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The Risk Assessment Management of Disaster Prevention on Roads

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Abstract: *This study has focused on the background and current situation of how to apply disaster prevention and risk assessment management during and after a disaster accident within the life cycle stages of road construction projects in Taipei City.*
By using case study and questionnaire survey to establish the risk assessment matrix then derived risk factors from qualitative and quantitative analysis. The benefits of applying risk management for government includes it is reducing the probability of risk occurrence as well as the severity of hazard consequences, government cost, and improving public constructions' quality, agency KPIs, and etc. The safety of road user is critical and unbearable risk loss. If the government can consider the risk level of different road sections in the road budget planning and allocation, it will effectively reduce the probability of citizens encountering traffic safety accidents and reduce the severity of accident risks.

Keywords: Risk management; Risk assessment; Risk cost; Risk benefit; Disaster prevention.

1. INTRODUCTION

Public works are the basic construction to enhance national competitiveness and an important indicator of national living standards. Taiwan is crowded, and people live in neighboring areas near the city must commute frequently. The transportation construction has always been a closely related issue for people. The quality of road construction directly reflects the benefit of the application of government resource. To deal with poor construction quality of public works, government has invested a lot of money to improve it. But the public's satisfaction with the quality of road construction still falls far short of expectations.
This research will discuss the cases of road defect about national remedy and using the risk assessment matrix to analyze the cost and benefit. Final, to propose cost-efficient improvement strategies to improve the defect of roads and significantly enhance the management efficiency of governance.

2. RESEARCH METHODS

This study has focus on the background of and current situation of how to apply disaster prevention and risk assessment management during and after a disaster accident within the life cycle stages of road construction projects in Taipei City. The research content focuses on the following aspect: Types of road disasters that may occur; Management actions at various stages of road disaster prevention; Risk assessment and matrix model establishment; and the strategies of disaster prevention. Collect relevant domestic and foreign literature, discuss the theoretical and practical methods of road disaster prevention and risk management, and the research problems, research fields and limitations and previous research results. The "Document Analysis" and "Case Study" are used for qualitative analysis and the "Questionnaire Interview" is used for statistical and quantitative analysis. Then the risk matrix model is established by the risk factors from qualitative and quantitative analysis.

2.1 Document Analysis

This research collects domestic and foreign road disaster prevention related disaster accidents, disaster prevention management and risk assessment management, as well as books, papers, journals, research reports and network resources related to this research. And discusses the risk assessment of road hazards in each life cycle on this basis, then establishes the risk assessment matrix model, and final proposes cost-efficient improvement strategies.

2.2 Case Study

This research selects a few appropriate road disaster accident cases, then conducts an in-depth study on the reasons why the case of road disaster may not be fully considered at each phase of whole construction life cycle and summarizes the road disaster risk factors. After, collect the opinions from engineering professionals, and the reliability of risk factor is getting increased, and the risk assessment matrix is established based on that. (see Fig. 1).

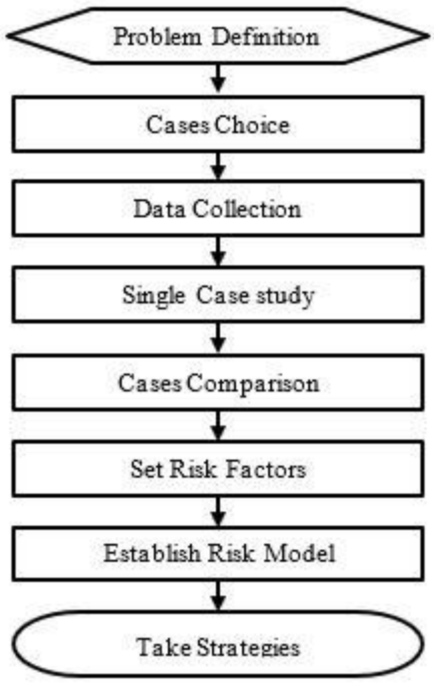

Fig. 1. Case Study Process

2.3 Questionnaire and Survey

2.3.1 Purpose and Process

Questionnaires collect the current situation and legal standards related to road disaster prevention and risk management. Based on the result, this research could obtain professional experience and cases; in addition, increase the scope of case studies. At the same time, establish appropriate risk factors of road disaster by statistically analysis. And the risk factors could be a reference for risk assessment matrix and measures about road disaster prevention (see Fig.2).

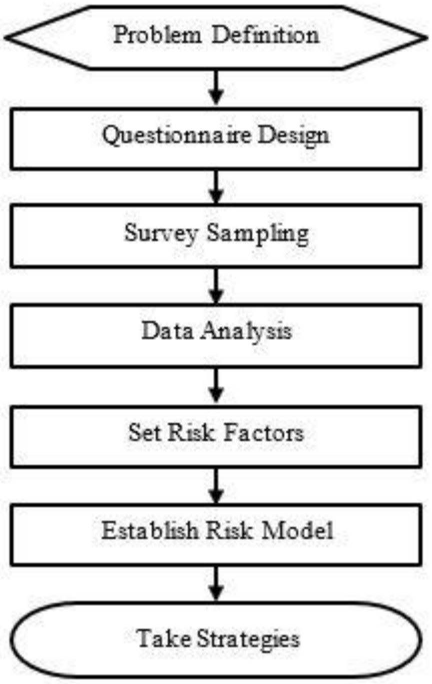

Fig. 2. Questionnaire Survey Process

2.3.2 Methods and Interviewees

This research uses mailed questionnaires, in-person visits and telephone interviews to collect the relevant data.
To establish the risk assessment matrix. Question surveys need to obtain the deeper information and opinions from experts and scholars, engineering professionals by in-person visits or telephone interviews.
On the other hand, question surveys can collect more sample data from civil engineers or relevant persons for statistical analysis and assessment of risk factor weights as a reference for establishing the risk assessment matrix by mailed questionnaires.

3. Literature Review

3.1 Road Defects and Disaster

Road defects (Pavement distress) and disasters are related, there is a clear distinction between the definitions of the two. Generally, the definition of defect of roads refers to the form of distress to the pavement surface. Research on the manual of maintenance and technical directions on urban road [1] pointed out that the urban roads are paved mainly by flexible pavement, so the road defects would be identified by the distress of asphalt concrete pavement. As the basis of calculation for calculating the Pavement Condition Index (PCI), the types of distresses in a pavement can be divided into the following 13 types:
1. Alligator or Fatigue Cracks 2. Longitudinal and transverse cracks 3. Block cracking 4. Potholes and Manhole Drop Off or Heave and Thin Overlay Separation 5. Rutting 6. Patching and utility cut patching 7. Shoving 8. Heave and Depression 9. Bleeding 10. Corrugation 11. Lane/Shoulder Drop Off or Heave 12. Slippage cracking 13. Polished Aggregate
Damage severity is divided into: L (light), M (medium), H (heavy)
The result of the analysis is a numerical value between 0 and 100, with 100 representing the best possible condition and 0 representing the worst possible condition.
The PCI is divided into seven classes as shown in table 1.

Table 1. Road damage condition by PCI

PCI range	Part name/ Manufacturer
85-100	Excellent
70-85	Very Good
55-70	Good
40-55	Fair
25-40	Poor
10-25	Very Poor
0-10	Failed

3.2 5 types of Road Disaster

1. The road sags and hollows out without warning.
2. The excavation surface on road is hollowed out and collapsed.
3. Abnormal water output from road excavation.
4. Ground subsidence caused by road excavation.
5. Risk of explosion due to accidental hitting of gas or petrochemical pipelines during road or pipeline construction.

3.3 Road paving factors

The Taipei City New Construction Office establishes an annual milling and paving plan at the beginning of the year every year. The milling and paving range was set according to each administrative district. After calculating the following paving factors, the priority road sections for milling and paving were determined:

1. Frequency of road damage.
2. Area of road damage.
3. Milling history.
4. Area of excavation application.
5. Public Appeals.
6. Flatness (IRI-International Roughness Index).

Each factor can be cross compared according to its importance (level 5~1, in order of absolute importance, extremely important, quite important, slightly important, and equally important). After calculating the AHP factor, a milling and paving maintenance plan will be established based on the calculated by year, budget, administrative area, length and width of the road section, front row, and other factors. The calculation method of road damage adopts PCI [2].

3.4 Disaster Phases

3.4.1 Mitigation

Refers to any long-term action that can reduce, eliminate, and avoid natural or man-made disaster risks on roads.

Through the implementation of disaster reduction actions and related policy management. The probability of disaster accidents can be reduced, and the degree of damage can be reduced [3].

3.4.2 Preparedness
Refers to the preparations for the protection of the road safety environment, according to the possible impact of road disasters, with the goal of minimizing the impact of disasters [3].

3.4.3 Response
Refers to the stages before, during and after road disasters. The emergency rescue is implemented to prevent the disaster from expanding and causing secondary damage [3].

3.4.4 Recovery
The final stage of road disaster management, the main work objectives include getting rid of the restrict of traffic, recovery of pavement condition and road facilities [3].

3.5 Life Cycle of Road Construction
3.5.1 Feasibility Study
Evaluate whether the road is suitable for development, and consider engineering technology, economic benefits, and the impact of the ecological environment by transportation construction. The feasibility assessment should include the cost and expected benefit analysis of the overall road project plan [4].

3.5.2 Planning
Confirm the functional requirements and make qualitative planning according to the administrative, regional, or functional. The road sections are used for the main and secondary arterial roads, gathering roads, or connecting roads.
Road configuration Assessment is a sophisticated tool for urban and transport planning process [4]. Therefore, it can be used as a planning tool to identify the level of vulnerability for road Crashes in existing roads and to identify the impact from proposed land use plans with new road networks. [5]

3.5.3 Tendering contract
Through procedures such as announcement, awarding of tenders and contract, select suitable construction companies to undertake road works [4].

3.5.4 Construction
Control the cost, quality, progress, and safety of the construction process. Then ensure that the construction company follow the construction plan, quality plan and occupational safety and health management plan [4].

3.5.5 Operation and maintenance
The maintenance and management mechanism should be improved to ensure that the road can still maintain a certain level of service during the maintenance phase [4].

3.6 Risk assessment and management
Risk and uncertainty: There are risk and uncertainty always in any newer concept's implementation. As Govt. or any private sectors always fear in the risk factor, any smart ideas always get late or remain unimplemented [6]. There are certain risks in road construction. Appropriate risk management can effectively control hazards and risks, thereby preventing and eliminating the possibility of disasters, or reducing the severity of disasters to improve risk management performance.

3.6.1 Definition
Something unplanned that might happen that could have a negative impact on your project
The basic definition of risk can be divided into two aspects, one is the "uncertainty of the occurrence of the accident", and the other is the "probability for the loss of the occurrence of the accident".
Risk = Probability × Consequence
(1) Uncertainty of the occurrence of the accident: Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequence, or likelihood.
(2) Opportunity for the loss of the occurrence of the accident: The probability of loss from the accident. The probability is between 0 and 1. 0 means no loss, and 1 means that loss will occur [3].

3.6.2 Risk assessment
Overall process of risk identification, risk analysis and risk evaluation. The process of risk assessment as shown below (see Fig.3).

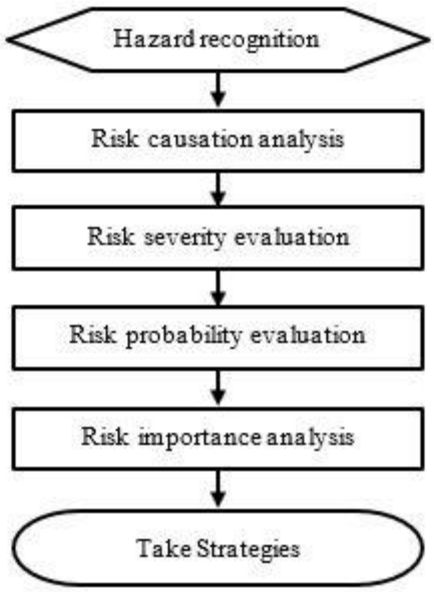

Fig. 3. Risk Assessment Process

3.6.3 Risk management
Coordinated activities to direct and control an organization regarding risk. Activities include identification, analysis, evaluation, and treatment. To minimize the losses caused by the risks with the least cost. The process of risk management as shown below (see Fig.4).

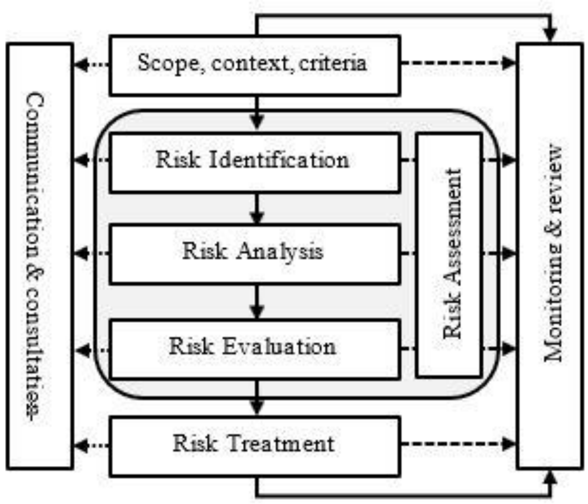

Fig. 4. Risk Management Process

3.6.4 Risk management

Risk management is mainly to use management methods to reduce the probability for the loss of the occurrence of the accident and the impact and losses caused by the accident, or to improve the management strategies of loss prediction, such as "risk avoidance" and "risk reduction". Risk management mainly uses methods such as "risk transfer" and "risk taking".

3.7 Cost benefit analysis of risk management

3.7.1 Cost of risk management

The cost of risk includes tangible and intangible costs. The tangible cost refers to the economic resources required for risk management. According to Mr. Douglas Barlow [7] defined the cost of risk as the sum of insurance premiums, self-funded losses, and risk control expenditures, as well as internal and external administrative costs.; Intangible costs mainly refer to the cost of worrying about losses for manager due to the uncertainty of risk.

According to Risk Management Manual:

A. Insurance premiums: The premium to be paid for the Insured risk.
B. Self-funded losses: When the loss occurs, the loss amount is not covered by insurance or adopted.
C. Administrative expenditures: Administrative expenses related to risk management.
D. Risk control costs: Costs incurred to prevent or control risks.
E. Residual value or other compensatory relief: government relief or tax reduction in case of loss.

Cost of Risk = A + B + C + D – E

3.7.2 Benefit of risk management

In the early days, public agencies paid less attention to risk management and developed slowly. Mainly because public management was more conservative and used to avoiding attribution of responsibilities. If reviewing risks, it would easily involve legal aspects. In recent years, the public sector has advocated a culture of openness and transparency. Rewards and punishments are based on the law. Risk policy promotion has flourished in the central and local governments. How to combine risk management with internal control and integrate it into governance performance management is the key point of application. The benefits generated include direct and indirect benefits:

(1) Direct benefits such as reducing the probability of risk occurrence and the severity of hazard consequences, crisis response and management, and reducing governance costs.
(2) Indirect benefits such as improving governance quality, agency KPIs, and building public trust.

3.7.3 Cost benefit analysis

The benefits of risk management should be analyzed in consideration of the hazards, priorities, and cost-benefit of various risk factors. Before conducting a risk cost benefit analysis, the following questions should be considered:

(1) How large are the risks from a single technology?
(2) Which risks merit the greatest attention?
(3) Which technology produces the least risk per unit of benefit?
(4) Are a technology's expected benefits acceptable, given its risks and other expected costs? [8]

After summarizing the above questions, according to the current situation analysis, current strategies, benefits, risks and risk management and other decision-making factors, corresponding to the evidence and uncertainties, conclusions and reasons, the overall risk cost-benefit assessment is made as shown in Table 2.

Table 2. Cost-Benefit-Risk summary assessment. (Adding slip-resistant material into pavement markings as an example.)

Decision Factor	Evidence and uncertainties	Conclusion and reasons
Analysis of condition	Motorcycle caused slippery accidents due to pavement markings.	Slippery accidents caused low BPN value.
Risk	Slippery accident due to rainy day.	Slippery accidents caused fast riding on rainy day.
Current treatment options	Add slip-resistant material into pavement markings.	Avoid slippery accident due to improving the slip-resistant.
Risk management	Reduce the risk probability and severity.	Improve the slip-resistant to reduce the risk probability and severity.
Cost-Benefit	Increase 3 times cost with thermoplastic pavement marking materials type II as well as BPN value from 45 to 65.	

3.8 Risk assessment matrix

As the hazards and the consequences have been identified. It includes the following topics:

(1) risk probability

(2) risk severity
(3) risk tolerability
(4) risk mitigation

3.8.1 Risk probability

The risk matrix is established according to the characteristics listed above, and the probability of risk occurrence is divided into 5 grades as shown in Table 3 [9].

Table 3. Risk probability

Likelihood	*Meaning*	*Values*
Frequent	Likely to occur many times (has occurred frequently).	5
Occasional	Likely to occur sometimes (has occurred infrequently).	4
Remote	Unlikely to occur, but possible (has occurred rarely).	3
Improbable	Very unlikely to occur (not known to have occurred).	2
Extremely improbable	Almost inconceivable that the event will occur.	1

3.8.2 Risk severity

After analyzing the probability of risk occurrence, the next step is to assess the severity of risk occurrence, including human death, serious or minor injury, or financial and environmental damage, etc., and divide the losses caused by risk occurrence into 5 grades as shown in Table 4 [9].

Table 4. Risk severity

Severity	Meaning	Values
Catastrophic	Multiple deaths. Equipment or environment destroyed.	5
Hazardous	Serious injury. Major equipment damage.	4
Major	Injury to persons. Serious incident.	3
Minor	Operating limitations. Minor incident.	2
Negligible	Few consequences.	1

3.8.3 Risk matrix

We can comprehensively analyze the risk index by the above two risk assessment indicators: risk probability and risk severity, and divide the risk index into 3 levels, each with its corresponding recommended disposal. The risk assessment matrix constructed by probability and severity is shown in Table 5 [9].

The risk assessment matrix is used to determine risk tolerability:

Risks falling in the red zone are extreme risks, with a high probability of occurrence and a very serious degree of severity, which is in an intolerable range, and mitigation measures should be taken immediately, even if it requires a high processing cost. Risks falling in the yellow zone are medium to high risks, initially assessed as intolerable. But after appropriate mitigation measures are taken, the risk will be transferred to the tolerable zone; however, the risk should still be monitored. For the risk in the yellow zone, cost-benefit analysis can be performed for decision-making judgment.

Table 5. Risk assessment matrix

Risk Matrix		*Severity*				
Probability		*Catastrophic* A	*Hazardous* B	*Major* C	*Minor* D	*Negligible* E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely improbable	1	1A	1B	1C	1D	1E

Risks falling in the green range are considered low risks and can be tolerated at the initial assessment without any mitigation measures.

3.9 Risk assessment and treatment

The public agency has established a risk assessment and processing summary table for risk management, as shown in Table 7 (see appendix). Analyze existing risk situation, evaluate, and compare the degree of risk reduction after strategies are taken from the risk probability and severity [10].

4. Research content

During the road-smoothing project of the Taipei City New Construction Office (NCO), for the road section with poor road conditions, a 4-stage road-smoothing improvement project was carried out, and the road conditions were significantly improved. The standard operating procedures for road maintenance operations were established by NCO, and the road construction quality control system was implemented.

The most common defects of roads in Taipei are cracks, unevenness of road surface, potholes, and damage near manhole cover. Road defects are mainly formed because of the large traffic flow in the urban area and the rainy weather. Heavy rain is more likely to cause the defect of road surfaces to get worse. If the citizens of Taipei want to report the defects of roads, they can dial 1999 to enter the voice system, and then the case will be dispatched to NCO. For common defects of roads, NCO will arrive at the scene within 1 hour, and complete emergency treatment within 4 hours.

4.1 National compensation cases

According to the annual statistics of the national compensation cases (2017-2021) by the Taipei City Research, Development and Evaluation Commission, as shown in Table 6 [11]. The analysis of national compensation cases based on different application reasons shows that defect of roads is the main reason for people to apply for state compensation. Unevenness of road surface, potholes, and damage near manhole cover are the most common types of defects. According to statistics from 2017 to 2021, a total of 1,218 state compensation applications were filed, of which 155 cases (12.7%) were unevenness of road surface, and 50 cases (4.1%) of damage near manhole cover, and 171 cases (14.0%) of road potholes and depressions. It indicates that the defects of roads accounts for about 30.9% of the cases of state compensation applications, which is an extremely important source of risk in Taipei City.

Table 6. National compensation cases cause statistics

Year	2017	2018	2019	2020	2021	Total
Unevenness of road surface	23	20	27	34	51	155
Damage near manhole cover	13	7	8	13	9	50
Potholes and depressions	43	30	48	36	14	171
Minor total	79	57	83	83	74	376
Others	165	164	178	185	160	852
Total	234	221	261	268	234	1218

4.2 Decision making

After compiling the national compensation cases at Taipei City. First analyze the defect of roads with pavement condition indicators (PCI) to determine the type and severity of the defect of damage. Then use the risk assessment matrix to analyze the level of the risk. If it is an extreme risk, mitigation measures should be taken immediately; if it is a low risk, no action is required. If it is a medium to high risk, a risk cost-benefit analysis should be carried out as a reference for decision-making.

5. Conclusion

Most roads in Taiwan are paved with asphalt concrete materials, which will inevitably lead to defects after a period of use. How to effectively manage roads and optimize resource allocation. In addition to cost-benefit analysis, risk management should be taken into consideration. The safety of road user is critical and unbearable risk loss. If the government can consider the risk level of different road sections in the road budget planning and allocation, it will effectively reduce the probability of citizens encountering traffic safety accidents, and reduce the severity of accident risks.

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7. APPEENDIX

Table 7. Risk assessment and treatment summary

Risk assessment and treatment summary table			
Annual Target		A	
Annual Project		A-1	A-2
Current Situation			
Current Strategy			
Current Level	*Probability(L)*		
	Severity(I)		
Current Value	R=L*I		
New Strategy			
Residual Level	*Probability(L)*		
	Severity(I)		
Residual Value	R=L*I		
Responsible unit			