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# PERFORMANCE-BASED CONTRACTS OPTIMIZATION FOR ENHANCED ROADS' CONDITION

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**Abstract:** Performance-based contracts (PBC) for highways are increasingly becoming an attractive mechanism for transferring traditional public sector activities to private duties. Increased financial pressures on governments, user demands for improved service levels, and the operational efficiencies offered by the private sector, all create a strong business case for PBC. This paper develops a series of mathematical optimization models that allow municipalities (pre-contract) to define: (1) performance indicators; (2) their threshold levels; and (3) appropriate penalties' and incentives' levels. Furthermore, its ability is expanded for post-contract decisions such that; it aids maintenance contractors in selecting the optimal M&R plan for both project and network-levels while minimizing the Life-Cycle Costs (LCC) and meeting the performance indicators' limits. The developed system extends the typical functionality of traditional pavement management systems to cover specific PBC contractual requirements. It revolves around four models: (1) asset inventory, which includes all the necessary physical, climatic, and traffic information, (2) deterioration models; where defect-specific pavement deterioration models are developed using multivariate regression and stochastic network-level deterioration models are developed using markov chains, (3) life cycle costing models; which are developed to cover specific financial obligations in PBC like penalties and incentives, in addition to traditional M&R expenditures, and (4) optimization engine; where genetic algorithms was used to trade-off various decisions. The models were applied to a 100-km rural highway in the Northeastern Egyptian governorate and the results showed the drastic effect of the penalties/incentives limits on the LCC and Pavement Condition Index (PCI), displaying a 12% increase in the LCC with 4% improvement in the PCI. In conclusion, the developed system is an effective tool for municipalities and contractors to make informed pre-contract and post-contract decisions on their approach to contractual risk allocation and M&R planning respectively.

## 1 INTRODUCTION

Performance-based contracts (PBC) are recently becoming an attractive contracting mechanism for several municipalities. It can be used as a standalone method of outsourcing road maintenance activities or part of a more comprehensive Public-Private Partnership (PPP) scheme where; the proponent is responsible for other activities such as: design, construction, financing (in case of new road infrastructure), and operations and toll collection. The increased reliance on PPP as a delivery method for new roadway construction projects is increasing the interest in better managing the performance and level of service provided to users. In spite the surge of interest in PPP, numerous PPP infrastructure projects have run into financial problems. For contractors that enter PPP consortia and are unfamiliar with the risks (and potential rewards) of managing a PBC, traditional pavement management approaches and technologies can lead to excessive costs, failure to meet contractual performance criteria, and applications of contractual penalties. A recent study by Oyedele (2013) examined 36 critical success factors that would help service providers avoid payment deductions in a PPP contract. Interestingly, the top 4 factors, all related to proper structuring of performance specifications and Key Performance Indicators (KPIs) are: 1) the strong interface among output :specification, KPIs, and performance monitoring systems; 2) the quality of service delivery to meet the requirements of output specification; 3) clear and transparent output specification; and 4) routine self-monitoring of performance and regular internal audit by Private Finance Initiative/Facility Management (PFI/FM) contractors.

Properly structuring contractual performance criteria and thresholds for applying penalties (or if applicable incentives) has been listed as a key requirement for successful implementation of PBC for road maintenance (De la Garza et al. 2009). One of the key tools used by entities responsible for pavement preservation is pavement management systems (PMS). Since their introduction in the early 1980s, PMS have served as a tool to store road condition data, forecast future condition based on likely deterioration factors, and select optimal treatment technologies based on the types of defects. PMS tools were primarily geared towards method-based road maintenance contacts that are self-performed by municipalities. The degree to which these tools can serve the needs of PBC has been questioned (Bemanian et al. 2005 and Jeong et al. 2014). In order to better support the implementation of PBC for road maintenance, the following areas of improvement have been noted for traditional PMS:

1. Ability to forecast a wide range of performance indicators that are commonly found in PBC.
2. Support to better understand the trade-offs between contractual thresholds of performance indicators and overall lifecycle costs during the contract period (the performance-cost trade-off).
3. Support to better understand the impact of contractual penalties and incentives on the eventual road performance and life cycle cost.

## 2 BACKGROUND

PBC is a special type of contracts that was conceptually designed to increase both the efficiency and effectiveness of infrastructure maintenance. It is similar to the PPP but limited to the operation and maintenance of the assets, without construction. Thus, it targets the operation and maintenance of the already-built infrastructure. It is “a type of contract that focuses on the outputs, quality, and outcome of the service provision and may tie at least a portion of the maintenance contractors’ payment as well as any contract extension or renewal to their achievement.” (Martin 2003). In other words, it is a “type of contract under which the maintenance contractor undertakes to plan, program, design, and implement maintenance activities to achieve specified short and long-term condition standards for a fixed price, subject to specified risk allocation” (Frost and Lithgow 1998). Simply, it sets forth the final expected performance rather than directing the maintenance contractor with the methods and materials to achieve the expected performance. It dates back to the second half of the 1970s and was developed by the US Department of air force defense (Ozbek 2004). Throughout 20 years of struggling, the Office of Federal Procurement Policy issued several pamphlets, guides, and best practices for PBC. Based on these efforts, many municipalities in the US started to convert their contracts to PBC under a pilot project. These municipalities were pleased with the maintenance contractors’ performance, where they reported an average of 15% reduction in the contract price and 18% improvement in the roads’ quality levels. In addition, Zietlow (2004) declared that a cost reduction between 10% and 20% took place in Australia, United States, and New Zealand after the application of PBC. Table 1 shows the cost savings of the PBC over the conventional contracts in different countries (Stankevich et al. 2009).

Table 1: *PBC cost savings over conventional contracts (Stankevich et al. 2009)*

| Country Cost savings, % | Cost Savings (%) |
|---|---|
| Norway About 20-40% | About 20% - 40% |

| Country Cost savings, % | Cost Savings (%) |
|---|---|
| Sweden | About 30% |
| Finland | About 30% - 35%; about 50% less cost/km |
| Holland | About 30% - 40% |
| Estonia | 20% - 40% |
| England | 10% minimum |
| Australia | 10% - 40% |
| New Zealand | 20% - 30% |
| USA | 10% - 15% |
| Ontario, Canada | About 10% |
| Alberta, Canada | About 20% |
| British Columbia, Canada | Some of might be in the order of 10% |

## 3 OBJECTIVES

Even though PBC has been successfully applied to several counties, the main concern of defining proper KPIs' limits to guarantee an acceptable level of service. Most of the previous scholars focused on the the contractual and risk management aspects of these contracts and missed the direct link between PBC and PMS. Therefore, this paper aims at linking the missing gap through developing a series of mathematical optimization models and a computational tool that allows municipalities and contractors to better structure the following contractual conditions in a PBC for road maintenance:

1) Selection of the performance indicators;
2) Definition of threshold levels for performance indicators; and
3) Decision of the appropriate levels of penalties and incentives.

The availability of such models and tools will allow municipalities and contractors that are unfamiliar with PBC to make more informed decisions on their approach in allocating the contractual risks.

## 4 METHODOLOGY

The overall framework for the research revolves around core computational modules as shown in Figure 1: 1) asset deterioration module, 2) financial module, and 3) prioritization/optimization module. The asset deterioration model uses existing roadway characteristics, traffic flow data and current condition resulting form the inspection module to forecast future roadway condition throughout the duration of the contract. Future roadway performance forecasts are aligned with any proposed performance indicators in the PBC (i.e. surface condition (PCI), level of service (IRI), etc…). Typical existing roadway characteristics such as: road segment lengths, widths, pavement type, and existing distresses are inputted to the central database in the asset inventory. Existing and forecasted traffic flow on the roadway throughout the duration of the PBC impacts both the expected deterioration rates and potential revenue generation in case the PBC is part of an ownership-based public private partnership (Jeerangsuwan et al. 2014). Deterministic forecasting using regression-based performance and stochastic forecasting using 5-state markov chains have been modelled. This paper will focus on the deterministic models as will be described later on. The financial module is based on estimates of roadway maintenance and rehabilitation costs throughout the duration of the contract. The model considers several typical maintenance and rehabilitation activities (crack sealing, patching, asphalt overlays, reconstruction, etc…) based on the types of distresses forecasted by the asset deterioration model. These activities can be modified and adjusted to suit local conditions and road maintenance practices. To simplify the model, costs are modelled as fully deterministic variables throughout the duration of the PBC. Uncertainties regarding cost estimates and their impact on viability of PPP in roadways have been addressed in a previous study (Osman 2005). The optimization module is developed to meet needs that arise within a PBC setting. In this paper, three optimization scenarios were developed, based on the following contractual conditions: 1) contract duration, 2) types and targets of indicators used to monitor performance, and 3) thresholds for triggering performance penalties and incentives. The formulation of these scenarios will be discussed in the upcoming sub-sections. Due to the complex nature of the optimization models, genetic algorithms were used. The engine allows both contractors and owners to simulate the impact of changes in PBC conditions to determine: 1) minimum lifecycle costs for the contract; 2) optimal maintenance and rehabilitation plans; and 3) optimal blend of performance indicators and penalties/incentives in a PBC.

The system is flexible to work in different contract phases (i.e. pre-contract and post-contract) and meet the requirements of the two contractual parties, municipalities and contractors, giving them the opportunity to: 1) plan for the budget through predicting the future expenditures needed for the highway to keep it in an acceptable level of service; 2) formulate an appropriate KPIs' and penalties/incentives (P/I) system, through an annual allowable budget for each highway, which allows the maintenance contractor to provide an acceptable monthly Maintenance and Rehabilitation (M&R) expenses; 3) conduct sensitivity analysis to evaluate the impact of changing the KPIs' limits and P/I system on the Life-Cycle Costs (LCC) and Pavement Condition Index (PCI). This will enable the municipalities choose the optimal KPIs' and P/I system that fits their budget. Furthermore, it will assist them in forecasting their future budget limits for maintaining each highway; 4) select the optimal M&R plan for a network/highway that both minimizes the LCC and meets the KPIs' limits; 5) conduct a trade-off analysis for the cases of minimizing the LCC from one side and maximizing the network/highway condition from the other side; and 6) distribute their resources properly throughout the network. It gives the contractors the full control to assign a limiting constraint, representing the number of M&R activities that could be conducted annually, to avoid the application of any penalties for failure to meet the contractual KPIs'.

### 4.1 Deterioration and future prediction module

The deterioration models are structured such that they support performance-based evaluation and forecasting of roadway under a PBC. Due to the fact that this paper deals with pavement maintenance, the following condition-based KPIs' were chosen: 1) International Roughness Index (IRI), 2) Rutting Depth, 3) Alligator cracking extent, 4) Surface Rating, and 5) Pavement Condition Index (PCI). The PCI integrates the other indicators as displayed in Equation 2. However, the developed model is flexible to account for other KPIs provided that their pattern is clearly understood, and their P/I application is well-defined. Independent variables used in the regression models include pavement age and Average Annual Daily Traffic (AADT). The regression model forecasts the value of each KPI, assuming no maintenance or rehabilitation, using the equations adopted from Abu-Samra et al. 2017. A sample of the IRI calculation could be displayed in Equation 1.

[1] $IRI_{in_i} = \{[(12.793 * N) + \langle(5.72 * 10^{-5} * AADT) * (1 + T)^{N}\rangle] * 0.057829\}$

[2] $PCI_{in_i} = \{\left(35\% * IRI_{in_i}\right) + \left(15\% * Rd_{in_i}\right) + \left(15\% * AG_{in_i}\right) + \left(35\% * SR_{in_i}\right)\}$

Where; $IRI_{in_i}$ is the annual initial IRI before applying any M&R; $i$ is the number of years (age) counter; $PCI_{in_i}$ is the annual initial PCI before applying any M&R; *N* is the number of years (age) of the highway; *T* is the annual traffic growth rate (%); and *AADT* is the annual average growth rate.

To represent the impact of M&R, the aforementioned equations are expanded to include the effect of various M&R methods. A binary variable *Xij* is introduced to represent the decision to undertake M&R method j on pavement section i. The suitability of any M&R method depends on the types and extent of defects on the pavement surface. As such applying a specific M&R method may have varying degrees of influence on a contractual KPI (i.e. crack sealing cannot improve alligator cracking and has a minor impact on IRI). A sample of the IRI computation, highway condition index (HCI) and new age could be displayed in Equations 3, 4, and 5 respectively.

[3] $IRI_{cal_i} = \sum_{j}^{j=m}\{\left[\left(12.793 * (X_{ij} * N_{new})\right) + \langle(5.72 * 10^{-5} * AADT) * (1 + T)^{(X_{ij} * N_{new})}\rangle\right] * 0.057829\}$

[4] $HCI = \frac{\sum_{i}^{i=n}(PCI_{cal_i})}{N}$

[5] $N_{new} = DE_j * N$

Where; $IRI_{cal_i}$ is the predicted IRI after M&R application; $\mathrm{j}$ is the M&R methods counter; $\mathrm{m}$ is the total number of maintenance methods; $\mathrm{n}$ is the total number of contractual years; $DE_j$ is the decision effect on the age (0% ➔Not Applicable M&R method on the KPI (N/A) and x% ➔ effect of each M&R method on each KPI); $\mathrm{N_{new}}$ is the new age of the pavement section after applying a certain M&R method; and $\mathrm{X_{ij}}$ is the decision variable that represents undertaking M&R method j on pavement section i. It is represented through numerical integers ranging from 0 for a "Do nothing" to m for M&R method m.

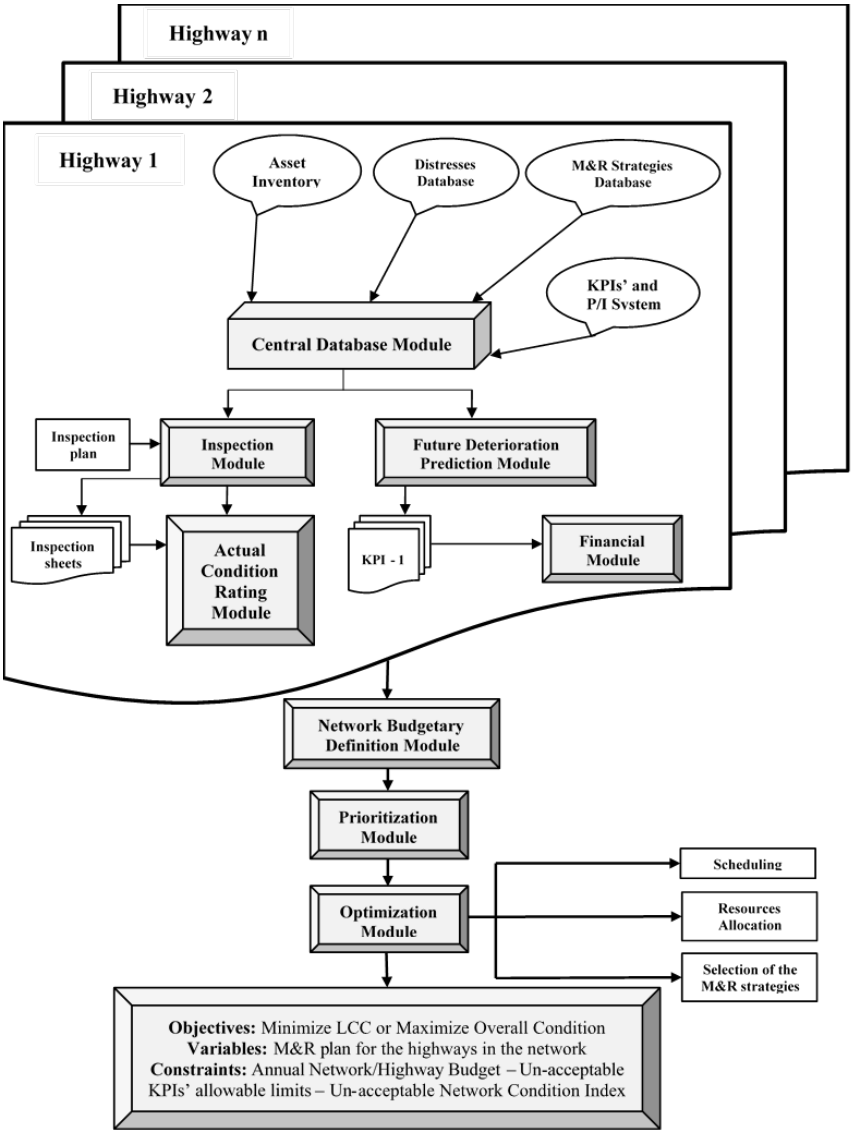


Figure 1: Research framework

### 4.2 Financial module

The requirements of a financial module is accomplished by extending traditional LCC models through adding costs for performance penalties (PEN) and performance incentives (INC). These are in addition to the rehabilitation costs (RB) and the preventative maintenance costs (PRM). Each cost element is calculated, based on the pre-defined contractual criteria. Total LCC is calculated for all expected future expenses including any penalties or incentives in the contract. Net present value (NPV) is used as the base evaluation metric. The calculation for each cost element and the total LCC are adopted from Abu-Samra et al. 2017. A sample of the penalties and LCC computations could be displayed in Equations 6 and 7.

[6] $PEN_{total} = \sum_{i}^{i=n} \sum_{d}^{d=r} \{ (P_{u_d} * Ap_{ij}) * (1 + in)^n \}$

[7] $LCC_{total} = \sum_{i}^{i=n} \{ PRM_i + RB_i + PEN_i + INC_i \}$

Where; $PEN_{total}$ is the total penalties as per defined in the contract; $LCC_{total}$ is the total LCC spent for this highway; $Ap_{ij}$ is the annual applicability index for each cost item based on the contractual KPIs' limits are defined in the contract. They are represented on a binary scale where; 0 ➔ Not applicable (N/A), 1 ➔ Applicable; *d* is the KPI calculator; and $\mathrm{P}_{\mathrm{u_d}}$ is the penalty unit cost for KPI 'd'.

### 4.3 Optimization module

The outputs of the performance-based deterioration model and lifecycle costing model are inputted to the optimization module. Based on various contractual conditions three optimization scenarios are developed as discussed in the upcoming sub-sections.

### 4.3.1 Constrained budget-performance determination

This scenario aids municipalities in preparing the KPIs' and P/I system to enforce the contractors meet the pre-defined contractual limits with a constrained highway agencies budget. The optimization attributes could be mathematically formulated through Equations 8 to 14:

[8] $Minimize\ LCC_{total}$ - Subject to the following constraints:

[9] $PCI_{cal_i} < PCI_{LT}$;[10] $HCI < PCI_{LT}$; [11] $SR_{cal_i} < SR_{LT}$; [12] $IRI_{cal_i} < IRI_{LT}$; [13] $AG_{cal_i} < AG_{LT}$; [14] $LCC_i < HBT_i$

The constraints represent the previously-defined indicators as well as the available budget ($HBT_i$). Integer programming was used to represent the decision variable. The decision variables, representing the M&R methods are (0) Do Nothing, (1) Crack Sealing; (2) Slurry Sealing; (3) Micro-Surfacing; (4) Thin Overlay; (5) Structural Overlay; (6) Patching; (7) Milling and Filling; (8) Deep Patching; and (9) Re-Construction.

### 4.3.2 Optimal M&R plans under performance constraints

The risks that the maintenance contractors bear in the PBC are usually much more than those in the traditional contracts. Those risks are more comprehensive and are associated with a P/I system. Performing a series of what-if scenarios would investigate the financial effect of changing the contractual KPIs' and P/I system. Therefore, these scenarios would support in achieving optimal M&R plans where, municipalities can track the impact of increasing the KPIs' allowable limits and the P/I system on the KPIs' from one side and on the LCC from the other side. Furthermore, it allows municipalities inform the users with the budget increase to improve the level of service. This will be further discussed in results and analysis section.

### 4.3.3 Multi-objective Optimization

The balance between LCC and delivered performance is a key asset management decision. Cost and performance are naturally conflicting objectives, which lend themselves well to goal optimization principles. The goal optimization formulation can consider multiple, conflicting and incommensurable objectives, which is the case with the time, cost and criticality objectives (i.e. minimal acceptable KPI limits) (Schniederjans 1995). Goal optimization, sometimes referred to as goal programming (GP), is a mathematical optimization technique that is quite similar to linear programming but has the capability to handle several conflicting goals (Lee and Nwak 1999). In GP terminology, a set of goals, Gi, where i=1, 2, 3, …, n, need to be achieved simultaneously. The objective function is then formulated to minimize the sum of deviations from these prescribed goal values.

The optimization process proceeds in a two-stage process. First two distinct single-objective optimization problems are solved considering each objective separately followed by a multi-objective optimization where all the objectives are considered simultaneously. For the single-objective optimization, each solution is different and yields different LCC and HCI goals. The formulation uses HCI as a proxy for performance but can be extended to consider all contractual KPIs. Secondly, the objective function is formulated such that normalized deviations from goals are minimized to reach a zero (0) deviation from the budget and condition pre-defined limits. The objective function could be formulated in Equation 15:

$$[10]\ Minimize\ DEV_{total} = \left(\frac{LCC_{total}-LCC_{limit}}{LCC_{limit}} + \frac{HCI_{limit}-HCI}{HCI_{limit}}\right)$$

*Where;* $\mathrm{DEV}_{\mathrm{total}}$ is the overall budget and condition deviation; $LCC_{limit}$ is the life cycle cost pre-defined limit for the highway under study within the life cycle time; and $HCI_{limit}$ is the minimum allowable highway condition index that could be reached even after applying the P/I system.

## 5 RESULTS AND ANALYSIS

The system was applied on a 200 Km-long rural highway (100 Km per direction) in North Eastern Egyptian governorate of Al-Ismailiyah, which is owned and operated by the General Authority for Roads, Bridges and Land Transport. The case study was divided into 4 sections, divided as follows (62 Km, 38 Km, 38 Km, 62 Km), with 35 segments with an increment of 6 Km. The rationale behind choosing this local case study is its unique international dimension. Cairo-Ismailiyah highway is an example of a third-world country horizontal infrastructure connecting between an international waterway (Suez Canal) and a large cosmopolitan consumption center (Greater Cairo). Furthermore, Cairo-Ismailliyah highway is characterized by its' heavy traffic, which results in an increased deterioration rate and a higher need for M&R actions. In this case, the PBC contractual-analysis period was chosen to be 25-years. However, the actual data available from the highway agency was for only for 8-year of traditional contracts given that PBC has not been used yet in the Egyptian highway maintenance program because of the escalated contingencies resulting from the increasing uncertainties.

To display the link between the KPIs' and the LCC and PCI, a sensitivity analysis was carried out. It opts at measuring the impact of changing the the KPI's allowable limits and/or P/I system on the financial and/or condition. It starts by running the baseline case and hence after, calculates the new allowable limits for the other six cases, ranging between a -30% and 30% with a 10% increment. Then, the optimization model runs the other cases to obtain the lowest LCC and highest PCI based on the pre-defined KPIs and P/I. The results of the system were promising and showed a better utilization for the financial resources to achieve a better condition. The different scenarios are discussed in the upcoming sub-sections.

### 5.1 KPIs' effect on the M&R costs and P/I system

The first scenario was changing the KPI's allowable limits with increments of 10% to track the impact on both the LCC and PCI along the contractual analysis period. This scenario aids the municipalities identify appropriate KPIs' thresholds in the early pre-bidding phase through analyzing the effect of increasing/decreasing the KPIs' thresholds on both the M&R costs and accordingly P/I system. The results showed that the KPI's allowable limits have a non-uniform direct proportional relation with both the M&R costs and PCI. This could be shown in Figure 2 where it was apparent that a 19% savings in the M&R costs was obtained in the 30% KPIs' allowable limits decreasing scenario, reaching a 49% PCI. On the contrary, a 17% jump in the LCC was obvious in the 30% improvement scenario, reaching a 91% PCI. Furthermore, it was obvious that the KPI's allowable limits are directly proportional with the penalties as shown in Figure 4 where the penalties decreased by 19% in the 30% KPIs' allowable limit decreasing scenario. However, they increased by 17% in the 30% improvement scenario. Finally, the analysis showed an inversely proportional relation between the KPI's allowable limits and the incentives where; the incentives increased by 14% in the 30% KPIs' allowable limit decreasing scenario. Conversely, they decreased by 8% in the

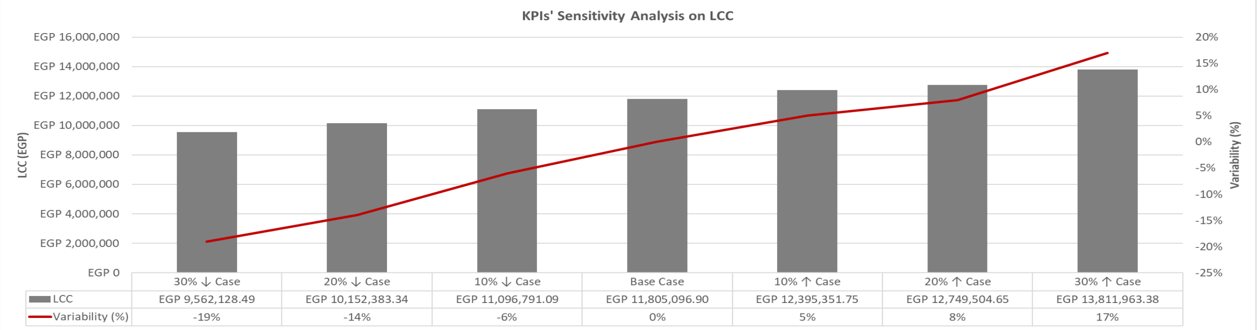
30% improvement case. In the case where; PBC is fully or partially funded from a road toll, this analysis will allow the highway agencies to communicate and accurately predict the following: 1) what service improvements can be attained from increasing a road toll and diverting the revenue to a PBC; and 2) what loss in level of service will result if there is a public demand to reduce road tolls.

### 5.2 Penalties effect on the LCC

The second scenario was changing the value of the penalties applied in case of not meeting the KPI allowable limits, by increments of 10%. This scenario helps municipalities evaluate the impact of increasing/decreasing the penalties on both the LCC and PCI. The optimization module was run to solve the minimization problem while considering the new penalties of the different what-if scenarios. The results showed an inversely proportional relation between the penalties and the LCC where; an 11% savings in the LCC were obtained in the 30% penalties decreasing scenario, reaching a 39% PCI as shown in Figure 4. However, a 13% jump in the LCC was resulted in the 30% improvement scenario, reaching 94% PCI.

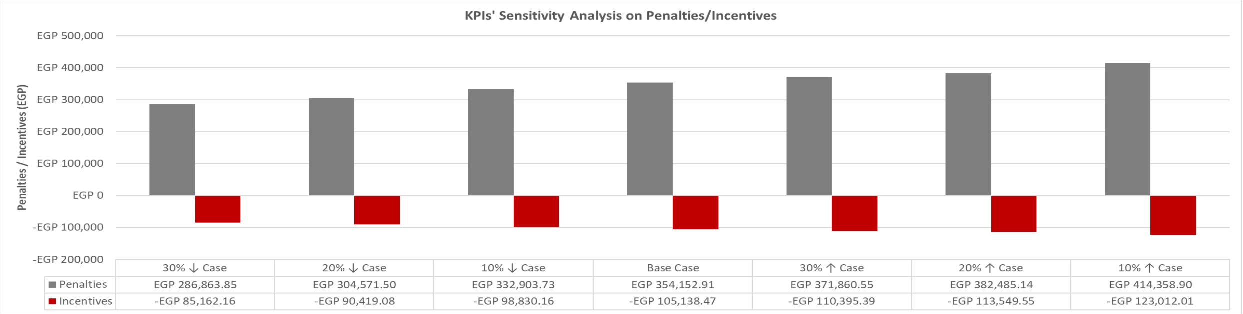
### 5.3 Incentives effect on the LCC

The last scenario was changing the value of the incentives applied in case of not meeting the KPI allowable limits by increments of 10%. This scenario helps municipalities evaluate the impact of increasing/decreasing the incentives on both the LCC and PCI. The first step was the definition of an incentives system to calculate the variability in the incentives based on. The optimization module is then applied to solve, taking into consideration the new incentives, for a minimal LCC. The results showed a directly proportional relation between the incentives and the LCC where a 9% savings in the LCC were obtained in the 30% incentives decreasing scenario, reaching an 89% PCI as shown in Figure 6. However, a 12% jump in the LCC was achieved in the 30% improvement scenario, reaching 62% PCI.



| | 30% ↓ Case | 20% ↓ Case | 10% ↓ Case | Base Case | 10% ↑ Case | 20% ↑ Case | 30% ↑ Case |
|---|---|---|---|---|---|---|---|
| LCC | EGP 9,562,128.49 | EGP 10,152,383.34 | EGP 11,096,791.09 | EGP 11,805,096.90 | EGP 12,395,351.75 | EGP 12,749,504.65 | EGP 13,811,963.38 |
| Variability (%) | -19% | -14% | -6% | 0% | 5% | 8% | 17% |

Figure 2: KPIs’ sensitivity analysis on LCC



| | 30% ↓ Case | 20% ↓ Case | 10% ↓ Case | Base Case | 30% ↑ Case | 20% ↑ Case | 10% ↑ Case |
|---|---|---|---|---|---|---|---|
| Penalties | EGP 286,863.85 | EGP 304,571.50 | EGP 332,903.73 | EGP 354,152.91 | EGP 371,860.55 | EGP 382,485.14 | EGP 414,358.90 |
| Incentives | -EGP 85,162.16 | -EGP 90,419.08 | -EGP 98,830.16 | -EGP 105,138.47 | -EGP 110,395.39 | -EGP 113,549.55 | -EGP 123,012.01 |

Figure 3: KPIs’ sensitivity analysis on penalties/incentives

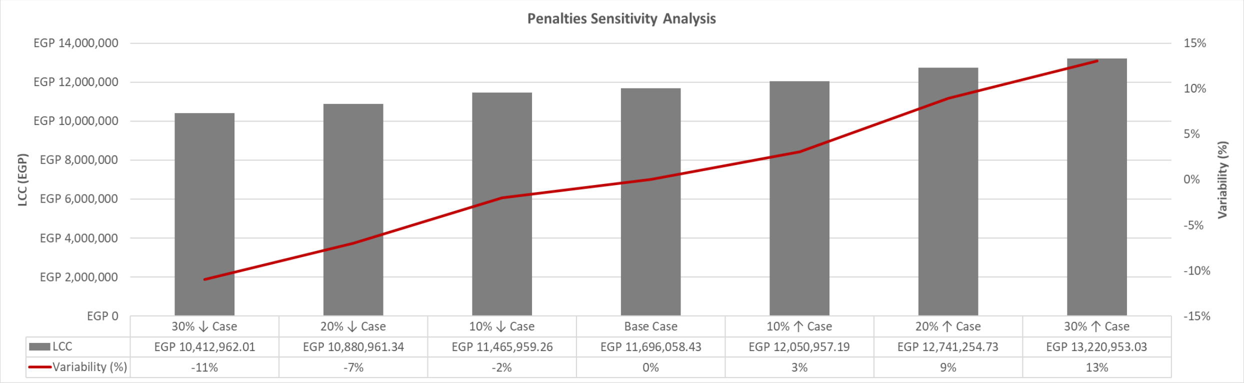


Figure 4: Penalties sensitivity analysis on LCC

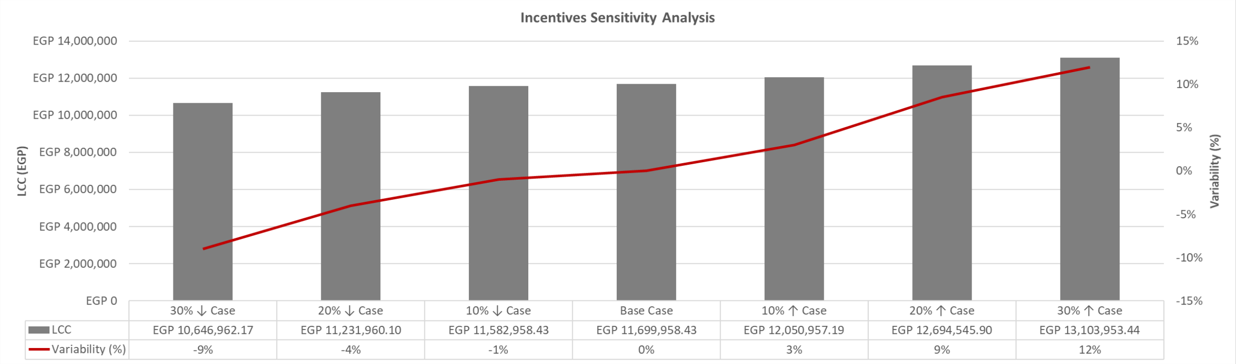


Figure 5: Incentives sensitivity analysis on LCC

# 6 CONCLUSIONS

Increasing trends of private sector involvement in the delivery of road operations and maintenance activities has not been matched with a similar increase in computational tools to support optimal management and decision making under their unique contracting frameworks. This research presents an overall framework and a series of optimization models to help municipalities and contractors to better structure and manage PBC. The presented models are effective during both the pre-bidding and contract implementation phases. During the pre-bidding phase, municipalities can use these models to 1) select the most appropriate contractual KPIs and their thresholds; 2) determine the most appropriate level of penalties and incentives to include in the contract; and 3) develop a preliminary budget for the PBC. Maintenance contractors can benefit from these models by 1) determining the most optimal M&R plans under given contractual conditions; and 2) developing a detailed project budget for the PBC. During the contract implementation phase, the tools can be used by both parties for managing and controlling the PBC. After applying the models to a 100 Km-long rural highway in North Eastern Egyptian governorate, the results showed the drastic effect of the P/I limits on both the LCC and PCI. The LCC will experience a 12% jump for increasing the PCI threshold by 30% to reach a network condition index of 62%.Furthermore, the KPI sensitivity analysis showed the considerable effect of KPI limits variability among the M&R costs, P/I, and PCI. In the 30% improvement scenario, 17% increase in the penalties and 8% decrease in the incentives were experienced. The results were a 17% jump in the LCC while reaching 91% PCI.

Even though the model is a good starting point for linking the PBC and PMS, the future work is required to overcome some of the limitations that include: 1) expanding the cost model to capture user and third party costs from enhanced roadway performance; 2) incorporation of the impact of M&R activities on road capacity and levels of service; 3) integrating the model with construction resource planning and optimization for M&R activities; 4) precisely estimating the after-repair behavior of each KPI as it’s not always the same as the before-repair behavior; and 5) integrating the network data through spatial GIS technologies to facilitate the management and decision-making processes for highway agencies.

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