# Design and Economic Evaluation of a Rubber Modified Asphalt Plant in Trinidad and Tobago

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**Abstract.** The issue of management of waste rubber from used vehicle tyres presents major social, environmental and economic challenges for Small Island Developing States (SIDS) such as Trinidad and Tobago. Such challenges arise mainly due to associated negative effects on aesthetics, public health and ecosystems. A possible mitigation strategy involves the blending of used tyres in the form of Crumb Rubber (CR) with asphaltic binders for road paving. Laboratory studies demonstrated that the addition of 5% CR wt of particle size ≤250 µm enhanced the performance attributes of rutting, aging, and cracking resistance of the indigenous paving materials Trinidad Lake Asphalt (TLA) and Trinidad Petroleum Bitumen (TPB). Accordingly, a rubber-asphalt processing facility was designed to examine different processing capacities up to 800,000 scrap tyres per year and utilizing different machine specifications. The plant design utilized the ambient process for CR formation and the wet process for the blending process. At a production of 714kg/hr., crumb rubber with 300 production days and a daily production rate of 12 hours, the Net Present Value (NPV) was found to be about $4.3 million for the assumed opportunity cost of 10% of the capital cost. In addition, the internal rate of return (IRR) is 49% with a payback period of 4 years. Such a facility is an economically beneficial and feasible venture presenting a sustainable disposal strategy for waste tyres and one that should be duly considered for implementation.

**Key words:** TLA, TPB, crumb rubber, plant design, economic evaluation.

## Introduction

Waste management continues to be a major social, environmental and economic issue that has been receiving attention worldwide as it negatively affects aesthetics, public health and global ecosystems (Intergovernmental Panel on Climate Change, 2007). The quantity and complexity of generated waste are increasing and it is estimated that 11.2 billion tonnes of solid waste are collected yearly, which contributes approximately five (5) percent of global greenhouse gas (GHG) emissions (United Nations Environment Programme, 2011). Trinidad and Tobago, a Small Island Developing State (SIDS), is a petroleum based economy which has experienced growth in urbanization and industrialization which has intensified associated health and environmental problems (Achankeng, 2003; Ministry of the Environment and Water Resources, 2011). In 2010, a Solid Waste Management Program Waste Characterization and Centroid Study was conducted for Trinidad which classified the waste dumped in landfills in Trinidad. The results of this study are shown in Fig. 1 (CBCL Limited, 2010).

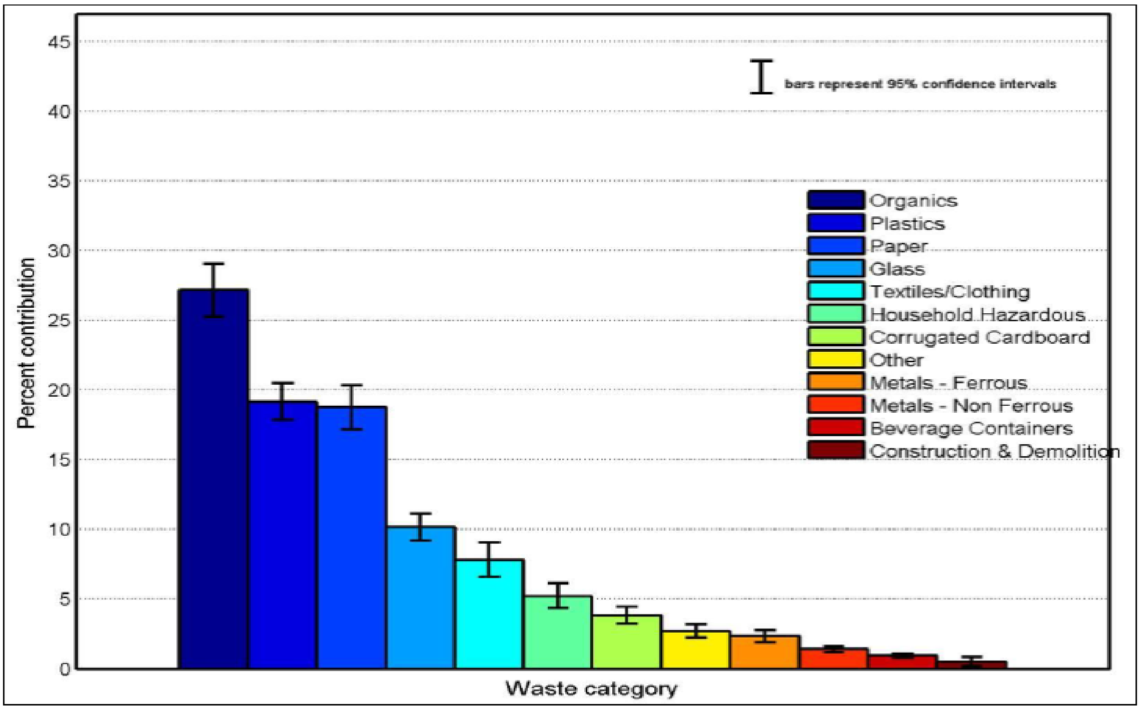


Fig. 1. Average overall household waste composition in Trinidad (Source: CBCL Limited, 2010)

The statistics reveal that for 2010, approximately 700,000 tonnes of waste was generated in Trinidad and Tobago and based on the overall population, it is estimated that 1.50 kilograms of waste is generated per person per day. The survey revealed that the main contributors of household waste are organic based materials and plastics. In Trinidad and Tobago, as of January 2010 there were approximately 518,831 vehicles registered (Ministry of Planning and Development, 2018) and with regards to waste tyres, during 2003 to 2007, an estimated 1.5 million tyres were imported into Trinidad and Tobago while only 15% were exported. The disposal of the non-biodegradable waste tyres involves unsustainable methods such as stockpiling, illegally dumping or landfilling. Landfilling of tyres pose major engineering problems as the tyres come up to the top of landfill due to its low density and can damage caps and liners. Due to their large volume and 75% void space, they utilize valuable landfill space. In Trinidad scrap tyres occupy approximately 4.6% landfill space (Waste management topics-SWMCOL, 2011) and their presence serve as a breeding ground for harmful vermin, insects and rodents and can result in the proliferation of vector-borne diseases such as Dengue and Chik-V. Accidental fires caused in tyre dumps can burn for weeks releasing toxic fumes. The indiscriminate dumping of tyres apart from the negative health issues is an eyesore and contributes to clogged waterways, thus increasing the incidence and magnitude of flooding.

The limited land resources to site landfills and fragile ecosystems further exacerbate the challenge of waste management in SIDS such as Trinidad and Tobago. Economically, an inefficient waste management policy has detrimental effects on the sustainable operations of major local industries such as tourism, agriculture and fisheries. Unlike several developed countries in North America and Europe who have banned landfilling of whole tyres and made recycling mandatory, the implementation of policies and action geared towards waste minimization and recycling in Trinidad and Tobago has been regrettably underdeveloped. Existing policies in Trinidad and Tobago such as the

National Environment Policy (Ministry of the Environment and Water Resources, 2011) and the National Waste Recycling Policy (Ministry of Planning and Development, 2018) specifically promotes the recovery of waste, recycling and reuse as well as to promote economic instruments and market incentives and the involvement of the private sector in waste management. Any recycling or reuse initiative to reduce the occurrence of such a large quantity of CR will be tremendously beneficial and can involve government, community and private sector for infrastructure and mechanisms for collection, storage, processing, recovery, conversion and distribution of the products. Such a strategy will promote entrepreneurship, provide employment, and contribute to the social and economic development of the country (Singh et al., 2009: 42-49).

One potential strategy involves the blending of the used tyres with asphalt which is beneficial as in developing countries such as Trinidad and Tobago it will help reduce landfill waste as well as the cost and required land space for such a disposal method and can even improve the durability characteristics of road paving materials. The use of scrap tyre rubber as a modifier for asphalt paving applications has been developing since the late 1980s, however in recent years the focus on the development of this engineering technology has shifted to focus on its potential as a solution to the environmental solid waste problem that the waste tyres present. Pavement performance using rubber modified asphaltic binders is a critical component in determining if the use of scrap tyre rubber is cost-effective. Since variable conditions (environmental and the chemical composition of the asphaltic binder and aggregate) determine pavement performance, it is probable that some areas will not benefit from this technology.

Laboratory studies on the performance of Crumb Rubber (CR) added to indigenous paving materials Trinidad Lake Asphalt (TLA) and Trinidad Petroleum Bitumen (TPB) presented encouraging results for the potential use of CR modified asphaltic pavements as they found an improvement in rutting, aging, and cracking resistance (Maharaj el al., 2009: 181-191). The highest complex modulus (G*) value was recorded for the blend containing 5% CR for both TLA and TPB. A subsequent study conducted using TLA and TPB provided confirmatory results as they found that the concentration to maximize rutting resistance were particles ≤250 μm at 5% CR concentration respectively and will form the basis for any facility design (Hosein et al., 2013: 321-335).

A literature review revealed that currently there exists no asphalt production facility producing crumb modified TLA and TPB although the technology is being used in other countries. The technology used for the manufacture of rubberized asphalt over the last 40 years is the so-called “wet process” which is described along with other alternative methods (Presti, 2013: 863-881). In the production process the key interaction processes between bitumen and the added rubber materials is material-specific and depends the base binder properties: composition and source as well as the particle size of the added rubber as these ultimately affect processing variables such as temperature, time and device (applied shear stress). This study also suggested that the modification process must be properly designed by taking into account the chosen processing conditions and on the characteristics of the selected materials to be blended. The design of a Rubber-Asphalt Blending Plant using TLA and TPB therefore cannot be adopted from other territories that utilize other asphaltic materials because TPB and to a far greater extent TLA have unique chemical compositions and physical properties and a relevant design must be developed locally. Such a facility will allow Trinidad and Tobago to capitalize on the performance improvements associated with the utilization of CR as a modifier as well as take advantage of the great potential for an innovative, entrepreneurial, economically sustainable and environmentally friendly strategy for the disposal of used tyres. The aim of this study was to design a rubber asphalt blending facility and to determine its economic feasibility for evaluating the viability of establishing such a plant in Trinidad and Tobago.

## Material and Methods

A literature survey was conducted to determine the various industrial processes related to the production of rubber modified asphalt. The various production methods found in the literature were analyzed and a method was selected by performing SWOT analyses (SWOT Analysis, 2011). SWOT analyses were also performed to select the individual unit operations, which were used to construct a block flow diagram which would become the basis of the final process flow diagram containing information on mass and energy balances and process conditions. Both the process and financial models were simulated using Microsoft© Excel. Relevant design equations were used to fully design and size equipment. This was followed by construction of a financial operating model in Excel which ultimately calculated Net Present Value (NPV), Internal Rate of Return (IRR), and Payback period. These factors were used to determine economic feasibility of the plant, accompanied by relevant sensitivity analyses. Hazard and Operability (HAZOP) and Health, Safety, and Environment (HSE) assessments were also investigated, along with consideration of site location and plant layout.

## Results and Discussion

*Process Selection*

The process involving the addition of crumb rubber to asphaltic materials intended for road paving involves much more than just grinding up waste tyres and then adding the rubber to the hot asphalt. Instead, the process is cautiously planned and monitored to ensure a rubber material which is of a consistent standard.

For TLA, the particle size of the crumb rubber used was less than two hundred and fifty micrometers (250μm) which can be produced either by utilizing the cryogenic process or by the ambient process (Hosein et al., 2013: 321-335). The criteria used to determine the selection were the capital and maintenance cost, the ease of operation, its ability to be used for other applications and the environmental consequences of the operations. Despite the fact that the cryogenic process surpassed the ambient process using these criteria, there were two major associated drawbacks. Firstly, the cryogenic process involves cooling to a temperature typically between -87 to -198 $^{o}$C and would inevitably involve the use of liquid nitrogen (0.5-1.0 kg liquid nitrogen per kg tyre input) which would prove to be very expensive. Secondly, a very small portion of a grounded tyre (approximately 4%) is suitable for cryogenic processing, while the remaining 96% is usually set aside for ambient processing making the ambient process the preferred choice.

The blending process for CR and asphaltic materials can be executed by either the wet or dry method (Ibrahim et al., 2014: 240786). In the dry method, the effect of the rubber-asphalt reaction is minimal and therefore the process has limited effect on the mixture performance, thus making this method unattractive. In the wet method process however, the crumb rubber reacts with the asphalt binder causing the rubber particles to swell thus transforming the physical and chemical properties of the asphalt binder. This allows the ability to manipulate the process to produce a blended product of desirable attributes making this process the favorable choice.

The resultant preliminary design therefore involves the ambient processing technique where the waste tyres are grounded or processed at or above room temperature to produce irregularly shaped crumb rubber with grain size ranging from approximately 5 to 0.5mm. This is then followed by the wet blending process where the crumb rubber particles are further reduced to obtain the fine mesh recycled tyre rubber which will be primarily used as the asphalt modifier.

*Process Flow*

The results of the SWOT analyses performed to select the individual unit operations were used to derive a block flow (BFD) and process flow diagram (PFD) and are shown in Fig.1 and Fig. 2 respectively. The mass and energy balances were calculated utilizing data from the literature which outlined a basis of one ton of incoming scrap passenger US Department of Transportation Federal Highway Administration, 2014) tyres with a composition of 86% rubber, 4% fiber and 10% steel (Siefers, 2010: 26-42). In this process design, the metals are screened out in a shredding operation and carries with it loose and adherent residual rubber or waste rubber in amounts of 5-8%. After passing through the shredder, 95% of the metal are removed and 8% of residual rubber is lost. Thus, resulting in 0.8362 tonnes of tyre chips entering the granulator for further reduction in size. Within this granulation operation, 90% of the fiber as well as 5% of the metal is separated and 6% of the rubber is lost. Upon leaving the granulator, 0.7525 tonnes of material continues to the grinder stage. Here, 5% fiber and 4% residual rubber are removed. Thus, only 0.72 tonnes of crumb rubber material progresses to the hopper.

Upon exiting the hopper, the crumb rubber material and the asphalt blend (TLA and TPB) are blended in 5:95 ratios in a mixing tank for a period of time before being sent to a reaction tank. This ratio was derived from the work conducted by previous studies (Maharaj et al., 2009: 181-191; Singh et al., 2009: 42-49). Typically, the asphalt binder and the crumb rubber react at fairly high temperatures (350-400˚C) for approximately 45-60 minutes (US Department of Transportation Federal Highway Administration, 2014). During this reaction time the particles of crumb rubber absorb some of the light fractions of the asphalt binder and swelled, resulting in an increase in viscosity of the asphalt binder blend. Mineral aggregate is then added to the blend as a structural filler to aid in the binding together of the rubber modified asphalt.

Typically, the crumb rubber process and the wet process both takes approximately 1 hour thus allowing for the production of approximately 11 batches per day of CR modified asphalt. The process flow diagram shows the mass flows and the compositions of the streams. Any minor equipment is excluded.

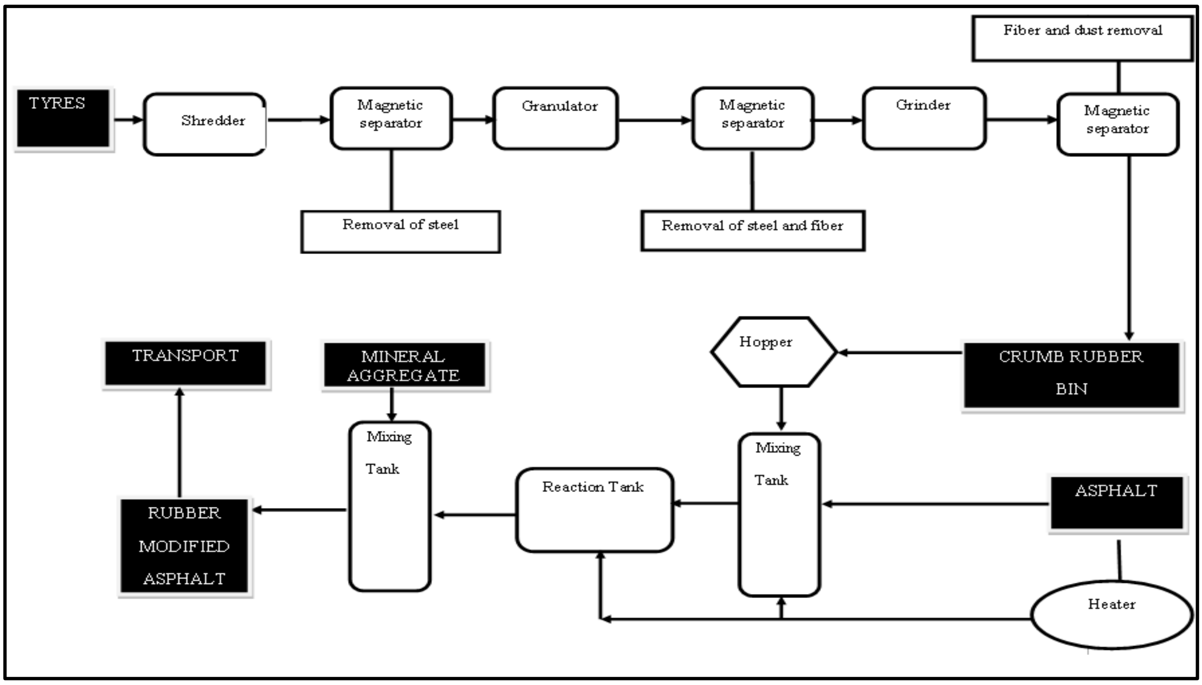


Fig. 2. Showing Block Flow Diagram of Process

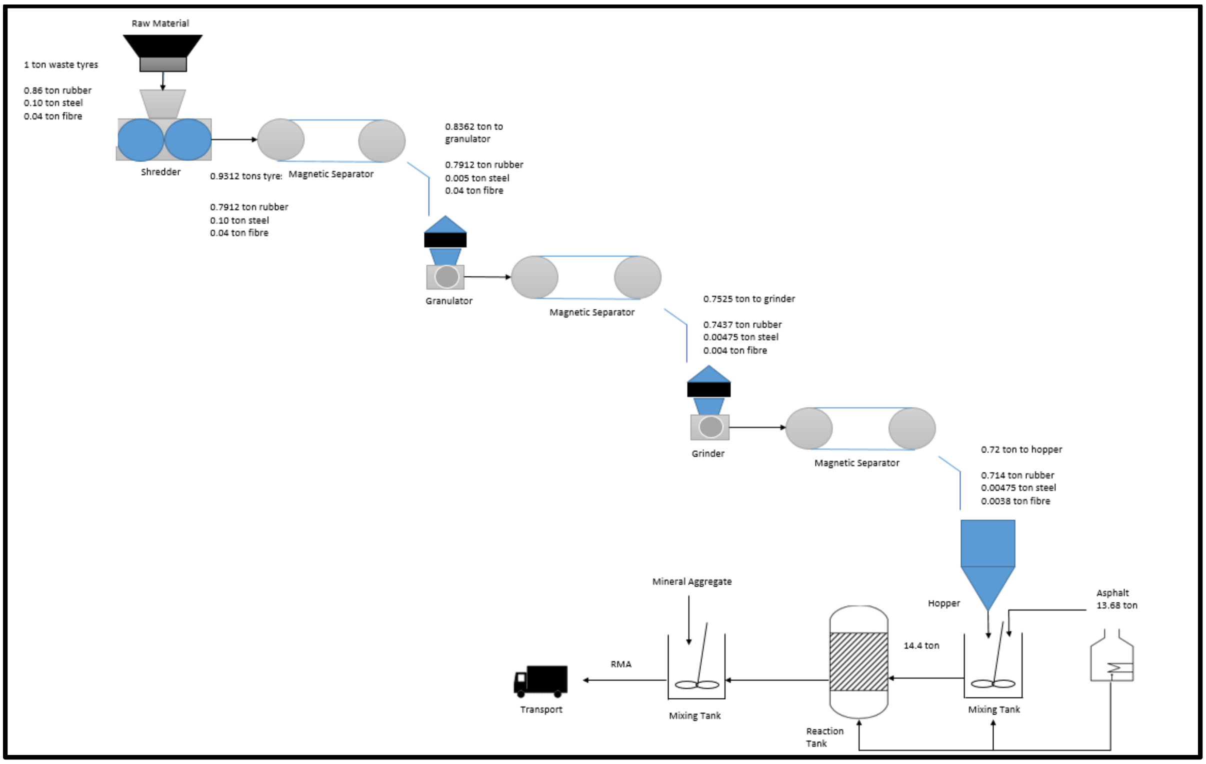


Fig. 3. Showing Process Flow Diagram of Process

*Financial Model and Sensitivity Analyses*

A detailed financial operating model was developed using Microsoft Excel tool to determine the profitability and feasibility of producing 714 kg/hr. of crumb rubber from waste rubber tyres in Trinidad and Tobago. Fixed capital investment, the total operating expenditure, taxes on profit as well as a cash depreciation of 10% were taken into consideration in this model. The majority of the fixed capital cost was contributed by the PV system, tyre processing plant, reaction tank and mixing tank.

The total operating expenditure covered the labor, utility, raw materials and administrative costs. Operating revenue was calculated based on the sale of not only the crumb rubber, but also, the fiber and scrap steel sold, the car and truck tipping fee and the rubber modified asphalt (RMA). Prices for the commercial sale of crumb rubber is USD$1 per kg, fiber cost is USD $0.25 per kg and scrap steel cost is USD $0.75 per kg. In addition, the cost of the car and truck tipping fee is USD$0.12 and USD$ 0.16 per kg respectively. Assuming a production of 714kg/hr. crumb rubber with 300 production days and a daily production rate of 12 hours, the revenue generated from the crumb rubber per year is USD$2,570,323.97.

The process of making rubberized modified asphalt (RMA) encompasses two distinct processes: the ambient process (crumb rubber formation) and the wet process (rubberized binder formation). Each process has a specific time in order to attain a desired product formation. The ambient process precedes the wet process and therefore the wet process can only start once crumb rubber has been produced. Thus, a sensitivity was done on the tonnes of tyres used per day versus the crumb rubber process time, in addition to the time taken to use one-year supply. Fig. 4 shows that as the crumb rubber process time increases, the number of tyres used per day decreases since there are less batches being produced on the plant. Additionally, as the crumb rubber process time increases the time taken to use one year of scrap tyres increases since less batches are done per day, therefore a slower rate of production and hence a longer time to utilize the scrap tyre supply.

From the figure seen on next page, where both lines intersects indicate the most optimal time of 2 hours which would utilize 6.2 tonnes of tyres per day in the crumb rubber process which would take approximately 3.5 years to be consumed.

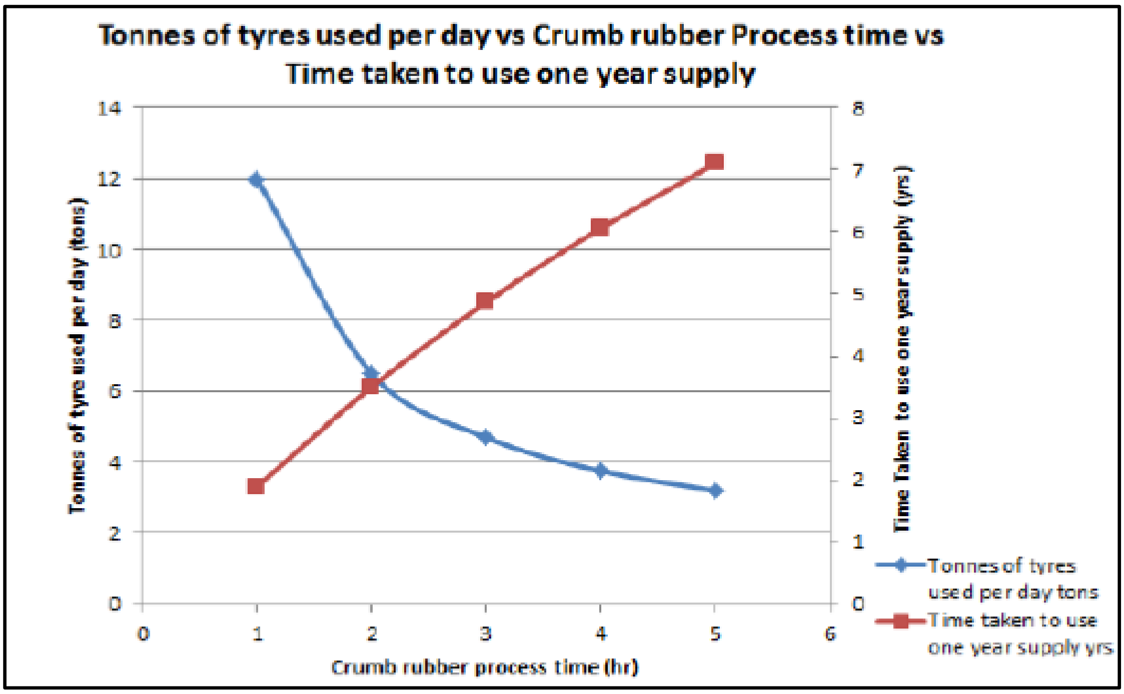


Fig. 4. Showing sensitivity of tons of tyres used per day vs crumb rubber process time vs time taken to use one-year supply

*Economic Summary*

Table 1 below shows that the crumb rubber production facility is economically feasible. A model was created to examine different processing capacities up to 800, 000 scrap tyres per year, different sources of scrap tyres (truck and car tyres), in addition to different machine specifications. The base case shown in Table 1 shows that the Net Present Value (NPV) is positive of about $4.3 million for the assumed opportunity cost of 10% of the capital cost. The internal rate of return (IRR) is 49% with a payback period of 4 years to recover the initial investment.

Table 1. Economic Summary for Crumb Rubber Production Facility

| Crumb Rubber- Production Facility | |
|---|---|
| Net Present Value (USD) | $4,275,125.99 |
| Internal Rate of Return (%) | 49% |
| Payback Period (Years) | 4 |
| Fixed Capital Investment (USD) | $776,761.48 |
| Total Operating Cost (USD) | $2,841,190.88 |
| Total Revenue per year (USD) | $3,500,878.97 |

*Waste Rubber Utilization*

In Trinidad and Tobago, as of January 2010 there are approximately 518,831 vehicles registered (Maharaj et al., 2009: 181-191). By which a significant proportion is assumed to be attributed to cars. As vehicles require tyres and the typical lifetime of a tyre is recommended at 2 years, there are a lot of tyres being used and disposed. Thus, to produce a significant impact on waste rubber reduction, its utilization in the production of rubber modified for the purpose of asphalt will prove to be beneficial to the environment and for diversification.

## Conclusion

The design of Rubber Modified Asphalt Plant for Trinidad and Tobago; the process of making rubberized modified asphalt (RMA) encompasses two distinct processes: the ambient process (crumb rubber formation) and the wet process (rubberized binder formation). The results show that the crumb rubber production facility is economically feasible. A model was created to examine different processing capacities up to 800,000 scrap tyres per year, different sources of scrap tyres (truck and car tyres), in addition to different machine specifications. Assuming a production of 714kg/hr. crumb rubber with 300 production days and a daily production rate of 12 hours, the Net Present Value (NPV) is positive of about $4.3 million for the assumed opportunity cost of 10% of the capital cost. The internal rate of return (IRR) is 49% with a payback period of 4 years to recover the initial investment. Such a facility operating in Trinidad and Tobago is an economically beneficial and feasible venture presenting a sustainable disposal strategy for waste paper and should be implemented.

## Acknowledgement

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