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LIFE-CYCLE ASSESSMENT TOOLS FOR MAINTENANCE MANAGEMENT AND RESOURCE CONSERVATION

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ABSTRACT:

Life-Cycle Assessment (LCA) is a systemic analysis of the environmental effects caused by a product or a process from extraction of raw materials to waste treatment. The paper demonstrates LCA modeling tools and evaluates the performance of some materials used in site maintenance in respect to environmental and economic criteria. Materials evaluated include those used in site improvement and in site electrical utility. Materials used in parking lot are selected to include: Asphalt with cement maintenance, Generic Portland cement, Generic 20% Fly ash cement, Asphalt with Seal-Bind maintenance, and Lafarge Portland type I cement. For electrical utility transformer oils are selected to include: Bio Trans transformer oil, Generic mineral oil based transformer oil, and Generic silicon based transformer oil. The method of evaluation depends on a computer based technique suggested by the National Institute of Standards and Technology, U. S. Department of Commerce. The results are: As for parking lot paving materials, both Asphalt with GSB88 Seal-Bind maintenance and 20% Fly ash cement have the same performance in overall evaluation, although they recorded different values in economic and environmental performance separately. And as for transformer oils, Bio Trans transformer oil records the best overall maintenance amongst the selected types.

1-INTRODUCTION:

LCA is vital to support the development of eco-labeling schemes. LCA enables a manufacturer to quantify energy and raw materials used, and how much waste is generated, at each stage of the product's life. This concept emerged in response to increased environmental awareness. For a manufactured product, LCA involves making detailed measurements during the manufacture of the product, from the mining of the raw materials used in its production and distribution, through to its use, possible re-use or recycling, and its eventual disposal. At every stage of the life cycle there are emissions and consumption of resources. The environmental impacts from the entire life cycle of products and services need to be addressed. To do this, life cycle thinking is required. Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle.

LCA provides an adequate instrument for environmental decision support. Life cycle assessment has proven to be a valuable tool to document the environmental considerations that need to be part of decision-making towards sustainability. A reliable LCA performance is crucial to achieve a life-cycle economy. The International Organization for Standardization

(ISO), a world-wide federation of national standards bodies, has standardized this framework within the ISO 14040 series on LCA[1].

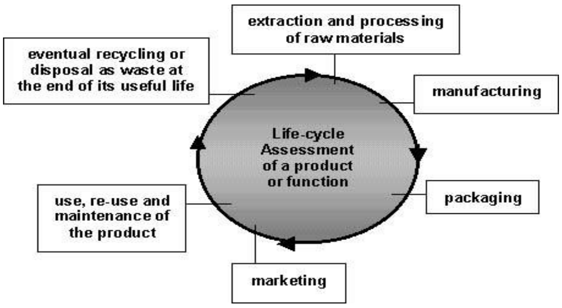


Diagram (1) Life-cycle assessment of a product

2-WHY PERFORM LCAS?

LCA is performed by an industry sector to identify areas where improvements can be made, in environmental terms. Alternatively the LCA may be intended to provide environmental data for the public or for government. In recent years, a number of major companies have cited LCAs in their marketing and advertising, to support claims that their products are *'environmentally friendly'*. All products have some impact on the environment. Since some products use more resources, cause more pollution or generate more waste than others, the aim is to identify those which are most harmful. Even for those products whose environmental burdens are relatively low, the LCA should help to identify those stages in production processes and in use which cause pollution, and those which have a heavy material or energy demand. Breaking down the manufacturing process into such fine detail can identify the use of scarce resources, showing where a more sustainable product could be substituted[2].

3-LCA MODELING TOOLS:

Life Cycle Analysis must be used cautiously. With the trend towards more open disclosure of environmental information by companies, and the desire by consumers to do the least harmful purchases, LCA is a vital tool.

3.1-Materials Production Level:

3.1.1-SimaPro:

SimaPro is a professional LCA software tool. Complex products with complex life cycles are easily compared and analyzed. Since its introduction in 1990, SimaPro is the most widely used software for life cycle assessment [3]. Simapro has several databases focus on building materials, energy, transport, processing, and waste treatment. SimaPro has all the expected features of a professional LCA software package, several impact assessment methods, assessment calculations from each point in a project, and weak point analysis. It also analyzes disassembly of products, waste treatment and recycling scenario's[4].

3.1.2-TEAMTM:

TEAMTM is a powerful and flexible tool. Selecting and defining inputs and outputs is simple by using the tool bar of the software. The use of formulas to specify allocation methods for each process unit is a unique feature of TEAMTM. Calculating the LCA inventory from anywhere within the system is another flexible feature of TEAMTM. The model contains ten categories contain 216 individual data files for product and material production, energy generation and transportation. The categories are soft tissue and paper; petrochemicals and plastics; inorganic chemicals; steel; aluminum; other metals; glass; energy conversion; transportation; and waste management. This tool uses formulas and variables that allow development of a dynamic system which facilitates sensitivity analysis. The

output of the inventory is displayed in tabular form thru "Eco-view" templates[5].

3.1.3-KCL-ECO:

The graphical interface of KCL-ECO makes system development easy. System variables can be specified by the user. The use of variables and equations offers another degree of flexibility when defining the system. Sensitivity analysis within the program is one of its advantages. KCL-ECO data is a separate product containing modules based on Finnish and European data related to paper industry and its related services. The output is very detailed and arranged in a very logical manner. The report lists all of the inputs, outputs and governing equations along with the specified amounts. Finally, if a sensitivity analysis is performed a distribution along with descriptive statistics is provided. The flow diagram can also be printed[6].

3.1.4-The BOUSTEAD Model:

It Includes data for energy carriers, fuels production and transportation. Processes, and product data are included for common operation and materials manufacturing systems. Data are input via the construction of a data table for each process. The database contains information on over 2,000 unit operations. Unit operations data represent a mixture of U.K., general European, and U.S. conditions. The program consists of a collection of routines, which perform separate functions. The output is a tabular representation of the data[6].

3.1.5-GABI:

It includes 800 different energy and material flows. Each flow belongs to a flow group which allows the user to develop a hierarchical system. Ten process types contain 400 specific industrial processes are included. The 10 process types include industrial processes, transportation, mining, power plants, transformation processes, servicing, cleaning, repairing, wear, and processes of reduced consumption. Besides common process data from around the world, the database consists of special data from companies in Germany. The standard LCIA method is subdivided into five steps: selection of the critical ecological fields, classification, determination of the impact assignments, standardization, and evaluation. The output is an exportable balance sheet to Excel application[6].

3.1.6-PEMS:

The graphical interface of PEMS makes system development easy. Material flows and transportation are represented by arrows between blocks. Sensitivity analysis, impact assessment, and comparison of results are easy to understand and customize. Tables and graphs can be easily customized and exported to other applications. Multiple transportation options can be defined for a single flow allowing urban, rural, and motor way combinations to be selected. Data included are lists for 109 materials, 49 energy sources, 16 transportation options, and 37 waste management options. Two impact assessment calculation methods are available: problem-oriented and media-oriented critical volume assessment methods[6].

3.2-Lca At Building Component Level:

3.2.1-LISA :

LISA (LCA in Sustainable Architecture) is a decision support tool for construction. It was developed in response to requests by architects and industry professionals for a simplified LCA tool to assist in green design. Also, detailed LCA studies often divert attention from the key

environmental issues, and tend to focus attention on inter-material competition, rather than on optimum construction systems. LISA is designed to help identify key environmental issues in construction, give designers an easy tool to evaluate the environmental aspects of building design, and enable designers to make choices based on life environmental considerations. LISA is adding case studies in university buildings, multi-storey offices, high rise buildings, wide span warehouse, and road and rail bridges[7].

3.2.2-Eco-Quantum:

Eco-Quantum is a calculating method to provide quantitative information on the environmental pollution by a building. Eco-Quantum looks at the building from cradle to grave. It deals with the effects of extraction of raw materials and production of materials, construction, its use and management, possible renovation or new use and ultimate demolition and reuse of the building components and materials. Implementing LCA study at building level is a complex matter in which care has to be taken of environmental effects that extend beyond the level of building components. Examples are energy consumption and maintenance activities in the use phase, the different life spans of building components and the options of demolition or renovation. The information can be drawn up for the life cycle of a complete building, cross-sections of the building, a particular material, a single component, a phase from the life cycle, by surface area, by volume or per person[8].

3.2.3-EQUER:

This model EQUER (Evaluation de la Qualité Environnementale des bâtiments) is developed by Ecole des Mines de Paris. It applies the LCA method to the building sector. The project develops a simulation tool, which allows the comparison of alternative designs. The different phases considered for a buildings life cycle are fabrication of components, construction, utilization, renovation and the renewal of components, final dismantling, and treatment after use of components. EQUER considers for the environmental assessment of a building only its influence on the outside environment. The used inventories contain impact factors used resources emissions, and waste[8].

3.2.4-Athena:

Athena Sustainable Materials Institute set up a LCA-based analysis of design and material choices for commercial buildings. Athena's database contains detailed North American LCA data for specific structural assemblies of different material types and configurations, as well as for a variety of building envelope components and materials. The software enables users to describe a building in architectural terms, and then provides LCA-based environmental evaluations of alternative designs and material choices. The database includes wood Products, steel Products, cladding Products, gypsum wallboard and finishing materials, galvanized decking, heavy trusses, concrete structural products, insulation and vapor barriers, windows and glazed curtain wall, and paint finishes[9].

3.2.5-Japan BRI- LCA (J):

This model is to calculate the energy consumption and CO_2 emission in each life stage. Addressed users are building designer, house designer, researcher, etc. Object of evaluation are building products, building process, structural construction site, building service, renewal and renovation, and

demolition. The method is a direct system for calculating energy consumption and CO_2 emission in the building materials production process. Information includes building type, building site, building materials, and demolition methods[8].

3.2.6-The ECO Methods:

The ECO methods are derived from research projects in Switzerland and Germany since 1989. Life cycle impact assessment is related to standard cost and energy calculations. The methods are based on the following general basic data pre combustion, energy transformation, transport, building material of German Swiss and Austrian material producers for over 100 materials and composite materials, aggregation coefficients, and building description by Swiss and German standards[8].

3.2.6.1-ECOPT:

The tool applies at the design level. It addresses planers and owners. Up to four alternatives can be analyzed to determine the environmental impact, the cost and the standard energy needs of a new construction, a transformation/refurbishment or a different use of existing buildings at different locations. The general questions: do we need a building? If yes, do we need a new building or can we transform an existing building. The percentage of new construction, refurbishment/transformation and simple maintenance can be chosen also. The impact from transport (users, clients, companies) and from specific activities (office work, restaurants) resulting from building use can be estimated[8].

3.2.6.2-ECOPRO:

The tool addresses architects and engineers. It assists in taking decisions concerning functional and constructive solutions and material choices. ECOPRO uses the same data as for cost planning. An element is composed of several layers which have material characteristics. Therefore energy related values like conductivity, mass, life duration of a layer, waste categories and environmental impact and cost criteria are associated to each layer and then added for each element and for 3 life cycle phases (construction, refurbishment, disposal). Buildings are composed of element groups for structure, fabric, interior divisions, coatings, HVAC and electric equipment, and exterior surface treatment. The main questions are: which design alternative is fulfilling the target values? And if it does not fulfill all target values, which elements are responsible[8]?

3.2.6.3-ECOREAL:

The tool addresses the specification and construction phase. It uses the same element classification as ECOPT and ECOPRO. It takes into account the situation of the element in the building and the specific construction process. There is a qualitative risk assessment. The general question is: How to build?[8].

3.2.7-Green Building Advisor USA:

The model uses artificial intelligence technology to enhance decision-making processes in facility design, construction and operations with current environmental data. Application includes the stages of decision making process. GBA can be used to plan a building design, or evaluate an existing design. Addressed users are Investor, user, planner, and constructor. Evaluation includes building products, building processes, structural elements, single buildings, and services. Information includes basic building description. Life cycle model gives the user design ideas from database of 20 example buildings,

sustainable design methods and green building products[8].

3.2.8-SIA D0123 (CH):

The model is an assessment catalogue concerning construction elements and materials. Scope of application includes the overall building performance, stages of decision making process and project phase. Addressed users are architect and consultant. Information includes construction elements and materials. Main environmental issues include material and energy flow, environmental loadings, effects on flora and fauna, and effects on human health. Life cycle model is a product model of the building as for cost estimate[8].

3.2.9-Optimize:

It is a Canadian method estimating the life cycle energy requirements of a house and its environmental impact measured in outdoor and indoor pollutant. The program assists architects, designers and builders in selecting material options that minimize the negative environmental impact of buildings. It describes how the life cycle cost of a building may be determined. The embodied energy of life cycle includes that used during all the building's life cycle. This includes maintenance energy, repair energy, energy for the replacement of some element of the skeleton, demolition energy and energy for the transportation of the demolished elements. The main components of the calculation of the life cycle cost are cost of the materials, cost of maintenance, demolition energy and energy of transportation of the waste, recycling of building's materials, and cost of utilization for the building[8].

3.2.10-BEES USA (Building for Economic and Environmental Sustainability):

BEES is a methodology for selecting building products that achieve the most appropriate balance between environmental and economic performance according to the standards of ISO14000. Scope of Application is the stages of decision making process. Addressed users are all except services enterprise during the period of use. Life cycle stages include preliminary stages, manufacture of building products, maintenance of building, and servicing and attendance. Information includes inventory flow items (raw materials, energy, water, etc.)[10].

3.2.11-Energy LCA Model for Building Design (SBI):

In 1990, the Danish Building Research Institute initiated a research project concerning buildings' energy consumption and energy related emissions of CO_2 and SO_2. The aim is to enable employers and consulting engineers to choose building designs that require the lowest consumption of energy resources and cause the lowest pollution from energy production. CO_2 and SO_2 are only considered because they are the major substances in term of volume and contribute to both the greenhouse effect and the acid rain. The model divides the building's life cycle in three phases: construction, operation, and demolition. The database contains energy consumption figure for various types of construction products, the energy consumption for specific construction and demolition processes and emission values for different types of fuels and systems[11].

4-APPLICATIONS:

This part of the study presents the practical work which focuses on evaluating the performance of some materials used in building site work maintenance in respect to their environmental and economic criteria. BEES is the LCA tool used in this evaluation. It was chosen because the software is very easy to use, the input of data is simple, and the output of results is easily understood figures and tables.

To run BEES, three main steps should be followed:

1-Set your study parameters to customize key assumptions.

2-Define the alternative building products for comparison. BEES results may be computed once alternatives are defined.

3-View the BEES results to compare the overall, environmental, and economic performance scores for your alternatives.

Economic performance of a product represented herein takes into consideration the initial cost together with the future cost (calculated based on the life cycle cost using a discount rate) of a product during its lifecycle. While the environmental performance of the product expresses the potential impact of a product on the environmental settings such as: acidification, air pollutants, ecological toxicity, eutrophication, fossil fuel depletion, global warming, habitat alteration, human health, indoor air quality, ozone depletion, smog and water intake. For the overall performance of a product, the graph displays the weighted environmental and economic performance scores and their sum.

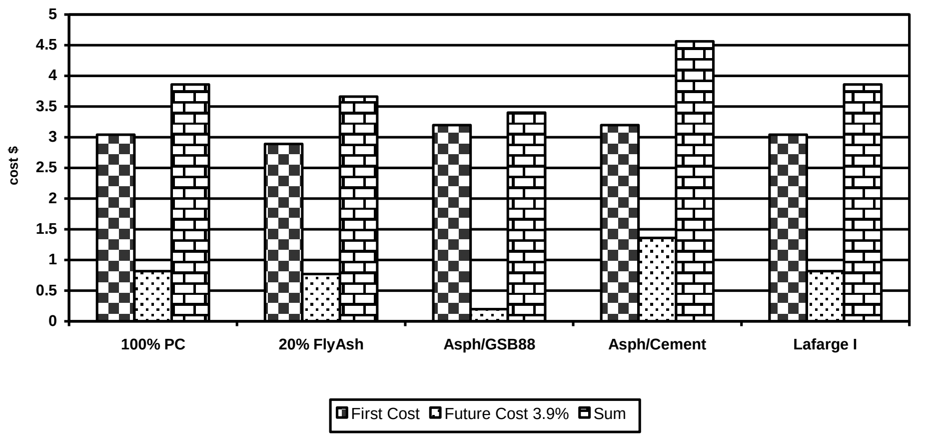
4.1-Parking Lot Paving Materials:

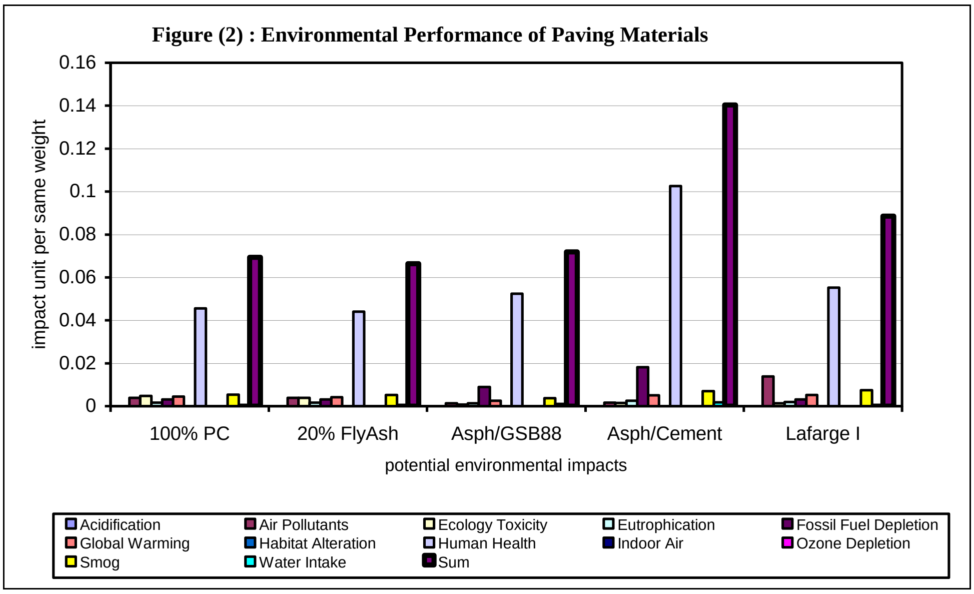
For site work improvement, some materials used in parking lot are selected: Asphalt with cement maintenance, Generic 100% Portland cement, Generic 20% Fly ash cement, Asphalt with GSB88 Seal-Bind maintenance, and Lafarge Portland type I cement. Applying the BEES software, the outputs are as shown in Figure (1).

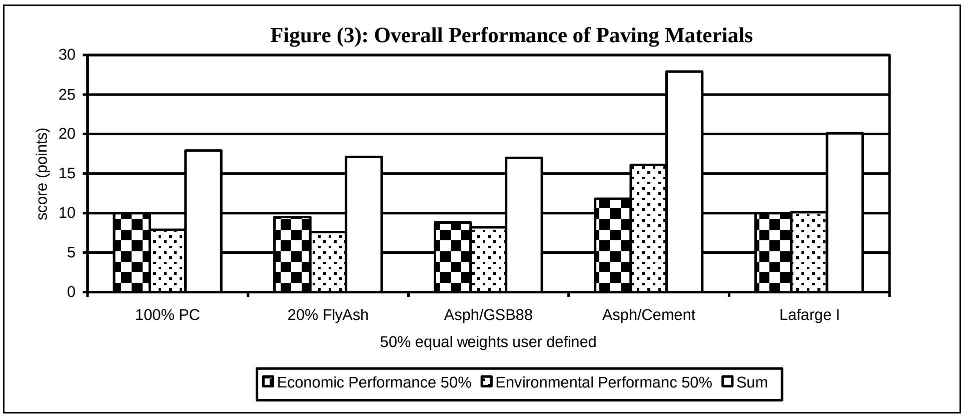
4.2-Transformer Oils:

For site electrical utility, some materials used as transformer oils are selected to include: Bio Trans transformer oil, Generic mineral oil based transformer oil, and Generic silicon based transformer oil. When applying the BEES software the following outputs are recorded:

Figure (1): Economic Performance of Paving Materials







Note: Lower values are better

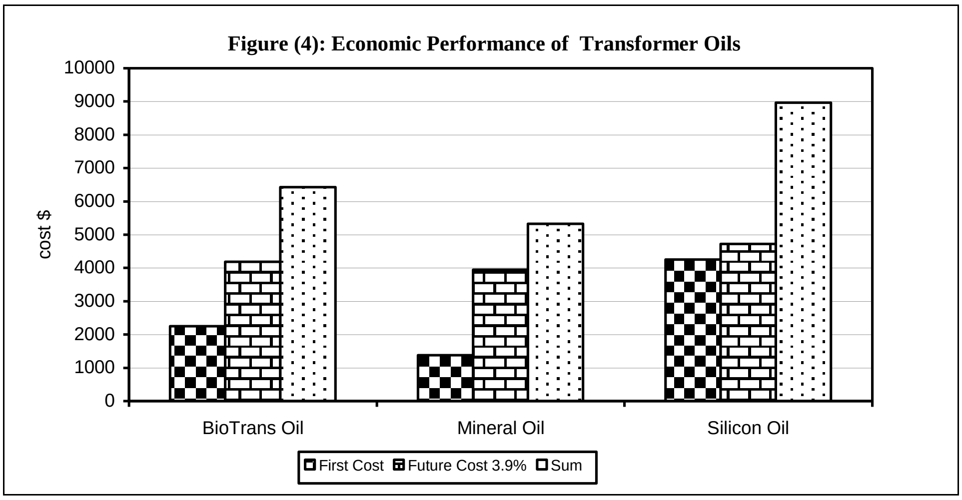


Figure (5): Environmental Performance of Transformer Oils

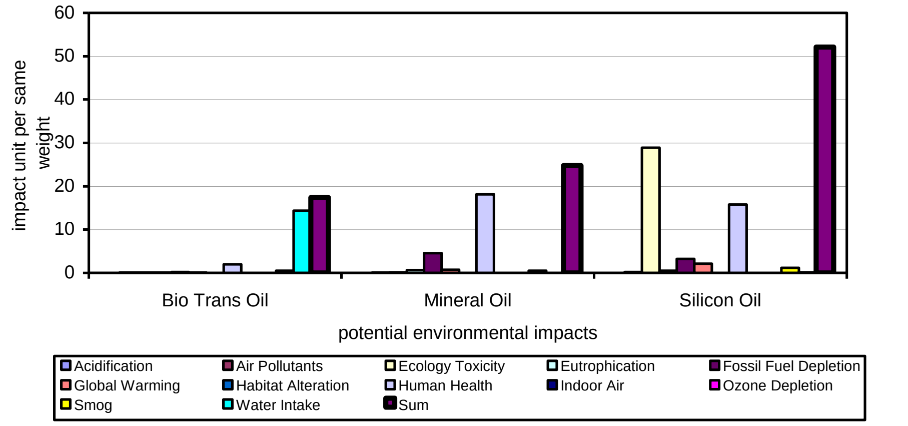
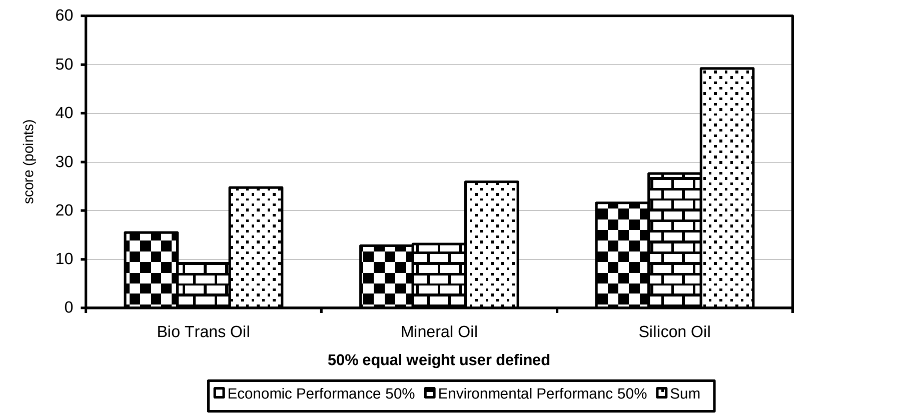


Figure (6): Overall Performance of Transformer Oils



Note: Lower values are better as they represent lower environmental harmful effects, and lower burdens on the economy whether initial or future cost.

5-CONCLUSIONS:

As obvious in Application 4.1 for the economic performance of parking lot paving materials, Asphalt with GSB88 Seal-Bind maintenance records the best value followed by 20% Fly ash Cement, 100% Portland Cement and Lafarge type I Cement, and finally Cement with Asphalt maintenance. While as for the environmental performance, 20% Fly ash Cement records the best value followed by 100% Portland Cement, Asphalt with GSB88 Seal-Bind maintenance, Lafarge type I Cement, and finally Cement with Asphalt maintenance. So, the overall performance gives an advantage to Asphalt with GSB88 Seal-Bind maintenance, followed by 20% Fly ash Cement, 100% Portland Cement, Lafarge type I Cement, and finally Asphalt with cement maintenance. So the preferred paving material to be used for both environmental and economic concerns is Asphalt with GSB88 Seal-Bind maintenance.

As for Application 4.2, for the economic performance of electrical utility materials, Mineral oil based transformer oil records the best value followed by Bio Trans transformer oil, and final Silicon based transformer oil.

Whereas, for the environmental performance Bio Trans transformer oil comes in the first place followed by Mineral oil based transformer oil, then Silicon based transformer oil. So, according to the overall performance the Bio Trans transformer oil gets the advantage over the Mineral oil based transformer oil. While the Silicon based transformer oil records the lowest advantage value.

6-RECOMMENDATIONS:

- **LCA models and tools should be vital methods in decision making process.**
- **More attention should be given to the importance of LCA techniques in production, operation, and maintenance phases.**
- **Organizations, institutes, and governments should play important roles to increase the public awareness of the importance of keeping our products environmentally-friendly.**
- **LCA tools should be undergone further sophisticated studies to be eligible for application in all fields of sciences (Engineering, Architecture, Medicine, Pharmacy, Commerce, Environment, etc.).**

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وسائل تقييم دورة الحياة لإدارة عمليات الصيانة مع الحفاظ على الموارد البيئية

محمد عبد الموجود عبد الغفار

مدرس بقسم الهندسة المعمارية– كلية الهندسة – جامعة طنطا

بعد زيادة الوعي البيئي على مستوي الدول والحكومات والأفراد، برزت أهمية تقييم دورة حياة المواد والعمليات والموارد المستخدمة اليومية. فهي عملية تحليل نظامي للتأثيرات البيئية الناجمة من مادة أو عملية ما منذ عملية استخراج المادة الخام إلى عملية معالجة المخلفات الناتجة، وهى تمكن المصممين والمنتجين والملاك من تحديد كميات الطاقة والموارد البيئية المستخدمة وكذلك كميات المخلفات الناتجة في جميع مراحل حياة المنتج، كما تمدهم بالمعلومات البيئية التي تمكنهم من تحديد مراحل عملية الإنتاج التي تحتاج إعادة نظر وتطوير نظرا لعبئها الكبير على البيئة من حيث إنتاج المخلفات أو استهلاك الموارد والطاقات.

وتستعرض الورقة البحثية وسائل تقييم دورة الحياة وأداء بعض المواد المستخدمة في صيانة مواقع الجراجات العامة فيم يخص التأثيرات الاقتصادية والبيئية لها. تنقسم وسائل تقييم دورة الحياة إلى:

١– وسائل خاصة بتقييم مراحل إنتاج المواد وتضم:

SIMAPRO, TEAMTEM, KCL-ECO, BOUSTEAD, GABI, PEMS,

٢– وسائل خاصة بتقييم مكونات وعناصر عملية البناء وتضم:

LISA, ECO-OUANTUM, EQUER, ATHENA, JAPAN BRI, ECO METHODS, GBA, SIA, OPTIMIZE, BEES, SBI.

تم تقييم تأثير دورة حياة المواد المستخدمة في تمهيد وصيانة أماكن انتظار السيارات على أساس المقارنة بين أداء وتأثيرات عدة مواد هي:

١– مواد الإسفلت المعالج بالأسمنت, الأسمنت بورتلاند العادي, أسمنت الرماد المتطاير, خليط الإسفلت ومعالج الشروخ, اسمنت لافارج.

٢– مواد الخدمات الكهربائية وتشمل الزيت الحيوي للمحول, الزيت المعدني العادي, وزيت السيلكون.

تعتمد طريقة التقييم على استخدام برنامج كمبيوتر مقترح من المعهد الوطني للمقاييس والتكنولوجيا بوزارة التجارة الأمريكية BEES وحققت الدراسة النتائج التالية: أفضل المواد في تمهيد وصيانة مواقف السيارات هي اسمنت الرماد المتطاير والإسفلت معالج الشروخ فلهم نفس الأداء العام بالرغم من اختلاف أدائهم البيئي والاقتصادي كل علي حده. أما بالنسبة لزيوت المحولات فحقق الزيت الحيوي أفضل النتائج.

ويوصي البحث بان تكون عمليات تقييم دورة الحياة مؤثرة على عمليات اتخاذ القرار مع ضرورة الاهتمام بها وتأكيد أهميتها في جميع مراحل الإنتاج والتشغيل والصيانة, وضرورة توجيه المؤسسات والمعاهد والحكومات والعامة إلي ضرورة المحافظة على واستخدام المواد صديقة البيئة.