KYOTO UNIVERSITY - UTC JOINT SUMMER SCHOOL

SEPTEMBER 25 - 27, 2007

UNIVERSITY OF TRANSPORT AND COMMUNICATIONS

HANOI, VIETNAM

Road Infrastructure Asset Management Course

JOINTLY ORGANIZED BY:

KYOTO UNIVERSITY

UNIVERSITY OF TRANSPORT AND COMMUNICATIONS

Chaired by Prof. Kiyoshi Kobayashi, Kyoto University

Predict the deterioration process of road pavement using Stochastic model

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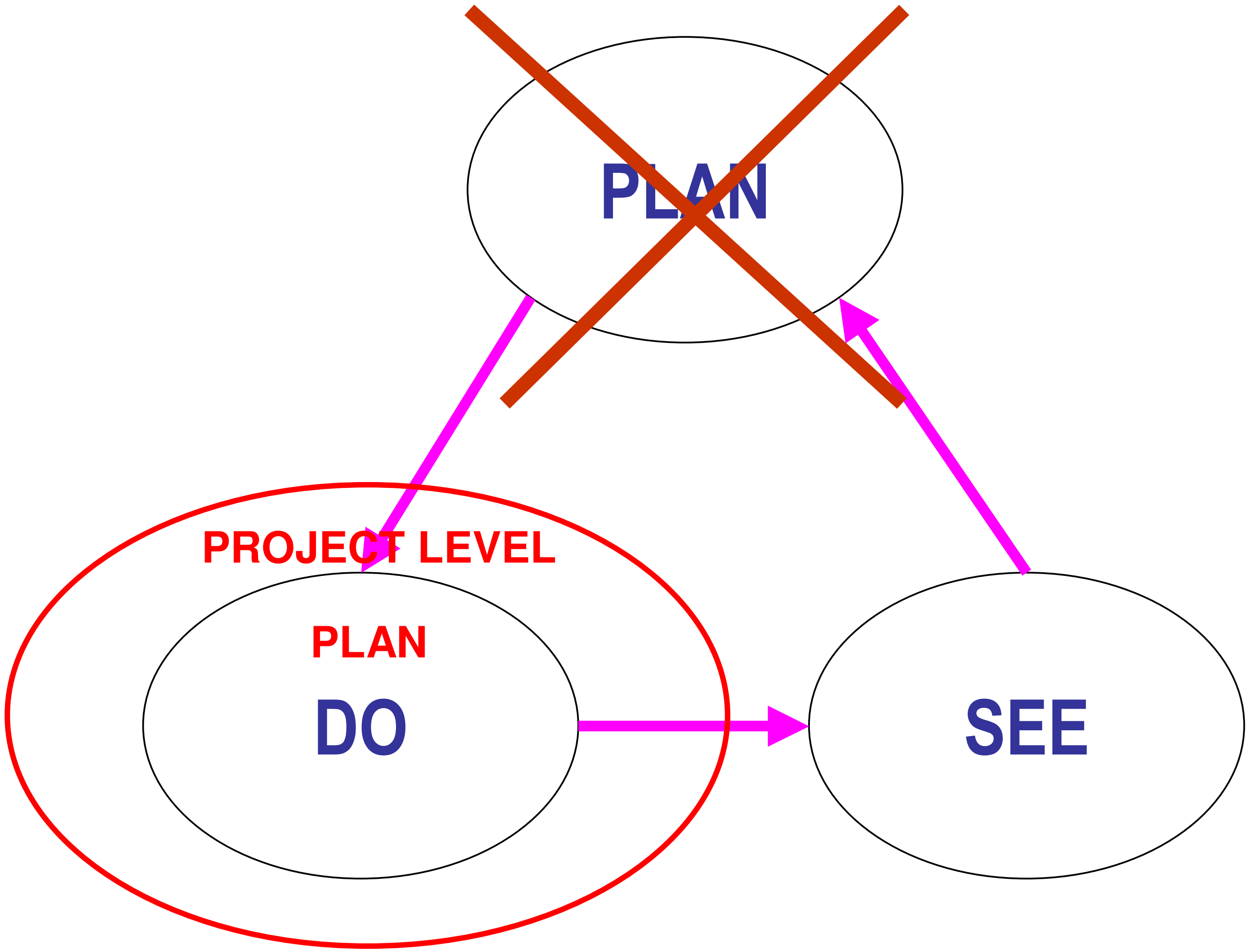
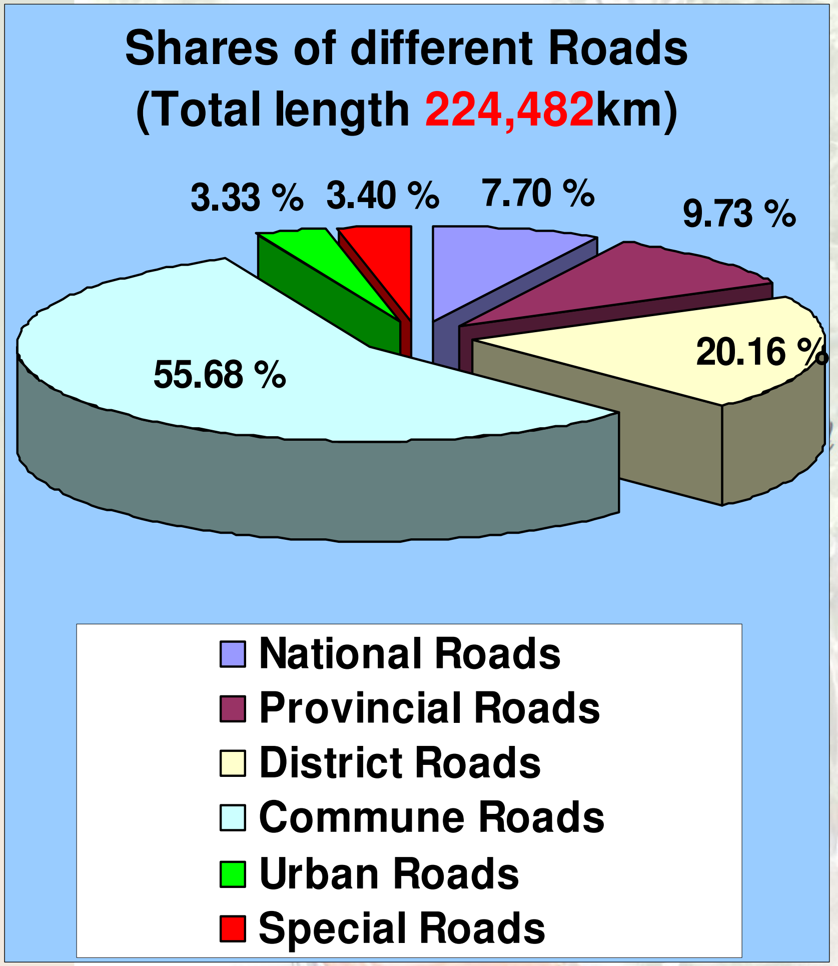
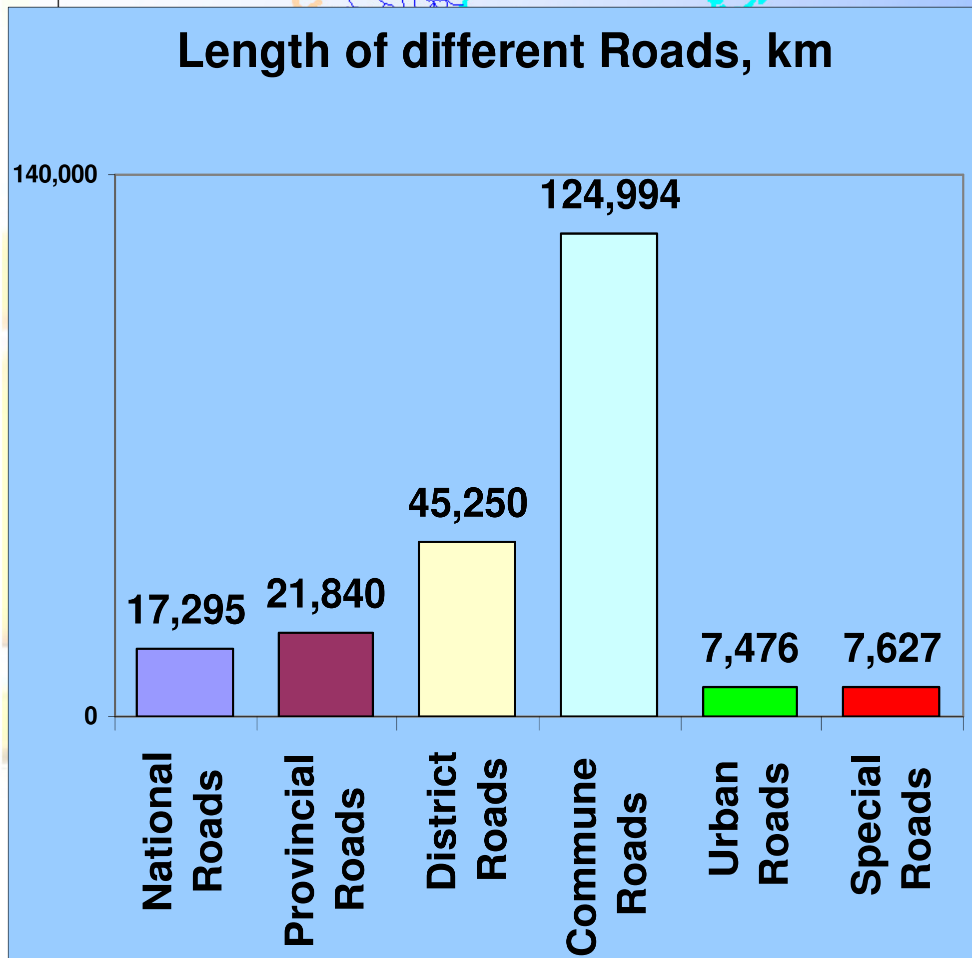
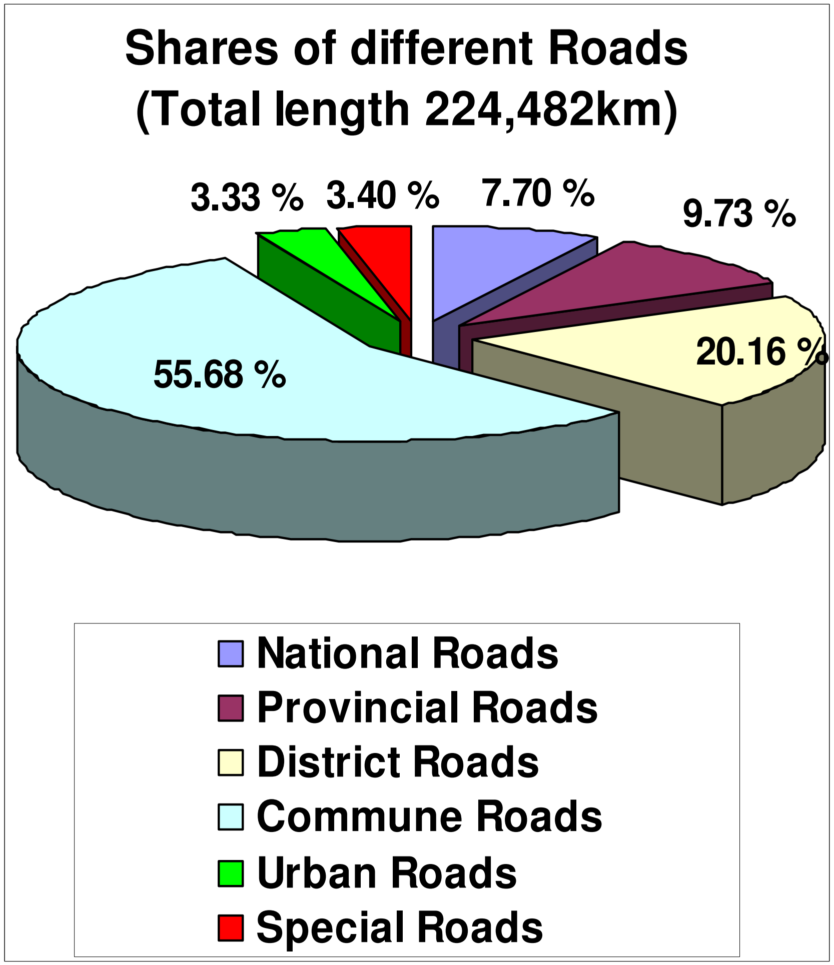


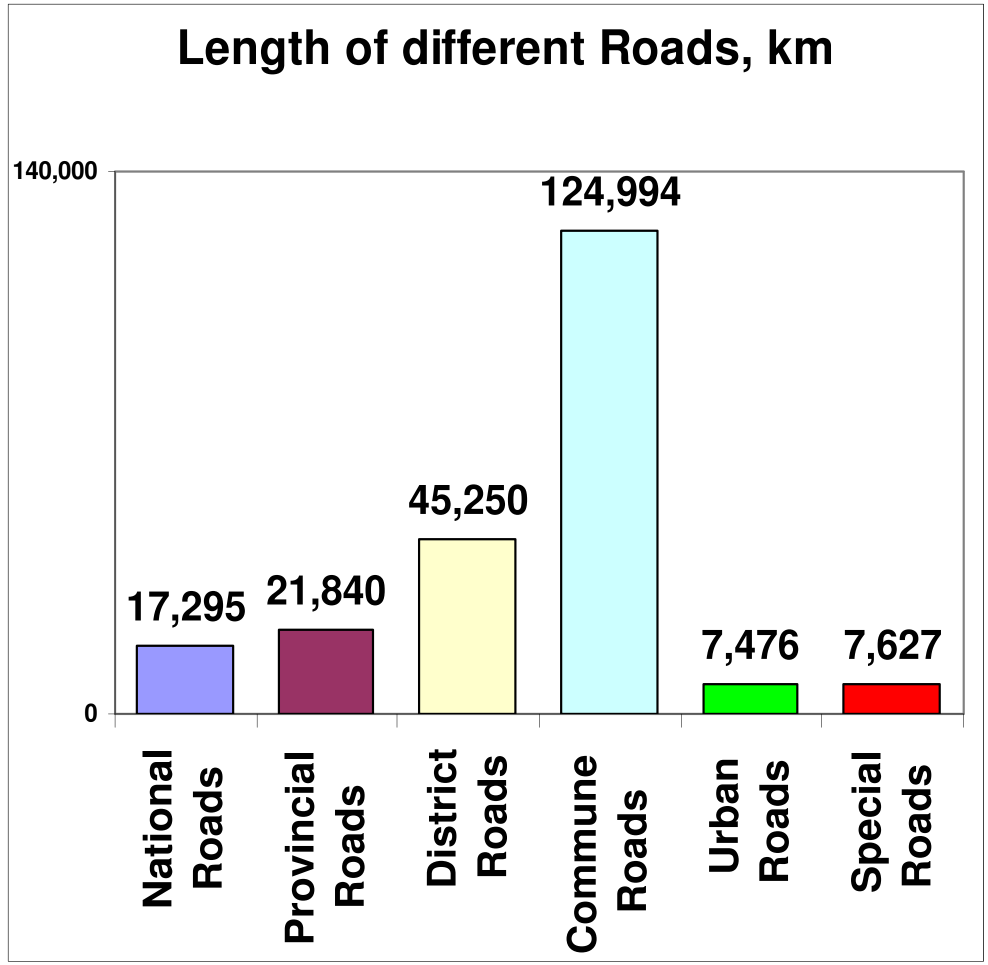
Vietnam Road Network





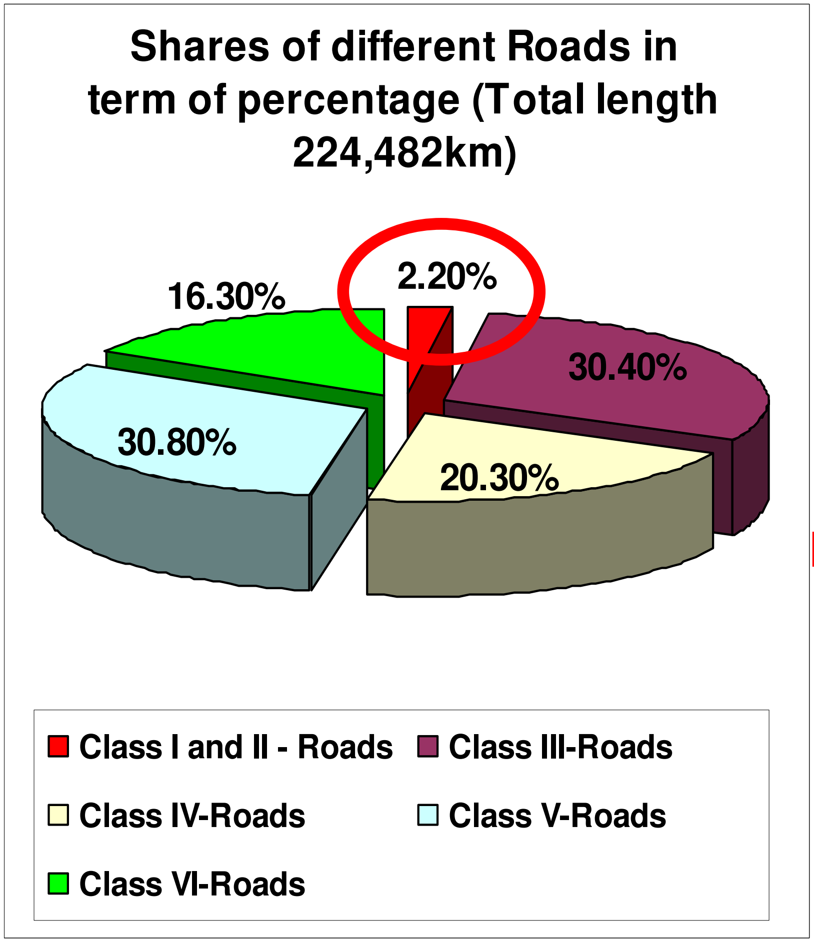
Shares of different Roads in the networks

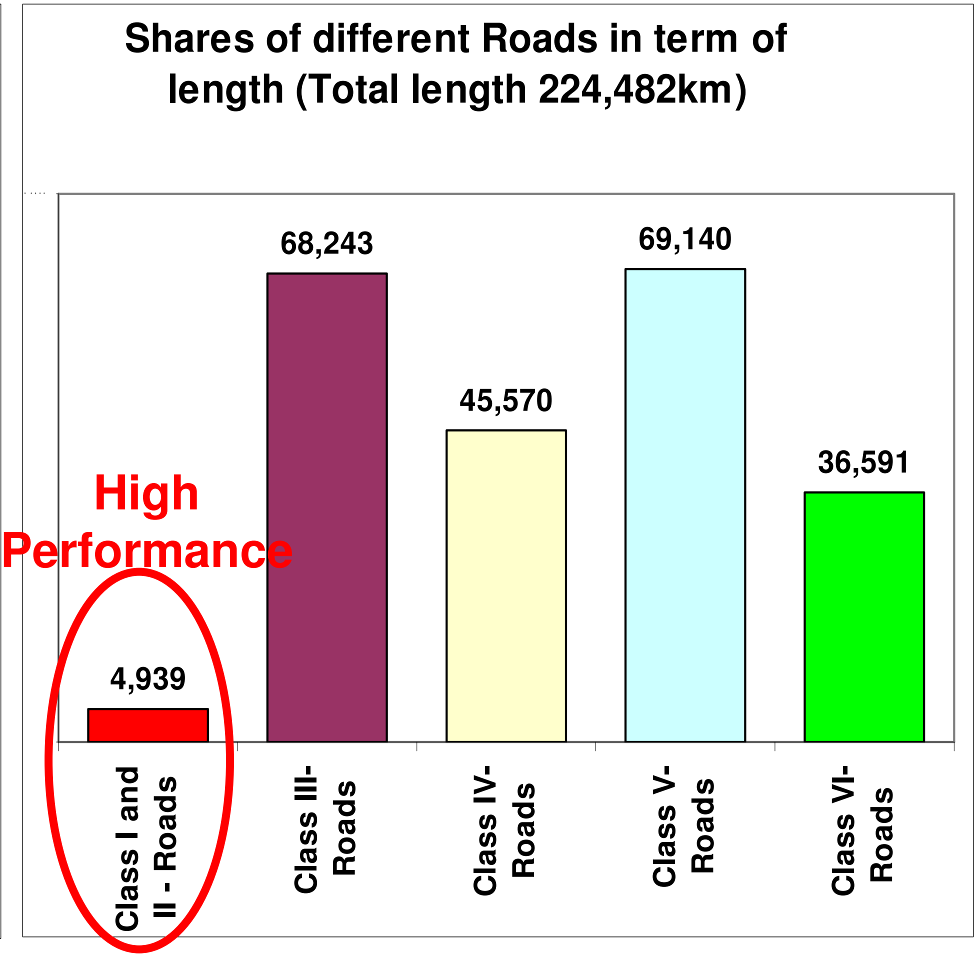




The total number of bridges were 34,933 with the total length of approximately 606,915m.

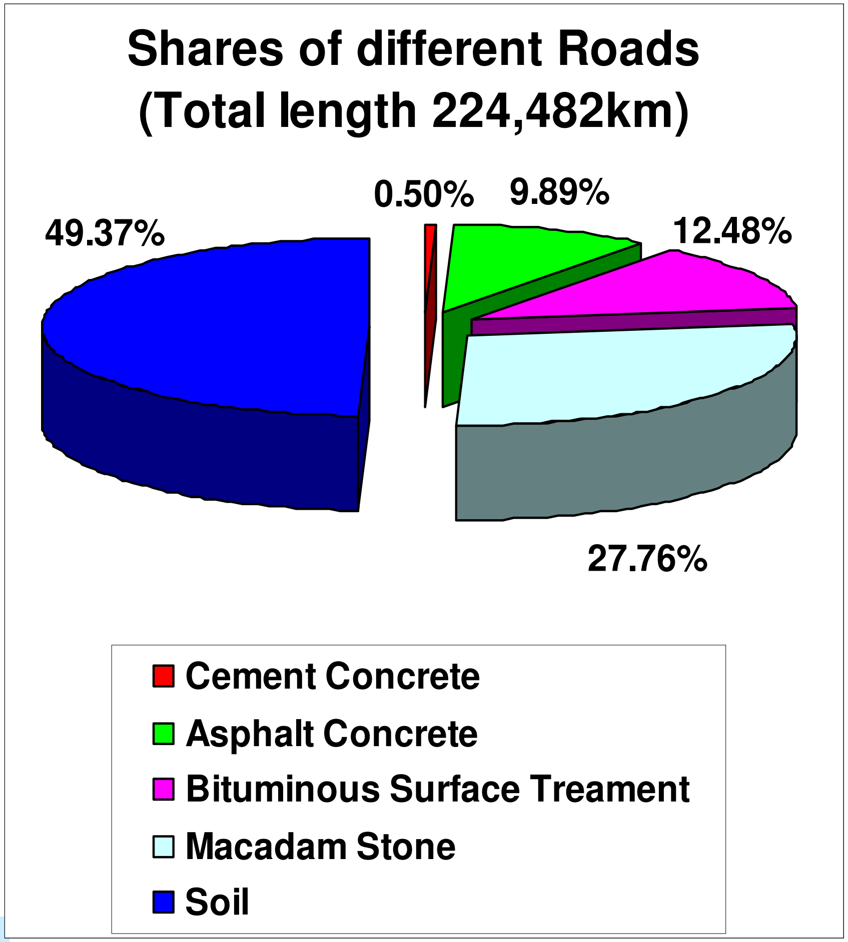
Shares of different Roads in the networks

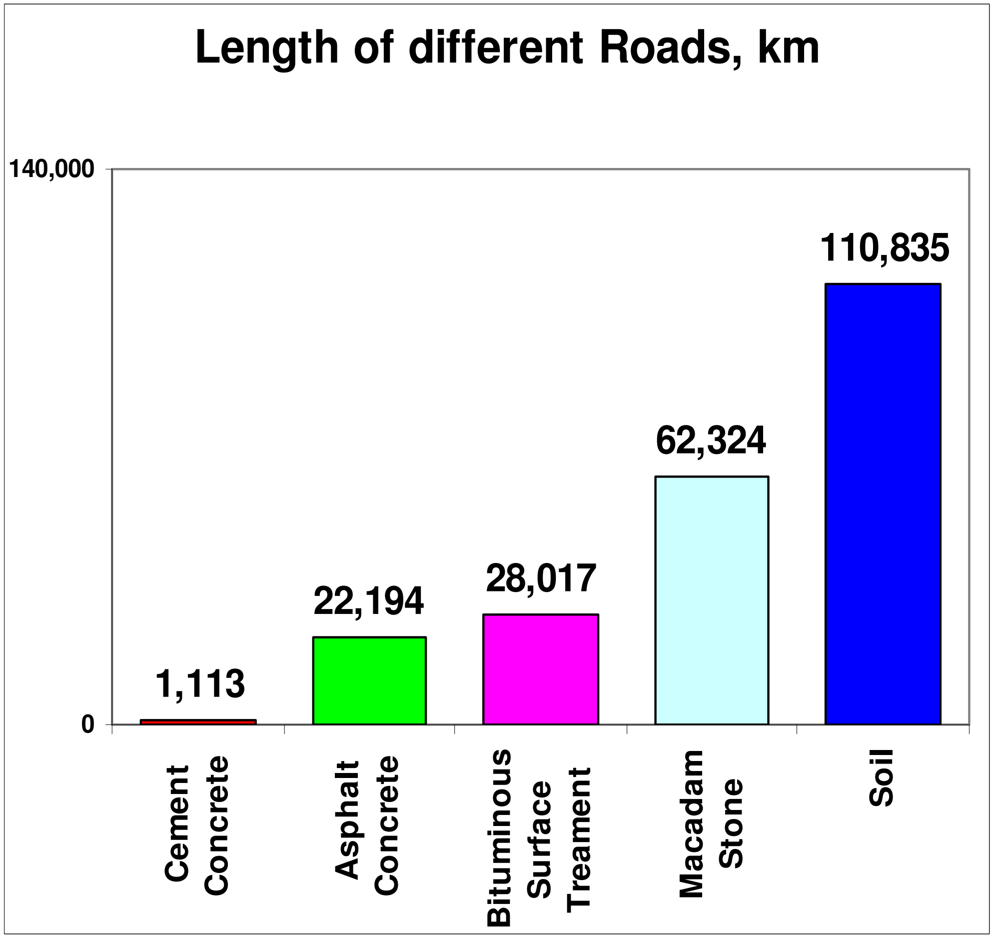




(Classes of roads are defined according to Highway Specification for Design, code TCVN 4054-1998)

Shares of different Roads in the networks based on types of pavement



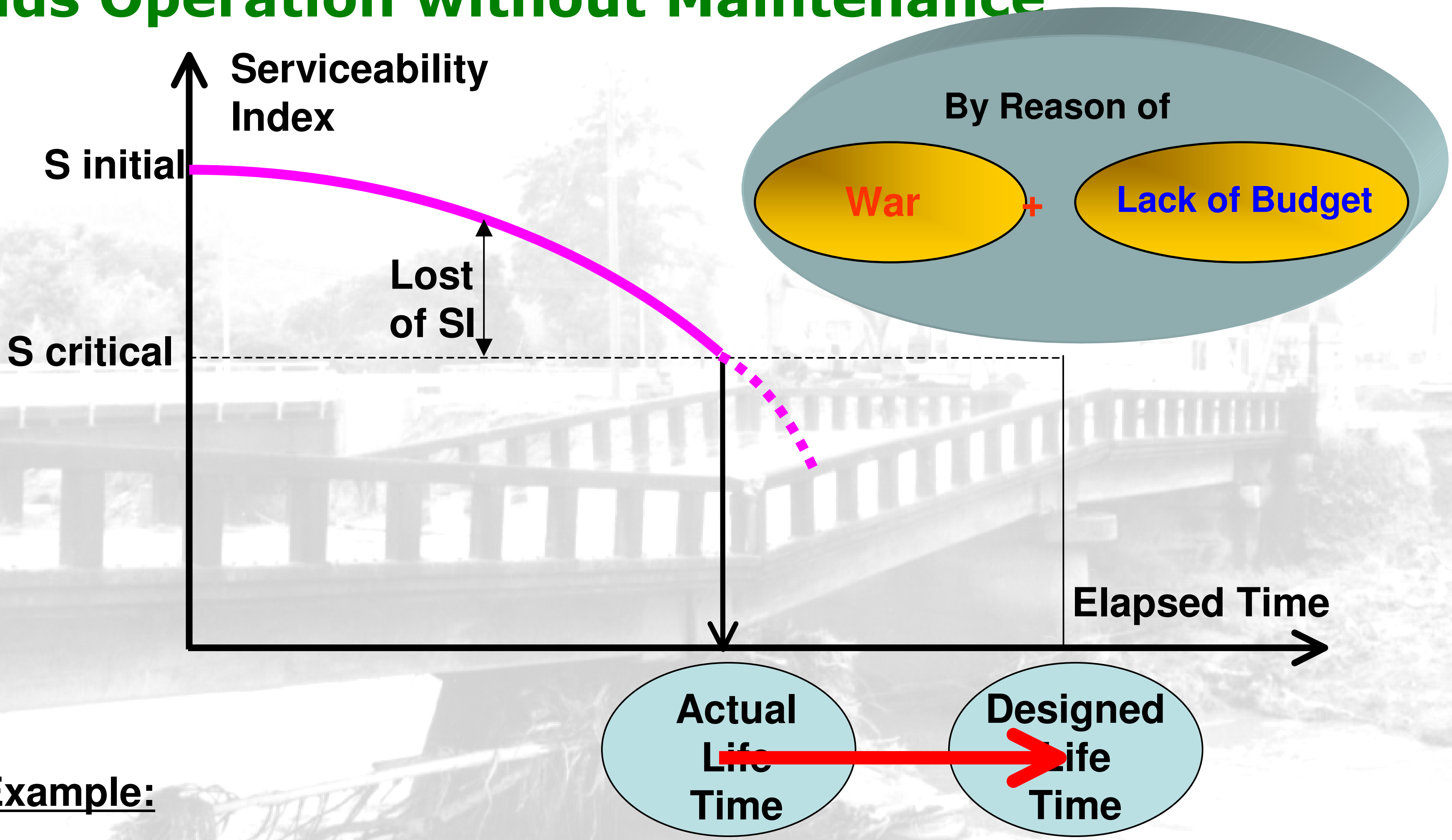


Management and Maintenance

NH.1 Haivan Pass

NH.1 Haivan Pass

Roads Operation without Maintenance

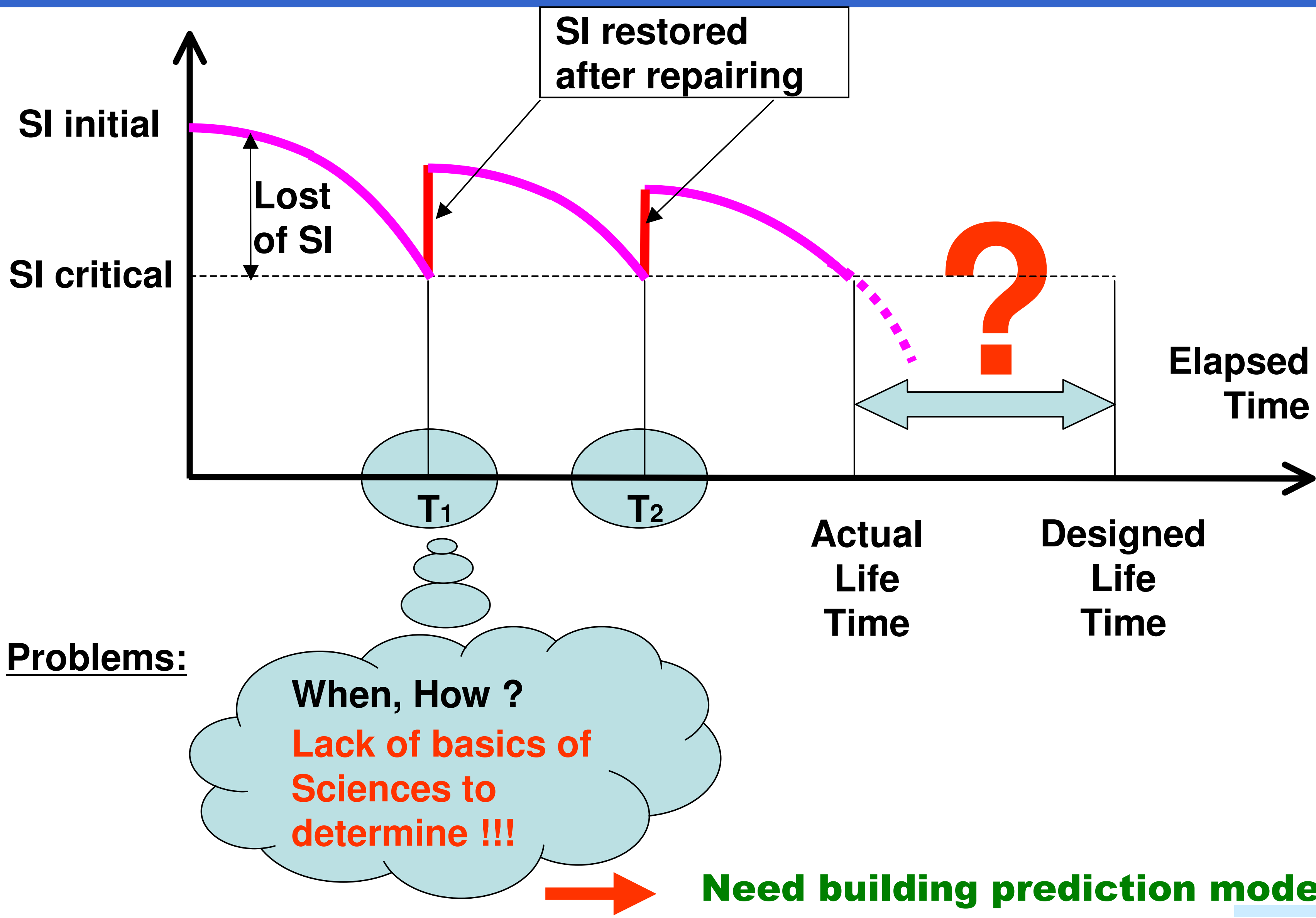


Example:

Rao Bridge in HaiPhong Province: **Operated without any maintenance, so collapsed in 1987 with Life Time of 7 years 4 months.**

Railway Tunnels System: built by French in maintenance for 70 years, so in 1993 Tun collapsed.

Roads Operation with Maintenance/Problem of Planning for Maintenance Work



Problems:

Need building prediction model

Contents

Part 1. Introduction Road System

Part 2. Develop Prediction Model

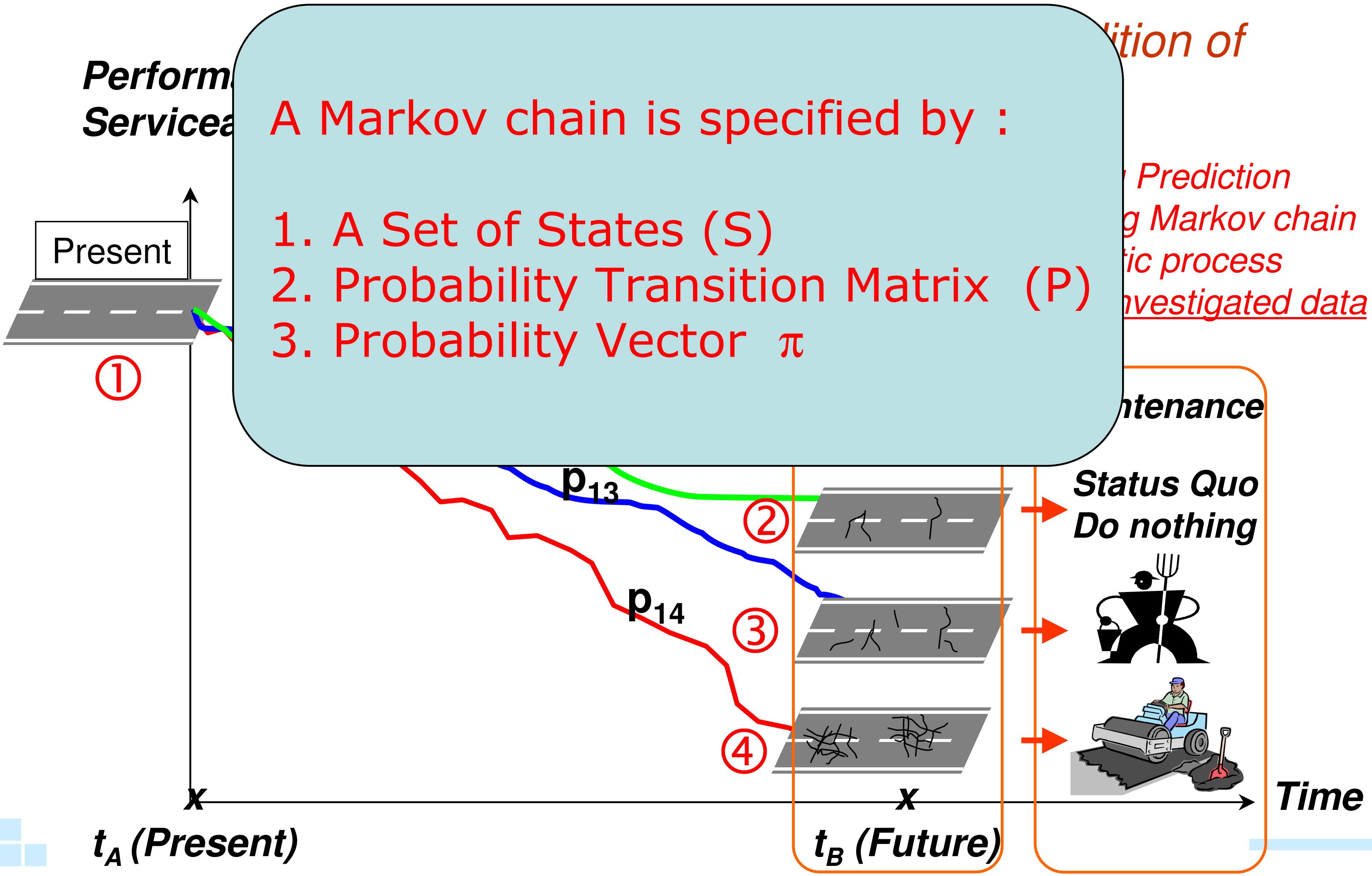
Part 3. Application Prediction Model

Part 4. Conclusion

Forecasting/Predicting Deterioration of Facilities

A Markov chain is specified by :

1. A Set of States (S)
2. Probability Transition Matrix (P)
3. Probability Vector π



Markov Chain

Let's study the change of condition states of a system within a set of condition states **S**.

A Markov chain is a sequence of random discrete variables having the property that, given knowledge of the present, the past is irrelevant for predicting the future.

In other words,

$$Pr\left\{X_{n+1}=s_j \,\middle|\, \text{[illegible]}\; X_n = s_i\right\}$$

$$= Pr\left\{X_{n+1}=s_j \,\middle|\, X_n = s_i\right\}$$

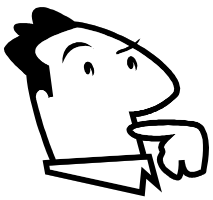
Markov Transition Matrix

If the space of states is finite, the transition probability distribution can be represented as a matrix, called the transition matrix P.

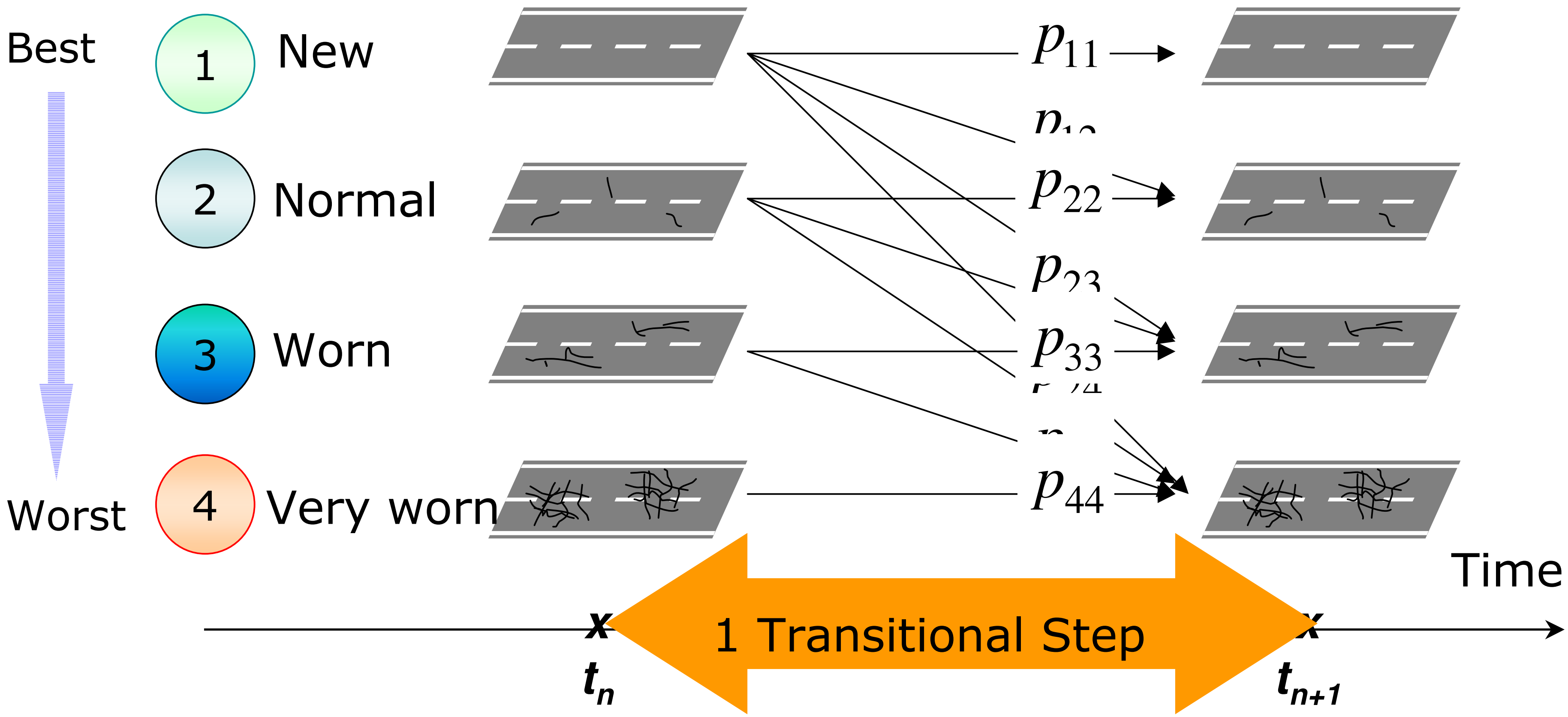
$$\mathbf{P} = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1\mathrm{K}} \\ p_{21} & p_{22} & \cdots & p_{2K} \\ \vdots & \cdots & \ddots & \vdots \\ p_{K1} & p_{K2} & \cdots & p_{\mathrm{KK}} \end{pmatrix}$$

$$p_{ij} = Pr\left\{ X_{n+1} = s_j \,\middle|\, X_n = s_i \right\}$$

Transitional Probabilities



Pavement condition



Initial probability distribution (vector) on the set of states: π

Probability Vector/Distribution

π : Initial probability distribution (vector): K components (Ex. K=4)

i^th^ component of π means probability that facility is in state **i** at the current time.

$$\pi^{(1)} = \pi P$$

$$\pi^{(2)} = \pi^{(1)} P = \left(\pi P\right) P = \pi P^{(2)}$$

$$\pi^{(3)} = \pi^{(2)} P = \left(\pi^{(1)} P\right) P = \pi P^{(3)}$$

...

$$\boxed{\pi^{(n)} = \pi P^{n}}$$

ith component of $\pi^{(n)}$ means ?

Contents

Part 1.

Introduction Road System

Part 2.

Develop Prediction Model

Part 3.

Application Prediction Model

Part 4.

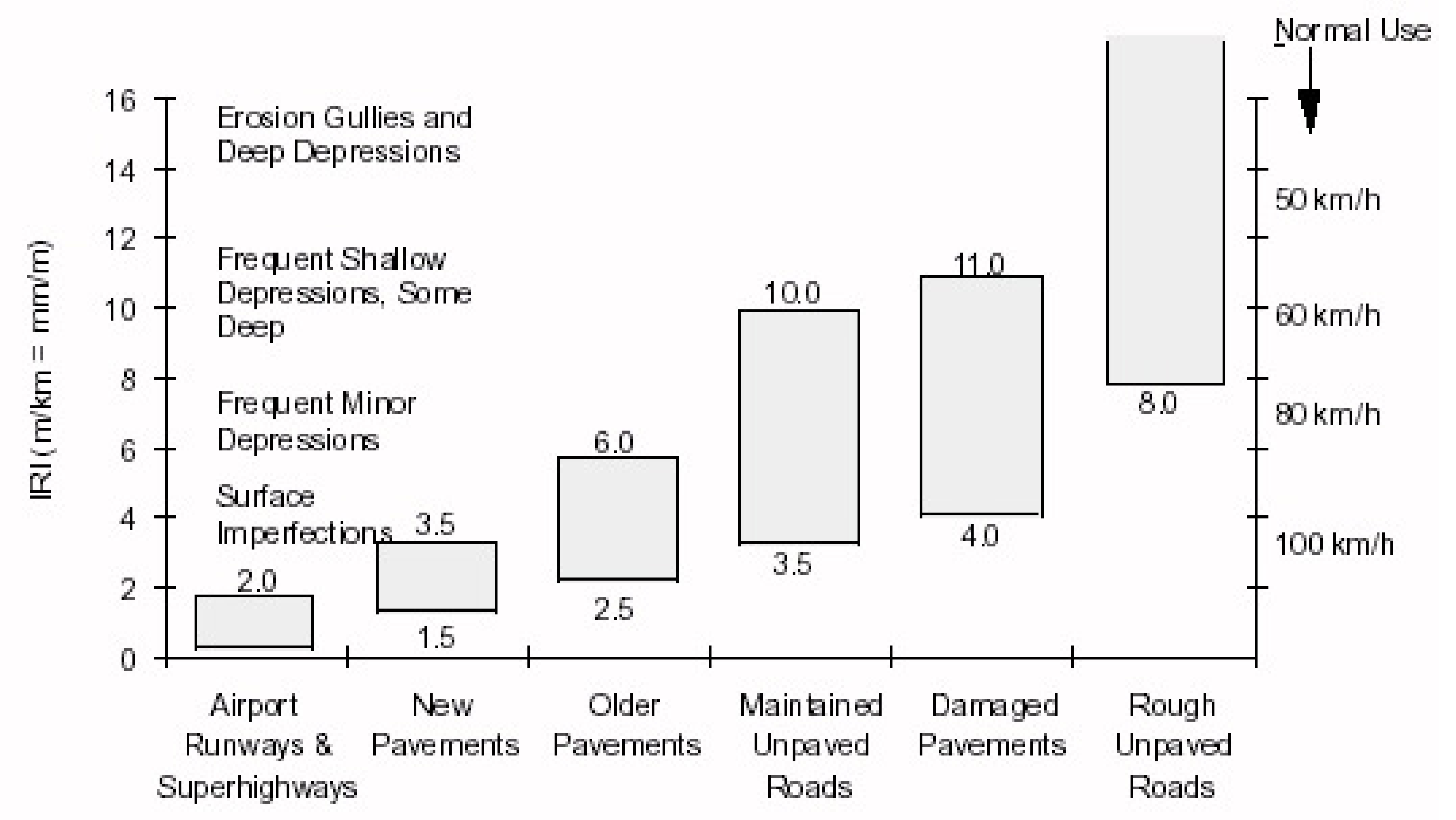
Conclusion

Application

Predict the deterioration of some highways in term of Roughness Index (IRI) in Vietnam based upon the investigated data.

The common IRI scale

(http://training.ce.washington.edu/WSDOT/)



Pavement roughness Ratings according to Vietnamese Standard (22TCN-277-01)

AC Pavement

Design speed (km/h)	IRI (m/km)			
	Good	**Fair**	**Poor**	**Very Poor**
120 ;100 ; 80	(0 ; 2]	(2 ; 4]	(4 ; 6]	(6 ; 8]
60	(0 ; 3]	(3 ; 5]	(5 ; 7]	(7 ; 9]
40 ; 20	(0 ; 4]	(4 ; 6]	(6 ; 8]	(8; 10]

Bituminous surface treatment Pavement

Design speed (km/h)	IRI (m/km)			
	Good	**Fair**	**Poor**	**Very Poor**
60	(0 ; 4]	(4 ; 6]	(6 ; 8]	(8; 10]
40 ; 20	(0 ; 5]	(5 ; 7]	(7 ; 9]	(9; 11]

Selected pavement roughness Ratings

IRI (m/km)	States	Notation of states
IRI ≤ 3	Very Good	①
3 < IRI ≤ 4	Good	②
4 < IRI ≤ 5	Fair	③
5 < IRI ≤ 6	Quite Fair	④
6 < IRI ≤ 7	Poor	⑤
IRI > 7	Very Poor	⑥

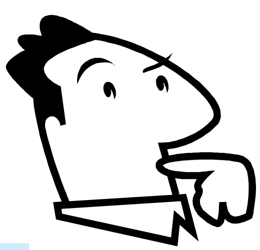
Data of Road condition investigated by VRA in 2001 and 2004

IRI (m/km)	Notation of states
IRI ≤ 3	①
3 < IRI ≤ 4	②
4 < IRI ≤ 5	③
5 < IRI ≤ 6	④
6 < IRI ≤ 7	⑤
IRI > 7	⑥

. . .	ROUGHNESS (M/KM)					. . .	NMT_LTYPE
. . .	[76]					. . .	[159]
	(2001)	(2004)	Rating2001	Rating2004	Change		
	2.75	4.27	1	3	13		4
	2.73	3.50	1	2	12		4
	2.56	3.54	1	2	12		4
	2.65	3.70	1	2	12		4
	2.74	3.85	1	2	12		4
	2.85	[illegible]	[illegible]	[illegible]	12		4
	2.08	4.70	1	3	13		4
	2.15	3.76	1	2	12		4
	2.40	3.66	1	2	12		4
	. . .	. . .	. . .	. .	. . .		. . .
	3.93	5.09	2	4	24		

Classification of road conditions in 2001 and 2004 based on investigated data

State	Number of road sections	
	2001	2004
①	122	0
②	137	35
③	26	85
④	31	80
⑤	2	63
⑥	1	56
Sum	<u>319</u>	<u>319</u>



How roads changes from states to states ?

Changes of condition states of selected road sections in term of IRI ratings from 2001 to 2004

319 sections (~ 319 kilometers) of 3 highways : NH10, NH18, NH4B

State	①	②	③	④	⑤	⑥	Sum
①							122
②							137
③							26
④							31
⑤							2
⑥							1
Sum	0	35	85	80	63	56	319

Transition matrix P in Tabular Form

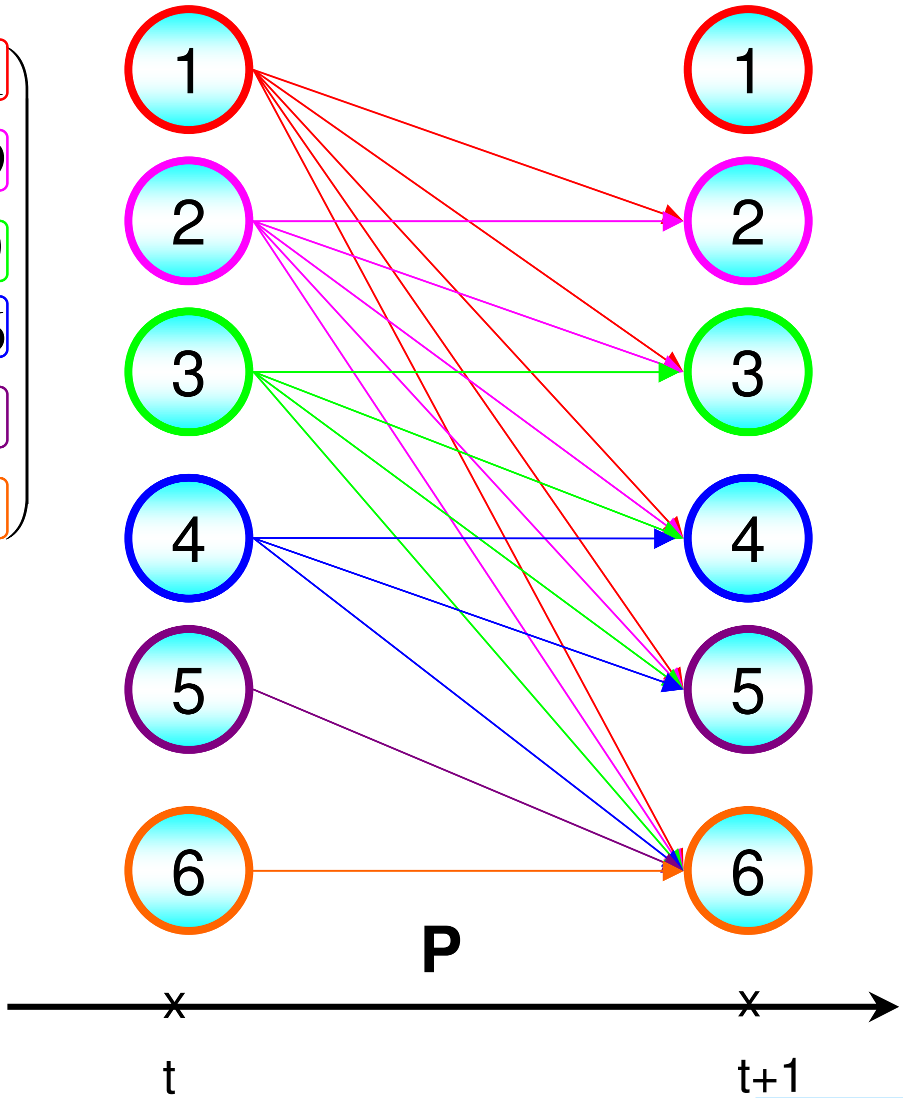
State	①	②	③	④	⑤	⑥	
①	0	0.213	0.295	0.254	0.197	0.041	→ $\sum_{j=1}^{6} p_{1j} = 1$
②	0	0.066	0.350	0.307	0.139	0.139	→ $\sum_{j=1}^{6} p_{2j} = 1$
③	0	0	0.038	0.231	0.231	0.500	→ $\sum_{j=1}^{6} p_{3j} = 1$
④	0	0	0	0.032	0.452	0.516	→ $\sum_{j=1}^{6} p_{4j} = 1$
⑤	0	0	0	0	0	1	→ $\sum_{j=1}^{6} p_{5j} = 1$
⑥	0	0	0	0	0	1	→ $\sum_{j=1}^{6} p_{6j} = 1$

Transition matrix P in Canonical Form

$$P = \begin{pmatrix} 0 & 0.213 & 0.295 & 0.254 & 0.197 & 0.041 \\ 0 & 0.066 & 0.350 & 0.307 & 0.139 & 0.139 \\ 0 & 0 & 0.038 & 0.231 & 0.231 & 0.500 \\ 0 & 0 & 0 & 0.032 & 0.452 & 0.516 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Transition matrix P in Canonical Form/Illustration

$$P=\begin{pmatrix} 0 & 0.213 & 0.295 & 0.254 & 0.197 & 0.041 \\ 0 & 0.066 & 0.350 & 0.307 & 0.139 & 0.139 \\ 0 & 0 & 0.038 & 0.231 & 0.231 & 0.500 \\ 0 & 0 & 0 & 0.032 & 0.452 & 0.516 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$



Classification of road conditions in 2001 and 2004 based on investigated data

State	Number of road sections	
	2001	2004
①	122	0
②	137	35
③	26	85
④	31	80
⑤	2	63
⑥	1	56
Sum	<u>319</u>	<u>319</u>

Initial probability vector is the initial probability distribution on the set of states in 2004

$$\pi = (0,\ 0.110,\ 0.266,\ 0.251,\ 0.197,\ 0.176) \rightarrow \sum_{i=1}^{6} \pi_i = 1$$

Calculation probability vector π

Given Transition Matrix P, Initial probability vector π, and

$$\pi^{(n)} = \pi P^{n}$$

$\pi^{(0)}$ = (0.000, 0.110, 0.266, 0.251, 0.197, 0.176)

$$\pi^{(1)} = \pi P = (0,\ 0.110,\ 0.266,\ 0.251,\ 0.197,\ 0.176) \times \begin{pmatrix} 0 & 0.213 & 0.295 & 0.254 & 0.197 & 0.041 \\ 0 & 0.066 & 0.350 & 0.307 & 0.139 & 0.139 \\ 0 & 0 & 0.038 & 0.231 & 0.231 & 0.500 \\ 0 & 0 & 0 & 0.032 & 0.452 & 0.516 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$\pi^{(1)}$ = (0.000, 0.007, 0.049, 0.103, 0.190, 0.651)

. . .

Number of sections in state ⑥ 319 x 0.651 = 208

Given Transition Matrix P, Initial probability vector π, and

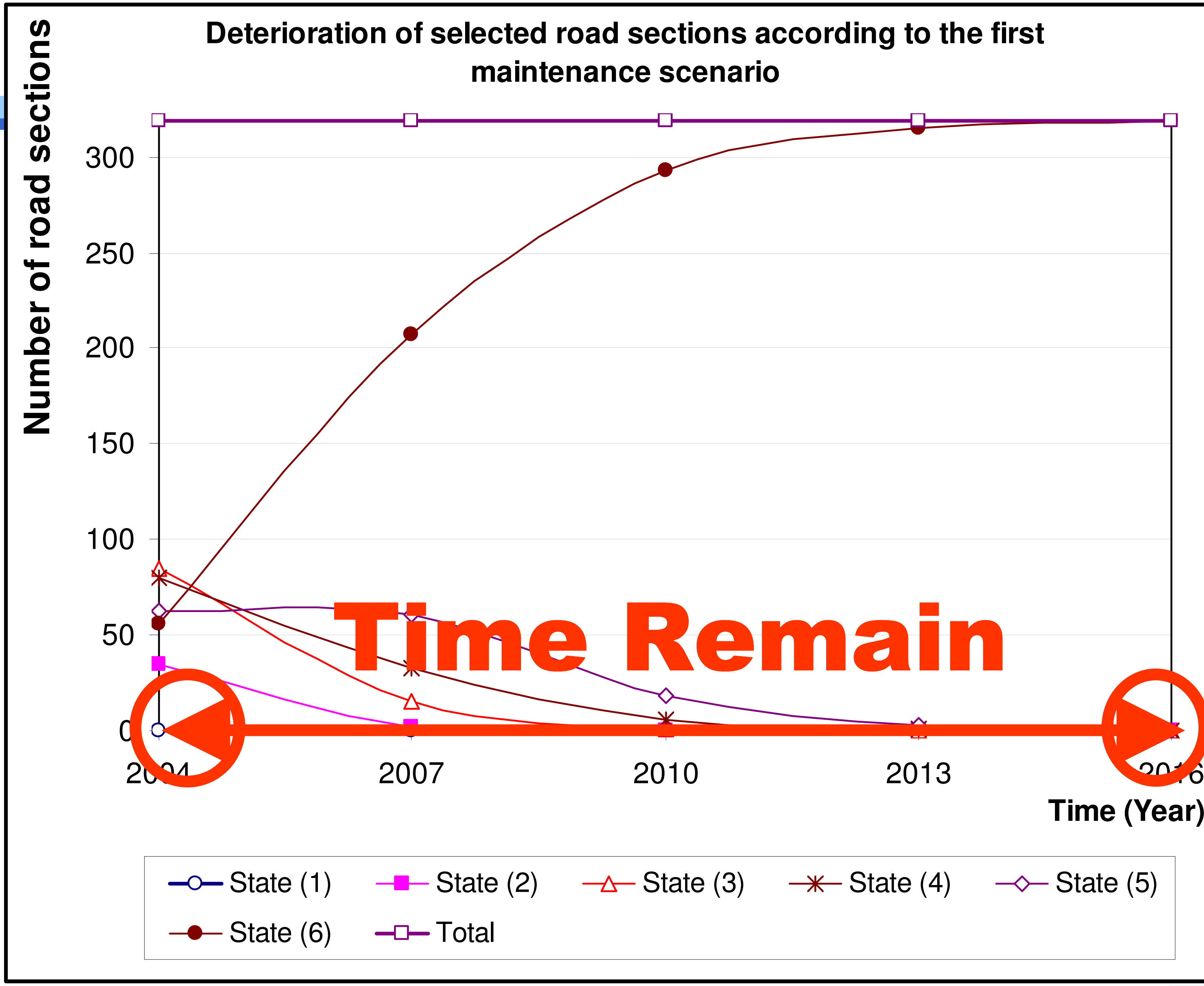
$$\pi^{(n)} = \pi P^{n}$$

$\pi^{(0)}$ =	(0.000,	0.110,	0.266,	0.251,	0.197,	0.176)
$\pi^{(1)}$ =	(0.000,	0.007,	0.049,	0.103,	0.190,	0.651)
$\pi^{(2)}$ =	(0.000,	0.000,	0.004,	0.017,	0.059,	0.920)
$\pi^{(3)}$ =	(0.000,	0.000,	0.000,	0.002,	0.009,	0.989)
$\pi^{(4)}$ =	(0.000,	0.000,	0.000,	0.000,	0.001,	0.999)

Predicted number of road sections in each condition state in the future

State		①	②	③	④	⑤	⑥
Number of road section in year	2001	122	137	26	31	2	1
	2004	0	35	85	80	63	56
	2007	0	2	16	33	61	208
	2010	0	0	1	5	19	293
	2013	0	0	0	1	3	316
	2016	0	0	0	0	0	319

Absorbing State



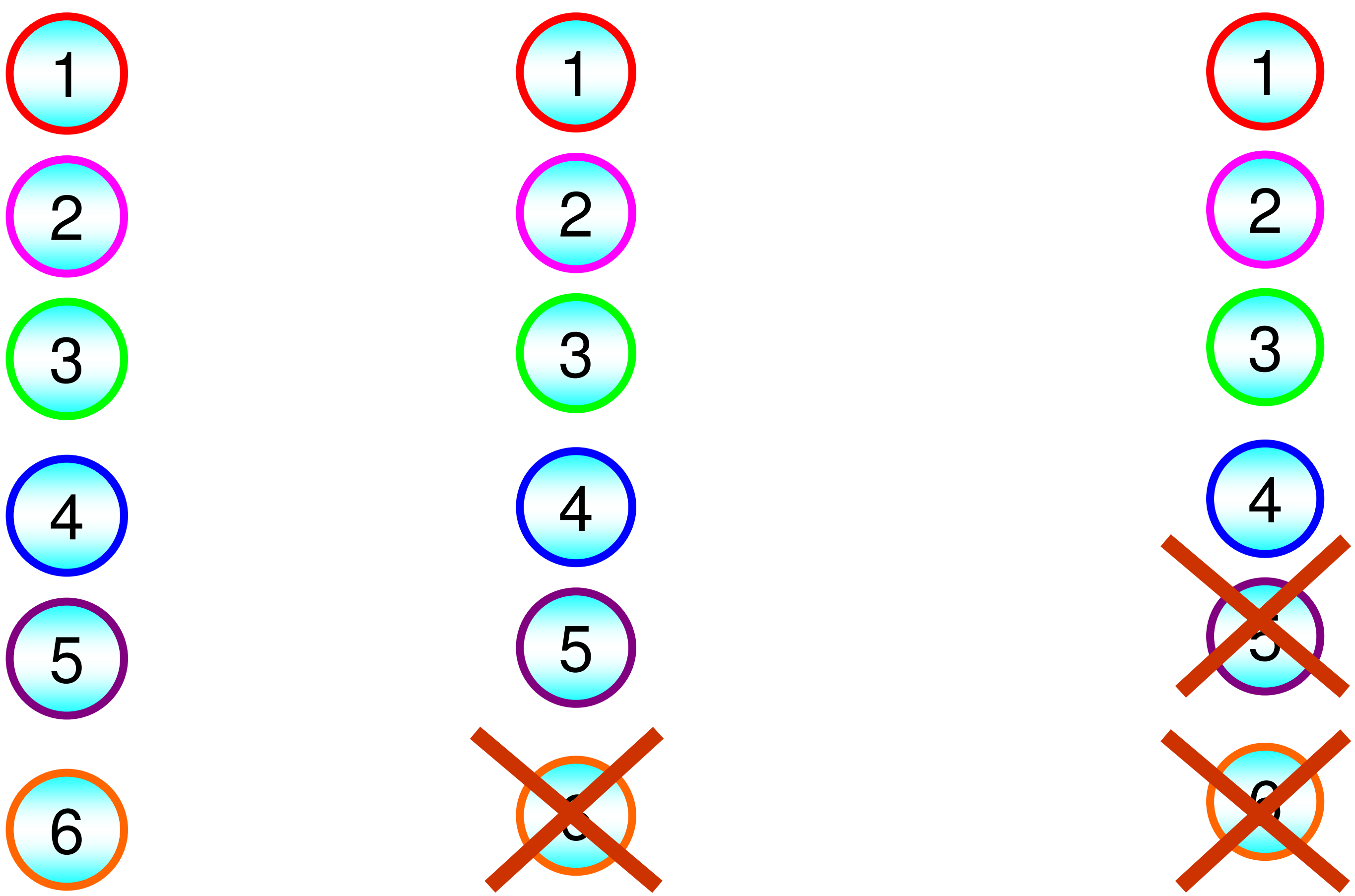
Deterioration of selected road sections according to the first maintenance scenario
Number of road sections
300
250
200
150
100
50
0
2004
2007
2010
2013
2016
Time (Year)
State (1)
State (2)
State (3)
State (4)
State (5)
State (6)
Total
Time Remain

Maintenance & Repair Scenarios considered

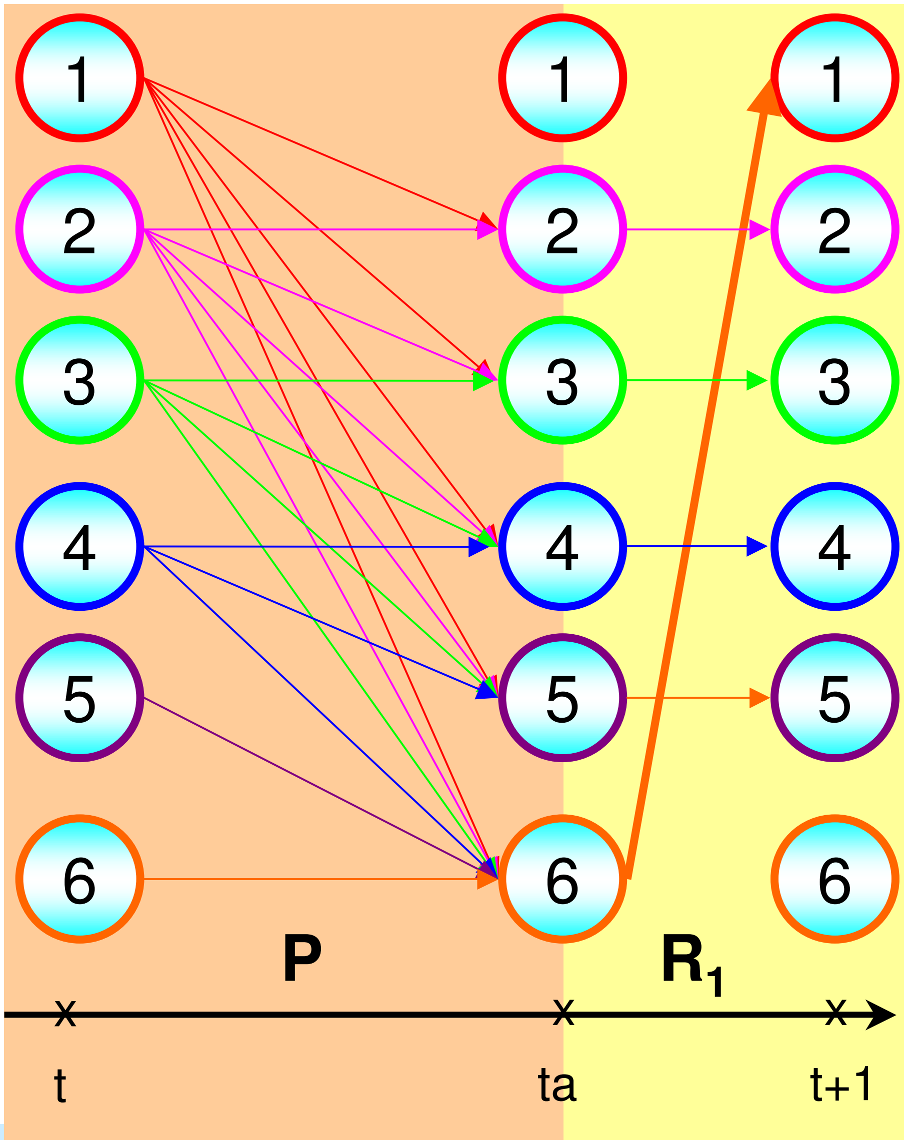
The first scenario: natural deterioration.

The second scenario: conducting periodic maintenance or repair to avoid being in state ⑥

The third scenario: conducting periodic maintenance or repair at higher scale and wider scope to avoid being in states ⑤ and ⑥

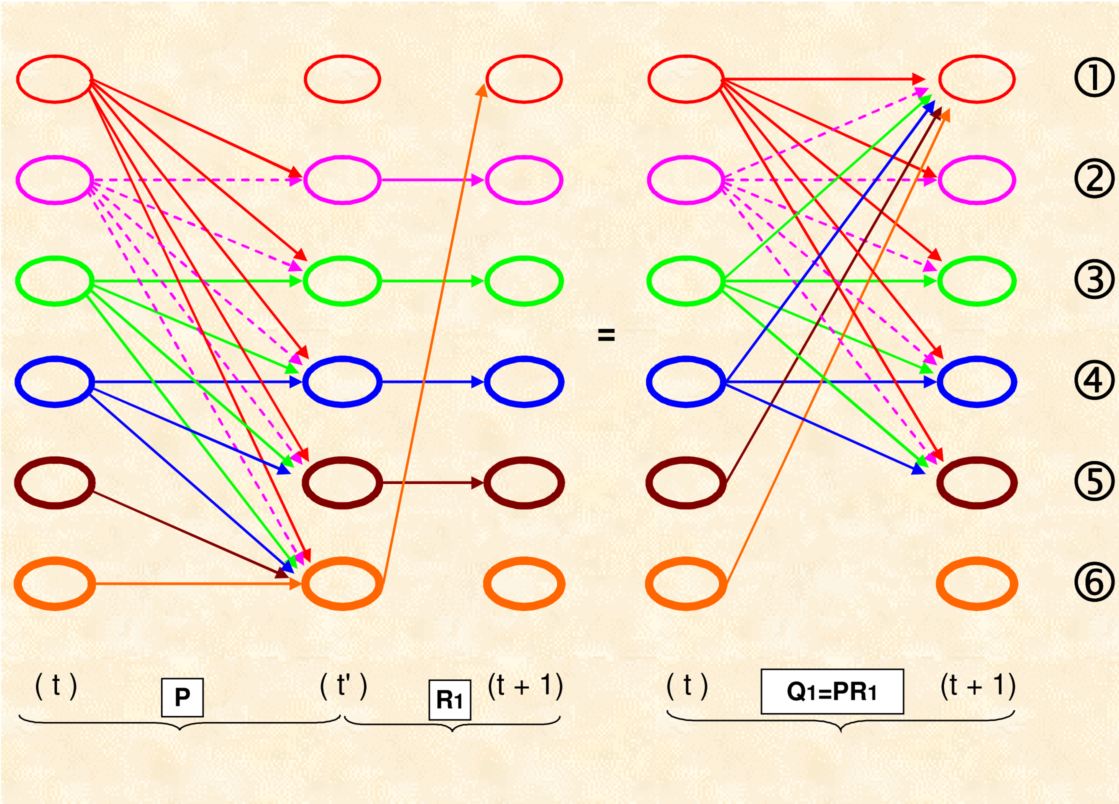


Modelling 2nd Maintenance & Repair Scenario



$$P = \begin{pmatrix} 0 & 0.213 & 0.295 & 0.254 & 0.197 & 0.041 \\ 0 & 0.066 & 0.350 & 0.307 & 0.139 & 0.139 \\ 0 & 0 & 0.038 & 0.231 & 0.231 & 0.500 \\ 0 & 0 & 0 & 0.032 & 0.452 & 0.516 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$R_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & & 0 & 0 & 0 & 0 \\ 0 & 0 & & 0 & 0 & 0 \\ 0 & 0 & 0 & & 0 & 0 \\ 0 & 0 & 0 & 0 & & 0 \\ & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$



$$P = \begin{pmatrix} 0 & 0.213 & 0.295 & 0.254 & 0.197 & 0.041 \\ 0 & 0.066 & 0.350 & 0.307 & 0.139 & 0.139 \\ 0 & 0 & 0.038 & 0.231 & 0.231 & 0.500 \\ 0 & 0 & 0 & 0.032 & 0.452 & 0.516 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$R_1 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Q_1 = P. R_1 →

$$Q_1 = \begin{pmatrix} 0.041 & 0.213 & 0.295 & 0.254 & 0.197 & 0 \\ 0.139 & 0.066 & 0.350 & 0.307 & 0.139 & 0 \\ 0.500 & 0 & 0.038 & 0.231 & 0.231 & 0 \\ 0.516 & 0 & 0 & 0.032 & 0.452 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

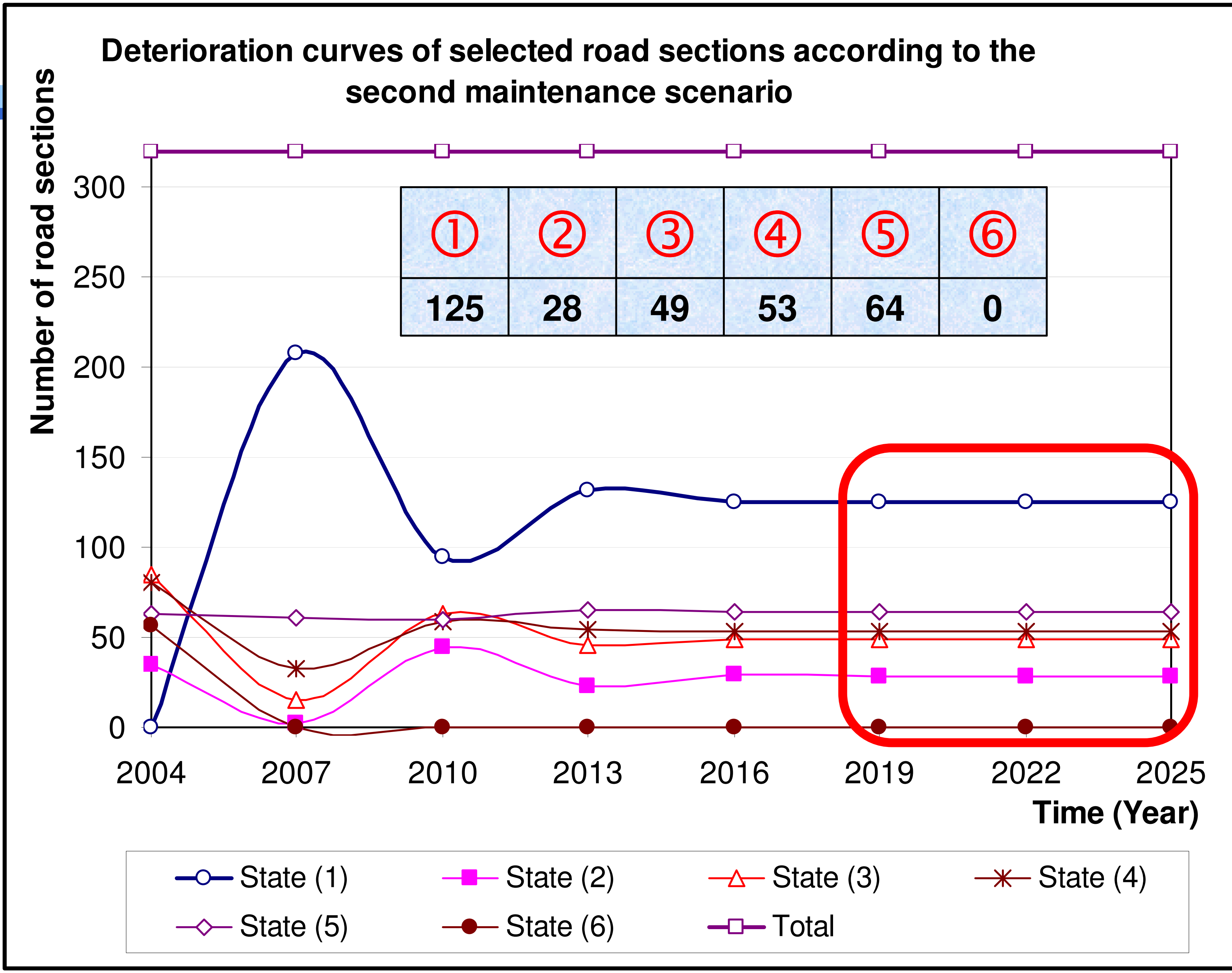
Given Transition Matrix Q_1, Initial probability vector π, and

$$\pi^{(n)} = \pi \times Q_1^{\ n}$$

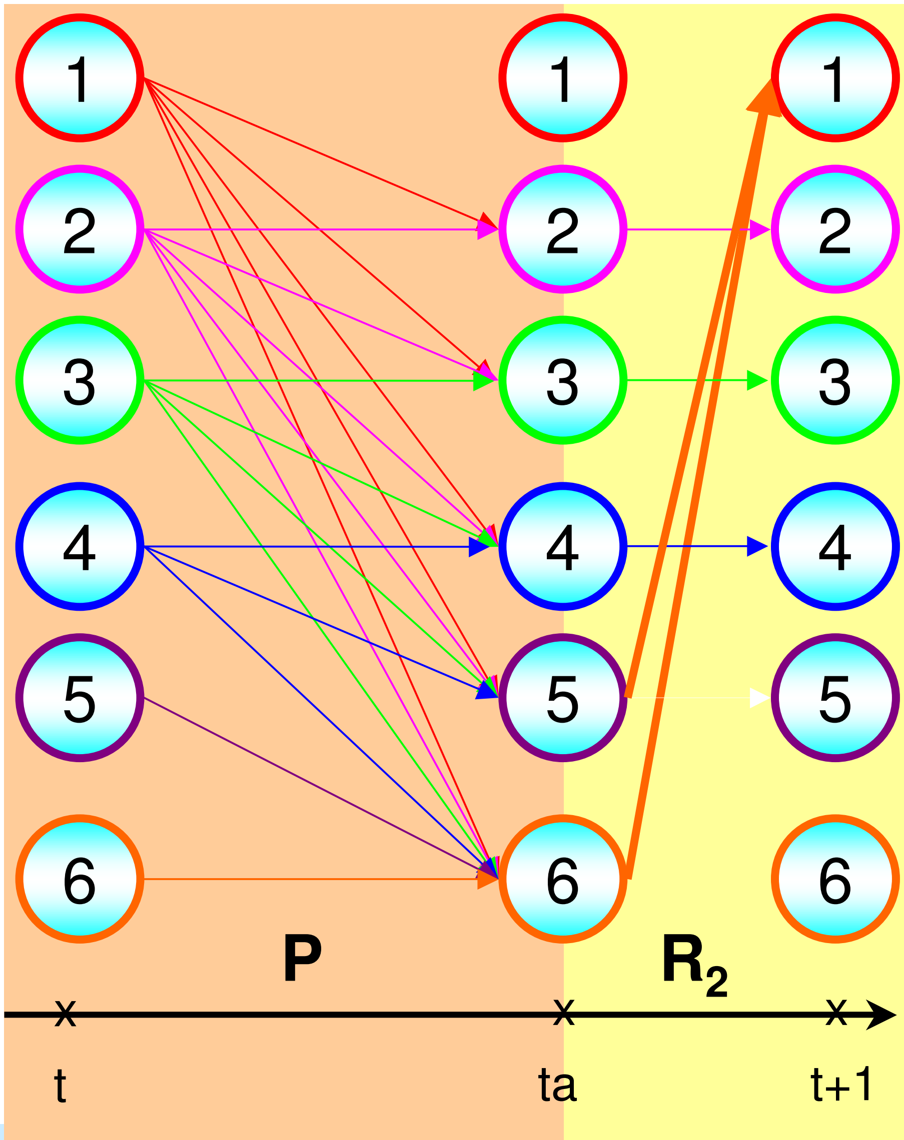
$\pi^{(0)} =$	(0.000,	0.110,	0.266,	0.251,	0.197,	0.176)
$\pi^{(1)} =$	(0.651,	0.007,	0.049,	0.103,	0.190,	0.000)
$\pi^{(2)} =$	(0.295,	0.139,	0.196,	0.182,	0.187,	0.000)
$\pi^{(3)} =$	(0.411,	0.072,	0.143,	0.169,	0.205,	0.000)
$\pi^{(4)} =$	(0.391,	0.092,	0.152,	0.165,	0.200,	0.000)
$\pi^{(5)} =$	(0.390,	0.089,	0.153,	0.168,	0.199,	0.000)
$\pi^{(6)} =$	(0.391,	0.089,	0.152,	0.167,	0.200,	0.000)
$\pi^{(7)} =$	(0.391,	0.089,	0.152,	0.167,	0.200,	0.000)

State		①	②	③	④	⑤	⑥
Number of road sections in year	2004	0	35	85	80	63	56
	2007	208	2	16	33	61	0
	2010	94	44	63	58	60	0
	2013	131	23	46	54	65	0
	2016	125	29	48	53	64	0
	2019	124	28	49	54	64	0
	2022	125	28	49	53	64	0
	2025	125	28	49	53	64	0

Steady State


Deterioration curves of selected road sections according to the second maintenance scenario
Number of road sections
300
250
200
150
100
50
0
① ② ③ ④ ⑤ ⑥
125 28 49 53 64 0
2004
2007
2010
2013
2016
2019
2022
2025
Time (Year)
State (1)
State (2)
State (3)
State (4)
State (5)
State (6)
Total

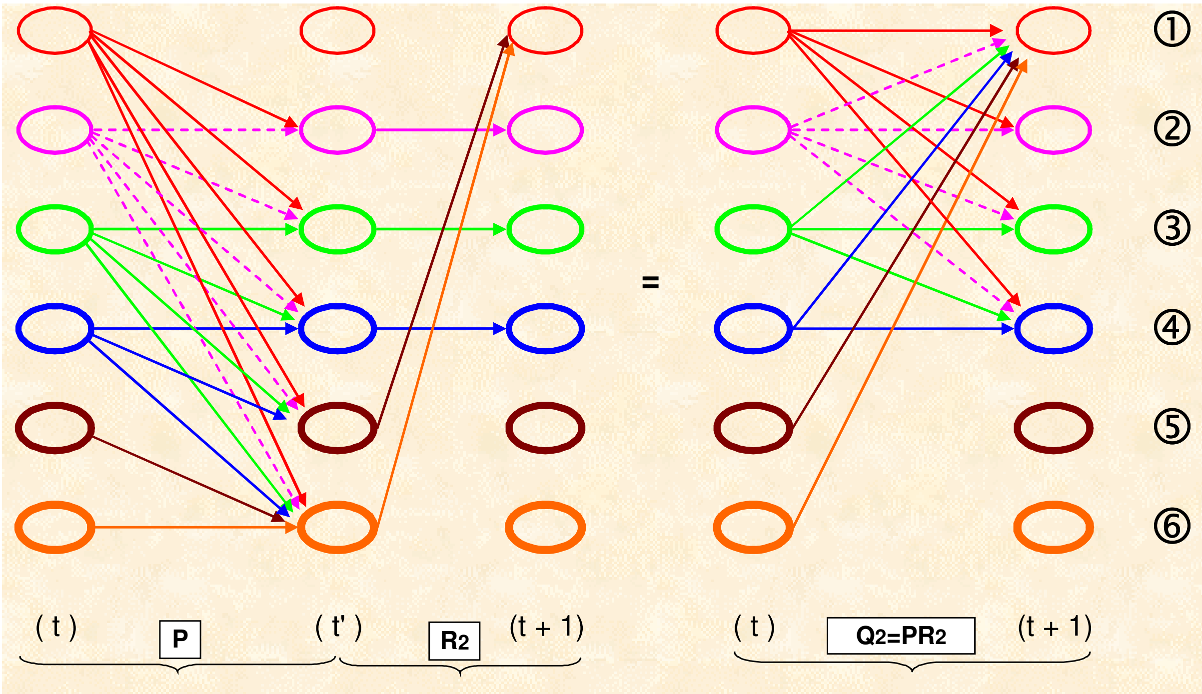
Modelling 3rd Maintenance & Repair Scenario



$$P = \begin{pmatrix} 0 & 0.213 & 0.295 & 0.254 & 0.197 & 0.041 \\ 0 & 0.066 & 0.350 & 0.307 & 0.139 & 0.139 \\ 0 & 0 & 0.038 & 0.231 & 0.231 & 0.500 \\ 0 & 0 & 0 & 0.032 & 0.452 & 0.516 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$R_2 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & & 0 & 0 & 0 & 0 \\ 0 & 0 & & 0 & 0 & 0 \\ 0 & 0 & 0 & & 0 & 0 \\ 1 & 0 & 0 & 0 & & 0 \\ & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Modelling 3rd Maintenance & Repair Scenario



$$R_2 = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$Q_2 = P.\ R_2$ →

$$Q_2 = \begin{pmatrix} 0.238 & 0.213 & 0.295 & 0.254 & 0 & 0 \\ 0.277 & 0.066 & 0.350 & 0.307 & 0 & 0 \\ 0.731 & 0 & 0.038 & 0.231 & 0 & 0 \\ 0.968 & 0 & 0 & 0.032 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

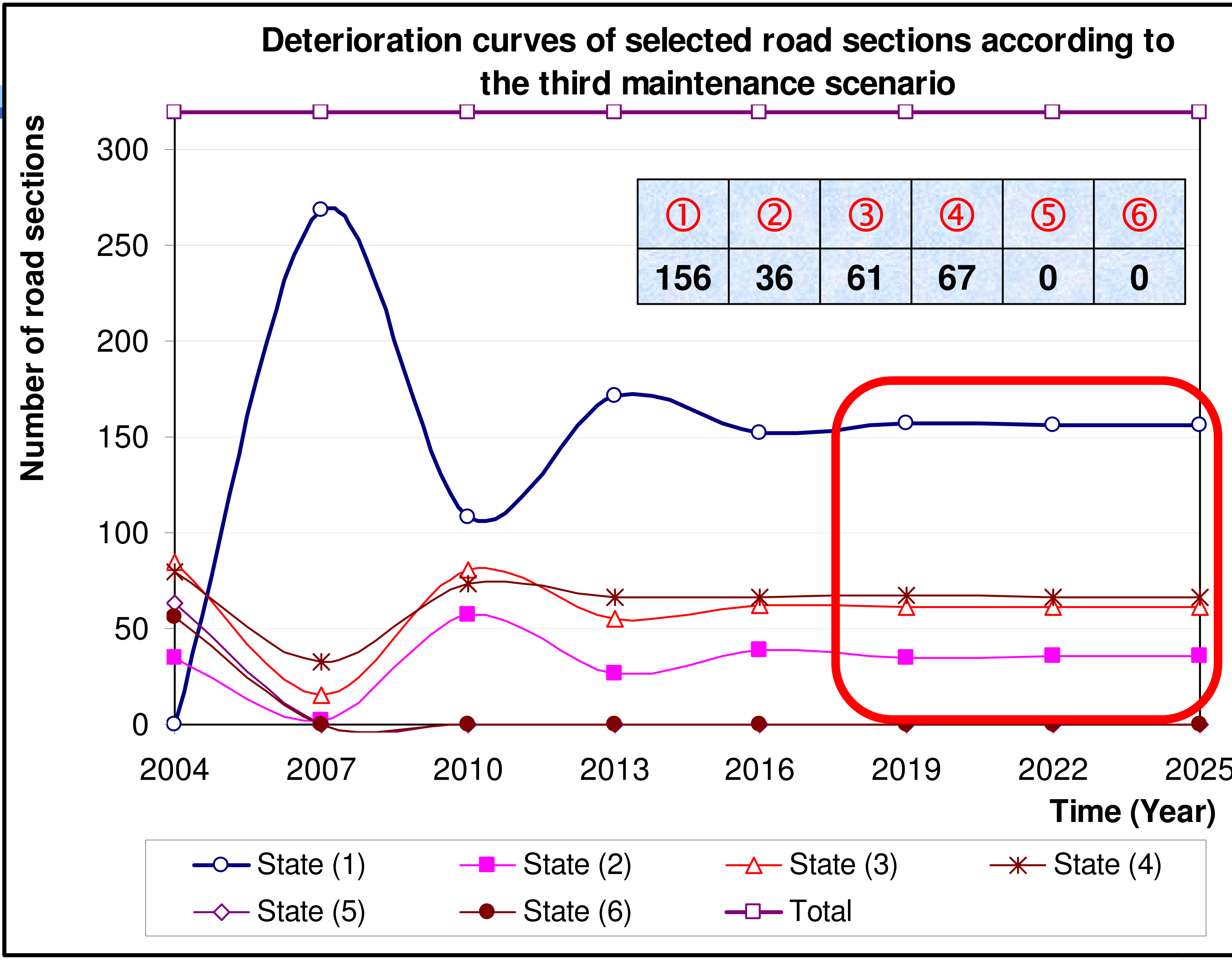
Given Transition Matrix Q2 , Initial probability vector π , and

$$\pi^{(n)} = \pi \times Q_2^{\ n}$$

$\pi^{(0)} =$	(0.000,	0.110,	0.266,	0.251,	0.197,	0.176)
$\pi^{(1)} =$	(0.841,	0.007,	0.049,	0.103,	0.000,	0.000)
$\pi^{(2)} =$	(0.337,	0.180,	0.253,	0.230,	0.000,	0.000)
$\pi^{(3)} =$	(0.538,	0.084,	0.172,	0.207,	0.000,	0.000)
$\pi^{(4)} =$	(0.477,	0.120,	0.195,	0.209,	0.000,	0.000)
$\pi^{(5)} =$	(0.491,	0.109,	0.190,	0.210,	0.000,	0.000)
$\pi^{(6)} =$	(0.489,	0.112,	0.190,	0.209,	0.000,	0.000)
$\pi^{(7)} =$	(0.489,	0.112,	0.191,	0.209,	0.000,	0.000)

State		①	②	③	④	⑤	⑥
Number of road section in year	2004	0	35	85	80	63	56
	2007	268	2	16	33	0	0
	2010	108	57	81	74	0	0
	2013	171	27	55	66	0	0
	2016	152	38	62	67	0	0
	2019	157	35	61	67	0	0
	2022	156	36	61	67	0	0
	2025	156	36	61	67	0	0

Steady State



Deterioration curves of selected road sections according to the third maintenance scenario
Number of road sections
300
250
200
150
100
50
0
2004
2007
2010
2013
2016
2019
2022
2025
Time (Year)
①
②
③
④
⑤
⑥
156
36
61
67
0
0
State (1)
State (2)
State (3)
State (4)
State (5)
State (6)
Total

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CONCLUSION

Predicting the deterioration process of road infrastructure is always the significant and challenging task for road management agencies to ensure the effectiveness of the maintenance and management work.

Using prediction model based upon Markov chain of stochastic process, future condition state of roads are definitely determined. Consequently, the most proper scenario of road maintenance should be established.

Will be presentated in "Life Cycle Cost Analysis (2)".

Q&A

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Thank you very much for your attention!