TRAFFIC MODELLING OF URBAN TOLL CORRIDORS
A review of current South African practice, as applied within the Johannesburg Pretoria toll corridor.

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ABSTRACT

This paper examines the evolution of traffic modelling techniques in congested urban networks, with specific reference to the recently completed development Gautrans Provincial Toll Study. It presents illustrative techniques in the following areas:

- The use of matrix estimation techniques within a framework of comprehensive traffic counts, roadside interviews and other origin-destination information.
- The role of stated and revealed preference studies to establish acceptable monetary values of time whereby toll tariffs can be incorporated into driver route choice.
- Stochastic user equilibrium traffic assignment techniques, which address variations in driver perceptions in travel costs, under congested and free-flow conditions.
- Model calibrations to meet external audit requirements.
- The application of micro-simulation models to supplement operational analyses of toll plazas, interchanges and critical intersections.

The presentation focuses on the broader principles of urban toll modelling by clarifying the conceptual approach, as opposed to in-depth technical analyses.

1. INTRODUCTION

In the past, the primary focus of regional strategic traffic studies in Gauteng was aimed primarily towards effective planning of the provincial road network. Calibration of trip matrices, in the main, was based on dated OD surveys that were done during the seventies and eighties, whereas modal split and traffic assignments were validated using "broad-brush" cordon and screen-line comparisons. Traffic modelling was confined to the morning peak hour, with home-based work trips enjoying priority. Nevertheless, the accuracy of the resulting travel demand forecasts was acceptable within the regional context and the prevailing road construction *modus operandi*.

More recently, road construction budgets have decreased substantially at national, provincial and local levels. At a national level, this resulted in the emergence of the Build Operate Transfer (BOT) projects, whereby new road construction projects are financed via toll revenue, with toll concessions being granted to privately owned companies or consortia. Currently, all new national freeway road construction follows this route. The BOT approach places the onus on prospective concessionaires to conduct comprehensive traffic modelling, determine optimum toll strategies and complete the detailed design. Since financial viability of BOT projects depends almost entirely on accurate toll revenue estimates, the financial backers of prospective concessionaires rely heavily on external traffic auditors to scrutinise the traffic estimates. This has resulted in the establishment of stringent and rigorous calibration and validation standards, all aimed at improving the accuracy of traffic modelling and forecasting. Without such scrutiny, the concessionaires face serious financial risk.

In recognition of the burden that the BOT process places on prospective concessionaires (particularly where bids are unsuccessful), Gautrans took upon itself the task of developing a comprehensive toll model which would satisfy such stringent external audit requirements. In anticipation of the possible devolution of BOT projects to the Provincial level, this model establishes a viable framework wherein the Johannesburg Pretoria toll corridor could be managed in an integrated manner.

2. OBJECTIVES OF THE GAUTRANS STUDY

The overall goal of the study was to produce a *toll diversion model* for the Johannesburg Pretoria corridor that would satisfy the following study objectives:

1 The model should be sufficiently robust to enable a wide range of possible toll strategies to be tested, all within the context of an *integrated toll management* approach for the corridor.

2 The standard of model design, calibration and validation should be of sufficient quality to satisfy the rigorous scrutiny of possible *external traffic audits* by internationally accredited transportation consultants.

3. MODEL DESIGN

Figure 1 illustrates the interaction between individual components of the study.

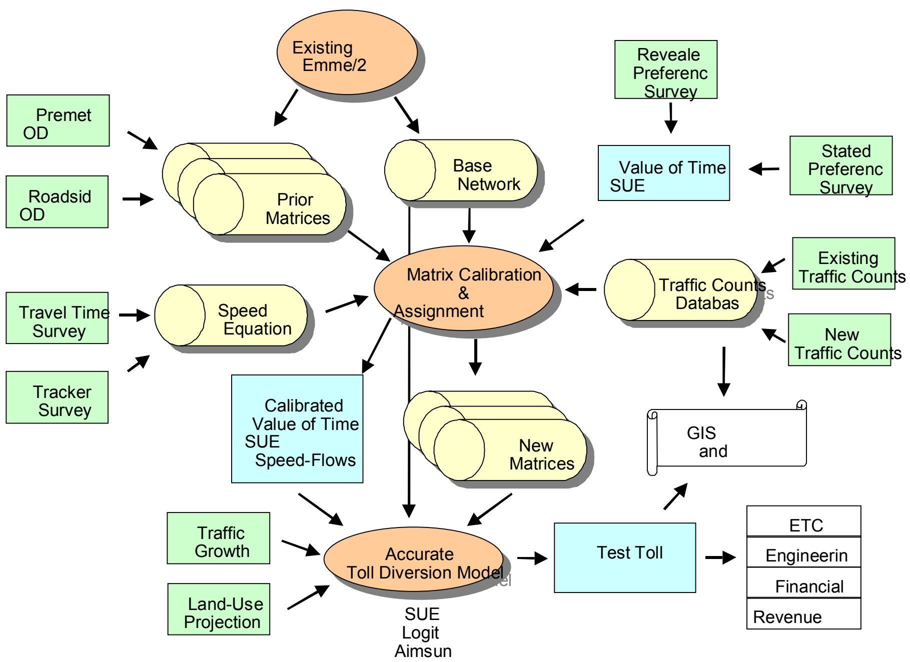

Figure 1: Model design

4. DATA COLLECTION

A comprehensive data collection exercise was carried out consisting of traffic count, origin-destination surveys, journey time surveys, electronic tracking of heavy vehicles and attitudinal surveys covering stated and revealed preferences.

4.1 Traffic counts

Within a context of this study, the traffic counts data was required for the following reasons:

- As input to the transportation model.
- To validate the model by comparing assigned volumes with actual traffic volumes.
- To provide traffic flow measurements on road segments where travel time surveys are done.
- To provide information on the level of traffic congestion on the roads within the corridor during both peak and off-peak periods.
- To determine a percentage of heavy vehicles for the purpose of toll revenue projections.

The existing and new traffic counts information was compiled in a comprehensive traffic count database (TCDb). The information was captured in the same format as found in the CTO manuals.

4.2 OD surveys

Two limited sample O-D traffic surveys were undertaken by interviewing motorists at selected freeway service areas (FSAs).

Origin-destination surveys were performed at the following two locations:

- Ben Schoeman Ultra City FSA (N1/21) on 20 September 1999
- Highveld 1-Stop FSA (R21/P157-2) on 21 September 1999

4.3 Electronic tracking

Electronic information generated by the vehicle tracking fraternity was identified as an innovative approach to develop an accurate and comprehensive database of journey travel times and origins and destinations of heavy vehicles in the Gauteng region.

This technology is primarily used for security reasons although freight operators have successfully applied this technology for fleet management purposes. Currently, in excess of 150 000 vehicles are being monitored across Southern Africa on a daily basis. However, only between 5 000 and 10 000 vehicles are monitored using the Global Positioning System (GPS) technology providing accurate real-time information.

For the purpose of this study the required data could be obtained for approximately 300 vehicles only, monitored by Matrix Vehicle Tracking (Pty) Ltd. From the outset it was clear that due to the relatively small sample size, the information received from this source would not accurately predict origin/destination information. The scope of the investigation was therefore restricted to the prediction of journey travel times on the Gauteng main road network.

4.4 Journey travel times

Two types of journey time surveys were carried out in order to assist in the calibration of the matrices to be used in the modelling of the corridor between Pretoria and Johannesburg for the following purposes

- Validation of the volume-delay functions used in the EMME/2 model
- Checking of the travel times over relatively long distances with the travel times obtained from the model.

4.5 RP and SP surveys

The revealed preference (RP) and stated preference (SP) surveys were crucial elements of the study. These entailed market research of existing and potential toll road users for incorporation of users' preferences and attitudes into the toll road model.

The purpose of RP and SP surveys was to obtain relevant data that would provide supporting information to the EMME/2 trip assignment model on road users route choice behaviour. The route choice is essentially based on a trade-off that users make between toll fees and savings in travel time taking into consideration other factors such as trip purpose, income and traffic conditions. Values of time (VOT's) were the primary end-results obtained from the RP and SP surveys. Travel characteristics obtained from the surveys are shown in Tables 1 to 3.

Table 1: RP surveys - travel characteristics

Description	Quagga % distribution		Gosforth % distribution		Dalpark % distribution	
	Toll	Alt	Toll	Alt	Toll	Alt
Trip purpose						
- Home to work	46	40	33	38	36	26
- Business	28	39	56	50	58	57
- Holiday	6	4	2	2	1	0
- Other	20	17	9	10	5	17
Trip frequency (per week)						
- 1 to 4	36	30	42	35	51	46
- 5 and more	64	70	58	65	49	54
Vehicle occupants						
- 1	41	54	68	67	65	51
- 2	31	19	23	23	26	13
- >2	28	27	9	10	9	36

Table 2: RP route choice information

Description	Quagga		Gosforth		Dalpark	
	Toll User	Alt user	Toll User	Alt user	Toll user	Alt User
Alternative route available						
- Yes	58%	93%	65%	30%	55%	93%
- No	42%	7%	35%	70%	45%	7%
Travel time						
- Toll road time as % of alternative route time	69%	114%	77%	107%	77%	108%
Trip length						
- Toll road length as % of alternative route length	87%	115%	86%	106%	85%	105%

Table 3: Travel Characteristics of SP Sample (light vehicles)

TRIP PURPOSE	% DISTRIBUTION
Commuting	72
Business	19
Other	9
VEHICLE CLASS	% DISTRIBUTION
Car	90
LDV	1
Minibus/4x4	9
VEHICLE OCCUPANCY	% DISTRIBUTION
1	57
2	23
3	7
4	7
5	6
Ave	1.7
MAIN ROUTE USED	% DISTRIBUTION
R21 (JIA freeway)	20
R25	6
N1 (Ben Schoeman freeway)	54
R101	9
R55	10
R511	2

5. TOLL BEHAVIOUR MODELLING

Modelling of a route choice behavior of drivers eligible to use toll roads was an important component of this study as it had to provide the input to a conventional network assignment model for reliable projections of traffic flows on roads (both toll and no-toll roads) in the Johannesburg-Pretoria corridor. The results of the RP and SP surveys were used to develop the adequate route choice behavior models and subsequently to provide the input for the EMME/2 route choice model that was used in this study.

RP and SP techniques rely heavily on LOGIT models to establish discrete route choice characteristics. In contrast, conventional modelling tools employ user equilibrium or Stochastic User Equilibrium (SUE) techniques to assign traffic to the road network. Although sharing a common ancestry via the use of exponential equations, these techniques differ substantially. The challenge was to develop a reliable approach whereby the results of the discrete choice Logit model could be applied successfully within network traffic assignment using SUE .

The study team carried out two exercises, firstly to compare the LOGIT route choice technique with the SUE technique as provided in EMME/2, and secondly to test LOGIT route choice model taking congestion into account. Comparison of the two route choice techniques was also used to determine the correlation between obtained results in order to determine SUE parameters that would represent LOGIT RP and SP models most closely.
Preliminary investigations showed that there is a relatively high correlation between the assignment results obtained by applying a LOGIT route choice model and the results obtained by applying the SUE assignment technique in EMME/2.

5.1 Calibration of SP and RP models

The ALOGIT software developed by The Hague Consultants was used for calibrating the LOGIT models. As the main purpose of the LOGIT models was to estimate values of time for various road user market segments, the calibration focussed on time and cost variables, although a few models with other variables were also calibrated.

The calibration process to translate the LOGIT function from the SP and RP models to the EMME/2 network assignment model, required a LOGIT model to be calibrated including only generalised time as a single variable. Generalised time was defined as follows:

GEN TIME = TOLL FEE / VOT + TIME

The VOTs estimated for different user segments and from the SP and RP models are shown in table 4.

Table 4: Summary of VOTs according to user segment and model type

User Segment	Time Variable	Cost variable	VOT (R per hr) SP model	VOT (R per hr) RP model
Commuter All periods	Stopped Time	Toll Fee	22.20-30.6	
Commuter All periods	Total Time	Toll Fee	18.00	67.20
Commuter All periods	Total Time	Running Cost	-	28.80
Business All periods	Total Time	Toll Fee	42.60	-
Social/Other All periods	Total Time	Toll Fee	8.40	-
AM peak	Total Time	Toll Fee	19.80	58.80
PM Peak	Total Time	Toll Fee	27.00	
Off Peak	Total Time	Toll Fee	30.60	

It was recommended that the calibration of trip matrices in EMME/2 be done using values of SUE parameters based on the SP scenario.

5.2 Determining Final SUE assignment parameters

The SUE assignment technique with the Normal distribution of costs and the variance of 0.1 was applied in the subsequent toll modelling process.

6. BASE YEAR CALIBRATION

One of the issues that the modelling team needed to resolve was the choice of model platform: EMME/2 or SATURN. On comparison of assignment results, it was found that while the two programs give similar results, they are not identical. It was decided to use EMME/2.

6.1 Matrix calibration

The initial matrix (2000 morning peak hour) was adjusted based on origin-destination information for trips between the Greater Pretoria and Johannesburg areas. These adjustments had the effect of increasing the number of vehicle trips in the initial matrix from 364 778 to 377 021.

The calibration of the matrices was then carried out using the Matrix Estimation technique in order to obtain the model to meet the set criteria. An examination of the data contained in Table 5 shows that the sets of calibration criteria had been satisfied. It was therefore concluded that the updated network and the calibrated matrices provide a sufficiently accurate model of the corridor between Pretoria and Johannesburg.

Table 5: Compliance with Calibration Criteria, Individual Links

Period	Criteria	Achieved
Morning peak	Within 400 vph for flows > 2700	37 out of 37 = 100%
	Within 15% vph for flows 700 – 2700	118 out of 138 = 86%
	Within 100 vph for flows < 700	73 out of 85 = 86%
	Total	228 out of 260 = 88%
Afternoon Peak	Within 400 vph for flows > 2700	31 out of 31 = 100%
	Within 15% for flows 700 – 2700	119 out of 140 = 85%
	Within 100 vph for flows < 700	77 out of 89 = 87%
	Total	227 out of 260 = 87%
	GEH	222 out of 260 = 85%
Off-Peak	Within 400 vph for flows > 2700	18 out or 18 = 100%
	Within 15% for flows 700 – 2700	58 out of 62 = 94%
	Within 100 vph for flows < 700	152 out of 180 = 84%
	Total	228 out of 260 = 88%
	GEH	220 out of 260 = 85%

7. STRATEGIC TOLL MODELLING

The main aim of the toll modelling exercise was to determine the effects of various scenarios of Gautrans Toll Road Strategy on traffic conditions on the proposed toll roads and supporting road network, and also to provide transportation-related input for broad feasibility analyses of the toll strategy. The elements of Gautrans Toll Road Strategy were as follows:

- Traffic growth was based on the land-use predictions for future target years. During this exercise only the base year scenario was investigated – namely 2000.

- Two road network scenarios were investigated:

  - Status Quo Network – The existing network (1999)
  - Base Case Future Network – The status quo network altered with various network improvements.

- There are two alternatives with regard to the toll collection technologies:

    - Manual toll collection
    - Electronic toll collection

The Electronic Toll Collection (ETC) strategy provides for toll collection using electronic equipment, thus avoiding the delay at toll plazas. This toll strategy is also known as a "closed system" toll strategy. In this exercise only one toll fare level was modelled, namely 13c/km.

The Mixed Toll Collection scenario is also known as an "open system" toll strategy since road users are charged a fixed rate for a fixed predetermined distance. It was assumed that commuters would have a choice to pay either manually or electronically via transponders in their vehicles. The toll fare assumed for this scenario was also 13c/km.

7.1 Methodology

Toll strategies were modelled using the following methodology:

1. Identifying tolled links
2. Converting toll fees to travel time penalties

In this exercise the *stated* value of time was assumed as opposed to the *revealed* value of time. Table 6 lists the values applied in the model.

Table 6: Model Values of Time

Attitudinal Survey	AM and PM Peak Hours	Off Peak Hour
Stated Preference	33c/min = R19.80/hour	51c/min = R30.60/hour
Revealed Preference	110c/min = R66/hour	170c/min = R102/hour

3. Incorporating the toll-related time penalties into the model
4. Trip assignment

The following is a summary of trip assignment exercises:

- A multiclass assignment was performed for the Mixed Toll Collection scenarios.
- A single class assignment was performed for the Electronic Toll Collection scenarios.
- The Stochastic User Equilibrium (SUE) assignment method was used. The normal distribution of a random term and a variance of 0,1 were applied.
- The standard assignment parameters (no. of iterations, normalised and relative gaps) were kept the same as determined in the calibration phase of the model.

7.2 Analyses

Analyses of results showed the following:

- It is obvious that in the ETC scenarios the imposed toll had an almost constant diversion effect along the full lengths of the existing freeways, an effect ascribed to the characteristics of the "closed system" toll strategy. At the same time, a similar attractiveness effect is visible along the routes, alternative to the tolled freeways.
- In the Mixed Toll Collection Scenario the highest diversion occurred on road sections situated in the immediate vicinity of the proposed locations of toll plazas, an effect ascribed to the characteristics of the "open system" toll strategy.

Figure 2 compares the number of commuters using the tolled freeway against the number of commuters actually paying for it. When the ETC strategy is imposed, the model predicts that 72 000 commuters will use the toll roads with the same number of commuters paying for it. When the Mixed Toll strategy is imposed the number of commuters utilising tolled freeways is approximately 78 000 with only 21 000 (27%) paying for it.

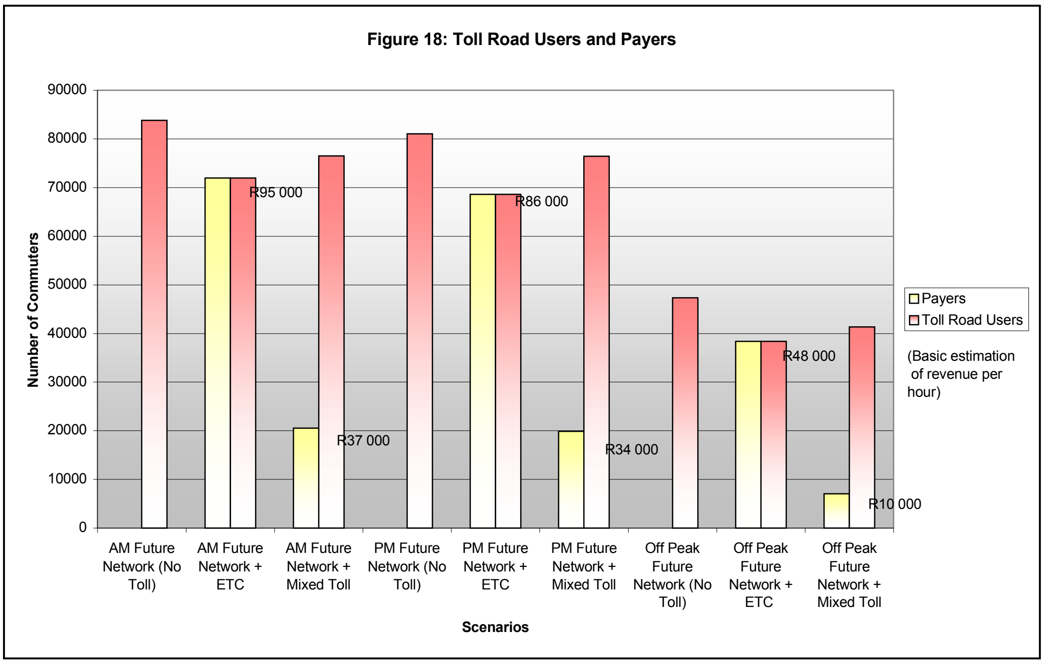

Figure 2: Toll Road Users and Payers

8. MICROSIMULATION OF TOLL SCENARIOS

Micro simulation is a new tool to evaluate traffic conditions and various methods to solve traffic problems. It is based on a dynamic assignment principle. Driver's route choice behaviour and vehicle's progression through the network are simulated individually for each vehicle loaded onto the network. Micro simulation therefore differs significantly from static modelling techniques.

AIMSUN2 (**A**dvanced **I**nteractive **M**icroscopic **S**imulator for **U**rban and **N**on-Urban **N**etworks) is a software tool which is able to reproduce the real-time traffic conditions of any road network on a computer. It is used for traffic state predictions, to test new traffic control systems and management policies as well as vehicle guidance systems and other real-time applications.

In order to set up a micro simulation model, it was necessary to adapt the matrices developed in the conventional Gautrans EMME/2 model. The network included both the Ben Schoeman and the R101 between Swartkop Airforce Base and the Kelvin Woodmead interchange on the M1. The western boundary is Road R511 and the eastern boundary is Road R50. This network thus includes all the immediate alternative routes to Ben Schoeman.

The AIMSUN2 model currently is set up and ready to test and evaluate various toll strategies using the micro simulation techniques. Some of the applications may include evaluation of the effect of congestion on route choice as well as the capacities of the proposed toll plazas.

9. GIS AND MAPPING

In view of the size of the study area and the extent of the data coverage, the study team felt that this storage could best be achieved in a Geographical Information System (GIS) format. GIS *viewing* software appeared to be the adequate solution, and products offered by Arcview and Mapinfo were investigated by the study team. In the end, Planet, a low-cost GIS system developed locally by Paul van Helden, was selected as the GIS viewing platform.

The customisation of Planet as applied within the study focused on the following key components, with a geographical view defined for each of the major groupings. These are:

- Base map:
- Traffic and planning zones
- Gautrans road network
- EMME/2 networks
- Traffic counts
- Thematic queries
- Aimsun simulations
- Videos

A number of interface software modules were developed during the course of the study to convert EMME/2 modelling results to the appropriate GIS format, as shown in the geographical views containing the EMME/2 features.

The study team also recognised the potential of extending the comprehensive database during future Gautrans traffic studies, so that the information can be updated and maintained in the long-term.

10. DELIVERABLES

This study consisted of a number of tasks that had to be accomplished in order to evaluate various scenarios with regard to the implementation of the Gautrans Toll Strategy. The following were the study deliverables:

Data Collection

- Comprehensive GIS database of traffic counts in the Johannesburg-Pretoria corridor
- A sample of OD trips in the Johannesburg-Pretoria corridor for different periods of the day.
- Established an approach to collect data related to heavy vehicle movements using the electronic tracking technology
- Verified and improved link performance curves in the Gautrans EMME/2 model
- Results of the attitudinal (RP and SP) surveys of the existing and potential toll road users

Toll Behaviour Modelling

- Practical approach in implementing characteristics of LOGIT route choice models into conventional assignment models (EMME/2, SATURN)
- Route choice LOGIT models for light vehicles based on both RP and SP survey results
- Values of time for light vehicle drivers for different trip purposes and peak periods

Update of the Gautrans EMME/2 Model

- Updated Gautrans EMME/2 Model

Strategic Toll Modelling

- Expected utilisation of the proposed toll roads in the Johannesburg-Pretoria corridor
- Expected diversion rates from the proposed toll network and impact on the supporting network
- Estimated operational and capacity conditions on the roads in the corridor for two toll scenarios
- First order estimate of toll revenues for the ETC and Mixed toll scenarios.

Microsimulation of Toll Scenarios

- Setup of the microsimulation model using Aimsun

GIS and Mapping

- Established conversion procedure between EMME/2 and GIS
- All the input elements and results of this study shown and stored in an affordable and locally developed GIS viewer

11. CONCLUSIONS

The two main objectives of this study were carried out successfully. The existing Gautrans EMME/2 model was updated within the Johannesburg-Pretoria corridor area conforming to international standards with regard to numerous audit criteria. The model now represents a powerful strategic tool that can be used for the evaluation of different toll scenarios and strategies and to assist in effective management of the toll corridor.

One of the burning issues of the Gautrans Toll Strategy is associated with the toll collection technology that should be applied. Three basic options could be considered: a full ETC, Manual toll collection or Mixed toll collection (providing lanes for both, electronic and manual toll collection). Two scenarios, namely ETC and Mixed scenarios were tested in this study. The evaluation results indicate that the ETC option appears to be a fairer option for the road users. Firstly, in the ETC scenario all toll road users are charged the toll fee equivalent to the exact distance travelled. Secondly, the model predicts approximately the same number of toll road users in both scenarios but the majority of them avoid paying the toll in the Mixed scenario, therefore resulting in a greater impact on secondary road network. It basically means that the long-distance trips would divert to the alternative roads to avoid toll plazas thus interfering with local trips and reduce LOS on the roads provided for local traffic. Furthermore, it means a substantial reduction in the toll revenue.

This study provides reliable projections of vehicle volumes and diversion rates for application in the following:

- as input into a full-scale financial model to evaluate the various scenarios, and
- a valuable tool and point of departure for further strategic toll road evaluations as may be required during tender phases and beyond.

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