Proposing a Green Maintenance Model in Order to Analyses the Effects of Influential Criteria on the Environment and Green Maintenance Index, Using System Dynamics Method

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ABSTRACT

Global environmental degradation is growing public concern and forcing many industries to use environmentally policies for design of product, manufacturing, service and disposal activities. The increasing amount of failures, breakdowns and maintenance of machinery has become a burden on the environment. Accordingly, there is a great need for tools and methods to understand, control, and predict defects. Maintenance strategies are one of these methods to reach these requirements. The maintenance generally brings the consumption of resources and energy, produces waste and induces pollution, therefore, new technologies, new processes and new equipment need to be applied and enterprise management should be strengthened to save resources and energy and decrease pollution. But maintenance work has many aspects of a complex system, as it requires interaction between many parties, events, and system variables in plant operation. For this reason, the purpose of this paper is using system dynamics trying to modeling and simulating the maintenance system with focus on all main and effective criteria and indexes specially, considering green maintenance index and studying system behavior. Results can helpful for all industries to utilizing effective polices in order to reducing their environmental impacts.

INTRODUCTION

Global environmental degradation is growing public concern and forcing many industries to use environmentally policies for design of product, manufacturing, service and disposal activities [1]. For this reason, the transition from hardware and software to service and maintenance is changing the world everywhere. Still, the understanding of maintenance is poor compared to conventional manufacturing. Accordingly, there is a great need for tools and methods to understand, control, and predict failures [2]. Over the past decade there has been increased recognition that in a world class manufacturing, maintenance is not a separate, isolated function that makes repairs and performs assorted activities as needed. Rather, maintenance is a full partner striving together with the other functions to achieve the firm's strategic goals [3, 4]. During the last years, cost and time have been the basic drivers of manufacturing systems, while ensuring that reliability, safety and integrity are not compromised [5, 6].

The term maintenance includes various actions and tasks that are essential to keep a system in normal condition during the life cycle and plays an important role aim to increase or to retain the reliability and availability of the equipment, product quality, and safety requirements [7]. In addition to fulfilling the requirements of equipment inspection, lubrication and repair, it has an added responsibility of plant protection, pollution prevention, personnel safety and waste disposal [1]. Although managers often seems the maintenance activities only as an expense, however we should know that maintenance is not an expense; it is an investment in the future as a basic functions of a firm in order to improved manufacturing and production process [8]. However, in industries, defective or poor maintenance is a factor for financial loss as well as concern for safety because of system quality degradation making components partially or fully dysfunctional [9].

Also a practice of good maintenance of plant equipment and systems are essential for a safe, reliable and efficient performance of devices in any industries. However, in industries, defective or poor maintenance is a factor for financial loss as well as concern for safety because of system quality degradation making components partially or fully dysfunctional [10]. Maintenance is able to create new productivity and helpful to save raw
materials and energy, protect environment, increase profits in the industrial production, returns improved quality, safety, dependability, flexibility and lead times etc. [11, 4].

Proper maintenance practices can contribute to overall business performance through their impact on the quality, efficiency and effectiveness of a company’s operations. This can enhance the company’s competitiveness. Nowadays high competitiveness makes industrial enterprises search higher performances such as higher quality products, sustainability, productivity advantages, value advantages and long-term profitability etc. [12, 13, 14, 15].

The increasing amount of failures, breakdowns and maintenance of machinery has become a burden on the environment [1]. The environmental awareness should be infiltrated throughout every link of production design, manufacturing and maintenance. For example, the environmental guidelines are necessary to be founded so as to prevent the adverse effect on the environment from some machine faults. Different technologies and methods including some analysis based on life cycle assessment, reuse, recovery, and recycling of equipment maintenance and waste should be applied to eliminate the impossible environmental damages [16]. In this context, the designers and practicing maintenance personnel are facing the challenge in responding: how to do the necessary maintenance, with minimum negative environmental impact? Moreover, various environmental regulations/policies have put pressures on the organizations to service, repair and dispose of their equipment in an environmentally friendly manner [1]. The maintenance generally brings the consumption of resources and energy, produces waste and induces pollution, therefore, new technologies, new processes and new equipment need to be applied and enterprise management should be strengthened to save resources and energy and decrease pollution [16].

Researchers have tried to minimize the negative impact of maintenance on the environment by focusing on green maintenance. The concept of “green maintenance” was proposed, which required the aim of maintenance to be realized by using advanced technologies and equipment at the cost of the least resources and energy consumption, the least waste and environmental impact [16].

Green maintenance is an attempt and an important technological way to realize the sustainable development and maintenance more environmental friendly by eliminating all waste streams associated with maintenance, which can achieve reductions and has become an important link in the recycling economy. Its activities involve the integration of product design issues with issues of maintenance planning and execution aimed at minimizing negative environmental effect; while at the same time ensuring health and safety of the personnel involved [1, 16].

Maintenance management of an industrial plant has always been a complex activity that involves handling a large amount of factors and information [17, 9]. Different frameworks, standards and methodologies have been developed over the years to guide these activities and show the relationships between factors and their impacts on other criteria [18]. Maintenance planning systems focus on scheduled based maintenance; they are not capable of multi-criteria decision making and do not considered complexity of system, the relationship between criteria and the impacts of factors as the environmental impact. There is poor visualization and of the environmental impact of manufacturing. In general, diagrams related to maintenance and failures are difficult to be represented due to their increased complexity [9]. Therefore, this paper aims to fill this gap, proposing a model based on system dynamics to considering these Characteristics and constraints.

Maintenance models were first built to manage the maintenance operations of a single component [19]. A maintenance model is composed of a model of system reliability behavior and of a maintenance policy model. The main aim of a maintenance model is to evaluate the overall maintenance cost incurred by the maintenance decisions [20]. In the last decades, there have been many attempts to create maintenance models for availability optimization. Most of them concentrated on the availability aspect only without incorporating further aspects as profitability of the overall system, environmental impacts and green maintenance index etc. Based on this, classic models, limited to represent and optimize maintenance strategies under the light of availability, failed [21]. Thus a novel model, incorporating financial impacting processes of and around a production system, overall equipment effectiveness, reliability and availability of equipment, environmental impacts and green maintenance index, is needed.

System Dynamics (SD) is a computer-aided approach for analyzing and solving complex problems with a focus on policy analysis and design and also this approach uses a perspective based on information feedback and delays to understand the dynamic behavior of complex physical, biological, and social systems [22]. System Dynamics modeling and simulation have been shown to be invaluable in demonstrating the possible consequences of specifying desired levels of reliability in the context of a range of operational scenarios and provide a vehicle for testing maintenance strategies and assumptions underpinning design as well as demonstrating to the designer and end user [7]. The understanding of these processes is then used to draw causal loop diagrams (CLDs). CLD is a powerful graphic tool to see the relationships among a system’s parts and their interactions with each other [22].

Maintenance work has many aspects of a complex system, as it requires interaction between many parties, events, and system variables in plant operation. As a result, computer simulation and modeling using system
dynamics are ideal for studying system behavior, its change and effects, and for determining optimal strategy for a respective system [23, 7].

For this reason, the purpose of this paper is using system dynamics trying to modeling and simulating the maintenance system with focus on all main and effective criteria and indexes specially considering green maintenance index and studying system behavior, evaluating and analyzing the impacts of most importance criteria in this area and implementation green maintenance by a firm and its effect to reduce environmental impacts of maintenance and increase green maintenance index in Esfahan Steel Company in Iran country.

Because previous studies have not focused on the effects of implementing green maintenance on maintenance system with system dynamics implementation to analyzing system maintenance model, this paper provides a new contribution and the results of the study are beneficial for plant maintenance department seeking to adopt the proper maintenance strategy and activities for sustainable plant operation performance, reducing their negative environmental impacts and optimization green maintenance index on their system maintenance performance. Study results may be helpful as a reference to get management support to improve plant maintenance strategy and invest in best strategies and activities according to simulation of this maintenance dynamic model on their company and evaluating its results.

The paper is organized as follows. The methodology presented in section 2. Section 3 describes the model proposed in this paper. In section 4, we present analysis the model. Section 5 outlines the possible extensions and conclusions of the work.

Methodology:

System Dynamics (SD), first developed by Forrester [24]. System Dynamics is a computer-aided approach and it uses a perspective based on information feedback and delays to understand the dynamic behavior of complex physical, biological, and social systems and solving complex problems with a focus on policy analysis and design [22].

According to Jay W. Forrester, system dynamics “is a way of studying the behavior of dynamic systems to show how policies, decisions, structure, and delays are interrelated to influence growth and stability” [24].

The SD approach has proved to be very effective in modeling and analyzing complex dynamics systems affected by non-linearity, feedback loops and time delays, which significantly affect their whole system behavior [25, 26]. It emphasizes studying the effect of the system structure and decisions on the behavior of the system [27]. It has helped many managers to think through how a strategy might or might not work [26]. It represents also a powerful tool for formulating “what if“ analysis in order to test different policies and helping decision makers in making the most proper choice [25].

The dynamic model is “an interlocking set of differential algebraic equations developed from a broad spectrum of relevant measured and experiential data” [28]. The equations are represented by a diagram, shown schematically in Fig. 1, consisting of three basic elements, consist of: stock (or level) elements (also called state variables) that describe the state of the system; rates of flows elements that connect the levels and decision functions that control the rates. Levels accumulate the incoming and outgoing rates, e.g. they are represents such concepts as liquid tanks, stocks of materials or awareness levels. Rates represent instantaneous flows of materials, money, orders, persons and equipment. These flows are interconnected by information networks which are also systems of levels, rates and decision functions. The decision functions represent policies in the system, which define how the levels (system state) affect the rates [27]; and auxiliary variables and constants [29, 30].

Fig. 1: Schematic of a system dynamics model

The purpose of this paper is to present a case study of an effective maintenance strategy selection problem analysis with system dynamics.
Proposed Model:

In this section a systemic view to maintenance, through establishing a system dynamics model based on green maintenance and environmental impacts, in Esfahan Steel Company in Iran country, is given (see Fig. 2). A system dynamics model was developed using the defects management process first invented by Ledet [26]. A maintenance model is a model of system behavior and of a maintenance policy model. The main aim of a maintenance model is to evaluate the overall maintenance cost incurred by the maintenance decisions [20]. Maintenance models were first built to manage the maintenance operations of a single component [20, 19].

Nowadays, quality, time, maintenance department performance, costs, environmental impacts and etc., must be seen as main and effective competitive success factors, which effective on green maintenance index and have to be considered simultaneously. In this paper, green maintenance index consideration is our first motivations.

This model considers the relationships between break down rate, overall equipment effectiveness, overall maintenance effectiveness, overall human resource effectiveness, maintenance budget, total maintenance costs, maintenance department performance, environmental impacts, green maintenance index and all other relationships between these main factors. The model uses the causal loop diagram and developed to depict processes, concepts and interdependencies and to consider how the different items are affecting the main factors in system maintenance used in the field of system dynamics.

For the first this model provided three important factors; maintenance department performance, environmental impacts and budget of maintenance department that related to profitability of maintenance activities, these factors can affecting the main objective for analyzing relationships.

Fig. 2: A system dynamic model of green maintenance system in Esfahan Steel Company
Analysis Model:
As an investment in the future maintenance is the protection of safety and environment also is able to save raw materials, energy and increase profits in the industrial production. In this area there are many strategies to achieve these goals. But among them green maintenance is very effectiveness and in this model with proposing green maintenance index tried to study system behavior on it.

According to Fig. 2, green maintenance index affected by many criteria and activities and for increasing this index, it is necessary to achieve some requires as the maximum utilization of resources, the least waste index and environment negative impact in the life cycle of a product from its design, manufacturing, usage and waste treatment, also number of green maintenance operating technologies, equipment reliability number of new and green technologies and green maintainability are very effectively to increasing green maintenance index. The green maintenance operating technologies are used to eliminate or decrease the environmental impacts of equipment maintenance in its using stage, which are usually composed of green maintenance materials, surface technology and engineering, machining process, components-cleaning, heat treatment and so on.

The maintenance generally brings produces waste, consumption of resources and energy and release waste pollution, therefore, new technologies, new processes, new equipment and new maintenance operation technologies need to save resources and energy, decrease pollution (emission rate and hazard rate) and generally decrease environmental impacts. Also it is clearly that waste pollution generated by a separate maintenance of a product is very little compared to product manufacturing, the consumption of resources and waste pollution throughout its life cycle is very much.

During maintenance, many new technologies should be applied to improve quality and efficiency and decrease the possible pollution. It is necessary to increase investment in research and development to perfect the innovation system of green maintenance technology, The enterprises are encouraged to master the core technologies and key technologies by using new technologies introduction, cooperative development and so on. Some measures in product design and a complete set of analysis, evaluation, weighing technologies are very necessary to eliminated or weakened the negative impacts of maintenance on environment, to this purpose the environmental impact of preventive maintenance and reparative maintenance of expected products and analysis of the irreparable faults and the scrapped machines treatments should be considered.

According to environmental impact analysis of maintenance and treatment, the information on the reparable design of parts and components can be supplied for technical supports on development of maintenance process. The models and methods including time, cost, resources consumption and environment impacts of maintenance should be built.

Conclusions:
Green maintenance is beneficial to develop recycling economy, implementing the concept of scientific development, build a resource-saving, environment friendly society and sustainable development. It brings the fundamental reform in the tradition all concept and technologies in maintenance and a new growth in maintenance industry. And in this paper tried to modeling maintenance system based on green maintenance in desired system and analysis some important effective criteria and activities that affects green maintenance index.

For this purpose attention to some criteria and activities as: investment in new and green technologies and green maintenance operation technologies, reducing environmental impacts and wastes, increasing equipment reliability and green maintainability, attention to utilization resources and maintenance department performance which is very important in maintenance that is consist of overall human resource effectiveness, overall equipment effectiveness and overall maintenance effectiveness, are very effective to increase green maintenance index and green performance of a maintenance system in an industry that is very important in its competition.

REFERENCES