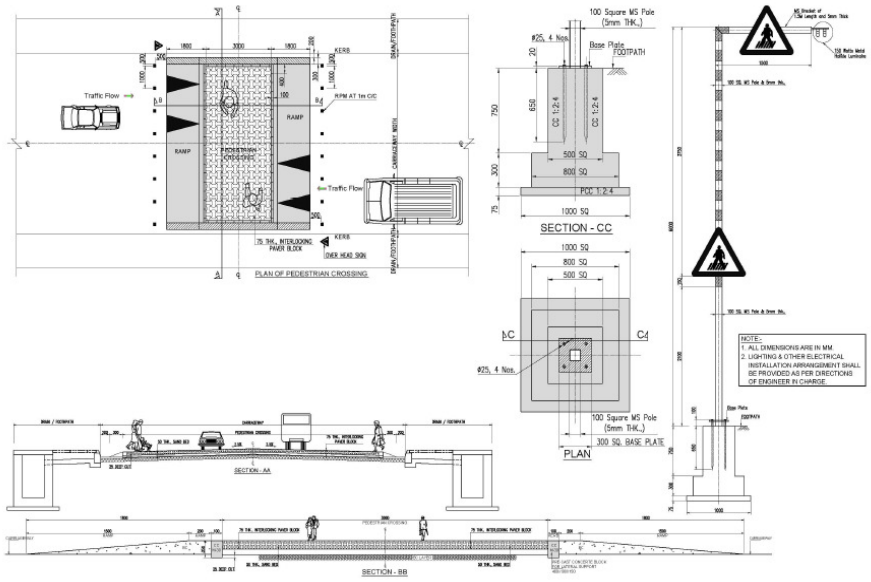
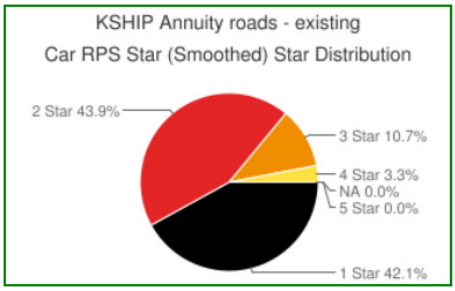
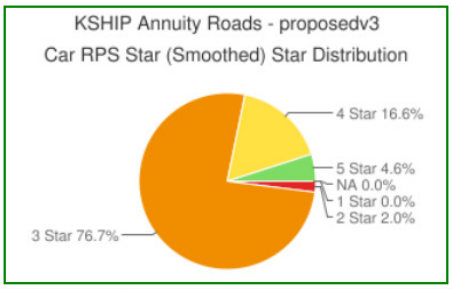
iRAP
INTERNATIONAL ROAD ASSESSMENT PROGRAMME

International Road Assessment Programme

A WORLD FREE OF HIGH RISK ROADS







Star Rating Road Designs

Performance Indicators for Roads in India

सत्यमेव जयते

GRSF
Global Road Safety Facility

About iRAP

The International Road Assessment Programme (iRAP) is a registered charity dedicated to saving lives through safer roads.

iRAP works in partnership with government and non-government organisations to:

- inspect high-risk roads and develop Star Ratings and Safer Roads Investment Plans
- provide training, technology and support that will build and sustain national, regional and local capability
- track road safety performance so that funding agencies can assess the benefits of their investments.

Road Assessment Programmes (RAP) are now active in more than 70 countries throughout Europe, Asia Pacific, North, Central and South America and Africa.

iRAP is financially supported by the FIA Foundation for the Automobile and Society. Projects receive support from the World Bank Global Road Safety Facility, automobile associations, regional development banks and donors.

National governments, automobile clubs and associations, charities, the motor industry and institutions such as the European Commission also support RAPs in the developed world and encourage the transfer of research and technology to iRAP. In addition, many individuals donate their time and expertise to support iRAP.

This report was prepared by:

Luke Rogers, iRAP, Australia
Devika K. R., Karnataka State Highway Improvement Project, India
Greg Smith, iRAP, Australia
H.S.Prakash Kumar, Karnataka State Highway Improvement Project, India
Prakash G.S., Scott Wilson India

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To find out more about iRAP, visit www.irap.org. You can also subscribe to 'WrapUp', the iRAP e-newsletter, by sending a message to icanhelp@irap.org.

Executive Summary

In 2009, seven multilateral development banks (MDBs) announced a package of measures to reduce road fatalities in developing countries, including improving safety performance measures in road design. The Commission for Global Road Safety has also recommended that desired design speeds for new roads are subject to achieving minimum safety ratings.

This report describes how iRAP Star Ratings, which provide a simple and objective measure of the level of safety attained by a given road network, were used to help shape the safe design of 550km of concession roads in the Indian State of Karnataka. The final design as used in this analysis resulted in a reduction of the percentage of road rated 1- or 2-stars (high risk) for vehicle occupants from 86% to 2%. For pedestrians, the percentage of high risk roads dropped from 100% to 12%. It is estimated that these improvements will prevent approximately 30,000 deaths and serious injuries over 20 years, with the estimated annual death toll on this corridor dropping from 248 to 111 per year, representing a 55% reduction across the surveyed network.

Acknowledgments

This project would not have been possible without the direct support of numerous people and organisations. These include:

- The Ministry of Road Transport & Highways (Government of India)
- The Government of Karnataka
- Karnataka Road Development Corporation
- Karnataka State Highway Improvement Project (KSHIP)
- Indian Road Survey and Management
- ARRB Group

The project was financially supported by the Global Road Safety Facility funded with support from Bloomberg Philanthropies.

1 Introduction

Star Ratings objectively quantify the level of risk associated with new road designs. This provides a platform to make evidence-based improvements to designs and is critically important in enabling safety related costs and benefits to be compared with vehicle operating costs and travel time savings - something which has been absent in road projects in low- and middle-income countries in the past.

In 2010 iRAP was invited by the Global Road Safety Facility (GRSF) to assist the governments of four Indian states: Andhra Pradesh, Gujarat, Karnataka and Assam, to help prevent road deaths and serious injuries on 3,000 km of high-risk roads. The iRAP India Four States Project is funded with support from Bloomberg Philanthropies.

As part of the project, iRAP has been working with the Karnataka State Highway Improvement Project (KSHIP) to provide an assessment of risk (Star Ratings) and recommended treatments (Safer Roads Investment Plan) for 550km of road selected for rehabilitation under DBFOMT (annuity) concessions (hereby referred to as the Annuity Roads).[1]

Analysis has been provided for the existing road network and at three stages of the design process to show the potential benefits of using safety performance indicators for new road design.

The following roads were included for analysis:

- Malavalli to Pavagada (175.5km)
- Mudhol to Nippani (108.5km)
- Shakaripura to Anandapuram (32.4km) and Shimoga to Hangal (122.5km)
- Managuli to Devapura (110.2km)

The process of road safety assessment described in this report has been developed by the International Road Assessment Programme (iRAP). It has drawn upon the extensive knowledge base of established Road Assessment Programmes (EuroRAP, AusRAP and usRAP), with the generous support of the FIA Foundation and World Bank Global Road Safety Facility, to target high-risk roads where large numbers of people are killed and seriously injured and inspect them to identify where affordable programmes of safety engineering can reduce death and injury.

iRAP uses globally consistent models to produce vehicle occupant, motorcyclist, pedestrian and bicyclist Star Ratings and Safer Roads Investment Plans. 5-star (green) roads are the safest, while 1-star (black) roads are the least safe. Star Ratings are not assigned to roads where there is very low use by that type of road user. For example, if no bicyclists use a section of road, then a bicyclist Star Rating is not assigned to it. The full methodology is described in:

- Star Rating Roads for Safety: The iRAP Methodology
- Safer Roads Investment Plans: The iRAP Methodology

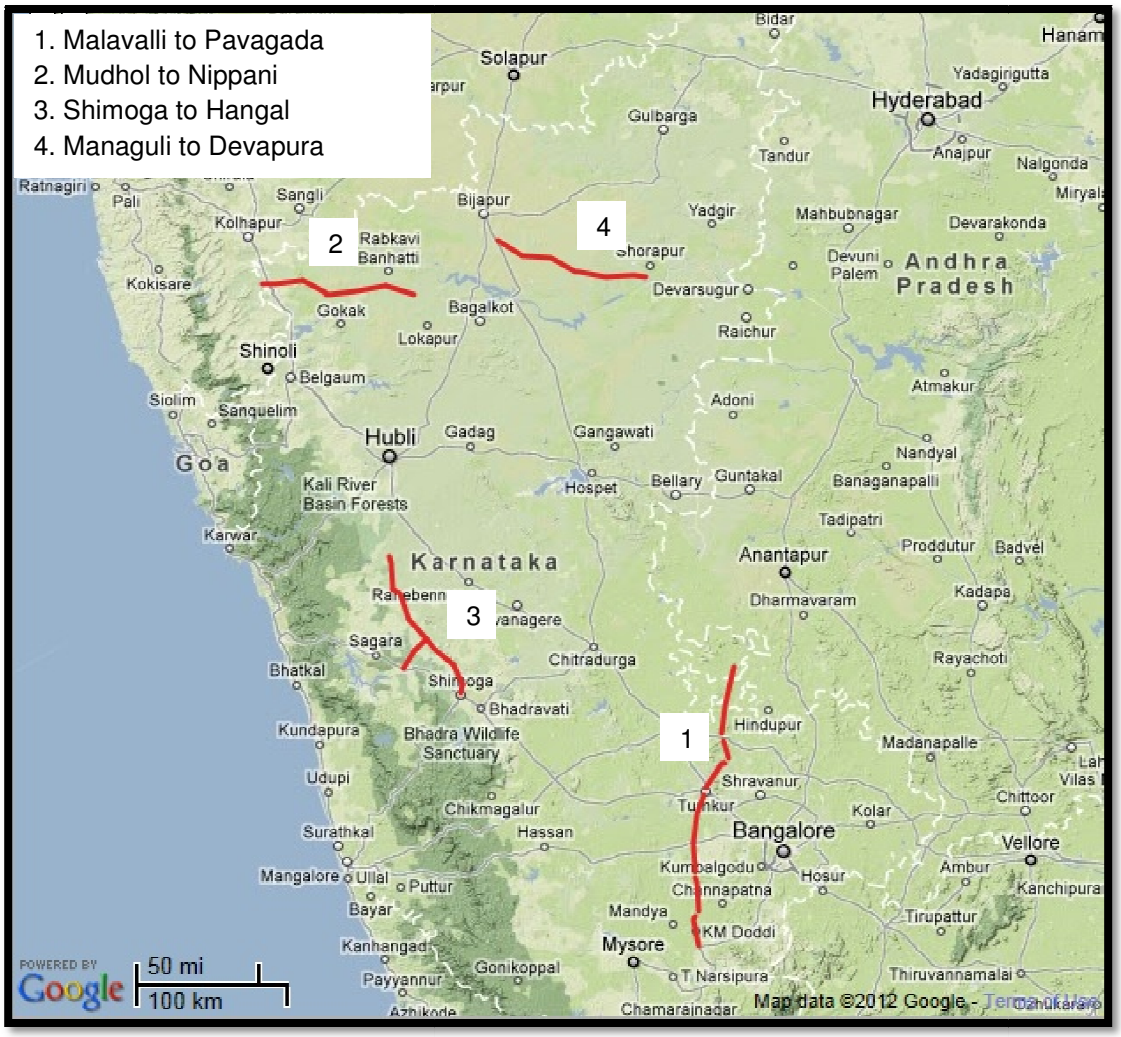
Both reports are available at: http://www.irap.org/library.aspx

iRAP has been working with KSHIP staff and design consultants Scott Wilson India to achieve a rating of at least 3-stars for vehicle occupants and to significantly improve the star ratings for other road users.

(Note: unlike other World Bank funded rehabilitation projects in India such as the KSHIP Safe Corridor Demonstration Programme, the Annuity Roads are not formally required to achieve a minimum star-rating. This was an objective set by KSHIP directors).

[1] Design-Build-Finance-Operate-Maintain-Transfer (DBFOMT)

Figure 1 Location of road sections included in the analysis



2 Star Rating Designs Process

The Star Rating design process used in Karnataka included the following steps:

- The World Bank and Government agreed to aim for a rating of at least 3-stars for the new roads.
- With funding support from the Global Road Safety Facility and Bloomberg Philanthropies, road safety inspections were carried out and baseline Star Ratings were calculated for the existing road.
- A Safer Roads Investment Plan was generated to provide guidance to designers on economically viable countermeasures
- Star Ratings were produced for the initial road designs.
- Star Ratings were used to test the relative benefits of different design options and iterations
- An economic assessment of the final design was undertaken to quantify the benefits associated with the design

Each of these steps is explained in further detail below.

2.1 Setting target Star Ratings for new road design

The Government of Karnataka has committed to improving the effectiveness and capacity of the state's road network in order to maintain Karnataka's current economic growth and competitiveness. However, there is increasing recognition that people's safety and well-being is not to be overlooked in favour of reducing vehicle operating costs and travel times in road design. As such, KSHIP have played a fundamental role in the Government of Karnataka's development strategy to sustain economic growth and regional development through infrastructure improvements whilst working in partnership with iRAP to ensure that the planned engineering upgrades eliminate high risk sections of road where possible.

iRAP has been assisting KSHIP to include engineering countermeasures in the new road designs for the four roads planned for upgrade under an annuity concessions agreement, referred to here as the 'Annuity Roads' and also the SH17 and SH20 which together make up the Safe Corridor Demonstration Program (SCDP), on which a minimum 3-star rating is to be achieved.

The Safe Corridor Demonstration Program has been established through a joint World Bank/Government of India agreement in order to help support the Government of Karnataka in the development, implementation and evaluation of major multi-sector road safety schemes. This enabling initiative seeks to build capacity within the Government to deliver numerous lead agency functions for future major projects throughout the state.

Various road safety initiatives will be undertaken along the demonstration corridors such as improving the engineering conditions, strengthening enforcement, enhancing road safety education and improving emergency medical response along the corridors. The engineering element includes road safety infrastructure improvements based on iRAP recommendations in order to achieve a minimum 3-star rating along both corridors (see *Second Karnataka State Highway Improvement Project- Project Appraisal Document* for further information).

Despite having no formal requirement to meet minimum Star Ratings, unlike (SCDP), the Managing Director (KRDCL) and Project Director (KSHIP) have agreed to set a minimum 3-star target (for vehicle occupants) and have committed to reduce 1-and 2-star sections for other road users where economically viable on all four Annuity Roads.

2.2 Baseline Star Ratings for existing road network

In February 2011 the Indian Road Survey and Management (IRSM) survey vehicle utilizing a '*Hawkeye 2000*' digital imaging system was used to collect wide angle digital images at 10m intervals and associated geo-reference data.

Upon completion of the road survey the digital images and geo-reference data was coded at 100 metre intervals by a team of engineers from KSHIP using the Hawkeye Processing Toolkit software, in accordance with the iRAP Coding Manual and under the supervision of experienced staff from ARRB Group, Australia. Table 1 shows a summary of the recorded road attributes.

Table 1 Summary road attributes

Road attribute	Category	Existing network (%)
Speed	40km/h or less	0
	50km/h	7
	60km/h	0
	70km/h	0
	80km/h	93
Number of lanes (per direction)	one	100
	two	0
Lane width	wide	27
	medium	22
	narrow	51
Paved shoulder width	wide	0
	medium	1
	narrow	1
	none	98
Unpaved (earthen) shoulder width	wide	6
	medium	64
	narrow	29
	none	1
Curvature	straight	78
	moderate	16
	sharp	6
	very sharp	1
Quality of curve	adequate	78
	poor	22
Delineation	adequate	15
	poor	85
Shoulder rumble strips (raised profile edge lines)	none	100
Road surface condition	good	8
	medium	27
	poor	65
Median type	physical <1m	1
	physical 1-5m	0
	centre line	99
Overtaking demand	none	1
	low	0
	medium	34
	high	65
Roadside severity (left)	safety barrier	0
	drainage ditch	0
	steep fill slope	2
	object 0-5m	38
	object 5-10m	25

Road attribute	Category	Existing network (%)
	object >10m	35
Roadside severity (right)	safety barrier	0
	drainage ditch	0
	steep fill slope	2
	object 0-5m	38
	object 5-10m	25
	object >10m	35
Intersections	merge lanes	3
	roundabouts	2
	signalised	4
	turn lanes	0
	others	770
Intersection quality	good	11
	poor	768
Sidewalk provision	none	99
	adj. to traffic	1
	within 1-3m	0
	physical barrier	0
Pedestrian crossing facilities	unsignalised	2
Pedestrian crossing quality	adequate	2
Bicycle lane	none	100
	dedicated lane	
Motorcycle lane	none	100

The majority of the existing road network consists of undivided, narrow single lanes (one lane in each direction) with no paved shoulder, poor delineation, poor road surface condition and hazardous roadsides. Facilities for vulnerable road users are particularly poor with no bicycle or motorcycle lanes, limited sidewalk provision and only 2 pedestrian crossing facilities.

Based on the road survey data, the iRAP model was used to generate baseline Star Ratings for the existing network for vehicle occupants, motorcyclists, pedestrians and bicyclists (see Table 2 and Figure 2). Table 2 shows that:

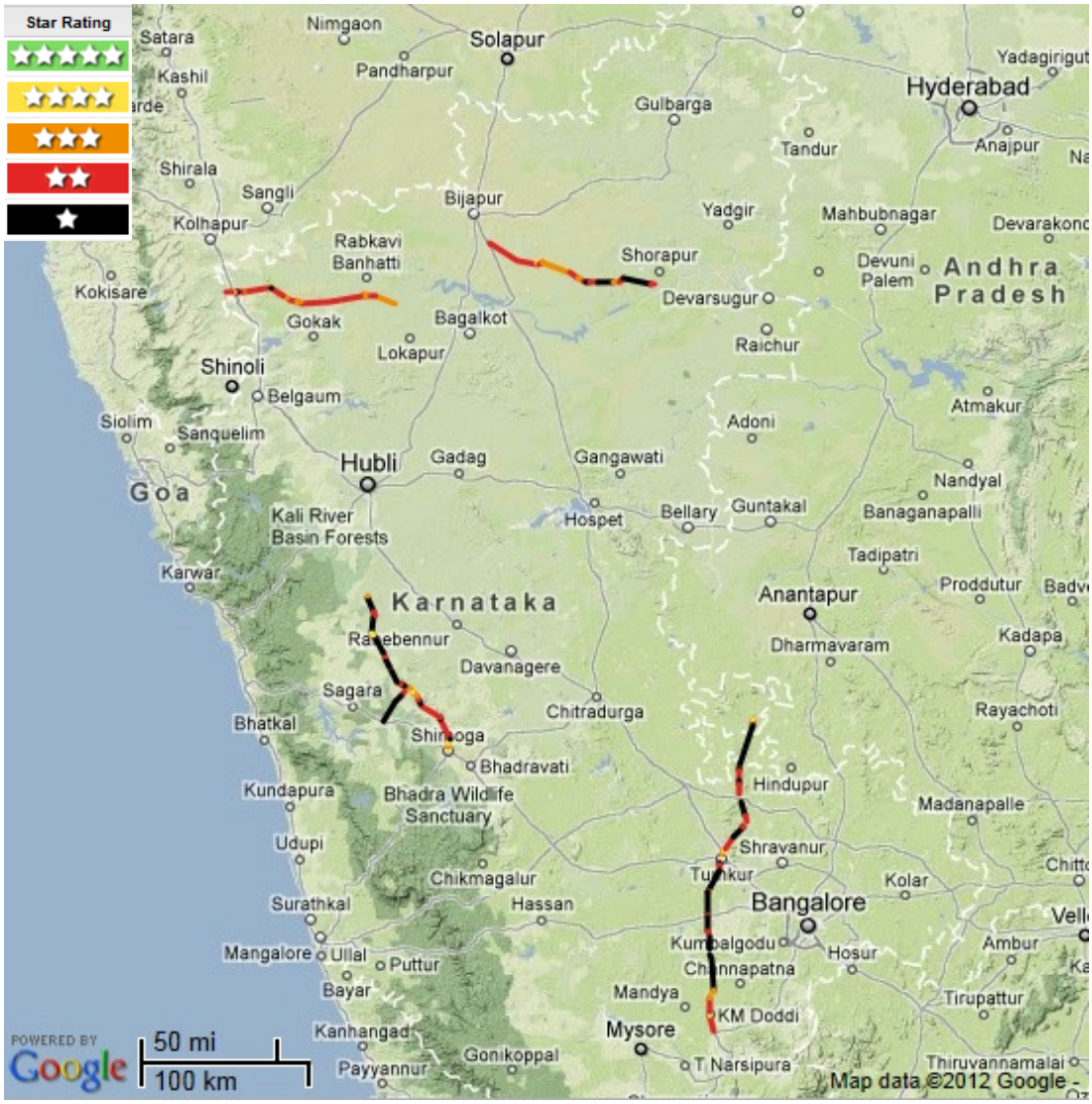
- 86% of roads were rated 1- or 2-stars for vehicle occupants
- 94% of roads were rated 1- or 2-stars for motorcyclists
- 100% of roads were rated 1- or 2-stars for bicyclists
- 100% of roads were rated 1- or 2-stars for pedestrians

These results provided a basis for comparison with the proposed new road designs.

Table 2 Baseline Star Ratings for existing roads

	Car Occupants		Motorcyclists		Bicyclists		Pedestrians	
Star Rating	Length (km's)	%	Length (km's)	%	Length (km's)	%	Length (km's)	%
★★★★★	0km	0%	0km	0%	0km	0%	0km	0%
★★★★	18km	3%	10km	2%	0km	0%	0km	0%
★★★	59km	11%	22km	4%	0km	0%	0km	0%
★★	241km	44%	154km	28%	167km	30%	549km	100%
★	231km	42%	364km	66%	231km	42%	0km	0%
	0km	0%	0km	0%	151km	27%	0km	0%
TOTAL	549km	100%	549km	100%	549km	100%	549km	100%

Figure 2 Baseline Star Ratings for existing roads



2.3 Recommended road safety countermeasures

The Safer Roads Investment Plan (SRIP) shows a list of affordable and economically sound road safety countermeasures, specifically tailored to reduce risk on the surveyed network. Each proposed treatment in the SRIP is supported by strong evidence that, if implemented, it will prevent deaths and serious injuries in a cost-effective way (a minimum threshold BCR of 1 was used). Nevertheless, each countermeasure should be subject to additional prioritisation, concept planning and detailed design before implementation.

In the absence of any reliable crash data, the number of deaths and serious injuries along the surveyed network was estimated. Based on the assumption that 0.45 deaths occur per km on the State Highway network in Karnataka, 247 fatalities were allocated to the surveyed network.[2]

It is important to ensure that improvements such as lane widening, resurfacing, additional lanes and paved shoulders do not result in excessive vehicle speeds, particularly where vulnerable road users such as pedestrians and bicyclists are present. In such cases vehicle speeds must be effectively managed in order to minimise risk.

The top-five recommended treatments based on the existing road network as of February 2011, in terms of the number of estimated deaths and serious injuries (KSI's) prevented are:

- Road surface upgrade (260km)
- Shoulder widening (396km)
- Lane widening (147m)
- Removal of roadside hazards (145km)
- Delineation improvements (291km)

These five treatments alone can be expected to prevent almost 20,000 deaths and serious injuries over the next 20 years.

[2] World Health Organisation (2007) point estimate of 198,410 road deaths in India. KSHIP Feasibility Study Report Chapter 4, page17 suggests that 10% of India's road deaths occur in Karnataka. Assumed 50% of road deaths in Karnatak occur on State Highway.

Table 3 List of recommended countermeasures (based on existing road attributes)

Countermeasure Type	Length	KSI's Saved (20 years)	PV of Safety Benefit (20 years)	Estimated Cost (20 years)	Cost per KSI saved	Program BCR
Road Surface Upgrade	259.7km	4,963.17	USD$ 117,624,655	USD$ 28,366,767	USD$ 3,402	4.15
Shoulder widening	395.5km	4,945.45	USD$ 117,204,682	USD$ 33,845,362	USD$ 6,844	3.46
Lane widening	146.6km	3,838.81	USD$ 90,977,777	USD$ 33,475,421	USD$ 5,191	2.72
Roadside Safety - Hazard Removal	144.6km	3,090.57	USD$ 73,244,987	USD$ 6,920,852	USD$ 2,239	10.58
Delineation	291.2km	2,567.97	USD$ 60,859,659	USD$ 1,980,721	USD$ 253	30.73
Roadside Safety - Barriers	198.4km	1,563.65	USD$ 37,057,885	USD$ 13,340,395	USD$ 8,532	2.78
Traffic Calming	24.8km	527.19	USD$ 12,494,198	USD$ 785,087	USD$ 886	15.91
Duplication	2.5km	352.20	USD$ 8,347,024	USD$ 1,635,337	USD$ 4,643	5.10
Pedestrian Crossing	140 sites	283.08	USD$ 6,708,735	USD$ 1,796,388	USD$ 4,204	3.73
Regulate roadside commercial activity	26.2km	87.43	USD$ 2,071,924	USD$ 434,250	USD$ 2,957	4.77
Bicycle Facilities	15.8km	67.61	USD$ 1,602,370	USD$ 687,924	USD$ 10,175	2.33
Additional lane	0.6km	51.52	USD$ 1,220,978	USD$ 629,588	USD$ 12,220	1.94
Intersection - delineation	14 sites	35.23	USD$ 834,826	USD$ 549,065	USD$ 5,111	1.52
Central Hatching	8.4km	32.33	USD$ 766,264	USD$ 61,355	USD$ 1,130	12.49
Intersection - right turn lanes (unsignalised)	12 sites	30.77	USD$ 729,205	USD$ 516,644	USD$ 9,995	1.41
Pedestrian Footpath	1.5km	18.72	USD$ 443,727	USD$ 347,795	USD$ 18,576	1.28
Intersection - roundabout	3 sites	16.47	USD$ 390,355	USD$ 222,978	USD$ 13,538	1.75
Parking improvements	1.4km	10.09	USD$ 239,158	USD$ 29,405	USD$ 1,734	8.13
Intersection - signalise	2 sites	8.96	USD$ 212,328	USD$ 182,436	USD$ 20,363	1.16
TOTAL		**22,491**	**USD$ 533,030,737**	**USD$ 125,807,770**	**USD$ 5,594**	**4.24**

2.4 Star Rating initial road designs

Initial design plans for the new roads were prepared by consulting engineers *Scott Wilson India* with support from the Project Implementation Unit (PIU) at KSHIP which included the Managing Director (KRDCL), Project Director (KSHIP) and other PWD staff, taking into account local design standards, environmental requirements and budget constraints. The designs met all the engineering and safety standards as prescribed in the Indian guidelines for road construction, including the Indian Road Congress (IRC) standards.

Ideally, this stage of design would also take into account the baseline Star Ratings and Safer Roads Investment Plan. However, the timing of this particular project meant that the designs and baseline Star Ratings were undertaken concurrently.

At the completion of the initial design phase, the designs were Star Rated, so that expected changes in infrastructure-related risk could be quantified and compared both with the baseline Star Ratings and the 3-star target.

The process for Star Rating the designs involved amending (or re-coding) the survey data for the existing roads to match the design attributes. This process was undertaken by KSHIP and consultant engineers from *Scott Wilson Indian* with support from iRAP staff. The designs included a combination of schedules listing locations of upgrades (see for example Tables 4 and 5) and standard cross-sections and drawings (see for example Figures 3 and 4).

Table 4 Schedule of speed restricted sections - Link 63A

Chainage		Speed (km/h)	Remarks
From	To		
0+000	0+650	30	Town Limit
3+850	4+650	30	Village Limit
8+750	9+450	30	Village Limit
9+550	10+050	30	Village Limit
10+450	12+850	30	Town Limit
17+750	18+260	30	Village Limit
21+850	22+800	30	Village Limit

Table 5 Schedule of major realignment - Links 63 and 64

Link ID	Realignment Length (Km)	Major Realignment
63A	-	-
63B	3.92	Huliyurdurga
63C	5.27	Koratagere
63D	-	-
63E	-	-
64F	7.73	Madhugiri
64G	-	-

Figure 3 Typical rural road cross-sections (Appendix B-I)

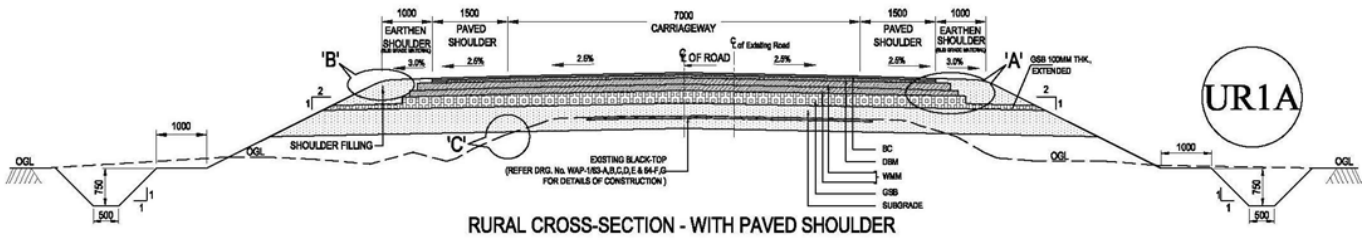
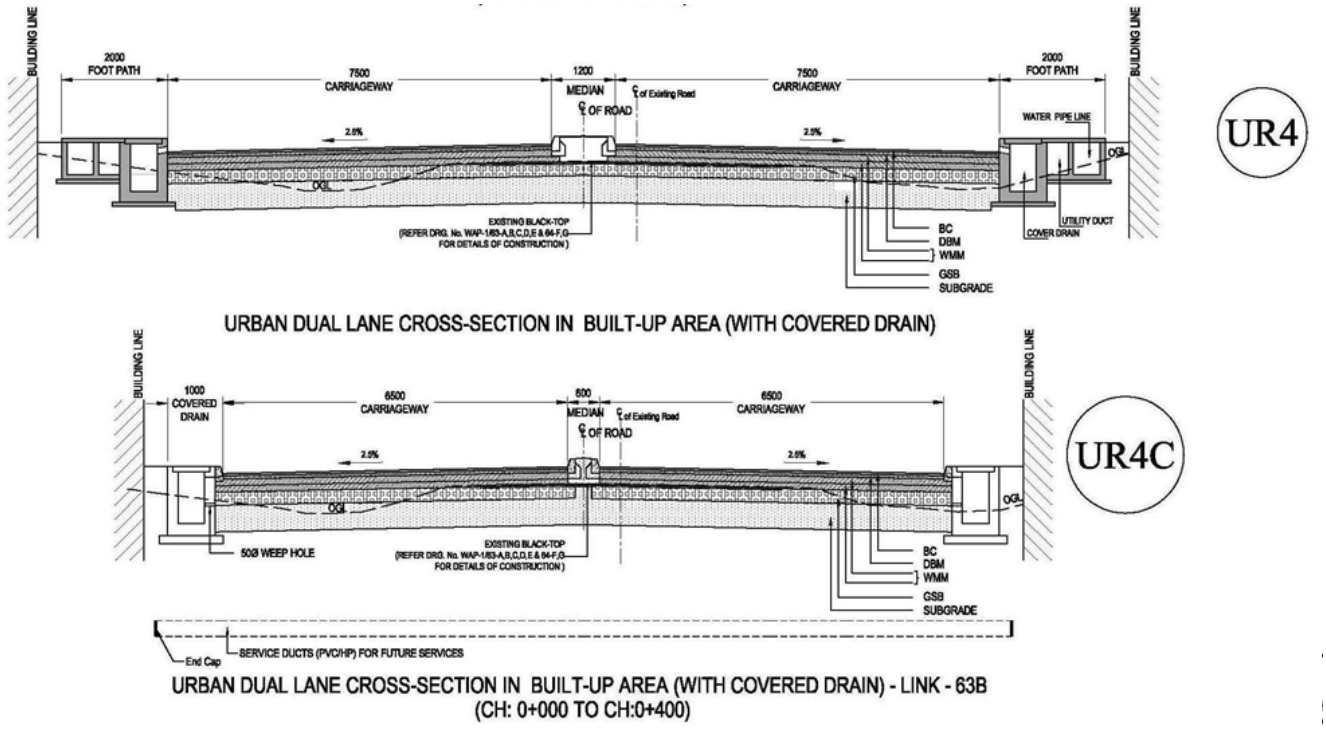


Figure 4 Typical urban road cross-sections (Appendix B-I)



The key changes and principal assumptions made in updating the survey data are listed below:

- Vehicle operating speeds were based on design speed. Therefore much of the predominantly rural network was coded with speeds set to 80km/h. Those sections where speed restrictions applied (see Table 4), incorporating traffic calming features such as road humps and transverse rumble strips were coded with speed set to 'less than 40km/h'. It is important to note that if speeds cannot be managed within these thresholds the Star Ratings will drop.
- Linear attributes, such as roadside safety barrier or sidewalk provision, were coded only where contiguous for 100 metres or more. Short sections of footpath or safety barrier for example were not recorded. Changes to linear attributes were recorded within the 100 metre segment in which the change occurred and coded continuously until a change occurred.
- Road surface condition was coded as 'good' where carriageway reconstruction or resurfacing was proposed.
- Delineation was coded as 'adequate' where centre lines, edge lines and warning signs at hazardous locations were proposed.
- Where carriageway edge lines were proposed, paved shoulder width coded as 0-1 metre minimum. This is consistent with the iRAP Star Rating Inspection Manual. The width was increased at specific locations as per design schedules.
- All proposed sign posts (for warning signs and directional signs) were assumed to be frangible with a diameter of less than 100mm, meaning they were not coded as hazardous roadside objects.
- Pre-cast concrete guard posts (approximately 150-200mm width, 450-1000mm in height) at 5m centres were coded as hazardous roadside objects. See Figure 5 below for example.
- Open concrete drains (as shown in Figure 3) were coded as 'deep drainage ditches'. If they are covered (as shown in Figure 4) the concrete drains were coded as sidewalk provision adjacent to carriageway.

- No purpose built bicycle or motorcycle lanes were proposed
- Overtaking demand was not amended. This attribute is a function of traffic flow, which is assumed not to change for this analysis, number of lanes and median type, neither of which changed significantly when compared to the existing road attributes

Figure 5 Result of a motor vehicle collision with pre-cast concrete guard post

Table 5 shows a comparison of the existing and initial design road attributes. It shows that nearly every attribute changed in the design. The key exceptions were: bicycle and motorcycle lane provision and overtaking demand.

Table 5 Summary road attributes (shaded cells show where attributes changed)

Road attribute	Category	Existing network	Initial design
Speed	40km/h or less	0	17
	50km/h	7	3
	60km/h	0	1
	70km/h	0	0
	80km/h	93	78
Number of lanes (per direction)	one	100	97
	two	0	3
Lane width	wide	27	100
	medium	22	0
	narrow	51	0
Paved shoulder width	wide	0	12
	medium	1	40
	narrow	1	48

Road attribute	Category	Existing network	Initial design
	none	98	0
Unpaved (earthen) shoulder width	wide	6	47
	medium	64	38
	narrow	29	6
	none	1	9
Curvature	straight	78	96
	moderate	16	4
	sharp	6	0
	very sharp	1	0
Quality of curve	adequate	78	100
	poor	22	0
Delineation	adequate	15	100
	poor	85	0
Shoulder rumble strips (raised profile edge lines)	none	100	100
Road surface condition	good	8	100
	medium	27	0
	poor	65	0
Median type	physical <1m	1	0
	physical 1-5m	0	2
	centre line	99	98
Overtaking demand	none	1	1
	low	0	0
	medium	34	34
	high	65	65
Roadside severity (left)	safety barrier	0	5
	drainage ditch	0	1
	steep fill slope	2	0
	object 0-5m	38	16
	object 5-10m	25	47
	object >10m	35	30
Roadside severity (right)	safety barrier	0	5
	drainage ditch	0	1
	steep fill slope	2	0
	object 0-5m	38	16
	object 5-10m	25	44
	object >10m	35	34
Intersections	merge lanes	3	0
	roundabouts	2	1
	signalised	4	2
	turn lanes	0	5
	others	770	562
Intersection quality	good	11	426
	poor	768	138

Road attribute	Category	Existing network	Initial design
Sidewalk provision	none	99	90
	adj. to traffic	1	9
	within 1-3m	0	1
	physical barrier	0	0
Pedestrian crossing facilities	unsignalised	2	183
Pedestrian crossing quality	adequate	2	183
Bicycle lane	none	100	100
	dedicated lane	0	0
Motorcycle lane	none	100	100

The coded data for the initial design was re-processed using the iraptools, and the new Star Ratings are summarised in Table 6. Despite there being a marked improvement in the star ratings for all road users, there remained significant sections of the network where risk was high. For vehicle occupants 13% of the surveyed network was categorised as 1- or 2-stars (see Figure 6). 48% remained in the 1- or 2-star category for motorcyclists. For non-motorised users, 40% remained in the 1- or 2-star range for pedestrians and 53% for bicyclists.

Table 6 **Proportion of high-risk roads, a comparison between existing network and initial design**

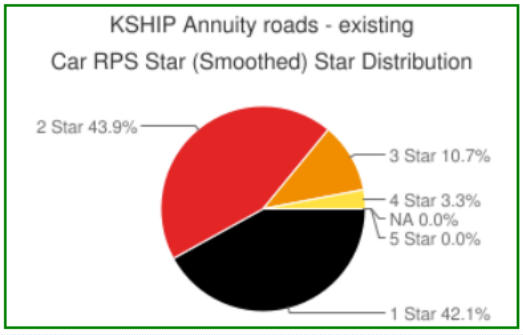
Road user	% rated 1- or 2-stars	
	Existing network	Proposed (initial design)
Vehicle occupants	86%	13%
Motorcyclists	94%	48%
Pedestrians	100%	40%
Bicyclists*	100%	53%

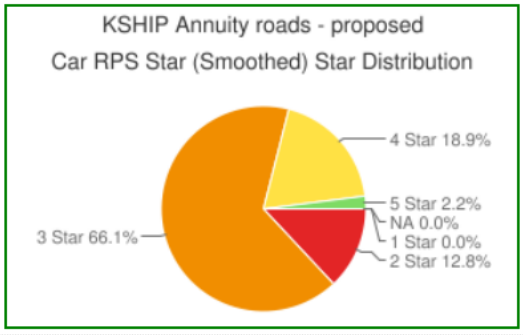
* where bicycle use is recorded.

Figure 6 **Star Ratings for vehicle occupants, a comparison between existing network and initial design**

CAR RPS STAR (SMOOTHED) STAR RATINGS

	★		★★		★★★		★★★★		★★★★★		Total
KSHIP Annuity roads - existing	0 km	0.0%	231 km	42.1%	241 km	43.9%	59 km	10.7%	18 km	3.3%	0 km	0.0%	549 km
KSHIP Annuity roads - proposed	0 km	0.0%	0 km	0.0%	70 km	12.8%	363 km	66.1%	104 km	18.9%	12 km	2.2%	549 km





2.5 Star Rating design iterations

By comparing the Star Ratings for the initial design and in conjunction with the Road Safety Toolkit (http://toolkit.irap.org) the PIU examined the iRAP recommendations from the SRIP in order to understand the potential benefits of the treatments being proposed and how to include further improvements.

The top-five recommended treatments based on the initial proposed design, in terms of the number of estimated deaths and serious injuries (KSI's) prevented are:

- Shoulder widening (49km)
- Removal of roadside hazards (54km)
- Roundabouts (28 sites)
- Pedestrian crossings (126 sites)
- Traffic calming (7km)

If incorporated into the Concession Agreement documents these five treatments would likely reduce the number of deaths and serious injuries by a further 1,000 over the next 20 years.

In an attempt to make further road safety improvements the design team sought to use the Safer Roads Investment Plan to include additional recommended countermeasures. After consultation, site visits and concept planning, the initial design was amended to include a 5m safe zone free of hazardous roadside objects, further speed reducing features within urban areas, horizontal realignment and several intersection upgrades. The key road improvements will include:

- Speed management and traffic calming including speed humps in urban/village areas
- The provision of raised/humped pedestrian crossings (see Figure 9)
- Purpose built footpaths
- Road surface improvements
- Shoulder widening / creation of bicycle lanes (see Figure 7)
- Lane widening
- Roadside hazard removal (creating 5m clear zone), including the removal of pre-cast concrete guard posts and the covering of open drainage ditches (see Figure 8)
- Delineation improvements particularly at high risk locations such as intersections and horizontal curves
- Turning lanes at major intersections (see Figure 10)
- Horizontal realignment (see Table 5)

Figure 7 Typical rural road cross-section through village (Appendix B-I)

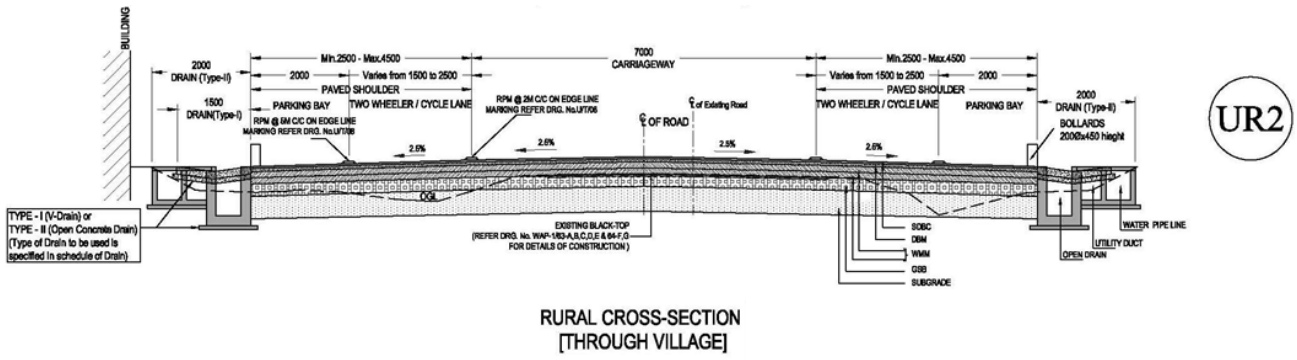


Figure 8 Typical urban road cross-section with covered drain (Appendix B-I)

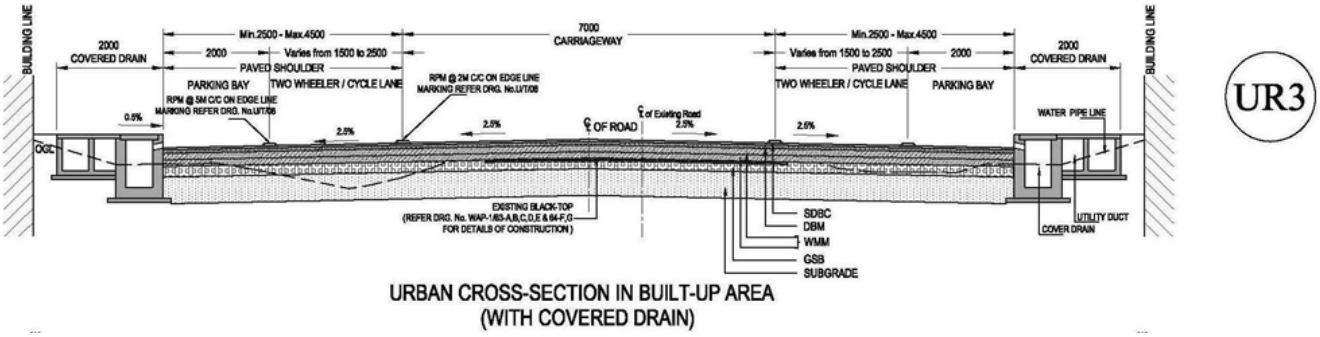


Figure 9 Typical details: Raised pedestrian crossing (Appendix C-I)

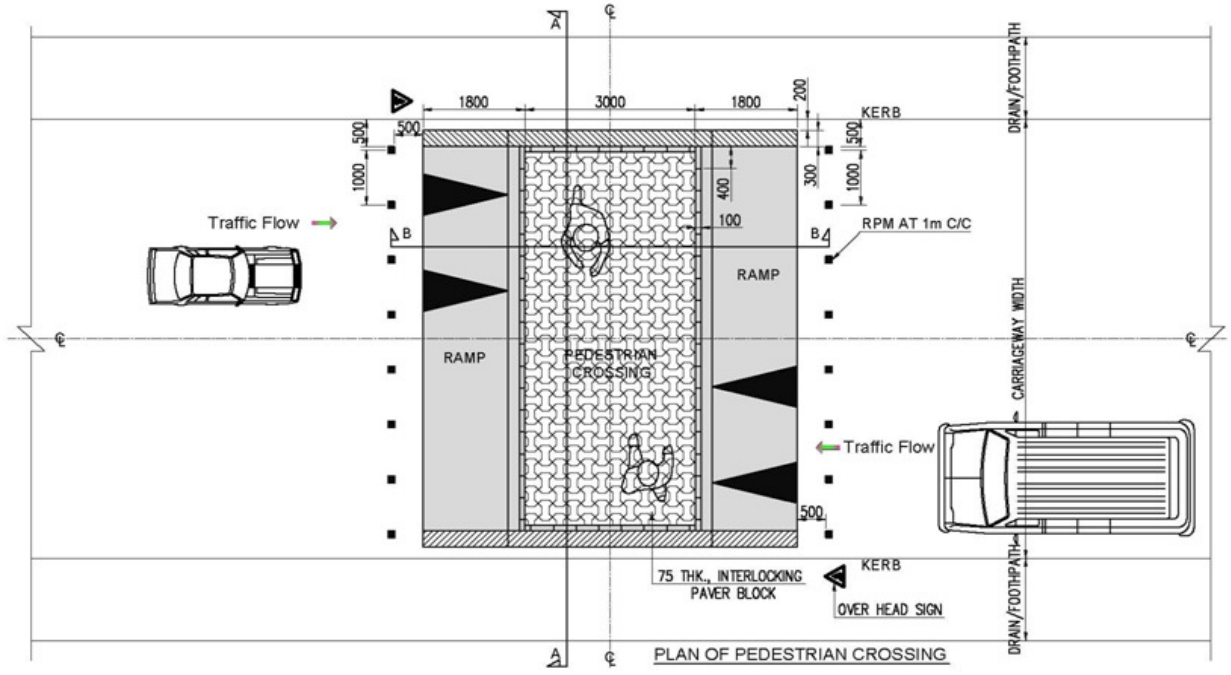


Figure 10 Typical details: 3-leg intersection with turn lane (Appendix C-I)

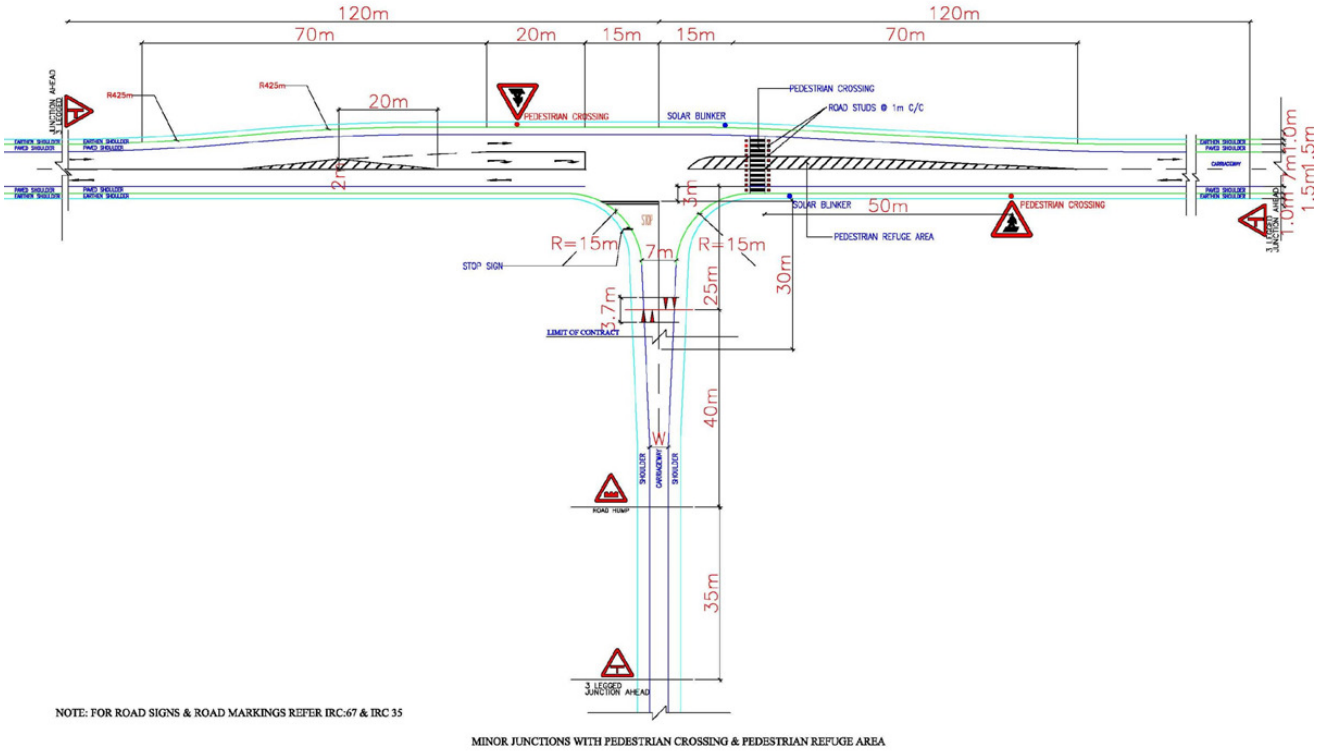


Table 7 Summary road attributes for each design iteration

Road attribute		Existing network	Initial design (Proposedv1)	Intermediate design (Proposedv2.2)	Final design (Proposedv3)
Speed	40km/h or less	0	17	21	21
	50km/h	7	3	2	1
	60km/h	0	1	1	1
	70km/h	0	0	0	0
	80km/h	93	78	76	76
Number of lanes (per direction)	one	100	97	97	97
	two	0	3	3	3
Lane width	wide	27	100	100	100
	medium	22	0	0	0
	narrow	51	0	0	0
Paved shoulder width	wide	0	12	12	12
	medium	1	40	40	40
	narrow	1	48	48	48
	none	98	0	0	0
Unpaved (earthen) shoulder width	wide	6	47	46	46
	medium	64	38	37	37
	narrow	29	6	7	7
	none	1	9	10	10

Road attribute		Existing network	Initial design (Proposedv1)	Intermediate design (Proposedv2.2)	Final design (Proposedv3)
Curvature	straight	78	96	96	96
	moderate	16	4	3	3
	sharp	6	0	0	0
	very sharp	1	0	0	0
Quality of curve	adequate	78	100	100	100
	poor	22	0	0	0
Delineation	adequate	15	100	100	100
	poor	85	0	0	0
Shoulder rumble strips (raised profile edge lines)	none	100	100	100	100
Road surface condition	good	8	100	100	100
	medium	27	0	0	0
	poor	65	0	0	0
Median type	physical <1m	1	0	0	0
	physical 1-5m	0	2	2	2
	centre line	99	98	97	97
Overtaking demand	none	1	1	1	3
	low	0	0	0	1
	medium	34	34	34	33
	high	65	65	65	63
Roadside severity (left)	safety barrier	0	5	5	5
	drainage ditch	0	1	1	1
	steep fill slope	2	0	0	0
	object 0-5m	38	16	1	0
	object 5-10m	25	47	70	70
	object >10m	35	30	23	24
Roadside severity (right)	safety barrier	0	5	4	4
	drainage ditch	0	1	1	1
	steep fill slope	2	0	0	0
	object 0-5m	38	16	1	1
	object 5-10m	25	44	70	70
	object >10m	35	34	24	24
Intersections	merge lanes	3	0	0	0
	roundabouts	2	1	0	0
	signalised	4	2	1	0
	turn lanes	0	5	4	53
	others	770	562	509	462
Intersection quality	Good	11	426	391	246
	Poor	768	138	124	270
Sidewalk provision	none	99	90	90	90

Road attribute		Existing network	Initial design (Proposedv1)	Intermediate design (Proposedv2.2)	Final design (Proposedv3)
	adj. to traffic	1	9	9	9
	within 1-3m	0	1	1	1
	physical barrier	0	0	0	0
Pedestrian crossing facilities	unsignalised	2	183	184	317
Pedestrian crossing quality	adequate	2	183	184	317
Bicycle lane	none	100	100	91	88
	dedicated lane			9	12
Motorcycle lane	none	100	100	100	100

Several interations of the design proposals were analysed, the results showing a gradual reduction in the percentage of high risk roads for each road user. The latest design is shown below as *Proposedv3*.

Table 8 Proportion of high-risk roads, a comparison between existing network and initial design, intermediate and final design

Road user	% rated 1- or 2-stars			
	Existing network	Initial design (Proposedv1)	Intermediate design (Proposedv2.2)	Final design (Proposedv3)
Vehicle occupants	86%	13%	4%	2%
Motorcyclists	94%	48%	44%	44%
Pedestrians	100%	40%	12%	12%
Bicyclists*	100%	53%	47%	45%

* where bicycle use is recorded.

The results show that implementation of *Proposed design v3* which incorporates simple, cost effective road safety treatments, has the potential to reduce the percentage of 1- and 2-star (high risk) roads from 86% to 2% for vehicle occupants. Similarly, the proposed speed reducing features combined with improved pedestrian facilities has the potential to reduce the percentage of high risk roads from 100% to 12% for pedestrians. Wide paved shoulders incorporating bicycle lanes help to reduce the percentage of high risk roads for bicyclists.

Figure 11 Star Ratings for final road design (*Proposedv3*)

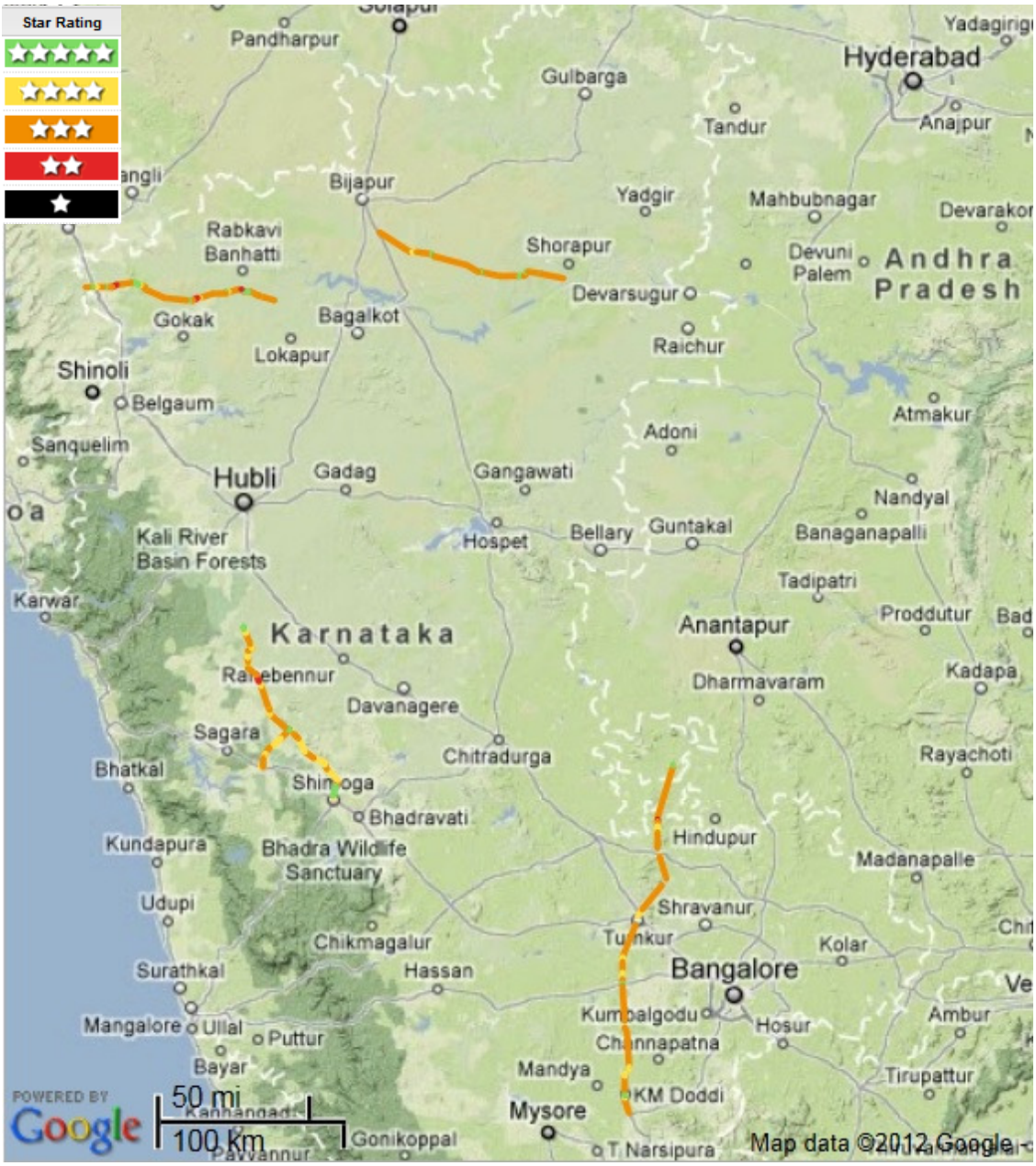


Table 9 Star Rating results for final road design (*Proposedv3*)

	Car Users		Motorcycle Users		Bicycle Users		Pedestrian Users	
Star Rating	Length (km's)	%	Length (km's)	%	Length (km's)	%	Length (km's)	%
★★★★★	25km	5%	25km	5%	6km	1%	0km	0%
★★★★	91km	17%	65km	12%	0km	0%	6km	1%
★★★	421km	77%	216km	39%	214km	39%	474km	86%
★★	11km	2%	242km	44%	178km	32%	68km	12%
★	0km	0%	0km	0%	0km	0%	0km	0%
	0km	0%	0km	0%	151km	27%	0km	0%
TOTAL	549km	100%	549km	100%	549km	100%	549km	100%

2.6 Economic assessment

By using these safety performance indicators for new road design an estimate of the number of deaths and serious injuries likely to be prevented, plus an assessment of the potential economic benefits is possible.

Using actual crash data where available, an estimate of the number of deaths and serious injuries that occur on the surveyed network is made. The iRAP model is used to provide an estimate of the number of road deaths that are likely to be prevented through the infrastructure improvements that are proposed.

The new road design is likely to reduce the number of fatal and serious injuries (KSIs) by 55%, preventing almost 140 roads deaths each year and over 30,000 deaths and serious injuries over the next 20 years.

Table 10 Deaths and serious injuries prevented

KSHIP Annuity Roads Project	Existing	Final design (Proposed v3)
Estimated road deaths per year	248	111
Estimated road deaths prevented per year	137	
Estimated KSIs per year	2,728	1,219
Estimated KSIs over 20yrs	54,560	24,386
Estimated KSIs prevented over 20yrs	30,174	
Reduction	55%	

Not only do road deaths and serious injuries cause emotional pain and distress, they also have a huge economic impact on both individual families (who may have lost a vital source of income) and to society as a whole. Current estimates put the cost of road crashes at around 3% of global GDP, therefore it stands to reason that well targeted road safety plans can realise large returns on investment.

It is estimated that the economic benefits of a reduction in the numbers of deaths and serious injuries from 2,728 to 1,219 per year, as seen in this study, would total approximately US $45 million per year in crash costs saved.[3]

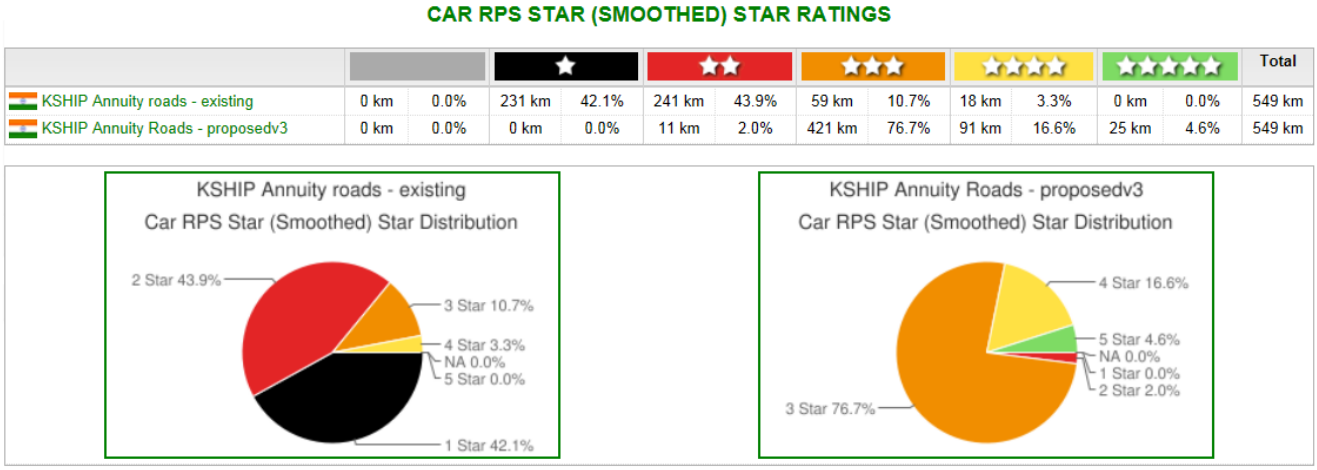
3 Conclusions

This analysis shows that the rehabilitation programme will remove all existing 1-star roads and all but 2% of the 2-star sections for car occupants. 76% of the proposed road design is rated 3-stars with the proportion of 4- and 5-star sections improving from 3% prior to rehabilitation to 20% post-construction as shown in Figure 12.

The proposed upgrades will see a significant reduction in risk for motorcyclists. 1-star rated sections will reduce from 66% to 0%. Although 2-star sections will increase from 28% to 44%, the proportion of 3-star rated sections will increase from 4% to 39% meaning that the high-risk sections (1- and 2-star roads) fall from 94% to 44%.

[3] Economic cost of road death estimated to be 70xGDP per capita (current prices), cost of a serious injury estimated at 0.25 times the cost of a death (as per policy paper *The true cost of road crashes, Valuing life and the cost of a serious injury* by K McMahon and S Dahdah). GDP per capita = INR 70,220 or US$1,334.00 (19.12.11)

Figure 12 **Star Ratings for vehicle occupants, a comparison between existing network and final design**



Improvements in facilities for pedestrians such as purpose built footpaths and pedestrian crossing facilities means that the overall rating improves from 100% 2-star before rehabilitation to 86% 3-star on full implementation of measures. Improvements for bicyclists, particularly the proposed on-carriageway cycle lanes as shown in Figures 7 & 8 (cross-sections UR2 and UR3) ensure that 39% of the network is rated 3-stars for bicyclists compared to 0% prior to rehabilitation works, whilst the 1-star sections (previously 42%) are eliminated.

This study has identified the locations at which there is likely to be the highest economic benefit from a range of measures including shoulder treatment, installation of barriers, provision of a range of pedestrian facilities, improved signing and delineation and pavement surfacing. Most of the recommendations (as shown in Table 3) have been incorporated into the bidding documents for the road rehabilitation works.

Local customs and practices and the lack of familiarity with established road safety measures as used in some other countries, means that opportunities may not be taken on this occasion to maximise safety. Dedicated motorcycle lanes, roundabouts and signalised intersections are examples of some of the recommendations that have not been included for consideration. However, the majority of iRAP recommendations have been included and the analysis shows that significant numbers of deaths and serious injuries can prevented over the next 20 years.

Due to the assumptions that must inevitably be made in generating star ratings from design schedules and typical cross-sections it will be important that post-construction analysis is undertaken to ensure star ratings are produced which accurately reflect the infrastructure upgrades as-built. This will help to validate the results and identify any problems with the methodology as described in this report.

There are obvious advantages to knowing the star ratings of proposed new road designs prior to construction and this type of analysis allows multilateral development banks and donors to set minimum star rating standards for all new road construction.

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