The Development of Practical Asset Management System for an Urban Expressway Network

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1. Introduction

Hanshin Expressway is an urban expressway network in Kansai Metropolitan Area in Japan since its foundation in 1962. The network currently expands to 233.8 km in total length and is used averagely by about 900,000 vehicles or about 1,300,000 people per day.

86% of the network is formed by viaduct structures. As of today, about 36% and more than 50% are over 30 and 20 years old respectively. While traffic volume is steady, maintenance and repair budgets are being curtailed due to the current social and economic circumstances. Therefore, like any other highway authorities, conditions are met to build an asset management system for keeping those aging structures healthy with limited budget in the longer term.

The unique prerequisites of the system building are that the volume of structural asset is tremendously large and that the vast amount of data, though basically in paper format, had been already accumulated through periodical inspection and repair works. Preparing a database of storage in digital format and its easy management system is necessary at first in order to avoid any unnecessary labor for finding and compiling and to refer the data more effectively.

A database and its management system of expressway structures called Maintenance Information Management System (MIMS) were completed in 1994. MIMS, being upgraded over years, has accumulated a vast amount of data on any structures including bridge elements, tunnel and earthwork. It is now supporting fair engineering diagnosis of their soundness and optimal maintenance/repair planning.

Based on data in MIMS, the development of its own version of bridge management system is now underway as more rationalized allotment scheme of the limited budget is critical as the financial condition is unlikely to be recovered in the near future. The system named H-BMS helps to plan annual budget allotment and work prioritization with life cycle cost minimization rule.

2. Maintenance Information Management System (MIMS)

As an initial stage of MIMS development, structural information database was built in 1990. After the trial period, the first-phase of database system was completed in 1993 and integrated into the process of maintenance/repair program making. After improving data compatibility and with the help of progress in computer technology, the original database system was revised and enhanced by the addition of data management system (Fig. 1), which not only enables the prompt and continuous database referencing and updating but also facilitates decision-making process of inspection and repair works.

2.1. Structure Information Database

Structure information database stores all information on expressway structures related to their physical features, conditions and the records of inspection and repair. The data is classified by structure element and location which is identified by the bridge management number attached to each span and pier. The contents can be displayed in text format as well as shown visually like drawings and photos. The data is exchangeable with related local offices through a client-server system.

Asset data is classified into 22 categories of structural elements including superstructure (girder, deck), substructure (pier and foundation), pavement and expansion joints. Data is basically written in ledger format. Drawings are also incorporated. More than 180,000 units of data are stored in the system at present.

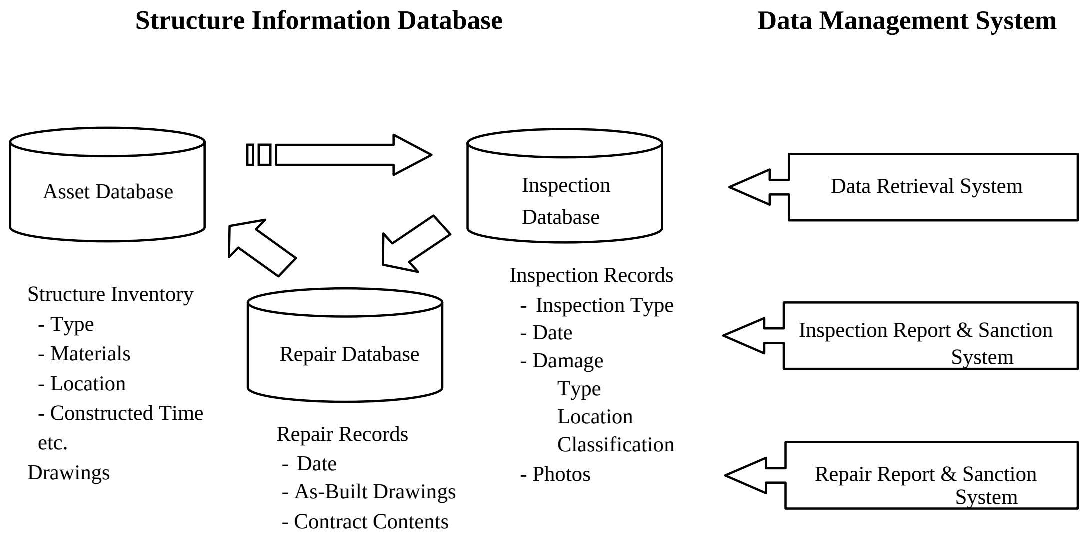


Figure 1. MIMS configuration

Data collected by regular inspection are immediately sent by the inspection work contractors directly to the headquarter via the system network. The digital photos and data in text format are automatically stored in the database. The system can now trace the inspection data up to the fiscal year of 1985.

There are 10 categories in the repair database and more than 310,000 units of data are stored in the system. Although it is ideal to store comprehensive records of all repair activities in the past, those conducted after 1985 have been stored in order to save cost required for data processing.

2.2. Data Management System

The data management system allows any client computers in the offices to access to the database in the server computer for retrieval, reference and data updating. All terminals are linked by exclusive network for confidentiality. The main components of this system are database retrieval system, inspection report and sanction system, and repair report and sanction system.

Data retrieval system is a key component of the data management system having various functions for searching and collecting information efficiently. The system has two interfaces for retrieval: multiple keywords retrieval and chart information retrieval. Either one can be used as desired according to the purpose of users.

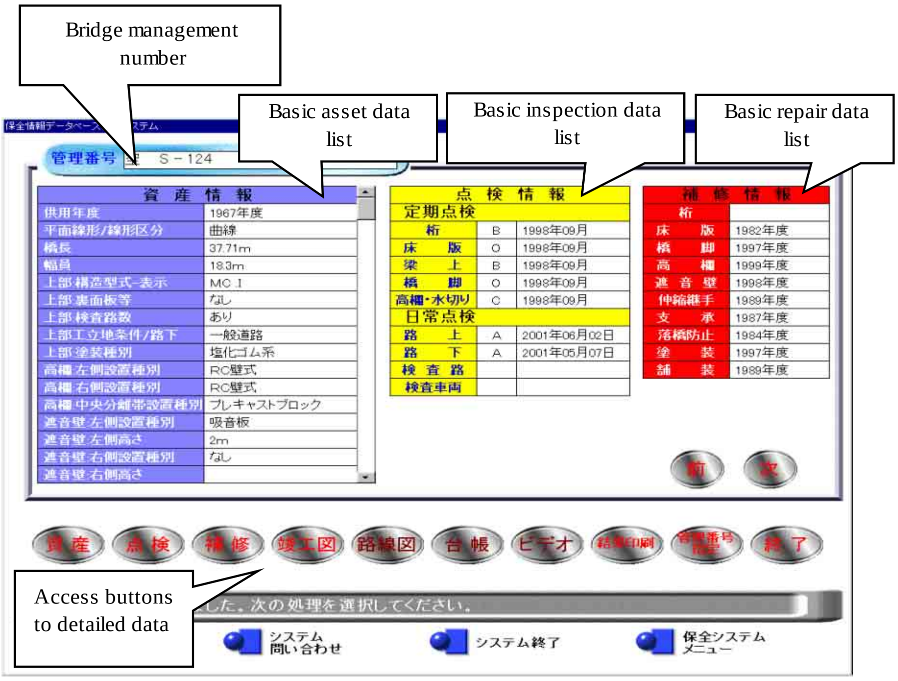
For example, chart information retrieval can extract information of individual structures by using bridge management numbers as a location identifier. The search results are displayed in a list form providing the overall view of latest information of the designated structure (Fig. 2).

All the due procedures required between Hanshin Expressway offices and inspection or repairing contractors can be completed through MIMS. They include data entry of inspection and repairing results, repair work instruction, and confirmation and sanction formalities by the local office in charge. Inspection reports have digital photos of damages attached so that engineers can confirm the information precisely and give the most appropriate instructions for repairing (Fig. 3).

3. Bridge Management System (H-BMS)

The development of H-BMS was initiated in 2002. As shown in the system architecture (Figure 4), the database is the core source of data processed in the H-BMS.

The main objective of H-BMS is to provide a systematical tool of building more rational, efficient and proper maintenance/repair scheme of bridge structures. This system facilitates the calculation of optimized maintenance/repair and other related costs on a long-term basis by using the concept of life cycle cost (LCC) minimization. With the same concept, a repair order can be presented by each structural element and it is reflected on a short-term maintenance/repair planning. Such system is very practical for highway authorities which are in charge of caring a wide variety and vast amount of bridge structures with limited budget.



管理番号 空 S－124

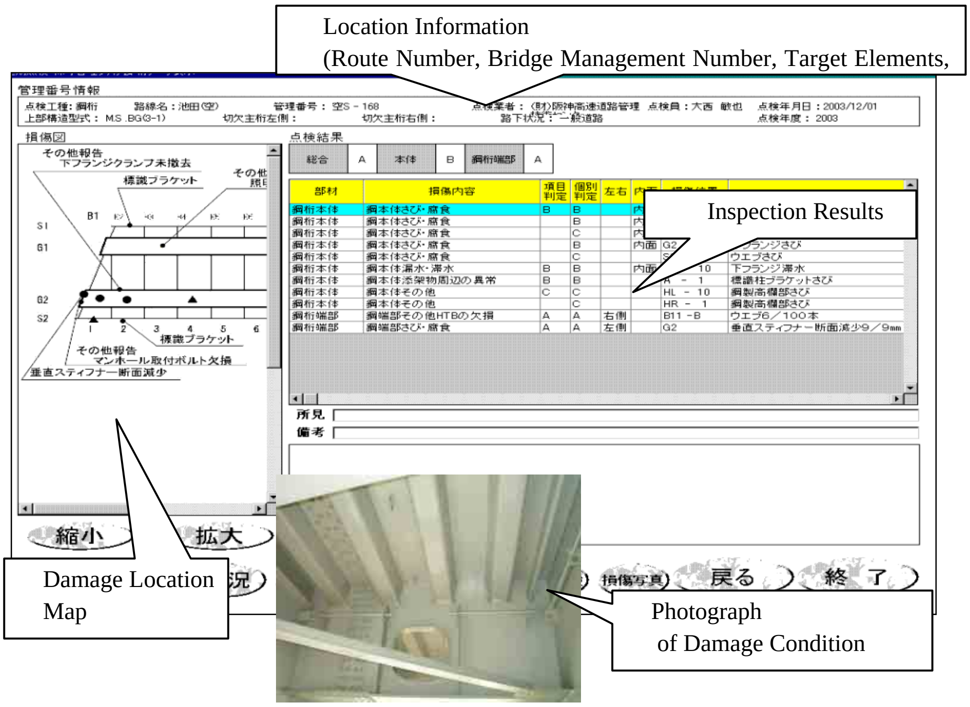
資　産　情　報	
供用年度	1967年度
平面線形/線形区分	曲線
橋長	37.71m
幅員	18.3m
上部.構造型式-表示	MC.I
上部.裏面板等	なし
上部.検査路数	あり
上部.工.立地条件/路下	一般道路
上部.塗装種別	塩化ゴム系
高欄.左側設置種別	RC壁式
高欄.右側設置種別	RC壁式
高欄.中央分離帯設置種別	プレキャストブロック
遮音壁.左側設置種別	吸音板
遮音壁.左側高さ	2m
遮音壁.右側設置種別	なし
遮音壁.右側高さ	

点　検　情　報		
定期点検		
桁	B	1998年09月
床　版	O	1998年09月
梁　上	B	1998年09月
橋　脚	O	1998年09月
高欄・水切り	C	1998年09月
日常点検		
路　上	A	2001年06月02日
路　下	A	2001年05月07日
検 査 路		
検査車両		

補　修　情　報	
桁	
床　版	1982年度
橋　脚	1997年度
高　欄	1999年度
遮 音 壁	1998年度
伸縮継手	1989年度
支　承	1987年度
落橋防止	1984年度
塗　装	1997年度
舗　装	1989年度

した。次の処理を選択してください。

Figure 2. An example of the result of chart information retrieval



管理番号情報

点検工種：鋼桁　路線名：池田(空)　管理番号：空S－168　点検業者：(財)阪神高速道路管理　点検員：大西　敏也　点検年月日：2003/12/01
上部構造型式：M.S.BG(3-1)　切欠主桁左側：　切欠主桁右側：　路下状況：一般道路　点検年度：2003

点検結果

総合	A	本体	B	鋼桁端部	A

部材	損傷内容	項目判定	個別判定	左右	内		
鋼桁本体	鋼本体さび・腐食	B	B		内		
鋼桁本体	鋼本体さび・腐食		B		内		
鋼桁本体	鋼本体さび・腐食		C		内		
鋼桁本体	鋼本体さび・腐食		B		内面	G2	フランジさび
鋼桁本体	鋼本体さび・腐食		C			S	ウエブさび
鋼桁本体	鋼本体漏水・滞水	B	B		内面	10	下フランジ滞水
鋼桁本体	鋼本体添架物周辺の異常	B	B			A － 1	標識柱ブラケットさび
鋼桁本体	鋼本体その他	C	C			HL － 10	鋼製高欄部さび
鋼桁本体	鋼本体その他		C			HR － 1	鋼製高欄部さび
鋼桁端部	鋼端部その他HTBの欠損	A	A	右側		B11 －B	ウエブ6／100本
鋼桁端部	鋼端部さび・腐食	A	A	左側		G2	垂直スティフナー断面減少9／9mm

所見
備考

Figure 3. An example of overhaul inspection report

The study of H-BMS focuses on all elements of bridge structures including piers, girders, decks, expansion joints, pavement and painting. At present, the prototype (version 0.5) with functions of pavement and painting work are completed. The system is now put into a trial use in several departments from which feedbacks from users will be expected. Also in the next version, expansion joint will be added along with overall system upgrading.

Pavement is explained hereafter as an example of actual calculation.

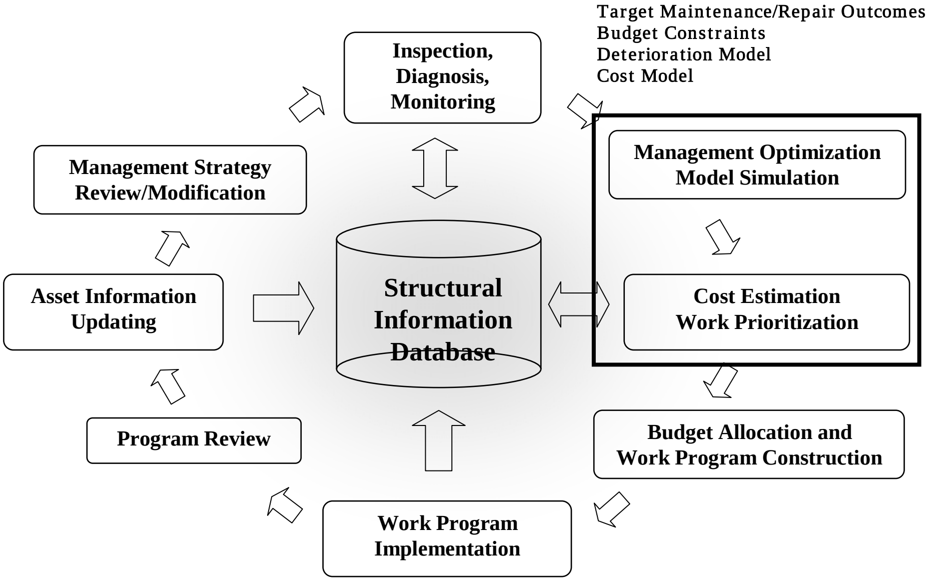


Figure 4. New management routine of expressway structures with integration of H-BMS

3.1. Calculation procedures

(1) Definition of LCC

LCC in H-BMS is defined as the sum of direct costs and the user costs for the next 100 years. Direct costs include actual maintenance/repair expenses estimated by the past payment. Maintenance cost includes emergency works like pothole refilling and bump removal and it increases in proportion to the deterioration level of pavement.

User costs are externalities like congestion and the increase of vehicle operation cost which are caused by re-pavement works and can be converted into monetary value. Fuel expenses and vehicle's depreciation expenses belong to the vehicle operating cost 1). Travel delay cost due to congestion is based on the amount of time lost in the slowdown section compared with driving by regular speed.

LCC is converted and expressed in the present value by considering the social discount rate, since the system includes the concept of conventional cost-benefit analysis which is mentioned later. Here the rate is fixed to 4% per year which is usually used for the cost-benefit analysis of infrastructure projects in Japan 2).

(2) Deterioration Model

Pavement's condition is expressed by a non-dimensional index value called Maintenance Control Index (MCI). MCI combines measured values of cracking ratio (the ratio of area where cracks over 1mm are identified to total area observed) and rutting depth. The measurement of both factors is mandatory in the inspection of Hanshin Expressway.

$MCI; = 10 - 1.51C^{0.3} - 0.3D^{0.7}$

where C is cracking ratio (%) and D is rutting depth (mm)

MCI is a common indicator of pavement condition in Japan which is introduced by the Public Work Research Institute of Ministry of Construction (now Ministry of Land, Infrastructure and Transport) 3).

Pavement's deterioration hysteresis is estimated by linear regression (Figure 5) of MCI from the past inspection results. The hysteresis is prepared by route and by deck type.

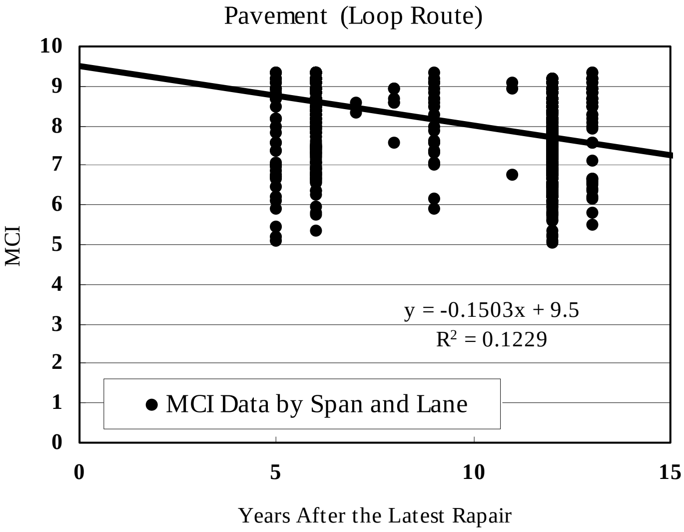


Figure 5. Deterioration pattern of pavement estimated by linear regression

(3) Repair Pattern Optimization

The optimal interval for repairing is where LCC is in minimum value (Figure 6). If the interval is longer than that, rougher road surface lowers the performance level of road service and repair cost per work is higher due to the advanced deterioration. If the interval is shorter, more repair works cause frequent congestion which also degrades the performance level as expressway. As such, LCC is calculated by span and lane since inspection data is prepared by this unit in the MIMS database.

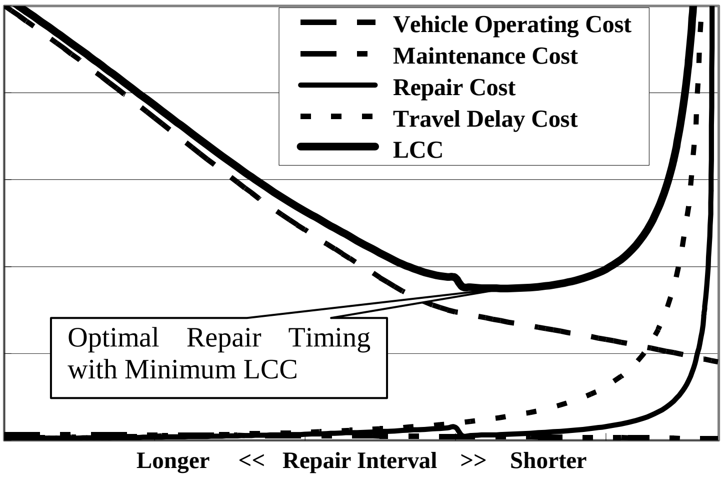


Figure 6. Changes of LCC by repair interval

(4) Repair Work Prioritization

The decision of which section should be repaired first is made by the comparison of investment efficiency ratio (D/C) as defined in Figure 7. The extra LCC incurred by deferred implementation of repairing from its optimal repair time in terms of lowest MCI is regarded as disbenefit (D). And the cost (C) is an estimated repair cost if implemented on the optimal time (C). Higher priority is given to the section with larger D/C because it can save more added cost if it could not be repaired on the ideal time.

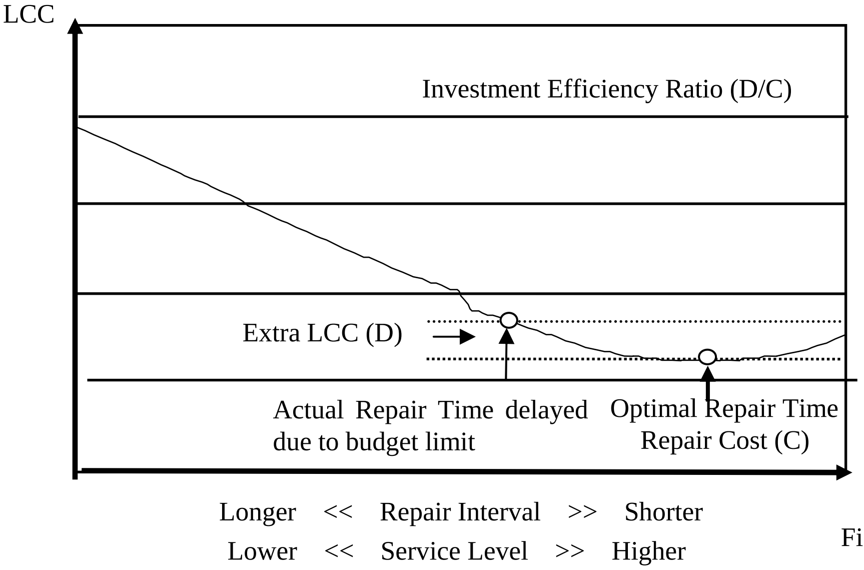


Figure 7. Concept of repair work prioritization

(5) Calculation of Yearly Cost Distribution

The optimized repair pattern is calculated with the rule of LCC minimization for all 29,400 pavement sections in Hanshin Expressway.

Figure 8 shows the total of direct costs needed during the bridge lifetime without any limit on annual budget. The average annual repair cost is about 850 million yen and it varies according to the number of sections reaching to its repair requiring year. Meanwhile the average maintenance cost per year is about 380 million yen with minor variance, but it is gradually decreasing as repair works progress.

The same calculation is made on the condition that repairs are performed within a fixed budget limit. Here, it is assumed that the balance of budget in the previous year is not carried over to the next year. Also the deferred repair works are carried out in the subsequent year by following the given order. Figure 9 shows the changes of average MCI with different budget limits. While the present average MCI level is sustained if 1,100 million yen can be earmarked for repairing annually, it starts declining from a certain year in case of 900 million or 1,000 million yen budget. The performance of pavement would not be maintained properly if budget goes below a certain threshold. It gives a clear suggestion of how much money is needed for keeping the pavement healthy on a long-term basis.

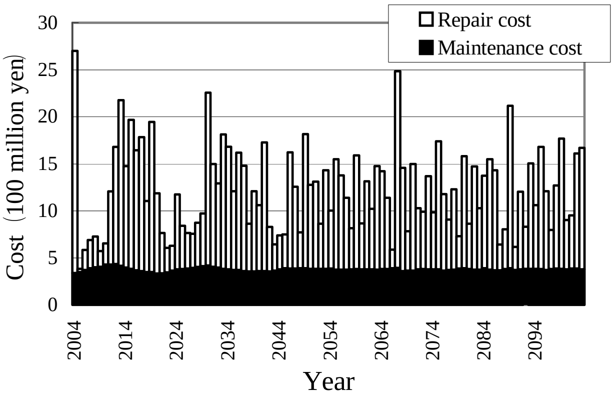


Figure 8. Transition of direct cost without budget limit

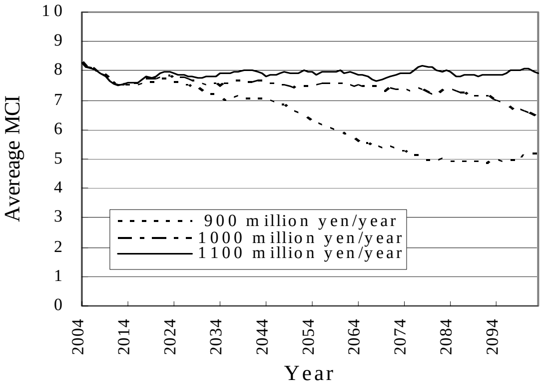


Figure 9. Changes in the average MCI

Figure 10 and 11 show the changes of the direct cost under the different budget limit. In case of 1,000 million yen, the maintenance cost increases over the period because the pavement performance is degrading indicating that budget insufficiency accelerates the deterioration. Therefore the total direct cost is swelling with increasing maintenance cost and the full use of annual repair budget.

On the other hand, 1,100 million yen allows the maintenance cost to keep constant and the repair budget is not always dried up every year, which might mean that the all the pavement remains healthy for the entire period.

Thus, these analytical results give an objective and useful suggestion on budget requirement. The money needed for maintenance/repair works of every year can be determined on the basis of long-term management view of structures.

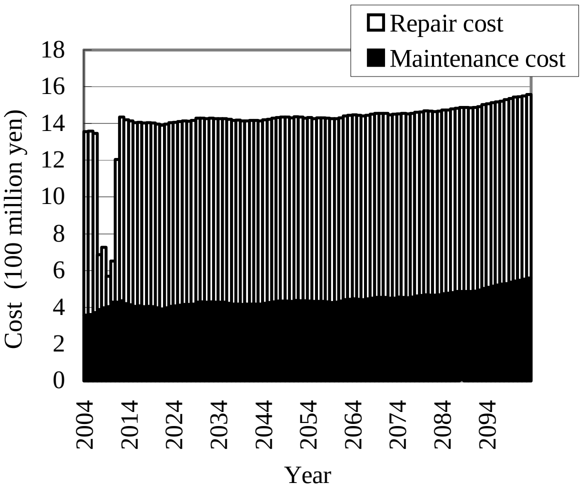


Figure 10. Changes of total direct cost with maximum budget of 1,000 mil. yen /year

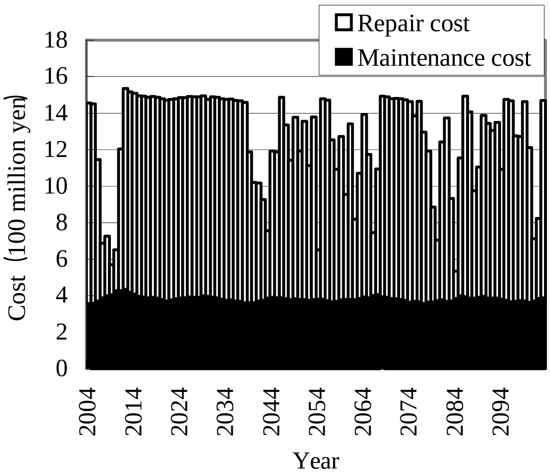


Figure 11. Changes of total direct cost with maximum budget of 1,100 mil. yen /year

4. Conclusion

MIMS has been developed as an efficient tool of data storage reinforced with reference functions. H-BMS meets the urgent need of preparing a logical and systematic method of building maintenance/repair planning, which used to be dependent rather on empirical approach. It should be noted these two systems also help to meet the rising demand of fulfilling accountability in every stage of decision-making process of structural management.

Both MIMS and H-BMS have been developed as a custom-made asset management system with components to match with the uniqueness of Hanshin Expressway: very busy highway network consisting dominantly of bridge structures. In the followings, the features of the systems are summarized by focusing on their practicality in comparison with similar systems.

4.1. MIMS

Before MIMS was built, many data had already been available from regular inspection and repair works. That is a big motivation to start its development as well as enables the system to get activated immediately after its completion and to be improved while using it. The system was developed to make storage place for data and to add the functions to use those data efficiently for referencing. Components and interfaces reflect types and formats of existing data.

Since a large volume of data are kept generated through new inspections and repair works, constant refreshing of database is essential to make the system useful.

4.2. H-BMS

The availability of completed database of MIMS makes the development of H-BMS easier and it can be put on a trial use immediately. Users need not wait until enough data are ready. H-BMS is the first application by taking account of the benefit of MIMS. Its data format is easy to be used as an H-BMS's basic input.

H-BMS is not ready for all bridge segments in the first version. Priorities are put on those which use more budgets for repair and which are simpler in terms of deterioration pattern and maintenance and repair treatments. Pavement and painting meet those conditions followed by expansion joints. Girder and pier are considered to take time. The system should start from smaller scale and be used to let first know its functions and usefulness.

H-BMS are used not only for estimating cost needed for a long time but also suggesting the appropriate order of repairing in a short time like planning the works for the coming year. The system is assumed to be used more often in the field office level for the latter purpose and expectations of usefulness are high in this level. Therefore the precision of outputs and their accountability is important. Accurate and frequently-updated data used in all the calculation processes can contribute the reliability of H-BMS

4.3. What is practical asset management system?

The followings are some key points to make an asset management system practical learned in the course of developing MIMS and H-BMS.

- There is a strong motivation to use the system. Integrating the systems in the decision-making process by the top-down order will be a momentum. The system is well-known among stakeholders in and outside of the organization. There should be a common agreement in terms of the contents of the system and how and to what extent the results are utilized
- The organization owns financial and technical capacities of continuous modification and updating. Frequent and proper feedbacks should be always available from users.
- The system is ready to use immediately right after the system is completed. Input data should be available beforehand.
- The given simulation conditions, such as deterioration model and cost factors, are based on data which are supposed to reflect the actual situation of assets. Also there should be a good balance between estimation by data and plausible theory.
- There is no big gap between the cost estimated by the system and the actual cost level in the previous years. Soft-landing is needed for the feasible and smooth change of budget estimation process.

REFERENCES

1) Anzaki, Y., Katakura, H. & Isa, S. (1989). A study on the Pavement Serviceability and Vehicle Operating Cost, General Proceedings of 18th Japan Road Congress, 710-711.

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