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THE BENEFIT EVALUATION FRAMEWORK OF USING PERFORMANCE-BASED CONTRACTING IN URBAN ROAD MAINTENANCE

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Abstract. Performance-based contracts (PBC) have been adopted increasingly in various countries. However, establishing an objective and convincing benefit evaluation framework to facilitate promotion remains a significant challenge for those who wish to use PBCs. A recent study introduced PBC in the context of daily inspection and repair of urban roads. The pilot program in that study successfully addressed the needs of road users, road maintenance authorities, and contractors. Consequently, this study develops the benefit evaluation framework for this type of PBC for broader applications. The proposed benefit evaluation framework, consisting of one qualitative and eight quantitative performance-evaluation items, calculates the effectiveness of introducing PBC to verify its practicality. The validation results show that qualitative benefit evaluation using the Pavement Condition Index achieves a "satisfactory" rating. For the quantitative benefit evaluation, an overall benefit-cost ratio (BCR) of 5.35 suggests that it is economically viable. The developed benefit evaluation framework can be used as a simple and easy-to-use evaluation tool for other organizations to assess whether to introduce PBC. This study fills this research gap by addressing the use of PBCs in the maintenance of all categories of toll-free roads, and contributes to expanding the application of PBCs in road maintenance services.

Keywords: performance-based contract, urban road maintenance, performance index, benefit evaluation, benefit-cost ratio.

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1. Introduction

The World Bank defines a performance-based contract (PBC) as "a type of contract in which payment for the deliverable is explicitly linked to the contractor's successful meeting or exceeding certain clearly defined performance indicators" (Gericke et al., 2014). With its emphasis on output and results, PBC has been utilized worldwide for over 20 years and has been applied in various fields with good results. PBC is mostly used for highways or major roads in the road sector. The contractor is responsible for large-area pavement rehabilitation and maintenance over a long warranty period. The contractor is paid after the performance index has been measured and achieved (Asian Development Bank, 2018). Under the PBC performance mechanism, the contractor must renew the road pavement and invest heavily in the initial phase of performance. The effectiveness of PBC can only be evaluated through the execution of long-term contracts and savings in the subsequent maintenance phase. Previous studies have analyzed the effectiveness of road maintenance authorities and road users under the PBC mechanism (Fallah-Fini et al., 2012), but have neglected the central role of PBC implementation; that is, contractors pose a serious challenge to the acceptance of PBC in the marketplace in the future. However, for the authorities to introduce a PBC, there is a need for a holistic, objective, and easy operational framework for benefit evaluation that can be evaluated quickly to inform decisions on promotion. Similar concepts have been identified in previous studies (Piñero & de la Garza, 2003; Sultana et al., 2012). For instance, to ensure the comprehensiveness and reliability of the evaluation process for PBC, a study introduced a five-area framework encompassing level of service effectiveness, cost-efficiency, timeliness of response, safety procedures, and quality of services (Piñero & de la Garza, 2003). The proposed framework has confirmed that PBC offers a more comprehensive and accurate approach compared to traditional contracts. It is worth noting that existing evaluation approaches have primarily focused on highway or major road maintenance, highlighting a clear gap in providing a benefit evaluation framework for urban road maintenance and for a new PBC user who requires instant evaluation outcomes.

The traditional methods of maintenance contracts for urban roads are unit price contracts in which the city road maintenance authority appoints a contractor to carry out the work and pays the contractor according to the manpower and repairs they dispatch. This type of contract is more concerned with the process of execution than the outcome. Furthermore, urban roads, often provided free of charge to users, present a challenge in terms of quality improvement due to the difficulty of allocating significant budgets, which can be comparatively easier in toll roads. The problems faced include the perceived poor quality of the road by the road user, the administrative workload of the authority, and the low flexibility of the contractor in terms of work and resource deployment (Yang & Chang, 2020). A previous study reported the experience of PBC in the State of Florida, USA, through interviews and surveys, in which identified benefits included cost savings, less administration, and an improved level of service (Fuller et al., 2018). This study introduces PBCs for urban roads focusing on performance outcomes rather than traditional maintenance processes to address issues with traditional contracts.

Unlike traditional large pavement renewal works, the scope of the PBC in this study covers routine patrolling and sporadic repair works on urban roads. The main objective of this study is to develop an implementation model for evaluating the benefits associated with such applications. Additionally, a simple and easy-to-understand framework will be established to assess the effectiveness of these PBCs. This framework will serve as a valuable reference for authorities when promoting and implementing similar applications in the future.

2. Literature review

2.1. Traditional contracts for road maintenance

Traditional contracts for road maintenance work focus on the execution process and not the outcomes. They often suffer from a range of common problems, including escalation of cost and time; poor quality of work and contractors, inadequate motivation of contractors, improper risk sharing between the owner and the contractor; overhead and inspection cost, delay in project completion, high level of political influence and corruption, and shorter road service life (Duran, 2021; Sultana et al., 2013; Winanri et al., 2019). Therefore, a government having a high ambition to renovate governance focuses on solving such problems.

To address the existing problems associated with traditional road maintenance and rehabilitation, adopting a PBC model is a preferable alternative. Drawing from Brazil's experience in improving efficiency in the management of traditional maintenance and rehabilitation, PBC offers advantages such as reduced rehabilitation costs, improved road conditions, and decreased workload for executing agencies (Lancelot, 2010). Recently, the World Bank group reported that inefficiencies, higher costs, and misaligned incentives between governments and contractors are frequently observed in traditional contracts. Achieving quality road maintenance and economic efficiency can be realized through the implementation of PBC (Ogita et al., 2022).

2.2. PBC for road maintenance

Several organizations and academics have been working on the development of PBC models to address the shortcomings of traditional contracts (Asian Development Bank, 2018; Gericke et al., 2014; Stankevich et al., 2009). Gericke et al. (2014) developed a PBC for road-construction projects. They examined unexecuted PBCs, PBC concepts, involvement of professional advisors, tenders, performance at various application levels, and authority/contractor implementation performance. Panthi (2009) developed a pavement performance model based on several performance indicators, including cracking, rut, and coarseness. The model was used to predict pavement deterioration and develop a methodological framework for estimating road maintenance costs. Sultana et al. (2012) suggested that the following relevant issues should be clarified before introducing a PBC: performance specification and setting up a standard, the expertise of the private sector, deciding on the initial project, risk exposures, employee issues, performance monitoring, and payment and termination of the contract. Road maintenance authorities should also consider these issues to introduce and implement PBC for maintenance works successfully. Asian Development Bank (2018) proposed different road maintenance options for Central Asia Regional Economic Cooperation (CAREC) member countries. These options were formulated by taking into account various factors, including maintenance types, maintenance areas, and contract periods. Samra et al. (2017) developed a predictable pavement condition and lifecycle cost model as a reference for contractors to assess whether to bid for road maintenance contracts.

Furthermore, the core elements of performance indicators for PBCs in various countries, including response time (tolerance), service standards, and penalty mechanisms (penalties and liquidated damages) corresponding to performance targets, have been compiled (Zietlow, 2005). Drawing from the experience in the Netherlands where PBC was implemented for highway maintenance, another study highlighted several PBC-induced risks for clients. These risks include challenges in translation and measurement of specifications, the ineffectiveness of incentives, contractors avoiding full responsibility, and contract management issues (Gelderman et al., 2019). Therefore, it is crucial for a government intending to implement PBC to thoroughly examine the potential benefits to ensure the likelihood of success. A previous study by Yang et al. (2023a) has established an implementation model for PBC in urban road patrolling and sporadic repair, that contains three key elements: output specifications, payment mechanisms, and performance monitoring systems. The practical difficulties and coping approaches in using PBC for urban road maintenance are out of research scope, but can be found elsewhere (Yang et al., 2023b). Notably, the above two references serve as the study's foundation.

2.3. PBC benefit assessment

Several studies have explored the benefits of PBC in the context of large-scale highway or main-road pavement maintenance. The benefits can be summarized as follows (Asian Development Bank, 2018; Fuller et al., 2018; Stankevich et al., 2009; Sultana et al., 2012): (1) potential costs reduction, (2) improved level of service, (3) transfer of risk to the contractor, (4) securing an appropriate level of multi-year financing, (5) more innovation for the PBC contractor, (6) more integrated services, (7) enhanced asset management, (8) ability to reap the benefits of partnering, (9) building a new industry and adding new skills to the existing contracting industry, (10) achieving economies of scale, (11) focusing resources on the long-term needs of the asset, (12) completing the conceptual design needs, (13) reduction in the level of corruption, and (14) improved customer satisfaction. Fuller et al. (2018) argued that PBC should be implemented for at least one year to achieve benefits such as cost savings and improved service standards. Anastasopoulos et al. (2010) proposed an approach to estimating cost savings from PBCs using multivariate statistical analysis (ordinary least squares), Tobit, binary logit, mixed logit, sensitivity analysis, and other predictive models to estimate the cost before and after the implementation of PBCs.

Manion and Tighe (2007) presented the results of a PBC for the maintenance of a performance-specified maintenance contracting (PSMC) case, PSMC 001, in New Zealand. The social cost of crashes is being reduced at a significantly higher rate in the PSMC 001 network than in the remainder of the state highway network. The value of savings, above the national trend, was more than NZ$ 31 million for the 3-year period. Fallah-Fini et al. (2012) reported a PBC benefits evaluation case in which the State of Virginia, USA, maintains 180 miles of interstate highway under a traditional contract and another 250 miles under a PBC. They developed an analytical approach for evaluating the relative efficiency of two highway maintenance contracting strategies and confirmed the advantages of PBC. Susanti et al. (2019) explored pilot-road projects in Indonesia; the effectiveness of the PBC reviews in terms of project life-cycle cost efficiency was calculated. Life-cycle cost calculations were conducted by considering the influence of the contracted road's length, initial conditions, and the project duration. Intriguingly, a previous study focusing on pavement markings and markers by PBC in San Antonio (Damnjanovic et al., 2018) reported that PBC implementation did not yield the anticipated benefits, including improved financing, reduced costs, and overall road network improvement. Therefore, there is a continued need for conducting a benefit evaluation for new adopters of PBCs to assess the potential advantages of implementing such contracts in different contexts.

In summary, the PBC benefit assessment issues have been addressed for many years. However, the benefits of using PBC to maintain urban roads have not been discussed. Furthermore, previous studies have mainly focused on qualitative benefits. Only cost savings and service standards were assessed by Fuller et al. (2018). As a result, there is a clear research gap in this area. This study aims to address this gap and serve as a starting point to draw the attention of other researchers to explore and delve deeper into this important issue.

2.4. Benefit-cost analysis approaches

According to the Highway Safety Benefit-Cost Analysis Guide (Lawrence et al., 2018), decision-makers can rely on benefit-cost analysis (BCA) to evaluate and compare the cost-effectiveness of different alternatives. The guide emphasizes that the most efficient alternative, in terms of cost-effectiveness, is the one that yields the highest benefit per dollar spent, resulting in a higher benefit-cost ratio (BCR). The BCA is commonly used by the states' Department of Transportation (DOTs) and national transportation research agencies in the USA when expressing the return on research investment. Therefore, the United States Department of Transportation (USDOT) recommends the use of the BCR or net present value (NPV) for most economic evaluations (Lawrence et al., 2018). A BCR greater than 1.0 indicates that benefits exceed costs and that the project is economically justified; in general, a higher BCR is desirable. The BCR is most appropriate for prioritizing alternatives when funding restrictions are applied (e.g., prioritizing countermeasures or locations within a project with a fixed budget). McCulloch (2021) mentioned that the incremental BCA proposed by Rashedi and Maher (2019) could be estimated for scenarios with an increase in benefits and costs. In evaluating public investment schemes, Babashamsi et al. (2016) proposed that the internal rate of return (IRR), equivalent uniform annual cost, BCR, and NPV are the most commonly used indices. When analyzing long-term public investments, costs are compared at several points for which a discount is necessary.

There is a rich body of literature regarding PBCs. It also examines how the benefits of road projects are evaluated. Some studies have used interviews or questionnaires with experts (Fuller et al., 2018; K. Shrestha & P. P. Shrestha, 2020). Some studies develop mathematical models to estimate benefits but are more complex to calculate, and the results are subject to parameterization and cannot be easily verified (Anastasopoulos et al., 2010). Some studies compare the benefits and costs of two contract implementation cases but mainly explore the benefits for the authority and the user, not considering the contractor (Fallah-Fini et al., 2012). There has also been an assessment of effectiveness based on the BCR but no details of the benefits and costs and the estimation process are available (Lawrence et al., 2018).

In the existing literature, the application of PBCs to the routine inspection and sporadic repair of urban roads has not been discussed, and there is a lack of integration of the needs of key stakeholders, such as road users, road maintenance authorities, and contractors. Although there is a study on using BCR to evaluate benefits, the benefits and costs to key stakeholders have not been fully considered. This study can fill the gaps in research on PBCs for wider applications.

3. Methodology

To address the benefit evaluation challenges associated with the use of PBC in urban road maintenance, this study has developed an innovative benefit evaluation framework. The steps for the framework development are shown as Figure 1. The research methods employed to achieve this objective are organized as follows.

3.1. Development of benefit evaluation framework

Recognizing the limitations of existing benefit evaluation frameworks in measuring the benefits of PBC in urban road maintenance, the development of a new benefit evaluation framework is necessary. Figure 2 illustrates the comprehensive benefit evaluation framework that takes into account the benefits for key stakeholders, including road users, road maintenance authorities, and contractors. Notably, the benefit evaluation items are directly linked to the goals of performance indicators of PBC for urban road maintenance, which have been developed and discussed elsewhere (Yang et al., 2023a). The structure and evaluation details of this innovative benefit evaluation framework will be presented in subsequent sections.

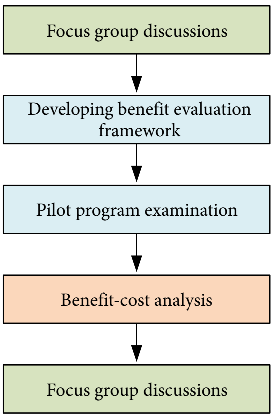

Figure 1. Steps for benefit evaluation framework development

3.2. Pilot program examination

A PBC pilot program was conducted in Zhongshan District, Taipei, the capital of Taiwan, from March to October 2021, using the PBC implementation model developed by this research team to carry out daily road inspections and repairs (Yang & Chang, 2021). The pilot program encompasses maintenance areas totaling 2,536,794 m^2. This study uses the data collected in the PBC pilot program to examine the practicality of developed benefit evaluation framework.

3.3. Benefit-cost analysis

This study proposes an innovative benefit evaluation framework. How to develop suitable benefit evaluation approach plays an essential role for successfully obtaining practical information, and accepted by users considering simple and easy-to-use principles. The economic viability of a public investment alternative is determined by applying the BCA method, which is commonly used to evaluate public investment alternatives, and using a BCR of greater than 1. Lawrence et al. (2018) pointed out that by using BCA, transportation professionals can compare the present value of costs and benefits among alternatives for a given analysis period. The BCA provides the most economically efficient investment alternative. This study adopts BCA for

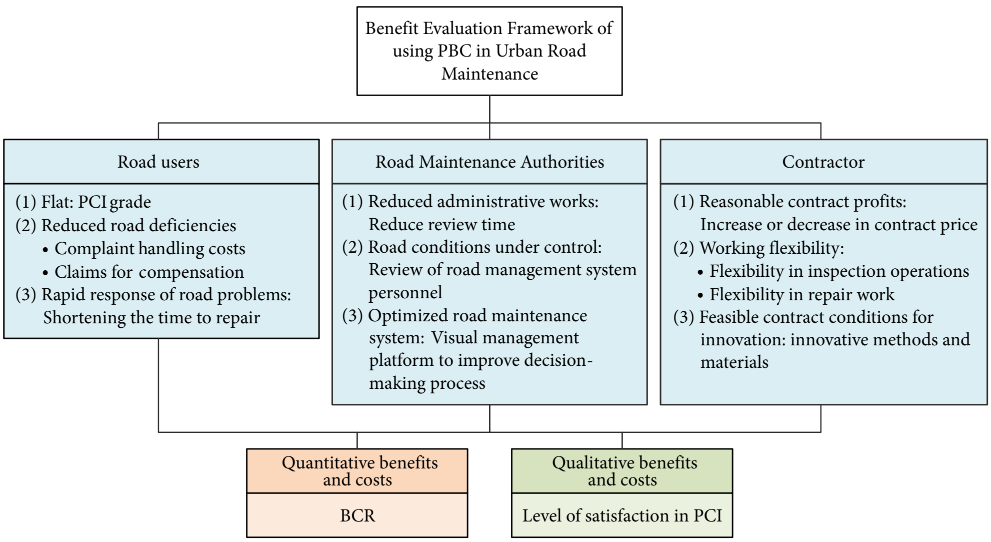

Figure 2. Benefit evaluation framework of PBC

the quantitative benefit evaluation of using PBC to maintain urban roads. Significantly, this study introduces the utilization of BCR as a means to evaluate the benefits of PBC implementation for the first time.

3.4. Focus group discussions

This study utilized focus group discussions as a means to acquire the essential practical information. When it comes to validating the benefits of a new contracting model, the process of obtaining the necessary practical information can be time-consuming and may not yield immediate results. As a result, this study has chosen to adopt a focus group discussion approach instead of relying on field data collection in order to obtain prompt outcomes.

The participants included authorities, supervisors, and contractors with intensive urban road maintenance experience. Table 1 provides a comprehensive overview of all 15 meetings conducted in relation to this study. The initial five meetings, conducted between May 2020 and September 2020, were held to explore the problems of maintaining urban roads with traditional contracts and develop a PBC implementation model to address these problems (Yang & Chang, 2020; Yang et al., 2023a). In order to validate the proposed benefit evaluation framework, a series of ten subsequent meetings were conducted. These meetings served as a platform to gather feedback from participants. This study drew conclusions on each issue based on the consensus reached among all participants in each meeting.

4. An empirical case of adopting PBC for urban road maintenance

4.1. Problems in traditional urban road maintenance approach

This study summarizes several key features of using a traditional road maintenance approach, which are the major concerns for adopting a new contracting approach in Taipei City, and targets evaluating the benefits of using PBC. After extensive observation executed by two research projects (Yang & Chang, 2020, 2021), and interviews with contractors and supervision units, the authors concluded that the traditional approach for urban road maintenance, particularly for road patrolling and sporadic repair works, has the following problems:

- The frequency and working hours of road patrolling are inflexible.
- The contractor is unable to deploy manpower and equipment resources effectively.
- The traditional contract focuses on whether the input resources of the contractor comply with those determined by the contract but it does not control the performance of the maintenance work.
- The contractor must submit the attendance information of personnel and equipment every month, along with before, during, and after photos, and the location, area, and quantity of road repairs to the supervision unit for review. This complicates and lengthens administrative work.

Table 1. Discussion issues and participants for 15 meetings

ID	Date	Discussion issues	Participant's role (number of Participants)
1	May 11, 2020	Problems in traditional contract, possible scope for pilot program	CONS (4), RMA (5), potential CTR (2)
2	May 25, 2020	Problems in traditional contract, performance measures, measurement approach, payment approach	CONS (4), RMA (6), potential CTR (2)
3	Jun. 5, 2020	Problems in traditional contract, performance measures, measurement approach, involving PCI for performance measure	CONS (3), RMA (6), potential CTR (3)
4	Jul. 6, 2020	Problems in traditional contract, commitment for PBC implementation	CONS (5), RMA (12), existing SPV (5), existing CTR (5)
5	Sep. 26, 2020	Problems in traditional contract, PBC in other sectors, obstacles in PBC implementation	CONS (2), RMA (19, including officers in department of accounting and government ethics), existing SPV (3), existing CTR (3), another city's maintenance authority (2)
6	Jan. 8, 2021	Location and duration for pilot program, PBC contract details	CONS (2), RMA (16), potential SPV (2), potential CTR (1)
7	Feb. 25, 2021	Performance monitoring mechanism	CONS (5), RMA (6), potential CTR (3)
8	Mar. 11, 2021	Segmentation in PCI, cost collection for performance evaluation	CONS (4), RMA (7), SPV (2) and CTR in pilot program (3)
9	Apr. 14, 2021	Issues to obtain commitment from management levels	CONS (3), RMA (11), CTR in pilot program (3)
10	May 4, 2021	Budgets for PBC implementation	CONS (1), RMA (6), SPV (2), CTR in pilot program (3)
11	May 17, 2021	Records collection for road performance	CONS (5), RMA (13), SPV (1), CTR in pilot program (2)
12	Jun. 1, 2021	Long-term PBC implementation policy in Taipei City	CONS (5), RMA (8)
13	Jun. 28, 2021	Liability allocation of road maintenance	CONS (5), RMA (9), CTR in pilot program (1)
14	Aug. 26, 2021	Differences between pilot program and other PBC projects	CONS (5), RMA (9), SPV (2), in pilot program (2)
15	Sep. 29, 2021	PBC execution processes, advanced tools for road maintenance	CONS (5), RMA (9), existing SPV (3), existing CTR (5)

Note: CONS = PBC consultant; RMA = road maintenance authority; SPV = supervisor; CTR = contractor.

- The contract stipulates repair techniques, materials, and corresponding unit prices for maintenance works, thereby not providing flexibility to the contractor to propose better repair techniques and materials.
- To receive better compensation, the contractor might not target the most urgently needed improvements, resulting in a waste of money and leaving no budget for the pavement that needs maintenance.
- In Taipei City, dozens of injuries are caused by road defects annually. In municipal satisfaction surveys, citizens often express dissatisfaction with road conditions, indicating that the traditional approach fails to meet the needs of road users.

4.2. PBC for urban road maintenance

PBCs differ from conventional technology- or process-based contracts because output and performance are the main measures. Based on the focus group discussion results, a previous study suggested that the urban road maintenance model should consider the needs of road users, road maintenance authorities, and contractors, as shown in Table 2 (Yang & Chang, 2020).

Additionally, a PBC is developed based on the requirements of urban road maintenance: timely response, work safety, work quality, work technicality, and road quality (e.g., performance indicators), as shown in Figure 3, and a full implementation model of service levels, supervision, and payment/deduction mechanisms. All the problems mentioned above are targets to be solved; therefore, this study uses Figure 3 to illustrate the connections between PBC service requirements and performance indicators.

Table 3 summarizes the performance indicators with their ID, purpose, requirement, measurement method, requirement tolerance, measurement frequency, service standard, and payment frequency. Each performance indicator has two sub-indicators. All indicators are briefly illustrated as follows (Yang et al., 2023a):

- PI-1 Quality of inspection works: the performance to be achieved by the contractor performing the inspection work, using the indicators PI-1.1 and PI-1.2.
- PI-2 Quality of inspection data processing: the performance to be achieved by the contractor in handling inspection data, using the indicators PI-2.1 and PI-2.2.
- PI-3 Quality of road maintenance execution: the performance that the contractor should achieve in its maintenance process according to the PI-3.1 and PI-3.2 indicators.
- PI-4 Quality of road maintenance: the performance of the repair works performed by the contractor, using the indicators PI-4.1 and PI-4.2.
- PI-5 Quality of proposed road maintenance suggestions: the performance of the proposed road maintenance suggestions regarding the contractor's service scope, using the PI-5.1 and PI-5.2 indicators.

Table 2. Stakeholder needs in urban road maintenance

Road User	Authority	Contractor
Flat (road leveling)	Reduced administrative works	Reasonable contract profits
Reduced road deficiencies	Road conditions under control	Working flexibility
Rapid defects improvement	Optimized road maintenance system	Feasible contract conditions for innovation

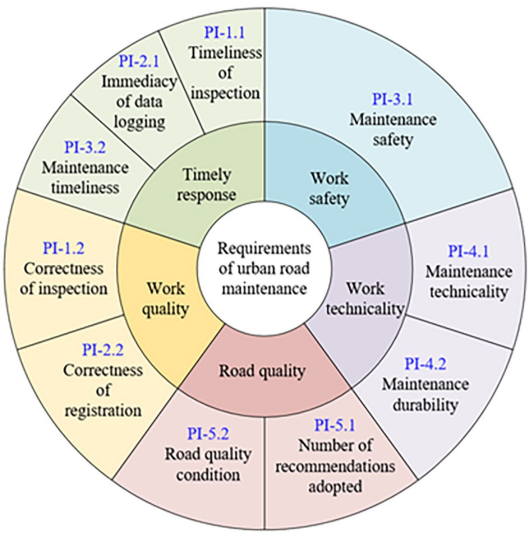

Figure 3. Requirements and performance indicators of urban road maintenance works

4.3. PBC pilot program

Pilot projects help test the feasibility of PBCs and increase the experience and confidence of stakeholders, who can then implement contracts with greater scope, increased complexity, and longer duration (Asian Development Bank, 2018). This study uses data from a PBC pilot program (Yang & Chang, 2021) to evaluate the performance of PBC for urban road maintenance. The key features of the PBC pilot program are as follows:

- The content of the PBC is formulated jointly by authorities, road inspectors, and contractors with the assistance of professional consultants.
- The original road maintenance contract budget is adopted as the initial budget for the PBC pilot program.
- The scope of maintenance services by the contractor was limited to the pavement of the road. Associated facilities such as sidewalk, gutters, street furniture, and other related infrastructure were excluded from the scope.
- The scope of the pilot program is divided into independent 250–350 m^2 sections following the recommendations for measuring the Pavement Condition Index (PCI) value defined in ASTM D6433-20 (ASTM International, 2020). The PCI values and ratings are measured monthly. The results serve as road quality data.

Table 3. Performance indicators, service standards, and payment methods

ID	Purpose	Requirement	Measurement method	Requirement tolerance	Measurement frequency	Service standard	Payment frequency
PI-1.1	Timeliness of inspection	The contractor should detect deficiency before others do	Number of contractor notifications / total number of notifications	1 hour after being notified	Monthly	≥95%	Monthly
PI-1.2	Correctness of inspection	Determination of damage type should be correct	Number of correct judgments / total number of judgments	1 week	Monthly	≥95%	Monthly
PI-2.1	Immediacy of data logging	Data to be logged after daily inspection	Number of entries / total number of entries	Immediate improvement	Daily	100%	Monthly
PI-2.2	Correctness of registration	Correct registration of road maintenance data	Number of correct data / total number of data	Within 3 days	Weekly	≥95%	Monthly
PI-3.1	Maintenance safety	Workforce should meet safety requirements	Achieved Safety Attendance / total attendance	Immediate improvement	Daily	100 %	Monthly
PI-3.2	Maintenance timeliness	Repair work should be completed within the specified period	Number of repairs completed on time / total number of repairs	According to the stipulated time	Weekly	≥95%	Monthly
PI-4.1	Maintenance technicality	The repair results should meet the technical standards	Number of qualified repairs / total repairs	Immediate improvement	Weekly	≥95%	Monthly
PI-4.2	Maintenance durability	Less than 5 recurrences of deficiency after repair	Number of repeated deficiencies at the same location	According to the stipulated time	Monthly	100%	Monthly
PI-5.1	Number of recommendations adopted	3 recommendations for road maintenance were adopted	Number of contractor recommendations adopted by the authority	Within 30 days	Quarterly	100%	Semi-annually
PI-5.2	Road quality condition	Simplified PCI* rating not lower than that of the previous month	Number of road sections in compliance / all road sections	Within 30 days	Semi-annually	100%	Semi-annually

Note: The simplified PCI has been adopted for the overall quality of road maintenance, and only five items are included: crack, pothole, repair, manhole/handhole, and rutting. The score remains the same with a total of 100 points and the grading scale is divided into 7 levels: good, satisfactory, fair, poor, very poor, serious and failed.

- The contractor employs a panoramic road inspection vehicle and 3D image recognition technology to categorize road defects' types and severity and generate objective pavement inspection results.
- The contract does not ask the contractor to provide warrants for its service after the contract is completed.

5. Benefit evaluation framework development and validation

This study develops a benefit evaluation framework of using PBC for urban road maintenance consisting of three major components: the performances of road users, road maintenance authorities, and contractors, as shown in Figure 2. Notably, the stakeholders discussed in this study do not include subcontractors, as their performance is typically transferred to major contractors and they do not directly sign contracts with road maintenance authorities.

This study uses one qualitative and eight quantitative performance evaluation items for the benefit evaluation. For quantitative items, we adopted the BCR measure and ignored the discounted time value of the costs because the contract duration is only for a year. Traditionally, benefit evaluation is typically carried out after the completion of a project. However, in order to obtain benefit evaluation outcomes in a more timely manner, this study implemented benefit evaluation during the execution of the pilot program.

We used data from the PBC pilot program executed from March to October 2021 to validate the outcomes of the proposed benefit evaluation framework. Excluding the cost data, the field data for traditional contract model and PBC model were collected through discussions with the participants in the pilot program. Furthermore, to collect the required data, ten focus group discussions were conducted during January and September 2021 with the participants from consultant, maintenance authorities, supervisors and contractors. The later ten meetings listed in Table 1 showed detailed discussion issues.

6. Benefit evaluation outcomes

The cost of manpower required to assess the pilot program's effectiveness is retrieved from the cost data for 2021 provided by the 1111 Job Bank in Taiwan (1111 Job

Bank, 2021). The unit cost is US$ 2,112/person/month, US$ 96/person/day, or US$ 12/person/hour, assuming the salary of a civil engineer with five years of experience. The effectiveness of the performance items in Figure 2 is assessed and described as follows.

6.1. Benefit for road users

- **The performance item – road leveling (flat) –** is defined with reference to the PI-4.1, PI-4.2, and PI-5.2 performance indicators and is used to indicate the condition of road leveling with a high or low PCI. From March to June 2021, the contractor arranges the road pavement in the pilot program area into 9,970 units in accordance with ASTM D6433-20 (ASTM International, 2020). The PCI for each unit is evaluated monthly. The monthly average PCI (standard PCI rating scale classes) ranges from 78.35 to 83.53, achieving a "satisfactory" level, which is much better than the "Poor" level (PCI below 55), as shown in Table 4. This performance item is qualitative. Based on the overall rating outcomes, this study finds that the performance of road maintenance works by the PBC model is maintained at a good level compared to the historical data from the traditional contract model. This confirms that the overall quality of road maintenance between the traditional contract and the PBC models is equivalent. However, if the PBC is implemented on a long-term basis, a reasonable level of service and contract price can be set in relation to maintenance costs over the same period, considering the changes in PCI.
- **The performance item – reduction of road deficiencies –** is developed with reference to the performance indicators PI-4.1, PI-4.2, and PI-5.2 and can be divided into two sub-items: the costs of public complaints and compensation claims. Figure 4 shows cases of public complaints and compensation claims.
  1. The first sub-item evaluates the processing and manpower costs of handling cases with and without the pilot program based on the number of complaints about road defects. After interviewing the staff in authority and obtaining information, the costs are calculated in Table 5 which shows that PBC saves US$ 61,632.
  2. The second sub-item evaluates the compensation costs applied to the municipality for physical or property damage suffered by people owing to road defects, with and without the pilot program. Notably, this study does not consider the actual compensation amounts paid to claimants. This is because the contractor bears the responsibility for compensations, and they are motivated to actively negotiate with

Table 4. PCI testing scenarios

Level	Jul. 2021	Aug. 2021	Sep. 2021	Oct. 2021
Number of pavement units for PCI ≦ 55	1,237	1,404	1,416	1,915
Number of pavement units for 55 < PCI ≦ 70	1,511	1,576	1,682	1,759
Number of pavement units for 70 < PCI < 100	2,835	3,022	3,125	2,985
Number of pavement units for PCI = 100	4,387	3,968	3,747	3,311
Average PCI	83.53	82.10	81.43	78.35
Overall rating	Satisfactory	Satisfactory	Satisfactory	Satisfactory

Table 5. Costs of handling complaints from the public

Type	Complaint cases	Processing time (day/case)	Manpower spent on handling complaints	Average salary (USD/day)	Cost (USD)
Traditional Contract Model	249	1	3	96	71,712
PBC Model	35	1	3	96	10,080
Cost Increased/ Decreased	–	–	–	–	–61,632

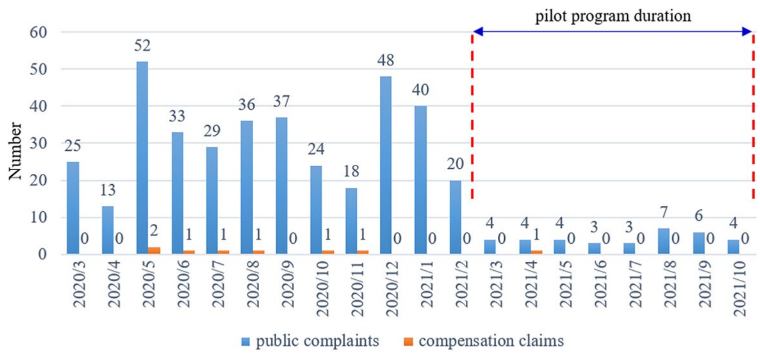

Figure 4. Number of complaints and applications for compensation from the public

claimants in order to reach compromises. Failure to reach a compromise may result in additional penalties being imposed on the contractor. Table 6 shows the costs of compensation claims in traditional contract and PBC models, in which PBC saves US$ 21,892. Hence, PBC saves US$ 83,524 (= 61,632 + 21,892) by considering the performance item "reduction of road deficiencies".

- **The performance item – rapid defect improvement –** is developed with reference to the performance indicator PI-3.2. When an urgent deficiency is identified, the contractor must rectify it immediately, both with and without the pilot program. There is no difference in processing costs. Interviews with the authority and the contractor revealed the following findings: in the traditional contract model, for general defects, contractors require approval from the supervision unit and authority before they can carry out the necessary work. In the PBC model, contractors should make a professional judgment on whether to repair based on a predefined low PCI level. Figure 5 depicts the processes for determining repairs using traditional contracts and PBC model. It highlights three distinct ranges of the PCI: PCI ≦ 55, 55 < PCI ≦ 70, and 70 < PCI ≦ 100. Each range triggers different remedial actions: remedial action, observation, and non-action, respectively. It is crucial for the contractor to closely monitor the PCI outcomes to accurately assess the necessary maintenance work for the urban roads. The time and costs of the process in the two models are calculated and listed in Table 7. The manpower for the two models is the same. The major difference is the duration of confirming the content of the construction notice. Table 7 shows that the PBC saves US$ 28,224 by considering the performance item "rapid defect improvement".

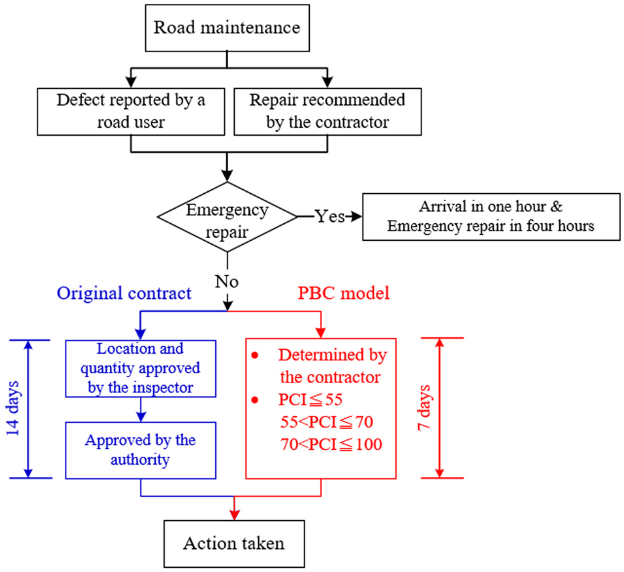

Figure 5. Flowchart of traditional and PBC models for repair determination

6.2. Benefit for road maintenance authorities

- **The performance item – reduction of administrative operations –** is developed with reference to the PI-3.2 performance indicators. It calculates the costs saved by the manpower to complete the necessary reviewing works to pay compensation to the contractor in the traditional contract and PBC models. The authority reviews the contractor's repair and pricing information during the execution of the traditional contract and reviews the performance statements for each effectiveness indicator during the pilot program period. The costs of the authority's administrative operations are listed in Table 8. The major difference between the two models is the time required to complete the necessary review works.

Table 6. Amounts and costs of compensation for the public

Type	Case	Date of incurrence	Amount of compensation requested (USD)	Total cost (USD)
Traditional Contract Model	1	May 23, 2020	357	22,621
	2	May 28, 2020	7,143	
	3	May 28, 2020	379	
	4	Jun. 26, 2020	11,387	
	5	Jul. 2, 2020	2,105	
	6	Oct. 15, 2020	1,250	
PBC Model	1	Sep. 16, 2021	729	729
Cost Increased/ Decreased	–	–	–	–21,892

Table 7. Time and costs of road repairs

Type	Duration for confirmation of the content of the construction notice (day/pcs)	Number of construction notifications (pcs)	Handling manpower	Salary (USD/day)	Cost (USD)
Traditional Contract Model	14	42	1	96	56,448
PBC Model	7	42	1	96	28,224
Cost Increased/ Decreased	–	–	–	–	–28,224

Based on the information shown in Table 8, the PBC saves US$23,328 by considering the performance item "reduction of administrative operations".

- **The performance item – road conditions under control –** is developed with reference to performance indicators such as PI-2.1 and PI-2.2. In the planning stage of a PBC tendering package, the authority has a good grasp of road conditions and can effectively set performance indicators, service levels, and contract prices and understand the risks, all of which are important factors in the success of a PBC (Gericke et al., 2014). The contractor with the traditional contract carries out the pilot program; that is, it does not adopt PBC; therefore, the benefits of the tender preparation phase are not evident. The authority assigns one person to check the road condition data completed by the contractor with and without the pilot program, and there is no difference in the manpower cost. With the increased number of projects using PBC in the future, the same number of staff can handle multiple cases and reduce costs. The information in Table 8 can be applied to calculate the corresponding costs when the PBC is used for wider implementation. This study ignores the benefit evaluation for the performance item "road conditions under control".
- **The performance item – optimized road maintenance system –** is developed with reference to the PI-5.2 performance indicators. The authority set up a visual management system for each unit with a PCI value. As shown in Figure 6, each road maintenance unit has a corresponding color denoting the PCI level according to ASTM D6433-20 (ASTM International, 2020; Wang, 2020). The decision-making process and man-days spent on each road maintenance unit for renewal before and after importing the platform are shown in Figure 7, wherein the decision-making process for the traditional contract and PBC models is the same. However, the duration of the PBC model is shorter than that of the traditional contract model. Table 9 calculates the costs of manpower and equipment in the traditional contract and PBC models. PBC saves US$ 19,968 in terms of manpower cost but increases costs by US$ 21,636 for paying for a visual management system. Hence, PBC increases the net costs by US$ 1,668 by considering the performance item of the optimized road maintenance system. Notably, in assessing the long-term effectiveness of equipment or system development, depreciation should be considered over the service duration of the equipment or system development, which results in decreasing costs each year.

Table 8. The time and costs of the authority's administrative operations

Type	Items and hours for review (hr./day)		Pilot program period (days)	Reviewing manpower	Average salary (USD/ hr.)	Administrative operation cost (USD)
	Inspection, repair and pricing information	Daily, weekly and monthly reports				
Traditional Contract Model	2	–	243	5	12	29,160
PBC Model	–	0.4	243	5	12	5,832
Cost Increased/ Decreased	–	–	–	–	–	–23,328

Table 9. Costs of renewing pavement decisions

Type	Manpower spent on handling (man-days)	Average salary (USD/day)	Manpower cost (USD)	Cost of developing visualization management system (USD)
Traditional Contract Model	302	96	28,992	–
PBC Model	94	96	9,024	21,636
Cost Increased/ Decreased	–	–	–19,968	+21,636

Figure 6. Visualization of road pavement conditions

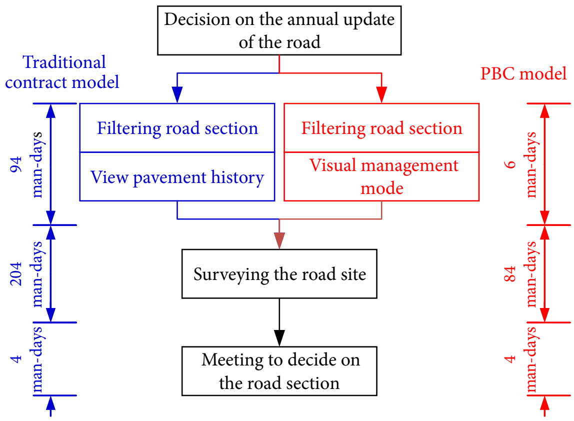

Figure 7. Decision-making process for pavement renewal

6.3. Benefit for contractor

- **Regarding the performance item – reasonable profit –** the contractor does not have to carry out extensive pavement milling and renewal in the early stages of the pilot program and therefore does not incur high costs. This study assumes that the original contract price of US$ 595,798 for eight months is retained. The contractor's profit under this contract is 11% in the traditional contract and does not increase or decrease in the pilot program. Although the PBC contractor can reduce overhead costs by 21% in the long term by effectively applying manpower, equipment, and materials to improve the workflow in other countries (Sultana et al., 2012), this study ignores the benefit evaluation for the performance item "reasonable profit".
- **Regarding the performance item – work flexibility –** the PI-1.1, PI-1.2, and PI-3.2 performance indicators are used to assess the contractor's effectiveness in inspection and repair operations.

1. For the first sub-item, inspection operations, a contractor in a traditional contract inspects a road over 8 m wide every four days on a fixed route, which amounts to 61 (243/4) inspections over a pilot program period of eight months (243 days). The PBC contractor conducts a comprehensive survey of pavement conditions and immediately repairs urgent or serious defects when the pilot program starts. After analyzing the survey results, depending on the location and severity of the defects, the inspection route can be flexibly adjusted to improve the efficiency of the inspection. In this pilot program, inspection operations are adjusted once every seven days according to professional judgments. During the pilot program period of eight months (243 days), the total number of inspections is 35 (243/7). The contractor has not yet completed a road pavement condition survey at the beginning of the pilot program. Therefore, it performs inspection operations using traditional and PBC inspection models, which does not reduce this cost. The inspection costs would be as shown in Table 10 if the PBC inspection model can be fully adopted; this cost is calculated using the feedback of the PBC contractor.
2. For the second sub-item, repair operations, this study considers the difference in payment mechanisms for the contract between the traditional contract and PBC models. Traditional contracts are paid monthly on a unit price basis but PBCs adopt a monthly uniform performance-based payment. In a traditional contract, to prevent the contractor from carrying out unnecessary repairs to obtain a higher profit, the repairs must be discussed or the area surveyed with the authority before they can be carried out. Subsequently, the authority pays for the actual repair. The PBC allows the contractor to decide on the location of the repairs according to its professional judgment, and

Table 10. Contractor's inspection costs

Type	Workforce (man)	Average salary (USD/month)	Manpower cost calculation approach	Cost (USD)
Traditional Contract Model	3	2,112	3×2,112×8	50,688
PBC Model	3	2,112	3×2,112×8× (35/61)	29,083
Cost Increased/ Decreased	–	–	–	–21,605

Table 11. Number and costs of contractor in repair operations

Type	Number of defects repairs	Repair unit cost (USD/ site)	Repair cost (USD) (A)	Time spent in repair with the authority (days/ month)		Pilot program period (months)	Manpower spent on handling	Average salary (USD/ day)	Manpower cost (USD) (B)	Total cost (USD) (A+B)
				Pre-repair discussion	Post-repair random inspections					
Traditional Contract Model	917	67	61,439	8	–	8	5	96	30,720	92,159
PBC Model	1,090	67	73,030	–	2	8	5	96	7,680	80,710
Cost Increased/ Decreased	173	–	+11,591	–	–	–	–	–	–23,040	–11,449

the authority carries out random inspections after the work has been carried out. According to the information provided by the contractor, the number of repairs made independently during the pilot program period and the associated costs increased; however, the time taken to discuss repairs with authority decreased. The number of repairs is shown in Figure 8 and the costs are shown in Table 11. Based on the information in Table 11, PBC saves US$11,449 by considering the performance item of work flexibility, in which PBC increased the cost of repair but decreased the cost of manpower.

- **The performance item – feasible contract conditions for innovation –** is developed with reference to the performance indicators PI-1.2, PI-2.2, and PI-3.1. The pilot program provides the contractor with flexibility in innovative methods and materials. Therefore, the contractor added AI equipment to the original inspection vehicle

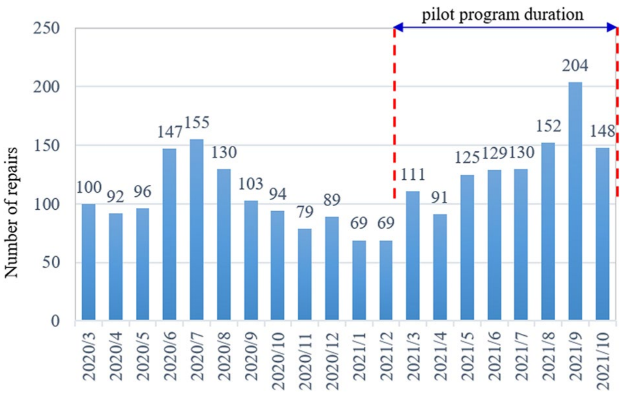

Figure 8. Number of repairs made without and with the pilot program

and assisted with the inspections from August to October 2021 (see Figure 9). The contractor used a high-resolution camera to capture pavement images and identify road defects using AI (artificial intelligence) equipment. The green box shows the extent of the defect and the blue text indicates the type and size of the defect. The contractor used two approaches – human beings and AI equipment – to complete the inspection work from August to October 2021. According to the information provided by the contractor, the number of defects identified in this way is 1.07 times that of a conventional visual inspection, as shown in Table 12. When comparing the same number of defects identified, the AI inspection method saves one man-month compared to traditional inspection. In the early stages of the pilot program, the contractor developed and tested the AI equipment and performed inspection work without the AI equipment until August 2021. During August and October 2021, the contractor performed inspection work using AI inspection equipment and traditional manpower simultaneously. This study adopts data from the costs between August and October to the costs for March to July to make an equal comparison of the two models. In other words, the cost of saving one man-month of manpower is used. This study uses the costs of manpower and AI inspection equipment (the contractor provides cost data through interviews), as shown in Table 13. It is clear that PBC saves US$ 16,896 in manpower costs but increases the cost by US$ 16,667 for AI inspection equipment by considering the performance item "feasible contract conditions for innovation". In assessing long-term effectiveness, depreciation should be calculated over the useful life of the equipment such that the annual costs can be reduced.

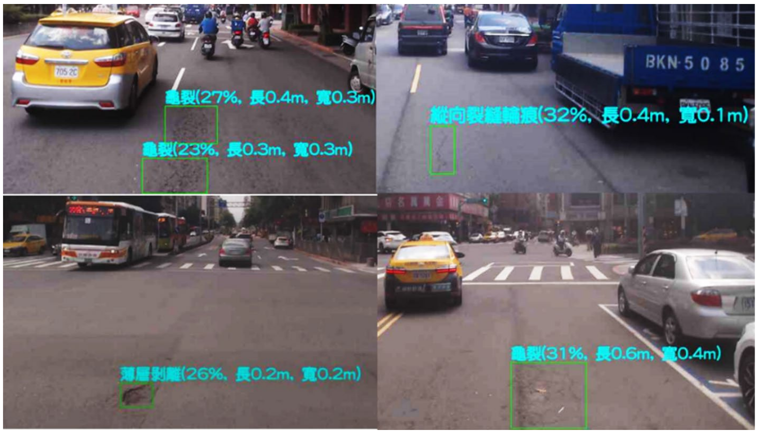

Figure 9. AI pavement inspection screen

Table 12. Numbers of defects before and after using the AI pavement inspection vehicle

Period	Number of defects from visual inspection by human on vehicle (A)	Number of defects inspected by the AI pavement inspection vehicle (B)	Increased percentage of defects (B/A)
Aug. 2021	21,174	21,709	102.5%
Sep. 2021	25,350	28,202	111.3%
Oct. 2021	22,892	24,365	106.4%
Total/Average	69,416	74,276	106.7%

Table 13. Costs of inspection manpower and equipment

Type	Calculation period (months)	Inspection manpower	Average salary (USD/person-month)	Manpower costs (USD)	Costs of AI pavement inspection equipment
Traditional Contract Model	From Mar. to Oct. 2021	11	2,112	185,856	–
PBC Model	From Mar. to Oct. 2021	10	2,112	168,960	16,667
Cost Increased/ Decreased	–	–	–	–16,896	+16,667

7. Findings and discussions

7.1. Findings

The result of the qualitative benefit evaluation shows that the average PCI value in the pilot program is at the "satisfactory" level. In other words, with and without the pilot program, the PCI level of road maintenance meets the needs of road users although there are still some existing complaints from the public. Hence, it is concluded that the PBC model achieves urban road maintenance above the basic performance standard. The result of the quantitative benefit evaluation is summarized in Table 14. This study summarized the traditional contract costs (C1) and pilot program (PBC) costs (C2), and conducted calculations to determine the resulting benefits ($\Delta B = C1 - C2$) in terms of cost reduction for the performance measures. The increased costs (ΔC) associated with PBC implementation were discussed in the previous section. Finally, the study calculated the overall benefit-cost ratio (BCR) by dividing the total benefits (ΔB, US$ 204,994) by the total increased costs (ΔC, US$ 38,303), resulting in a BCR of 5.35, which is greater than 1. The results of the benefit evaluation are economically viable for all the stakeholders.

Among the quantitative performance items, the most significant cost reduction for the road user is shown by the performance item "rapid defect improvement," determined by the contractor's professional decision to rectify the defects. The workflow is reduced from 14 to 7 days with significant benefits. Considering the road user perspective only, the BCR value is infinitely large because the user benefit (ΔB) equals US$ 111,748, and there is no incremental cost. This indicates that PBC has economically viable benefits for road users between traditional contract model and PBC model.

The pilot program built a visual pavement condition management platform with PCI values to assist in pavement renewal decisions and increase efficiency. Initially, it increases the costs owing to system development, but the cost will be shared in the long term. Considering the authority's perspective, with the value increased benefit (ΔB) US$ 43,296 and increased costs (ΔC) US$ 21,636, the BCR ($\Delta B/\Delta C$) value of 2.00 indicates that PBC has economically viable benefits for road-maintenance authorities.

The contractor flexibly adjusts the inspection route according to the condition of the pavement survey to improve inspection efficiency and reduce labor costs. Although an increase in the number of repairs carried out by the contractor may increase the cost of repairs, the authority's change to a post-checking approach to saving time shows that a PBC provides contractors with flexibility and increases their effectiveness. Considering the contractor's perspective, with the value increased benefit (ΔB) US$ 49,950 and increased costs (ΔC) US$ 16,667, the BCR ($\Delta B/\Delta C$) value of 3.00 indicates that PBC has economically viable benefits for road-maintenance contractors.

7.2. Discussions

The primary objective of road maintenance is to ensure the provision of high-quality roads for road users. When road users express their expectations regarding road quality, the term "flat" commonly denotes an ideal condition. Hence, the selection of the "flat" item as a benefit evaluation criterion for road users is justified. From a technical standpoint in road maintenance, the PCI serves as a suitable measurable indicator. It has been extensively utilized in practice and has demonstrated its effectiveness as a simplified method for evaluating pavement quality (Pinatt et al., 2020). The contractor was still investigating the conditions of the roads and equipment at the beginning of the pilot program. The performance indicators "road leveling (flat)" and "feasible contract conditions for innovation (innovative methods and materials)" have not yet been fully documented during the pilot program period but are still valuable for examining the effectiveness of the pilot program. The effectiveness of a PBC project will be more evident if a large amount of data is obtained and analyzed over a long period.

The pilot program period was relatively short and no new projects were executed; therefore, the original contract price was used. The benefits of the "road conditions under control" and "reasonable contract profit" performance indicators have not been fully evaluated; however, in accordance with the literature, the benefits of the PBC will increase in the long term (Gericke et al., 2014).

The evaluation framework developed in this study can be used to examine the benefits and costs of implementing PBCs for various stakeholders. The qualitative item represents the level of road conditions in terms of PCI, whereas the remaining quantitative items are used to directly calculate benefits and costs. The BCR method can be evaluated to determine whether it is economically viable and easy to calculate and whether the results are easy to understand to analyze the benefits and costs of implementing a quantifiable PBC.

The outcomes of the benefit evaluation show that the main benefits of a PBC project are savings in time and labor costs, which will increase throughout the contract.

Table 14. Overall BCR evaluation outcomes

Benefit Category	Performance measures	Traditional contract costs (C1)	Pilot program costs (C2)	Benefits (cost reduction) (ΔB=C1 – C2)	Increased costs (ΔC)	BCR (ΔB/ΔC)	Remarks
Road users	1. Reduced road deficiencies	71,712	10,080	61,632	–	–	Costs of handling complaints
		22,621	729	21,892	–	–	Compensation costs applied for by the public
	2. Rapid defects improvement	56,448	28,224	28,224	–	–	–
	Subtotal of measure 1 and 2	150,781	39,033	111,748	0	**Ignored**	ΔC = 0, BCR is infinite but ignored in this study.
Road maintenance authorities	3. Reduced administrative works	29,160	5,832	23,328	–	–	–
	4. Road conditions under control	–	–	0	–	–	No increase or decrease in benefits
	5. Optimized road maintenance system	28,992	9,024	19,968	21,636	–	–
	Subtotal of measure 3, 4 and 5	58,152	14,856	43,296	1,636	**2.00**	–
Contractor	6. Reasonable contract profits	–	–	0	–	–	11% of the original contract, but ignored in this study.
	7. Working flexibility	50,688	29,083	21,605	–	–	Flexibility in inspection operations
		92,159	80,710	11,449	–	–	Flexibility in repair work
	8. Feasible contract conditions for innovation	185,856	168,960	16,896	16,667	–	–
	Subtotal of measure 7 and 8	328,703	278,753	49,950	16,667	**3.00**	–
Overall		537,636	332,642	204,994	38,303	**5.35**	–

Initially, there is the issue of increased costs for equipment setup, but as equipment depreciates, the shared annual costs are reduced. The benefits will increase, and costs will decrease each year if the life cycle of urban road pavement is estimated to be approximately 8–10 years. Therefore, the BCR of a long-term PBC will increase, and the performance will be more significant.

8. Conclusions and recommendations

8.1. Conclusions

Assessing the performance of PBC is crucial for road maintenance agencies to determine whether to continue implementing this innovative contracting approach for future projects. While existing evaluation methods have mainly concentrated on highway or major road maintenance, there is a significant need for a comprehensive benefit evaluation framework specifically tailored to urban road maintenance. Such an evaluation framework would bridge the existing gap and provide valuable insights for decision-making regarding the adoption of PBC in urban road maintenance projects. The main objective of this study is to develop a benefit evaluation framework for PBC in urban road maintenance for inspection and repair. This study calculates the pilot program's effectiveness to validate the proposed benefit evaluation framework using a benefit-cost ratio (BCR) approach. The overall and individual stakeholder BCR are economically viable: the overall BCR, calculated by dividing the total benefits by the total increased costs, is 5.35, the BCR for road users is infinite but ignored in this study, the BCR for road maintenance authority is 2.00, and the BCR for contractors is 3.00. The road performance by the Pavement Condition Index (PCI) in the pilot program also achieved a satisfactory level. This information yields reliable validation results that confirm the practicality of the proposed framework, empowering urban road maintenance agencies with substantial data to make well-informed decisions regarding the implementation of PBC in their maintenance projects. In summary, this study significantly contributes to the urban road maintenance sector by facilitating prompt and effective decision-making in PBC implementation.

In the past, PBCs have been adopted in all stages of road construction and maintenance, but they are mostly used for maintenance or asset management of highways or major roads. There has been no research on using PBCs for inspecting and repairing roads in a well-developed city. This study attempts to bridge the gap in the service of PBCs for all types of toll-free roads. Therefore, this research contributes to expanding the application of PBCs in road maintenance services. Furthermore, a short-term pilot program was carried out in an administrative district in Taipei to assess the viability and efficacy of a proposed PBC contract model. The valuable experience gained from implementing PBC for urban road maintenance in Taipei has the potential to offer significant benefits to other well-developed cities worldwide. By sharing this knowledge, other cities can leverage the insights and lessons learned to enhance their own urban road maintenance practices, fostering global progress in the adoption of PBC for improved infrastructure management.

8.2. Research limitations

The purpose of this study is to develop a benefit evaluation framework for the use of PBC in urban road maintenance, which can assist organizations in assessing the feasibility of adopting and promoting PBC easily. It should be noted that while a pilot program has been tested in this study, the outcomes may vary when applied to other real urban road maintenance projects. Additionally, the introduction of new contracting approaches may impact the vested interests of existing stakeholders who have adopted different contracting methods. These factors impose limitations on the generalizability and application of the developed benefit framework.

Due to the challenges associated with obtaining real-time benefits and costs data through field observation, this study opted to collect data through focus group discussions. This approach may introduce certain discrepancies between the collected data and the actual experiences and perspectives of the participants. While the feedback provided by the participants offers valuable insights, it is important to consider the potential limitations and variations that may arise when comparing this data to real-world observations.

8.3. Recommendations

The PBC is piloted in an administrative district for eight months and found feasible and effective. This could be extended to citywide road maintenance based on the proposed benefit evaluation framework for providing decision requirements; PBC benefits all road stakeholders. The literature on PBCs for highway or major road maintenance shows that longer contract periods are required to demonstrate their advantages and disadvantages (Gericke et al., 2014).

This study concluded that the BCR for road users is infinite but ignored in this study. However, additional potential benefits for road users that could be further explored. These benefits may include intangible benefits such as time saved due to improved road conditions and cost reductions resulting from the prevention of tire punctures and associated expenses.

The proposed benefit evaluation framework aims to examine direct benefits and costs. In the future, indirect or external benefits such as user satisfaction, travel time reduction, accident reduction, and government reputation enhancement may be explored. In addition to PBC for road pavement maintenance, the scope of maintenance can be extended to include pavements, gutters, verges, street furniture, and other facilities. An implementation model and benefit evaluation framework can be developed to cover the full range of road maintenance operations and risks involved based on the activity types.

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Author contributions

People who contributed to the work are listed in this section along with their contributions: YJB conceived the study; TCC was responsible for data collection and analysis, wrote the first draft of the article; YJB and TCC were responsible for design and development of the data analysis, and data interpretation. All authors have read and agreed to the published version of the manuscript.

Disclosure statement

The authors declare no potential competing interest about this research.

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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