

# THE DEVELOPMENT AND IMPLEMENTATION OF A BRIDGE MANAGEMENT SYSTEM FOR SOUTH AFRICAN ROAD AND RAIL AUTHORITIES

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## ABSTRACT

This paper describes a bridge management system (BMS) developed in South Africa for various road and rail authorities including the South African National Road Agency, Spoornet (the South African rail authority), the Cape Town City Council, the Botswana Roads Department and the Taiwan Area National Freeway Bureau. Each authority is responsible for the maintenance of its bridges which range in number from approximately 80 to 5 000. The system has been developed for assisting in the maintenance of bridge structures. The approach taken has been different from traditional BMSs. The inspection, condition and budget modules have been based on an innovative approach to bridge inspections. Each of the 21 predefined elements of a bridge are assessed in terms of the defects (rather than the overall condition) by means of a 1 to 4 rating for Degree, Extent and Relevancy (DER). *Degree* is defined as the severity of the defect under consideration; *Extent* is the extent to which the defect occurs over the area of the bridge element; *Relevancy* is the importance of the defective element on the serviceability and safety of the bridge. The *Relevancy* forces the bridge inspector to evaluate the consequences of the defect in terms of the bridge serviceability and safety. Each of these parameters is combined in the condition module to determine a priority ranking of bridges requiring repair. A remedial work sheet is used during bridge inspections to summarise the items requiring repair. Remedial work is identified with associated unit costs and this is used as input for the budget module. The DER rating enlightens the bridge manager about specific problems experienced on the bridge network.

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## INTRODUCTION

Declining funds for road construction and maintenance in South Africa during the past ten years has resulted in more attention being paid to the preservation of the existing road infrastructure with the constraint of limited funds. The increase in the legal axle load from 8.2 to 9 tonnes in March 1996, pressure from the Southern Africa Development Community to implement a further increase to 10 tonnes and a low level of control of heavy vehicle overloading in most parts of the country do not help to alleviate the situation. Bridges and other road structures are key elements in any road network; effective management and proper maintenance of these structures is therefore essential. The economic benefits of using a systems approach to the management of structures has been proven by many authorities. Effective management requires that maintenance and rehabilitation are carried out when the greatest benefits are derived, as maintenance costs may increase substantially as serviceability levels of structures decline.

A Bridge Management System which was originally developed and implemented by the Division of Roads and Transport Technology of the CSIR for the Taiwan Area National Freeway Bureau during 1995 has more recently been modified and implemented for a number of road and rail authorities in southern Africa. The BMS was initially implemented for the city of Cape Town Municipality and Spoornet (the South African rail authority) during 1996/97, and is currently being implemented for the South African National Roads Agency and the Western Cape Provincial Administration as well as the Botswana Roads Department, the road authority of one of South Africa's neighbouring countries.

The approach taken has been different from traditional BMSs. The deterioration, prioritisation and optimisation models have been based on an innovative approach to bridge inspections. Each of the 21 predefined elements of a bridge are assessed in terms of the defects (rather than the overall condition) by means of a 0 to 4 rating for Degree, Extent and Relevancy (DER).

This paper describes various aspects of the implementation of the BMS for four of the bridge authorities. A brief description of the BMS modules and their inter-relationship as well as the inspection rating procedure are also presented.

## **IMPLEMENTATION OF THE SYSTEM**

To date the BMS has been implemented for the following road and rail authorities:

- The National Roads Agency of South Africa
- Spoornet - The South African railway authority
- The Western Cape Provincial Administration
- The cities of Cape Town, Port Elizabeth and Pietermaritzburg
- The KwaZulu-Natal Department of Transport
- The Botswana Roads Department
- The Taiwan Area National Freeway Bureau

Various aspects of the implementation of the system for four authorities are now described.

### **National Roads Agency of South Africa**

The Roads Agency is responsible for all bridges on national road network in South Africa. This comprises all major roads and freeways constructed to link the major cities such as Johannesburg, Durban, Pretoria and Cape Town. These 2 155 bridges consist primarily of road overpasses and underpasses, with a total deck area of two million m<sup>2</sup>, an accumulated bridge length of 140 kms and an estimated asset value of US\$ 2 billion. It is expected that in the future more of the urban freeways and other provincial roads will fall under the jurisdiction of the Roads Agency, which will significantly increase this total. In South Africa approximately 2.5 percent of the funds allocated to road rehabilitation projects is spent on bridge maintenance. Budgets are created with the help of the BMS. Bridge inspections are either carried out every five years under the Bridge Management System programme or during road rehabilitation projects. In the latter instance bridges are inspected and repaired together with the road pavements under the same contract. The CSIR and Stewart Scott International (SSI) were awarded the contract to fulfill the following functions:

- Develop and implement a new computerized bridge management system
- Implement the bridge inspection programme

In order to expedite the process, the two project components were carried out simultaneously. The existing BMS's developed for the city of Cape Town and Spoornet were customized and enhanced

to satisfy the requirements of the Roads Agency. The bridge inspection programme is currently in progress and is expected to be completed by the end of 1998. The method of implementation is unique when compared with the other systems implemented.

### **Implementation of the bridge inspection programme**

The work carried out comprised the following:

- Compilation of inventory sheets;
- Field inspections;
- Compilation of bridge inspection reports;
- Input of the inventory and inspection data into the computer using the BMS software.

For the successful implementation of this contract it was essential that persons were suitably qualified and experienced in bridge design and rehabilitation. Because of the crucial role the bridge condition survey fulfils in the BMS, and of the often complex behaviour of bridge structures, it was felt that structural engineers with a reasonable degree of experience should be used to carry out the principle inspections. The following minimum requirements for inspectors were thus specified:

- Have a verifiable minimum of five years experience in bridge design/engineering.
- Be registered as a professional engineer or technologist in the Republic of South Africa.
- Be available to carry out bridge inspections for at least half of their working hours in any month.
- Be available to attend a three day training course at their own cost.

### **Allocations of bridges to inspectors**

The road network was divided into three geographical areas, each inspection area representing approximately equal total bridge deck areas.

The following aspects were taken into consideration when allocating sections of roads to inspectors:

- The total bridge deck area allocated to each inspector was approximately the same;
- Where possible, inspectors were allocated bridges which were designed by their respective firms;
- Proximity of bridges to the inspector's work location.

### **Control assessments of bridge inspections**

Control assessments are carried out on bridge inspections by studying bridge inspection reports. The format of the written reports enables the client to validate bridge defect ratings. The validation is done in the form of spot checks on a small percentage of the total sample of bridges inspected. This is done as soon as the reports have been submitted. In exceptional cases, where there are significant differences between the control assessments and those of the inspector, an additional visit to the site is required by the inspector and a representative of the Roads Agency to review the ratings in question.

An important part of the report is the inclusion of the photographic record sheet which consists of a list of photographs of all defects together with descriptions. This ensures that control assessments can be carried out on inspectors rating of defects. During inspections the inspector is required to complete the photographic record sheet.

The reports will be made available to inspectors for future bridge inspections. Inspectors will be able to check whether defects have been repaired and if not, whether they have deteriorated. At this stage it is envisaged that principle inspections will be carried out every five years.

## **Spoornet**

Spoornet owns approximately 5 000 bridges and 10 000 culverts. The work included the development of a system for a client who owns a large number of steel bridges, of which a high proportion have bridge decks which are steel trusses. It was found that only minor modifications were required for the inspection rating procedure to cope with these types of steel structures. The system was implemented and completed by the end of 1997. In the case of the Spoornet system, it was decided by the client to carry out the inspections in-house by making use of maintenance personnel based at the regional offices. Some of the inspectors did not have adequate bridge experience resulting in the need for a more intensive programme of control on the defect ratings. Five training courses were run in the major centres in South Africa.

## **City of Cape Town**

The city of Cape Town owns approximately 300 bridges. As in the case of Spoornet, the inspections were carried out by in-house personnel. However, in this case, the inspectors were bridge engineers with experience in design. An important enhancement to the system was the monitoring option available on the inspection sheets. This allows the inspector to identify defects for monitoring during field inspections. These items may be excluded from or included in the budget. Reports from the computer program listing those bridges which require monitoring, the relevant defects and the monitoring frequency can be generated. An additional feature added during the project is the “make safe” input option on the inspection sheet. This enables the inspector to identify defects which need to be repaired immediately because of possible danger to the public, e.g. missing hand railing or guardrail protruding into the roadway. The repair should be carried out within a few days, and may be temporary; a proper and more permanent repair can be carried out at a later stage. Both the above enhancements were designed by the city bridge engineers department during the implementation of the system.

## **Botswana Roads Department**

The Botswana Roads Department owns 80 bridges, all but three of which are river bridges; the remaining three are road bridges over railway lines. This system was implemented in its entirety by the CSIR and SSI team. The field inspections were carried out by engineers from SSI. Drawings were available for a small number of bridges which meant that the majority of inventory data had to be captured on site during the field inspections. A number of important lessons were learned during the course of these inspections. The photographic record sheet, which assists the inspector in compiling inspection reports, was implemented during this project, as well as a recommended format for the bridge inspection reports. Both of these enhancements were used in the BMS project for the South African Roads Agency.

During the project, a record was kept of the time taken to complete various activities related to bridge inspections, which are presented in Table 1. The average time per bridge is 6 hours, both for the inspector and the assistant. The bridges inspected were all short and medium span structures with a maximum of 10 spans per structure.

**TABLE 1: Average time for bridge inspections**

<b>Time required for one bridge (hrs)</b>	<b>Inspector</b>	<b>Assistant</b>	<b>Total</b>
<b>Compilation of inventory</b>	1.5	-	1.5
<b>Field inspection</b>	2.5	2.5	5
<b>Inspection</b>			
<b>Travel</b>	1	1	2
<b>Writing of reports</b>	0.5	1.5	2
<b>Data input</b>	0.5	1	1.5
<b>TOTAL</b>	<b>6</b>	<b>6</b>	<b>12</b>

## COMPONENTS OF THE SYSTEM

The bridge management system currently consists of six modules as follows:

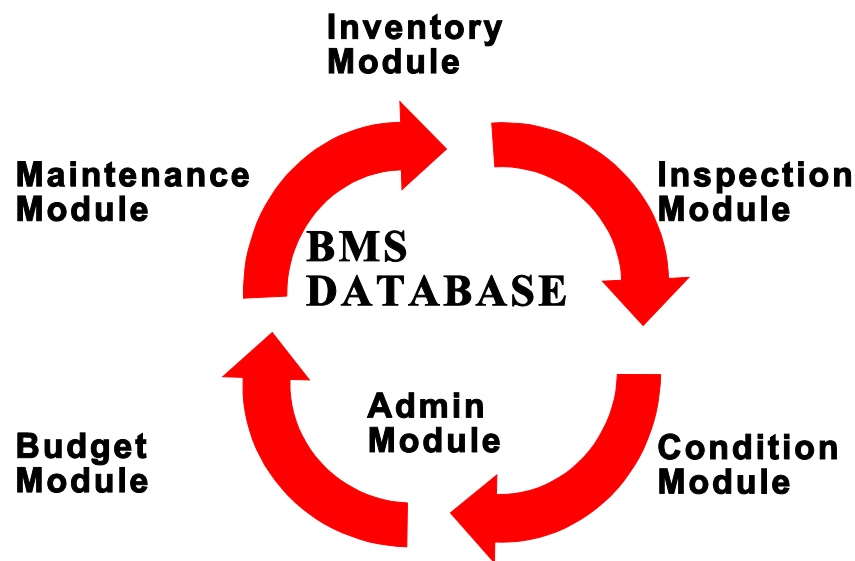
- Inventory
- Inspection
- Condition
- Budget
- Maintenance
- Administration

The system developed for the Taiwan Area National Freeway Bureau also contained a Seismic module, as Taiwan experiences earthquakes on a fairly frequent basis. Each of the modules contributes to a greater or lesser degree to the BMS database, and are linked together as illustrated in **Figure 1**.

### Inventory module

The first step in the implementation of a BMS database is to compile the bridge inventory which consists of a record of all bridges in the network with comprehensive details of the type of bridge, construction materials, major dimensions, clearances, etc. This information is obtained from "as-built" plans and confirmed and/or measured in the field. Details such as loading and hydraulic data, where not available on drawings, are obtained from the design engineers. Depending on the availability of drawings, the collection of inventory data can be a costly exercise.

The design of the inventory module usually varies to some degree from one bridge owner to another, for example, a national road authority, a rail authority and a city council. The services in or on a structure are generally far more complex in a city environment than on a rural road, and the inventory input screens will reflect these changes in circumstances.



Inventory data generally does not change with time except when some modification or improvement is carried out on the bridge or associated roads or services.

### Inspection module

Each structure must be appraised at a network level with respect to its condition of serviceability and safety. Standard inspection forms listing all the elements of a bridge structure with all the common defects normally encountered are completed by the inspector. Bridges have been subdivided into 21 items as follows:

- |   |                                 |
|---|---------------------------------|
| 1. Approach embankment                  | 11. Parapet/handrail            |
| 2. Guardrail                            | 12. Pier protection works       |
| 3. Waterway                             | 13. Pier foundations            |
| 4. Approach embankment protection works | 14. Piers & columns             |
| 5. Abutment foundations                 | 15. Bearings                    |
| 6. Abutments                            | 16. Support drainage            |
| 7. Wing/retaining walls                 | 17. Expansion joints            |
| 8. Surfacing/ballast                    | 18. Longitudinal members (deck) |
| 9. Superstructure drainage              | 19. Transverse members (deck)   |
| 10. Kerbs/sidewalks                     | 20. Deck slab                   |
|   | 21. Miscellaneous items         |

The appraisal is carried out regularly for all bridges but may be required more frequently for steel bridges and bridges subject to foundation settlements or flooding. In South Africa, some bridge authorities carry out their own inspections whereas others appoint one or more consulting firms to conduct the inspections. Principle inspections are carried out every three to five years, depending on the availability of funds. Monitoring inspections, to assess the deterioration of certain defects specified during the principle inspections, as well as after major disasters such as floods, are carried out more frequently. The deterioration of structures is monitored by means of both principle and monitoring inspections.

The rating system for the inspection of structures is discussed in detail in the

section entitled Inspection rating procedure.

## **Condition module**

The condition module is used to prioritise the bridges in the system based on the most recent inspection data. The overall priority index is based on the priority and functional indices. The functional index is calculated from various parameters in the inventory module which give an indication of the strategic importance of the bridge in the network. These include class of road or railway line, detour length, traffic volume, width between kerbs, type of structure and profitability of line (in the case of rail structures). Each of the parameters is given greater or lesser relative importance by user-defined weighting factors.

The priority index is based on the condition rating of the structure and is calculated from the D (Degree), E (Extent) and R (Relevancy) of each of the identified defects on each of the 21 predefined inspection items. More importance can be given to certain items such as deck slab, longitudinal members and piers as opposed to items such as guardrail and surfacing by means of user-defined weighting factors.

During an inspection, sub-items are inspected and rated individually, such as piers and deck spans. However, individual columns forming a single pier, or longitudinal members on one span, are considered as one sub-item.

A distinction is made between the condition index and priority index. The condition index gives an indication of the condition of the structure as a whole, taking into account each item and sub-item. For example, all nine piers (eight in good condition and one in poor condition) of a ten span bridge are included in the calculation. The priority index, on the other hand, which is used to determine the bridge ranking, only takes into account the worst rating of the sub-items of an item such as piers. Thus in the above example, only the one pier in poor condition would be used in the priority ranking calculation, and the piers in good condition are ignored. This approach assumes the philosophy that the strength of a chain is determined by its weakest link.

## **Budget module**

The main purpose of the budget module is to assist the bridge manager in allocating identified repair work into different budget years. The estimated quantities for repair which are done during inspections are used as a basis for determining budgets for the repair of each structure. During an optimisation procedure, the estimated cost of repair for each defect is compared with the relevancy of the defect to determine a benefit-cost ratio. In the case of limited budgets, maximum benefits can be achieved by first repairing items with the greatest reduction in risk to the road user and the lowest cost. In addition there is a facility whereby the bridge manager can overwrite the optimisation procedure by manually assigning selected bridges or types of repair work into a chosen budget year. The budget can then be re-optimised with the given constraints.

## **Maintenance module**

In order to complete the cycle of the BMS, all maintenance activities that have been successfully completed are required to be entered into the system. This includes information such as actual quantity of work done, contractor, date, actual cost and any other significant comments. The system will assume that the defect no longer exists on the relevant item once the maintenance work has been indicated as complete.

A preventative maintenance screen assists the bridge manager in identifying maintenance work (generally routine in nature) which must be done to a particular structure should a bridge maintenance team be carrying out other repair work on site.

## **Administration module**

The administration module allows the user to modify the drop-down or pick lists used in the other modules as well as the modification of the system parameters. The latter option is password controlled.

## **INSPECTION RATING PROCEDURE**

Perhaps the most important element of a bridge management system is the inspection rating or condition assessment procedure. The ability to accurately capture on paper the condition of the structure in terms of the structural integrity and the safety of the user has a major impact on the quality of the system outputs and ultimately determines the success of a BMS.

Ease, uniformity and completeness of reporting can be enhanced by the use of a prepared checklist or standard form, completed at the time of the inspection. The checklist, referred to as the inspection sheet, should remain simple but at the same time cover the important items and aspects of the bridges in the network. The main advantages are as follows:

- Facilitate bridge inspections
- Reduce the possibility of items being overlooked
- Improve the uniformity of inspections
- Allow comparisons of results from inspections conducted by different personnel at different times

The method chosen to inspect bridges is very important in that it is the only tangible record that can be used for rating of bridges and for the repair budget predictions. Simple and more precise inspections result in more accurate analyses. The emphasis should then be on more detailed inspections rather than superficial inspections for more accurate budget predictions.

Given the complexity of the structural behaviour of bridges it is also very important that the inspectors are suitably qualified. They should have adequate experience on the design, construction and maintenance aspects of bridges. To understand the consequence of defects on the serviceability and safety of the bridge is important that the inspector be able to correctly and accurately predict the future behaviour of bridge components.

In general when rating the main components of bridges the following considerations should apply:

- **Approaches:** Smooth transition onto the bridge, stability of the fill and the probable effects on the bridge.
- **Waterway:** Free flow of water under the bridge up to designed capacity, stability of the waterway and the probable effects on the bridge.
- **Superstructure:** Structural integrity.
- **Substructure:** Structural integrity.
- **Roadway:** Smooth and safe passage over the bridge.

In addition to rating identified defects, the inspector is also required to take at least one photograph of each defect, and in the case of the first inspection of a bridge, or where no photos of the bridge are on file, a number of standard photos of the bridge which are listed on the photographic record



sheet. These include photos such as:

- bridge from upper approach viewing along centre-line of deck (from both approaches)
- along deck edge (both sides) - to record deck profile and deflections
- bridge in elevation showing total deck length and full height of piers and abutments
- underside of the deck
- typical abutment and pier
- upstream and downstream sides of the river from the bridge (if a river bridge)

The photographic sheet allows the inspector to write remarks about each photo and to record the direction of the photo and the camera photo number. These latter items greatly assist in the preparation of the inspection report once the photos have been developed.

## Bridge inspection tools

In most cases, relatively few tools are required in order to carry out adequate network level bridge inspections. The recommended list of items includes the following:

- Clipboard, inspection sheet and remedial work activity list
- Paper for drawing sketches e.g. crack patterns
- Camera with a flash and zoom lens
- Spare film
- A good pair of binoculars e.g. 8 x 40, 10 x 25
- Compass
- Crack gauge
- Tape measure
- Bridge drawings if available

In some cases a ladder may be required, but most defects can be identified and studied with a pair of binoculars. A bridge inspection unit and/or boat will only be required in exceptional cases.

## The DER rating system

The essence of a bridge inspection is to identify the defects on a bridge and their relative importance so that they may be prioritised and the available funds allocated efficiently for their repair. It is thus important to rate the degree of each defect (how bad is the defect) and the extent to which the defects exist on the respective inspection item (how common is it). However the most important purpose of the rating is to identify the consequences of the defect with regards the safety and serviceability of the bridge. This coerces the inspector to not just give a visual rating of the defect but to look at the defect from a global point of view and to try and understand its influence on the structural integrity of the bridge. Because of the complexity of a bridge this last rating is very important; two defects that look the same may have significantly different influences on the bridge when one considers the safety of the motorist.

The rating system which has been used in the approach to condition assessments is referred to as a DER rating system and has the following components:

- D represents the **degree** or severity of the defect
- E is the **extent** of the defect on the item under consideration
- R is the **relevancy** of the defect. This rating considers the consequences of the current status of the defect with regard to the serviceability of the bridge and the

safety of the user (pedestrian, cyclist, motorist, passenger).

In addition to the above three ratings, the inspector is also required to rate the **urgency**, U, to carry out the remedial work to repair the defect. This rating considers possible future events which could adversely affect the defect, and provides a procedure for applying time limits on the repair requirements. Together with the urgency rating, the inspector is required to identify the remedial work activity (and estimated quantity) which must be carried out to repair the defect. The repair activity is selected from a standard list which is different for each bridge item. Activities include, for example, repair spalled concrete (all concrete items), backfill erosion/scour damage (approach embankment), remove sand, debris and vegetation (surfacing) and reinstate expansion gap between deck and abutment (abutments). Each of the repair activities has a unit rate which is used in the budget module to determine an *estimated* budget for the repair of the structure.

The rating is essentially a four point system (1 to 4), with the value of zero providing a way of identifying alternative meanings. The rating system is summarised in Table 2.

**TABLE 2: Details of four point rating system**

<b>Category</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Degree (D)</b>	Not applicable	None	Fair	Poor	Critical
<b>Extent (E)</b>	Unable to inspect	Local			General
<b>Relevancy (R)</b>	Uncertain	Minimum	Minor	Major	Maximum
<b>Urgency (U)</b>	Monitor only	Routine	within 5 yrs	within 2 yrs	A.S.A.P.

It is possible to use one overall condition rating by combining the above three ratings but it is more difficult to be consistent. By considering each of the above ratings separately one can concentrate on each one without confusing one for the other, and consequently obtain a more accurate rating of defects. It also simplifies the rating procedure and provides a more precise picture of the actual condition of the bridge to the bridge owner. With this method one can also produce more accurate budget predictions and maintenance, repair and rehabilitation actions to be used for preliminary work schedules used to carry out the work. In essence the bridge owner has a clearer and more accurate picture of the condition of the bridges in the network.

Furthermore, the rating of the degree and extent of each defect separately enables a more accurate calculation of deterioration rate; one is able to obtain actual rates of deterioration by observing the variation in degree and extent from one inspection to the next.

The relevancy rating, R, which assesses the consequences of the defect with regard to the structural integrity and safety of the motorist can also be used to optimise the budget based on the reduction in risk to the motorist.

## **CONCLUSIONS**

The BMS which has been developed and implemented for various road and rail authorities in southern Africa and in Taiwan has some unique characteristics:

- The inspection procedure focuses on defects only, making inspections simpler

- A relevancy rating of each defect is required, which forces the inspector to evaluate the consequences of defects
- Elements in good condition are not rated, thus reducing computer input
- Selected defects can be monitored only, and can be excluded from the budget calculations

During the implementation of the systems a number of lessons have been learned:

- There is little to gain by using inexperienced personnel for carrying out principle inspections, as these are particularly important and play a key role in the BMS. Monitoring inspections may be carried out by less qualified personnel because they can use previously completed inspection sheets to compare ratings and in so doing learn from the experience of others. Furthermore, when using inspectors with adequate experience in bridge design, they are able to provide valuable advice to the client on recommended repair procedures.
- In some cases, severe defects are identified during network level inspections that require further investigations. The proposal at this stage is to employ the same inspectors to continue with project level inspections if possible. During these inspections diagnostic surveys will be required to determine the reasons behind failures and also to obtain valuable information on the remaining life of the bridges.
- Adequate descriptions of photographs taken at the time of inspections greatly facilitates the compilation of bridge reports when returning to the office, particularly when a number of bridges are inspected during one trip. It is recommended that more photographs be taken than are actually required as these can be invaluable when discussing various defects with colleagues or the client, and may even save an additional visit to the bridge.
- Following a systematic approach during inspections ensures that all defects are noted and rated. An important lesson learnt is that inspectors need to pay attention to detail, as it is often the apparently minor defects that provide the solution to the cause of other major defects such as settlement and rotation.
- Special equipment for the inspection of bridges at network level is very rarely required. A good pair of binoculars is more than adequate for most bridges. A good quality camera with a flash and zoom lens was found to be essential.

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