PERFORMANCE ASSESSMENT MODEL FOR EXISTING BUILDINGS USING SYSTEM DYNAMICS TECHNIQUE

By

Noreihan Ateia Hamed Abdelrahman Seleem

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
STRUCTURAL ENGINEERING

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Performance Assessment Model for Existing Buildings Using System Dynamics Technique

Key Words:
Buildings Performance Assessment – Key Performance Indicators – Buildings Maintenance Policies - System Dynamics

Summary:
This research provides a framework for assessing the buildings performance throughout exploring the suitable quantifiable core key performance Indicators (KPIs) by studying their effect on each other. The proposed framework is developed using system dynamics technique throughout using the software packages Vensim PLE® and STELLA for creating the causal diagram and Stock and Flow diagram respectively. The research methodology followed is mainly depending on studying and collecting information about the core key performance indicators introduced previously in past literatures. Moreover, study the correlation of these factors on each other based on an applied maintenance policy; considering the effective factors in a sensitivity analysis. The results reveal that changing some variables (e.g., man-hours consumed, energy consumption, effect of changing dollar price, cost of expired systems) could have an impact on building performance, maintenance and replacement efficiencies on the long run with time horizon 50 years. The model helps facility managers and executive management teams to determine the efficiency of the maintenance policy applied and selecting relevant KPIs affecting it, which in turn has an impact in the decision making process for the existing project/building under study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC_y	Age Coefficient
BPE	Building performance evaluation
BPI	Building Performance Index
BTU	British Thermal Unit
CAFM	Computer-Aided Facility Management
CBM	Condition-based Maintenance
cfm	Cubic Feet Meter
CI	Condition Index
CLD	Causal Loop Diagram
CM	Corrective Maintenance
CPR	Corrective to Preventive Ratio
DM	Deferred Maintenance
EUI	Energy Usage Index
FI	Functionality Index
FM	Facility Management
FPE	Facility Performance Evaluation
HVAC	Heating, Ventilation, Air conditioning, and Cooling
IEQ	Indoor Environmental Quality
KPI	Key Performance Evaluation
kWh	Kilo Watt-hour
LCC	Life Cycle Cost
MBTU	Million British Thermal Unit
M_c	Corrective Maintenance Cost
MCI	Maintenance Cost Index
MEI	Maintenance Efficiency Index
M_p	Preventive Maintenance Cost
MPM	Maintenance Performance Measurement
MUI	Manpower Utilization Index
NAME	Normalized Annual Maintenance Expenditure
O&M	Operation and Maintenance
OA	Outdoor Air
OC_y	Occupancy Coefficient
PM	Preventive Maintenance
PMR	Preventive Maintenance Ratio
POE	Post Occupancy Evaluation
RCM	Reliability Centered Maintenance
REI	Replacement Efficiency Index
SD	System Dynamics
SDM	Spending Percentage on Deferred Maintenance
SRV	System Replacement Value
TAME	Total Annual Maintenance Expenditure
TDM	Targeted Deferred Maintenance

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ABSTRACT

Buildings' performance is a vital aspect of organizational activity in which it is affected by maintenance procedures and policies. Therefore, facility maintenance plays a crucial role in informing strategic decision making. This research proposes the use of facility key performance indicators (KPIs) to dynamically model and simulate the performance of existing facilities using system dynamics. The functionality of these KPIs is dependent on availability of data from buildings in use. Simulation transforms the descriptive analytics into predictive and prescriptive analytics by assessing the robustness of plans and policies set and by predicting future outcomes through analyzing of multiple scenarios. System dynamics modeling quantifies the interrelationship and interdependence of KPIs, and is potentially effective in analyzing how maintenance expenditures can be optimized to maintain a desired level of building performance as demonstrated by several simulation scenarios. All parameters and variables used are quantified in terms of cost and introduced in a dynamic model. The research is carried out in four main steps: 1) identifying the core performance factors affecting the building financially, functionally and physically using past literatures in the field of building maintenance and also by conducting structured interviews with experts in the same field; 2) defining the correlation between indicators and extract feedback loops by composing the casual loop diagram using Vensim PLE® software; (3) composing the Stock and Flow Diagram which quantifies the relationship between factors with each other using "isee STELLA" software; and 4) applying the sensitivity analysis using "isee STELLA" software using data from a project under portfolio of FM company in Egypt. The results reveal that changing some variables (e.g., man-hours consumed, energy consumption, effect of changing dollar price, cost of expired systems) could have an impact on building performance, maintenance and replacement efficiencies on the long run with time horizon 50 years. Furthermore, assessing a facility's performance using a set of KPIs provides the user with an opportunity to select the indicators of choice. The proposed research helps facility management professionals in not only tracking the indicators, but also quantifying and studying the correlation between them based on available information; leading to an enhanced facility management decisions with measurable facility performance outcomes.

CHAPTER 1
INTRODUCTION

1.1 General

Facility Performance Assessment is important for its contribution to organizational goals. Many approaches have been introduced in literature for assessing performance like the holistic key performance indicator (KPI) approach. However, there are broad lists of KPIs available. Accordingly, KPIs selected need to be relevant to facility goals and must be calculated, analyzed and evaluated to give a chance for the facilities to be performing well in future and at minimum cost level. Measuring and reporting performance is a key component in targeting continuous improvement. It is also essential in the communication processes between different levels inside an organization. The KPIs help managers to compare their operations with other facilities, identify if and where improvements are needed and to determine if it is meeting its asset management goals and objectives.

1.2 Operation and Maintenance for Building Facilities

The quality of building performance measurement system depends mainly on the proper definition, selection and organization of KPIs to provide relevant and reliable information on which the management decisions and actions will be taken. Unstructured and haphazard selection of KPIs leads to waste of time and effort in data collection and incomplete or misleading performance information and hence, leads to a low level of building performance.

Evidence from the literature reviewed suggests that building performance monitoring is an amalgam of at least four aspects of facilities provision and their ongoing servicing as functional facilities: 1) the appropriateness of the current asset base in meeting business objectives; 2) the provision of a satisfactory working environment for occupants and customers; 3) the minimization of operating and maintenance costs by managing the condition of the existing facilities; 4) the performance of the facilities as functional, operational assets supporting business processes [67].

In the process of optimizing buildings' performance, organizations must balance the interdependent and competing outcomes of asset performance aspects, in order to achieve their optimum service level. The purpose of this research is to: 1) determine the primary and secondary asset management and maintenance KPI's which could be possibly used in any facility performance practice,s and which are considered as core indicators for facility performance; 2) compose a System Dynamics Model for studying the effect of these indicators on each other and how this could help in achieving the organizational goals and help in decision making process.

1.3 Problem Statement

The starting point of performance measurement is a conceptual model that can be applied as a framework for identifying and developing the necessary performance indicators that meet the objectives of any performance measurement effort which at the end meets the organizational goals. The organizational plan can be divided into three levels. The first level contains organizational goals, which focus on different

stakeholders by achieving a set of goals that are believed to develop or enhance the organization. The second level is the level which supports these organizational goals and which commonly known as the facility performance assessment level. This level involves setting targets for different aspects of facility's operation, such as personnel (e.g. recruiting, training, retaining), maintenance issues (e.g. frequency, quality), environmental issues (e.g. noise, air quality, aesthetics), space (e.g. amount of space, quality of space, privacy), among other factors [46].

The third level, where at this level metrics are set (performance indicators PIs) to help measure past, analyze present, and predict future. These metrics are used to measure and calibrate the successfulness of the current applied plan and identify the necessary actions needed to achieve the preset targets at the second level. In other words, each lower level in this hierarchy supports reaching to the higher level, hence, the KPIs selected at this level help in achieving the organizational goals at the first level. The scope of this research is limited to the third level, which focus on defining and selecting the relative key performance indicators (KPIs) in order to set facility performance assessment measurement system. The proposed model studies the facility performance from three aspects only: Financial, Physical and functional through constructing a system dynamics model which studies the correlation between these KPIs as depicted in Figure 1.1.

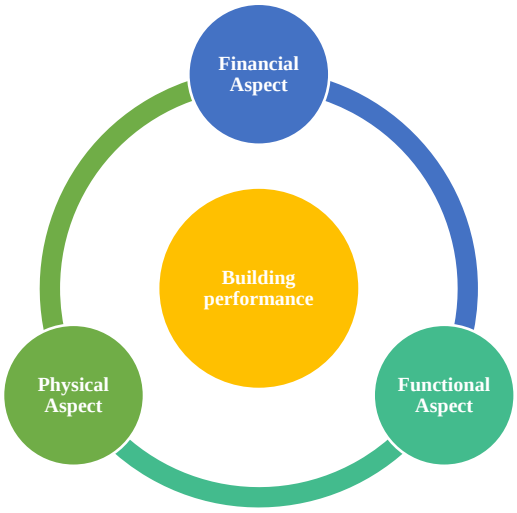

Figure 1.1: Building Performance Considered Aspects

1.4 Research Objectives

The main objective of this research is to provide a decision support tool that aids in selecting the maintenance policy that should be followed to achieve the desired performance for the building under maintenance by means of creating a system dynamics model. To achieve the main objective, the following steps are carried out:

1) studying the most effective and core quantifiable key performance indicators (KPIs) to assess the performance of an operated and maintained facility;
2) creating a system dynamics model to portray the correlations between the identified core KPIs;