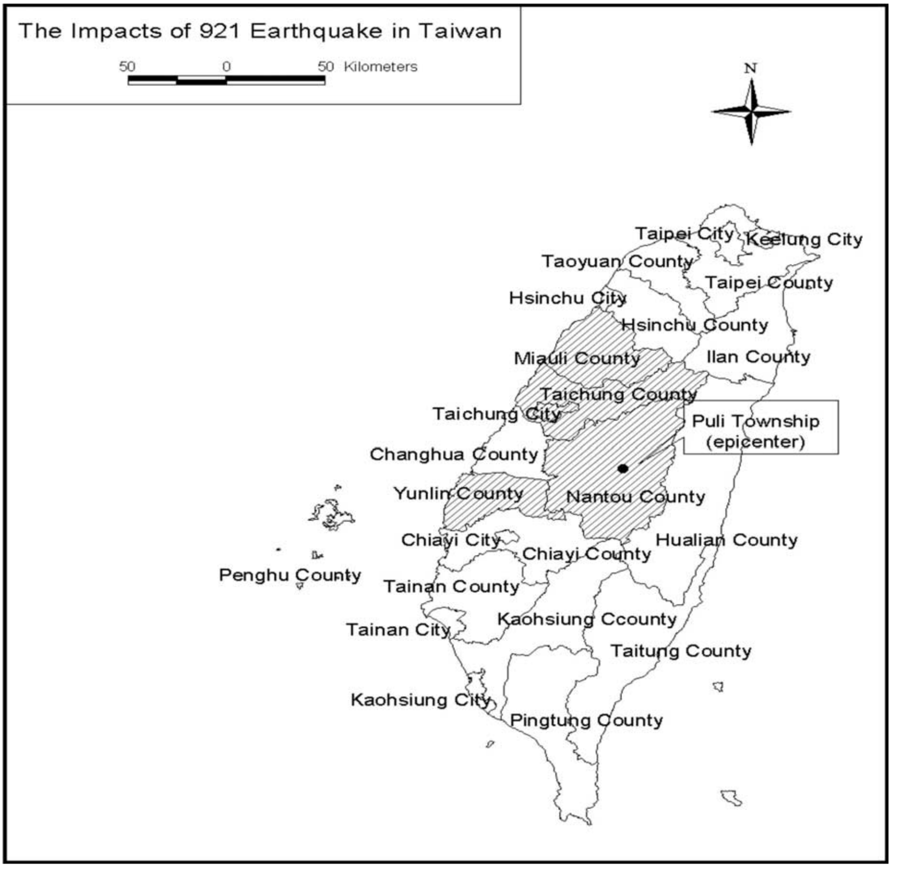


Fig. 1. The region affected by the disastrous earthquake in Central Taiwan (September 21, 1999).

Table 1
Typical composition of CDW stream and estimated recycling potential in Taiwan

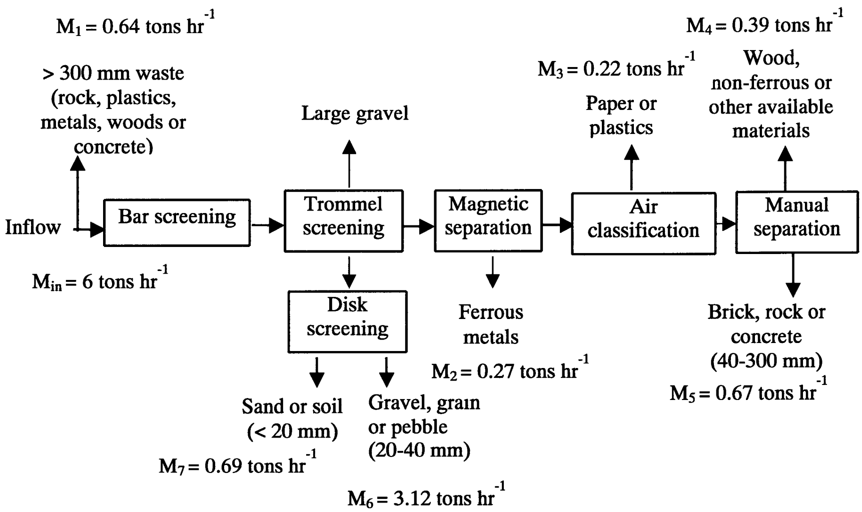
	Weight (%)†	Recycling (%)
Concrete		
Landfill	25.9	50
Road base refilling	15.5	30
Refilling materials	10.3	20
Brick, tile, glass, and stone		
Landfill	14.7	50
Road Pavement	8.9	30
Reuse	5.9	20
Steel and iron		
Reclamation	5.4	70
Non-ferrous metal		
Reclamation	0.1	95
Wood	10.9	N.A.‡
Plastics	2.4	N.A.‡

† Results are all normalized to 100%.
‡ N.A. denotes not available.

construction may generate renewed interest in converting C&D wastes into useful secondary materials. Recycling C&D wastes is a very common practice in many developed countries. A number of C&D recycling projects have been implemented in the US, Canada, and Europe (Science Council, 1991). For example, large scale C&D waste processing plants have appeared in both Europe and the US to manage waste streams ranging from 500 to 1500 tons day^{-1} (Perez, 1994). The design process includes initial screening of the waste material, sorting of recyclables, and processing the recovered material for specific secondary uses. The mass balance of a full-scale construction waste sorting plant also confirmed the technical potential of recycling

Table 2
The earthquake damage and loss statistics

Location	Building collapsed	Building damaged	People killed
Miauli County	484	298	3
Taichung County	17 512	14 220	1190
Taichung City	2926	3230	113
Nantou County	26 425	22 724	883
Yunlin County	573	553	80
Puli Township	5483	4878	200
Total	53 403	45 903	2356



Design basis : 6 tons hr^{-1} C&D waste.
Note: 1. 8 hours per workday.
2. The sorting process is at steady state.
3. M_{in} denotes the CDW inflow.
M_1 = flow of rock, plastics, metals, woods or concrete.
M_2 = flow of ferrous metals.
M_3 = flow of paper or plastics.
M_4 = flow of wood, non-ferrous or other available materials.
M_5 = flow of brick, rock or concrete.
M_6 = flow of gravel, grain or pebble.
M_7 = flow of sand or soil.

Fig. 2. The mass balance of C&D waste processing.

C&D wastes (Brunner and Staempfli, 1993). Yet very few sorting plants were built in Taiwan prior to the impact of the disastrous earthquake in 1999. Table 1 presents a typical composition of C&D wastes in Taiwan, in which the recycling ratios represent the previous efforts for recovery and reuse of the recyclables in C&D wastes by various ways.

This study represents a series of efforts in processing C&D wastes collected from damaged buildings in the affected region by the disastrous earthquake in Central Taiwan. The focus is primarily on an integrated assessment for a new mechanical sorting plant that was installed in Taichung City for recycling C&D wastes in 2000. This plant has several operation units, consisting of bar screening, trommel screening, magnetic separation, air classification, disk screening, and final manual sorting. A set of selected product tests was organized and conducted for ensuring that the secondary materials generated are suitable for reuse in other selected civil engineering projects. Finally, a cost-benefit analysis is designed to ensure if this C&D recycling program is economically attractive for private sectors.

2. Process description

Fig. 2 illustrates the mechanical sorting process, consisting of five operation units. They include bar screening, disk screening, magnetic separation, air classification, and final manual separation. This facility is designed to process 6 tons of material h^{-1} on one line. The C&D wastes are delivered to the facility site by trucks and dumped onto the floor. Bulky wastes (> 300 mm), such as rock, plastic, wood, steel, metal, or concrete, are first sorted using a vibrating screen. Wastes, such as sand, soil, gravel, grain, or pebbles, smaller than the mesh size of the vibrating screen are passed through the first operation unit and sent into the horizontal trommel screen and disk screen in sequence. Ferrous metals can be extracted from C&D wastes directly using an overhead magnetic separator. Recovered ferrous metals can be collected for material recycling, recovery, and reuse. The air classifier, blowing with a regular air stream of 250 m^3 min^{-1}, further isolates inert materials, such as glass, wood, or ceramics, from the other available C&D wastes. At the same time, most of the fluff plastics can be blown away for additional separation. Residual waste materials, passing through the air classifier, are sent into a manual sorting unit for further separation. Products gathered from the manual separation process consist mainly of wood chips and other residues, such as scrap tires.

3. Mass balance analysis

Because of the complex composition of C&D wastes, the examination of operation unit stability and its production rate has been a challenging topic for those people who want to understand how the sorting process achieves its efficiency. In the primary test run, the treatment capacity was set up at 48 tons day^{-1} (TPD). The working period was 8 h per shift. Only one shift per day was applied in the initial operation. Fully automatic control makes this mechanical sorting plant require very few skilled workers to take care of waste feeding, recording, and bulky waste removal. Fig. 2 illustrates the mass balance information throughout the mechanical sorting process. This diagram was obtained based on a continuous processing of 6 tons h^{-1} over a specific time period. On average, to process 6 tons of C&D waste, approximately 3.8 tons of construction materials (i.e. M_6 and M_7 in Fig. 2), such as sand, gravel, grain, or pebbles, can be produced, 0.27 tons of ferrous metals (i.e. M_2 in Fig. 2) can be recycled, and 0.61 tons of combustible waste streams (i.e. M_3 and M_4 in Fig. 2), such as paper, wood, and plastics, can be recovered. Disposal of other residues requires additional landfill operation efforts (i.e. M_1 and M_5 in Fig. 2).

4. Material testing for examining reuse potentials

For a reuse point of view in civil engineering projects, the sorting process can generate three types of useful product streams. Stream A is comprised of sand and fine soil with a diameter less than 20 mm (i.e. M_7 in Fig. 2). Stream B consists of gravel, grain, and pebbles (i.e. M_6 in Fig. 2). The residual stream is stream C that is mainly composed of brick, rock, and concrete mix (i.e. M_5 in Fig. 2). Both streams A and B might have relatively higher reuse potential so that advanced material tests are needed. Those wood chips, paper, and plastics collected from air classifier and manual separation (i.e. M_3 and M_4 in Fig. 2) are usually not valuable enough for reuse. They are generally regarded as trash that can be destined for incineration. Yet the larger rock or concrete mix (i.e. M_1 in Fig. 2) could be recovered via the use of a crashing machine as a pretreatment unit to reduce their size before sending them back to the sorting process.

For those product streams collected in M_6 and M_7, a sampling and analysis campaign was therefore carried out to further verify their reuse potentials. The material tests selected for those three product streams included the sieve analysis, LA abrasion test, friability test, organic content test, and the fineness test. They have been applied according to the standard methods used in both Taiwan (CNS) and the US (ASTM). Impurities, such as small wood chips, concrete mix and so on must be removed from the samples before these tests can be applied. Those impurities are generally classified as visibly unwanted constitutes of building materials that might have negative impact for the reuse of sand and gravel either from construction requirements or from environmental reasons.

One of the possible ways to recycle C&D waste streams is to use recovered fine and coarse particles as aggregates in concrete mixes. The need to recycle concrete making materials arises due to the following reasons (Tansel et al., 1994): (a) diminishing steady supplies of good quality natural aggregates; (b) securing ample supplies of concrete aggregates to the construction industry; and (c) decreasing C&D wastes disposal in urban regions. Therefore, more tests with regards to their physical and chemical properties help identify the reuse potentials of those secondary materials. Table 3 lists the standard methods for those tests in relation to the particle size distribution, abrasion, friability, fineness, and organic content. Once those tests are proven successful, advanced tests for ensuring the soundness of aggregate durability can be applied.

Table 3
The standard codes used in this study

No.	Test items	Standard codes	
		CNS	ASTM
1	Sieve analysis	386	C136
2	LA abrasion test	490	C131
3	Friability test	1171	C142
4	Organic content test	1164	C89
5	Fineness test[a]	491	C117

[a] The portion of material passed through the #200 sieve (75 μm).

Table 4
The distribution of streams A and B via sieve analysis

Category of stream	Coarse particle (%)[a]	Fine particle (%)[b]
Stream A	27.4	72.6
Stream B	36.4	63.6

[a] The particle size larger than the mesh diameter of #4 sieve.
[b] The particle size smaller than the mesh diameter of #4 sieve.

Particle sizes of samples are normally analyzed in either millimeter or sieve size. For sieve results, the outputs in this study can be correlated with current sieve tests so sieve analysis results match current data. For example, the mesh diameters are 4.74, 2.0, 0.425, and 0.075 mm corresponding to those sieves of #4, #10, #40, and #200, respectively. Samples of product stream A and B were screened out in the initial stage via using a #4 sieve. Fine particles were classified by the particle size smaller than the mesh of #4 sieve. Coarse particles were those left above the mesh of #4 sieve. Table 4 presents the information based on the percentage distributions of selected samples in streams A and B that could be classified as fine particles or coarse particles. It appears that product stream A has relatively larger portion of fine particles. Table 5 lists the percentage distributions based on several visible impurities in coarse particles with respect to product streams A and B, respectively. Most of the impurities in product streams A and B are small gravel and debris (91.4%) and tile/partition material (85.2%). Residual glass, scrap metal, scrap paper, and wood chips constitute a minor fraction of these impurities. These impurities have to be removed before performing further material tests. Only the fine particles separated from product streams A, B, and C are considered as materials with higher recovery and reuse potentials.

Tables 6 and 7 illustrate the size distribution of the fine particle in streams A and B. Research findings based on those two tables indicate that the particle size distribution of streams A and B presents a similar gross pattern. Yet relatively higher percentages of heavy materials exist in stream B. In comparison to the suggested distribution of concrete aggregate in CNS 386, it can be concluded that both product

Table 5
The composition of impurities in streams A and B

	Stream A (%)	Stream B (%)
Glass residuals	3.3	7.9
Scrap metal	2.6	1.1
Scrap paper/wood chip/PE	2.7	5.8
Small gravel and debris	91.4	–
Tile/partition material	–	85.2

Table 6
The size distribution of fine particles in stream A

Sieve no.	Diameter of sieve hole	Retained portion by weight (g)	Retained portion by percentage (%)	Summation of retained portion by weight (g)	Summation of passed portion by percentage (%)	Suggested distribution of concrete aggregate in CNS
#8	2.36 mm	77.2	9.1	9.1	90.9	80–100
#16	1.18 mm	116.6	13.8	22.9	77.1	50–85
#30	600 μm	181.9	21.5	44.4	55.6	20–60
#50	300 μm	178.3	21.1	65.5	34.5	10–30
#100	150 μm	131.8	15.6	81.1	18.9	2–10
#200		82.5	9.8	90.9	9.1	< 5
Residual		77.4	9.1	100.0	0.0	

Table 7
The size distribution of fine particles in stream B

Sieve no.	Diameter of sieve hole	Retained portion by weight (g)	Retained portion by percentage (%)	Summation of retained portion by weight (g)	Summation of passed portion by percentage (%)	Suggested distribution of concrete aggregate in CNS
#8	2.36 mm	75.8	9.8	9.8	90.2	80–100
#16	1.18 mm	93.4	12.1	21.9	78.1	50–85
#30	600 μm	135.4	17.5	39.4	60.6	20–60
#50	300 μm	151.1	19.51	58.9	41.1	10–30
#100	150 μm	140.0	18.1	77.0	23.0	2–10
#200		100.6	13.0	90.0	10.0	< 5
Residual		77.0	10.0	100.0	0.0	

Table 8
Additional physical tests for CDW streams A, B, and C

Test items	Test results			Suggested critical value
	Stream A	Stream B	Stream C	
Los Angeles abrasion test (LA abrasion test)	–	–	28.6%	< 50%
Friability test	6.7%	6.3%	–	< 5.0%
Organic content test	Over	Over	–	Standard color
Fineness test	10.3%	11.7%	–	< 1%

streams A and B are not suitable for use as concrete aggregates in construction projects in their present form. Reprocessing needs to be done before it could meet the quality assurance/quality control (QA/QC) requirements for reuse. The test method using Los Angeles machine to explore the properties from resistance to abrasion for those coarse particles in stream C can be found in CNS 490. The LA abrasion test outputs revealed that product stream C is qualified for use as coarse materials in civil engineering projects. Besides, the test method for clay lumps and friable particles in aggregate can be found in CNS 1171. The friability test is normally designed to ensure such applicability. A total of 3% is used as the critical value to judge those materials if they can be used as the surface materials in the pavement of roads, bridges, sidewalks, and garages in cold regions. Yet 5% is acceptable for cases in warm regions. Table 8 reports the testing results. In addition to the friability test, the fineness analysis test, designed to identify the portion of material that passed through #200 sieve (75 μm), is applied to justifying the same usage. The experimental results from this test verify that the clay lumps content exceeds the threshold and that the fineness is also beyond the limit. This could result in reducing the application potential for the materials of the fine portions in product streams A and B for use as the surface materials in pavement. Finally, the organic content in streams A and B also exceeded the limit. This implies that the potential of using fine portion in product streams A and B as horticulture soil is increasing. Table 8 summarizes the outcome of the physical and chemical tests.

Overall, in terms of using the recovered material as concrete mixes, the outputs of friability, fineness, and organic content detection are negative. Therefore, fine particles separated from streams A and B are not suitable for use as lightweight aggregates for structural concrete due to improper particle distribution and imperfect physical or chemical properties. As a result, advanced tests for soundness of aggregate durability are not necessary. Using the fine portion in stream A as construction material in roadbeds, however, could be feasible if the impurities can be removed beforehand. The product from stream B could be better suitable for use to cover daily waste streams destined for landfills. If the impurities can be removed in advance, the fine particles in stream B could also be used as the backfill materials in construction projects. The outputs of LA abrasion test suggest that product stream C can be used as coarse aggregate or pavement subbase for new structures.

5. Institutional consideration

For a successful C&D waste-recycling program, detailed information about the quantity and quality of the C&D wastes, location of the recyclable materials, as well as secondary material market is significant. Continuous changes in the composition of C&D wastes due to the different building materials used in different time periods and collected in different regions will affect the relevant treatment methods. As a result, quality requirements for concrete are more difficult to meet due to the inherent variability in the composition of C&D wastes. Concern about the secondary pollution if incidentally contaminated C&D wastes are recovered and applied would also influence the recycling potential of C&D wastes. Such an impact has stimulated the implementation of a QA/QC system by the recycling industry (Hendriks, 1994; Tansel et al., 1994). For example, managing specific wastes, such as asbestos, during the C&D recycling process would probably require using a solidification process designed by mixing asbestos with glass to entrap the asbestos in the glass matrix. The glass blocks can then be used as roadbed for road construction. Plastic use for various construction purposes has increased over time (Brunner and Staempfli, 1993). Recycling of plastics as construction materials either as construction components or aggregates would increase in the future due to the higher content of plastics in C&D wastes. Processes for recycling polymers into construction materials are being developed in many countries. For those areas that lack heat energy, incineration/gasification of plastics, wallpaper, and wood chips could be attractive (Chang et al., 2001a,b). Economic opportunities always exist in different types of recycling infrastructure programs so that the management policy provided by various levels of government agencies should involve institutional considerations that may coordinate multidisciplinary recycling program efforts with appropriate regulation support. For example, to resolve the residual earthquake impact, the C&D waste-recycling program in Taiwan requires an immediate subsidiary program and a complete QA/QC system to support the private sectors that are interested in this business.

6. Cost-benefit analysis

The cost-benefit analysis (CBA) can be thought of as providing a protocol for measuring the efficient allocation of resources, such as land, labor, and capital, deployed at their highest valued uses in terms of the goods and services they create (Boardman et al., 1996). From a broader sense, unlimited production of sand/gravel from the natural environment, such as from the river systems in Taiwan, has endangered many bridge abutments. Accidental collapse of a large bridge at the downstream area of the Kao-Ping River in 1999 released a warning signal with respect to the severe abuse of sand and gravel resources in the river systems. Without proper governmental subsidies to support C&D waste-recycling programs, recycling industries might not be able to sustain themselves when the secondary markets are not stable at the initial stage. In this case study, given a steady governmental subsidy as a premium, CBA decisions could be straightforward and simple. The capital costs include land and construction costs, machinery procurement, cost for planning and design, and investment depreciation. Operating costs include labor, power, maintenance, and other minor expenditures. The return on investment includes the cost control considerations from tipping fees, governmental subsidies, and income gained from various product sales in the secondary material markets.

Identification of a potential market could be an influential factor for a successful C&D waste-recycling program. It is known that wood chips can be sold to nurseries, park, and private garden for use as landscaping mulch. Other uses for wood chips include land cover, animal bedding, and producing refuse-derived-fuel for industrial boilers. Recycled steel can be sold to area recyclers for direct reclamation. Although asphalt from roofing has been successfully used for repairing pot of holes (Stein, 1987; Perez, 1994; Rabasca, 1994), recycling asphalt materials is not economically attractive in the secondary material markets in Taiwan. Sand and soil are useful in many civil engineering projects. Uniformly cracking gravel, grain, pebble, and rock might be a useful unit operation to improve the quality of recycled construction materials in stream C and, therefore, increases product sales in the secondary material markets. Sometimes, recycled steel can be sold to the steel manufacturing industry directly for a relatively better price.

Table 9 presents a summarized report of CBA for this C&D waste-recycling program. Currently, the tipping fee for the disposal of C&D waste streams varies from 20 to 28 US\$ ton^{-1}. The processing for each ton of C&D waste may acquire a constant governmental subsidy of 10 US\$ from Environmental Protection Administration (EPA) in Taiwan. The reason for including the government subsidy in the list of benefits is obvious. The revenues from the products of recycling are sometimes

Table 9
Cost/benefit analysis for this sorting plant

	US\$ year^{-1}
Cost item	
Construction cost	800 000
Machine procurement cost	4 500 000
Labor cost	309 375
Maintenance cost	56 250
Power consumption	15 000
Investment depreciation	449 770
Benefit item	
Tipping fee	424 800
Governmental subsidy	175 200
Sale of sand or soil	225 000
Sale of gravel, grain, pebble or rock	900 000
Sale of wood chips	155 000
Sale of other materials (e.g. steel, brick, plastics, etc.)	252 000
Payback time period (years)	3.0

not that great, the idea for asking for subsidies to support recycling is needed. From a national economy point of view it might be beneficial to preserve the natural resources from abuse by the construction industry. From an operators or waste managers point of view it makes slightly big difference due to the instability of the secondary material market.

Payback time period is the period of time required for the profit or other benefits from an investment to equal the cost of the investment. Yet the definition of pay back time period in this study would not consider depreciation of the investment and income tax. Being an approximate calculation, all costs and all profits prior to payback are included without considering difference in their timing. If the estimates of the costs and benefits are reasonable, this project will generate 6 130 395 US$ year^{-1} in costs and 2 132 000 US$ year^{-1} in benefits. This would result in a 3-year payback time period approximately. However, the benefits could be varying from the reasons of dynamic markets and of unstable product quality and thus, a longer payback time period is required.

7. Conclusions

Proper disposal of C&D waste streams has received wide attention due to significantly larger quantities of waste streams collected from those razed or retrofitted buildings in many metropolitan regions. Technical criteria, economic opportunities, and management policy on different levels can affect the possibility and success of recycling efforts for C&D wastes (Lauritzen, 1994). This analysis not only covers a technical appraisal for a mechanical sorting process with respect to three types of product streams but also provides a cost-benefit analysis for that operation. The technical considerations in this paper include the assessment C&D waste quality, investigation of the main sources and inventory in Taiwan, waste collection appraisal, separation and processing, procurement of essential machinery, identification of potential markets, and discussions on a QA/QC system. The sorting plant designed in this program is used to separate useful items, such as sand, gravel, pebbles, metal, and even wood chips, from C&D wastes. Typical operation units include bar screening, trommel screening, air classification, disk screening, and final manual sorting. The production capacity of this plant was verified by a mass balance analysis. Lab tests, such as sieve analysis, LA abrasion test, friability test, organic content test, and fineness test, with respect to three types of product streams (A, B, and C) were conducted in terms of several selected physical and chemical properties. Research findings indicate that the use of fine particles from stream A as construction materials in roadbeds could be feasible if impurities can be removed beforehand. The product stream B could be suitable for covering the daily solid waste in landfills. If impurities can be removed in advance, the fine particles from product stream B could also be used as backfill materials in construction projects. The LA abrasion test supports the use of product stream C as coarse aggregate or pavement subbase for new structures.

The economic considerations include capital and operating costs and the anticipated return on investment for the C&D waste-recycling program. Since the current prices of recyclables in the secondary material markets in Taiwan might not be able to support such a cost-effective recycling infrastructure program, the proposed cost-benefit analysis also confirms the economic potential for such a management practice with the aid of a government subsidy program. Although the government subsidy is less than 10% of the benefit estimation and cannot change the payback period much, cost-benefit analysis does yield an argument for subsidies. From a long-term perspective, regulations, policies, and guidelines with respect to the essential QA/QC procedures for waste collection, separation, and processing should be considered in relation to the suitability and conformance of recycled materials and the secondary material market potential.

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