INVESTIGATION OF DISTRESSES OF BLOCK PAVED ROADS AND CONDITION EVALUATION

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Degree of Master of Engineering

Department of Civil Engineering

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Sri Lanka

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Thesis submitted in partial fulfilment of the requirements for the degree

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DECLARATION

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ABSTRACT

Sri Lankan road network is consisted with high number of rural roads. Sri Lankan governments over the past decade or so have invested a substantial amount on rural road development. Large portion of them was allocated to improve rural roads with interlocking block paving. In 2013 and 2014 government allocated about 7 billion rupees for interlocking paving roads.

As we have large number of concrete block paved roads which is older than five years, this is a suitable time for reassess the performance of block paved roads. The study aims to identify common distresses in block paved road surfaces, evaluate pavement condition using interlocking concrete pavement distress manual, find out applicability of pavement condition index method to Sri Lankan paved roads and identify improvements to extend the service life of road surfaces.

Selected road sections with interlocking block paving in Gampaha District was evaluated to as a sample. The common distresses of the block paved roads observed were damaged pavers, depressions and edge restraint. The methodology proposed in the Interlocking Concrete Block Pavement Distress Guide was applied to evaluate the condition of the road sections. The results suggests that Concrete block paving is a durable road paving method with more than five years of service life, the cause for most distresses is poor drainage and 'Distress Manual' is reliable method for evaluation of block paved roads in Sri Lanka.

Result of this study would be useful for comparing the performance concrete block paving method with other pavement techniques and to identify remedial measures to in the construction method to mitigate the observed issues It further assesses applicability of PCI method as quality to assess the performance of block paved roads for maintenance.

Key words: Interlocking Concrete blocks, Rural roads, Pavement Condition Index

DEDICATION

To

My Loving Wife

Who Always Encouraged Me Towards Success.

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ABBREVIATIONS

PCI -Pavement Condition Index

RDA - Road Development Authority

1. INTRODUCTION

1.1 Interlocking block paving in Sri Lanka

In Sri Lankan road network, 72% of roads are categorized as rural roads. There was no proper development program for rural roads after establishment of 13th amendment in 1987 which was funded by central government. Before 2004 the responsibility of rural road development was bared by local authorities. That year government started a rural road development with 2013 million rupees as a pilot project. This project was continuously funded by GoSL after each year and attached this program under ministry of highways. This program was supervised through Road Development Authority and local governments and construction work carried out by community based organization. (maganeguma web site)

Table 1-1Rural road completed (km) 2004 to 2018

Year	Metalling & Tarring (km)	Gravelling (km)	Motor Grading (km)	Earth Works (km)	Concreting (km)	Concrete Block Paving (km)	Total Length (km)
2004	-	304.50	295.50	-	-	-	600.00
2005	381.29	329.04	-	-	21.05	-	731.38
2006	909.84	1,012.93	83.96	-	277.25	-	2,283.98
2007	240.53	184.37	-	-	776.93	-	1,201.83
2008	99.55	478.04	181.59	-	881.30	-	1,640.48
2009	223.06	559.74	638.81	54.72	519.88	0.62	1,996.83
2010	108.72	265.95	55.71	42.05	211.35	170.76	854.54
2011	7.83	2.16	-	0.60	2.44	540.27	553.30
2012	0.18	-	1.00	4.97	0.18	629.05	635.38
2013	-	-	-	-	-	638.99	638.99
2014	-	-	-	-	2.52	684.97	687.49
2015	17.27	40.36	-	-	87.01	311.96	456.60
2016	16.25	2.95	-	-	22.74	45.70	87.64
2017	0.53		-	-	47.87	115.86	164.26
Total	2,005.05	3,180.04	1,256.57	102.34	2,850.52	3,138.18	12,532.70

Source: (Maganeguma development, 2018)

At the beginning of the Maganeguma program the methods practiced for road paving were metalling & tarring and gravelling pavements. These roads were dilapidated when heavy rains coming. As an answer to this problem, the program introduced concrete paving roads. This method rapidly popular among communities as the road pavements could not damage by heavy rains and road surface is way better than gravelling roads. Due to public demand more and more roads were concreted from 2007. We all thought because of longevity of concrete pavements, the rural mobility burden prevailed so far would be resolved but after completing about 2500 km, by year 2009 the concreting program was terminated, instead it was replaced with cement block paving, and at the moment rural roads pavements are being carried out using these interlocking blocks, made out of cement and sand. Reason for immediate termination of concrete pavement works was not that concrete pavements were not suitable, for our rural roads, but due to the bad engineering governance executed over the whole process, disregarding the accepted designs and construction standards. Between 2010 and 2011 newspapers were flooded with public complains relevance to concrete paved roads. These news items demonstrate the status of engineering governance. Another reason for short life cycle of these roads was heavy vehicles used these roads which pavement had not design to bear such large capacity. (Rural roads.. the Island 22/06/2015)

Concrete block paving had better quality control as Blocks being produced at a central location it has been possible to maintain the required compressive strength and other quality standards, as a result not like in the case of onsite mixed and poured concrete, the block paved pavements seem relatively satisfactory for the moment. Even though quality of block can be assured, still base and edge curb construction was not adhered to the approved design. Because of this reason blocks paved pavements experiences settlements, point depressions. Yet compared with concrete pavements, blocks paved roads appear quite satisfactory. Other obvious advantages of block paved roads are cracks, point settlements won’t get propagated because blocks are inter blocked.

Interlocking concrete paved road demonstrated long service life with compared to other pavement methods hence it was popular among road users. As a result of this there were 684 km of roads with block paving in 2013 and government spent about 7 billion rupees on that year.

1.2 Research problem statement and background

Present day there are 3223 km of rural roads being constructed with interlocking concrete paving blocks. This value is merely containing roads constructed under Maganeguma program. There are some other rural road development programs which are funded by local authorities, foreign organization and private organization like estates. Therefore the total number of block paved roads must be higher than above recorded value. Even government and other institutes are continuously funding on concrete block paving there were no proper post condition assessment carried out for these roads. Under the contract of concrete block paving road constriction which is sign between the contractor and Maganeguma program, there is a six month defects liability period. The technical officer of RDA or local authority has to submit a condition report of road segment. This is the only occasion where condition debriefing doing in road construction. This report is not a comprehensive one and as this report produce very early stage of road functioning, almost all the roads are in good condition. This research try to fill the vacuum created with regarding to post assessment of pavement condition.

It is important to conduct periodically pavement assessment in any method of paving. Concrete block paved roads have less number of public complains compared to other road pavement methods. Even though present situation is non problematic as decision makers authorities needed to have idea about actual life time of block paved road and when should start rehabilitation programs. In the era of metalling and tarring was commonly used for road paving officers knew when should start reconstruction and how much would cost. This knowledge was gained by experience due to metalling and tarring had been used since colonial era. In contrast, when introducing concrete paving instead of metelling and tarring in 2005 it was claimed concrete paved roads would have life time of 30 years. Authorities simply accepted concrete paving without proper investigation. Roads had been destroyed within 5 years' time despite said 30 years of life time. This was due to overlook in supervision and not adhere to approved design of concreting. The responsible personal should have done proper survey at least every three years before increased fund for concrete paving. Then they could anticipate what would happen to roads and rectify problems. Finally, authorities abandoned concreting program and introduced interlocking block paving. It seems they are doing the same mistake with block paving by increasing funds without knowing correct life time of block paved roads. This research target to forecast life time of paved roads in Sri Lanka and when should start rehabilitation to achieve more economical advantage.

1.3 Objectives of the research

Identify distresses in Concrete Block Paved roads. Develop a methodology to evaluate condition of Concrete Block Paved roads.

1.4 Scope of the study

The scope of the research study covered on interlocking concrete block pavement in Gampaha district. It is investigated most of the distresses appeared on pavements and impact of these distresses on pavement condition.

The study is only focused on pavement in low traffic volume roads. Lanes and streets, which connect residential areas with main or sub artillery roads are selected for survey. It had been avoid concreted, metalling & tarring and asphalt concrete pavement surfaces when accessing distresses. All the distresses could be found in interlocking block paved pavements were covered through the survey. The surveyed pavements have been functioned for four to six years after construction. Sampling was carried out in a way that it covered three divisional secretariats in Gamapaha district.

As the adopted method for evaluate PCI value is a new method for Sri Lankan context, therefore a validation process was carried out. This method was comparing PCI value with manually decided PCI value. Cost estimation was studied for interlocking block-paved roads and considered it when calculating rehabilitation cost.

This research study is limited to threes divisional secretariats. Even there were location data of several districts survey was limited due to practical reasons. It did not cover all weather conditions in Sri Lanka. Mostly these areas are belonged to wet zone. There were no precise data of construction method carried out and sub base condition prior to road paving. Therefore it was assumed all are in same condition and constructed in same quality control measures. All cost calculations perform in this research was based on cost of the 2016 year.

2. LITERATURE REVIEW

2.1 Block Pavement Introduction

The concept of concrete block paving for road pavements was first introduced about 2000 years ago in Roman era. They first constructed road pavements by laying stones touching one another. The base of these pavers was compacted granular base with flexible nature. After centuries this basic paving stone concept was revised and used in Netherlands in late 1940s'. This paving method was introduced as substitute for clay brick road pavements. After the world war two block paving method was spread to the other countries in Europe as Germany in (1960) and in United Kingdom (1970). After that concrete paved roads were introduced other parts of the world such as Australia, North America and South Africa. Presently in North America, about 60 million of square meters of concrete pavers are produced annually. In Europe this value is approximately 300 million square meters. Now concrete block pavers are used effectively in other proposes than roads such as parking lots, container terminals, airports, sidewalks, ports, recreational areas and driveways.(Applied Research Associates, Interlocking Concrete Block, 2007)

2.2 Block Paving in Sri Lanka

In Sri Lankan context interlocking concrete blocks happened to be introduced due to failure of concrete paving roads. We all thought because of longevity of concrete pavements, the rural mobility burden prevailed so far would be resolved but after completing about 2500Km, by year 2009 the concreting program was terminated, instead it was replaced with cement block paving, and at the moment rural roads pavements are being carried out using these interlocking blocks, made out of cement and sand. But due to the bad engineering governance executed over the whole process, disregarding the accepted designs and construction standards. (Dias, 2015)

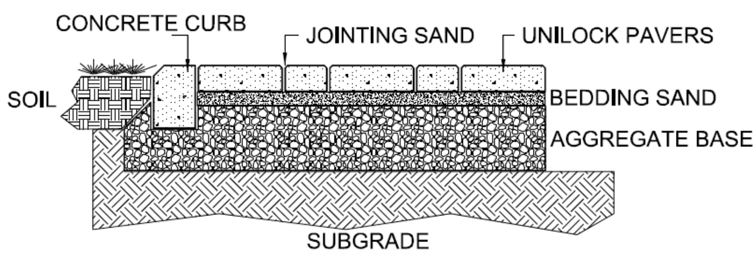


Figure 2-1 Design of typical Paved Road

Concrete block pavers can be seen in various colours, shapes and sizes in the market. Therefore the architectural advantages of interlocking concrete blocks are readily visible. The beauty offer by paving blocks cannot be obtained by conventional concrete or asphalt pavements. We can customize the pavement as we wish without compromising the strength of the road or paved area. Interlocking concrete blocks laid in diverse patterns. This includes straight lines, curve lines, intricate designs, and add liveliness to almost any background. (Specifications, 2008)

Road agencies evaluate existing pavements for the following three main purposes, listed in order of increasing detail: Medium to long term planning (known as network level), Short term planning (project level) and Pavement technology research. (Webb & Farrelly, 2012)

2.3 Common Distresses in block paving

Even concrete block paving started in 2010, still there were less amount of public complaints. The block paved pavements seem relatively satisfactory for the moment, but it would have been better if the authorities had followed the design provided by RDA. Unfortunately, because of this reason blocks paved pavements experiences settlements, point depressions, drainage deficiencies, all these have caused due to not adhering to the approved design. Yet compared with concrete pavements, blocks paved roads seem quite satisfactory. Other obvious advantages of block paved roads are cracks, point settlements won’t get propagated because blocks are inter blocked. (Dias, 2015)

Table 2-1Distress types of concrete block pavement

Load	**Climate/Durability**	**Moisture/Drainage**	**Other Factors**
Missing Pavers	Joint Sand Loss/Pumping	Missing Pavers	Missing Pavers
Damaged Pavers	Missing Pavers	Joint Sand Loss/Pumping	Damaged Pavers
Depressions	Heave	Depressions	
Patches	Patches	Heave	
Horizontal Creep	Variable Joint Width	Patches	
Edge Restraint			
Rutting			
Variable Joint Width			

Source:(Applied Research Associates, Interlocking Concrete Block, 2007)

When the roads have been encountered above distresses the sequence for design involves:

- Evaluation of the existing pavement conditions.
- Determination as to whether the overlay is to be structural or functional.
- Design of the overlay thickness for strengthening.
- Determination of the amount and type of required base pavement repairs prior to construction of the overlay. (Specifications, 2008)

Rehabilitation works do not involve major changes to horizontal or vertical alignment or width, but can include strengthening and sometimes minor widening works to meet the current cross-section standards, for the class of road and expected traffic loading. Rehabilitation works are much more expensive than periodic maintenance and are less frequent. Rehabilitation is usually chosen following an economic evaluation of alternative treatments. (Webb & Farrelly, 2012)

2.4 Pavement Condition Evaluation from literature review

In last three decades of twentieth century, interlocking block paving popular and there had been large number of researches and studies carried out regarding the design of concrete block paved pavements. As time passes more focus was drew to maintenance from design of pavement.

There are number of pavement evaluation methods were developed by countries such as Australia, Israel, United States and Netherlands. Most of them only focus on specific pavement distress types. Then additional waorks needed to be carryout for obtain pavement condition index. PCI value in significantly important for predict future of pavement condition for use in an overall pavement management system is quite difficult.

The method developed by Dutch can be consider as the most advancing method currently use. It is called VIAVEIW. Main drawback of this system is it consider only rutting and local unevenness. This method is sound but it is based on calibration for the Netherlands and extensive performance would be necessary to validate for other conditions.

Australian method identified five main distresses such as rutting, horizontal creep, spalling, cracking and lipping. In this method each distress quantify and multiply by specific weighting factor for obtain deduct value. The obtained deduct value (DV) convert in to pavement condition index (PCI) by 100 subtracting deduct value. Higher the PCI value implies better the pavement condition. In other words, when PCI value decreases over the time, pavement becomes poor in condition. When it comes to introducing quality PCI system it is necessary to determine reasonable weighting functions for individual distresses.

In 1992, US army crops developed a pavement management system for concrete block paved pavements. They have considered eight types of distresses and identify severity from low to high severity. However, the system does not calculate overall condition of pavement but give remedial measures base on condition of the pavement. (David Hein & Robert Burak, 2007)

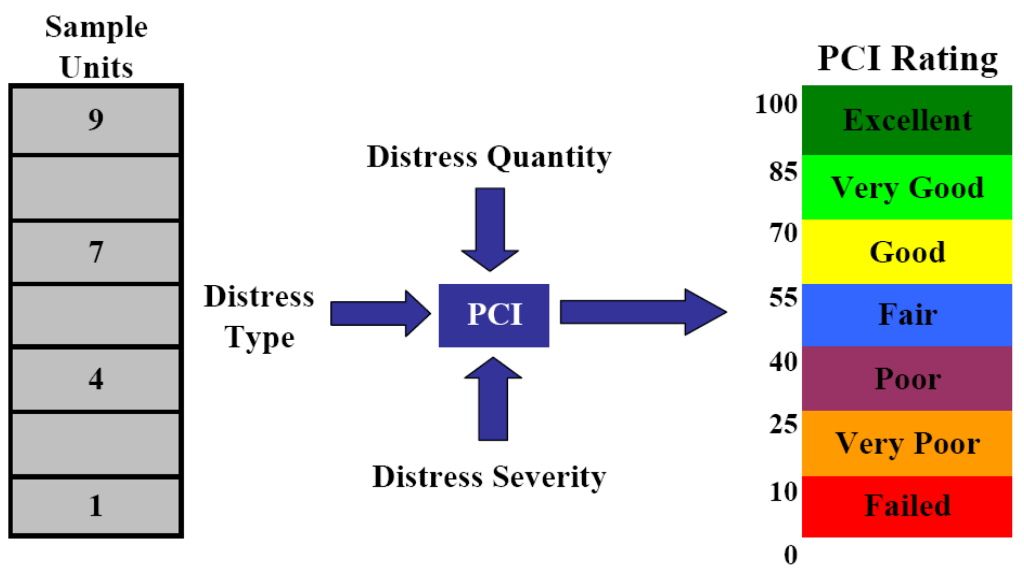


Figure 2-2 PCI rating

2.5 PCI for block paving

Most of the developed countries and some developing countries adopt pavement management systems (PMS) for their road network to manage financial allocation and future rehabilitation costs. Basically PMS is tool for collect and information monitor program on present pavement condition. Nevertheless it forecasts future performance and conditions. Decision makers and policy planners enable to evaluate and prioritize alternative reconstruction, rehabilitation, and maintenance strategies. Finally it achieves continuous and uniform system preservation at maximum productivity and efficiency with optimal level of performance. Australia, Israel, Netherlands and the United states have developed pavement management tools, however, all realized that further actions are important due to much of this works concentrated on selected pavement distresses types. It does not indicate overall pavement condition. (David Hein & Robert Burak, 2007)

A composite condition index is essential, foretelling the future pavement condition for practice in a complete pavement management system. Without proper index it is rather difficult. It is possible to identify following reasons to emphasize on introducing PCI for concrete block paved pavements.

- Most of commonly used pavement methods have well established pavement evaluation and management tools. There are competing product with concrete block paving such as gravel roads, seal coat, exposed concrete pavement and flexible concrete pavement.
- Pavement maintenance and management tools enable direct one to one comparison among gravel roads, seal coat, exposed concrete pavement and flexible concrete pavement. This can be done comparing pavement condition parameters like pavement condition index (PCI).
- Pavement performance curves (pavement condition verses time) will support for obtaining of applicable life cycle cost models for interlocking concrete block pavements. Continuous update and tracking of condition of road network by use of pavement condition index would be helpful for develop such curves.

- Local authority Engineers and planners with scientific data can prove by presenting data the benefits of concrete block paved roads. Pavement performance curves (pavement condition verses time) will support in the obtaining of applicable life cycle cost models for interlocking concrete block models. (David Hein & Robert Burak, 2007)

2.6 Life cycle cost

If the concrete pavements had been done as per the designs provided they would have had life spans of 30-40 years without any sort of maintenance burden, thus confirming that the concrete pavement is the least life cycle cost pavements option for our rural roads. When the present status of completed concrete pavements are considered none of these had been done in accordance with the designs provided, as a result almost all concrete pavements have failed structurally. (Dias, 2015)

The key components of life time engineering are,

- Integrated lifetime environmental impact assessment and minimization.
- Integrated lifetime design,
- Lifetime investment planning and decision making,
- Modernization, reuse, recycling and disposal,
- Integrated lifetime management and maintenance planning,

Life cycle engineering is not yet fully recognized science. Also it may even not popular among scientific personals. However, several of its elements have already been applied for road construction and management systems.(Flores, Montoliu, & Bustamante, 2016)

The least expensive pavement for the public is not the pavement which needs finance to the least to construct, but the pavement which yields the best return for the financial cost on it over pavements service life. When it comes to assess fundamentally equivalent (from a structural perspective for pavements) substitutions using different materials, it is prudent to consider not only the initial cost of each alternative but also the total expenses added over its service life. The alternative which had the lowest primary cost may not be the least expensive once factors such as maintenance, rehabilitation, inflation and interest (the value of money invested today for future use, differ from inflation) are taken into consideration. The lifecycle cost analysis is one of the most effective methods of measuring the cost-effectiveness of alternative designs. (Specifications, 2008)

Generally 20-30 years is considered as the life-cycle analysis periods used for pavements. This is because of some highway authorities' trend to go towards long lasting pavements and life cycle analysis period extended. Generally pavements which have longer design life or extended life cycle analysis period allowed to having lesser life cycle costs. The design axel load and traffic through the analysis time period must be considered for design purposes. (Specifications, 2008) The graph below illustrates that block paved road take about 25 years to decline their condition to PCI value of 40. This means the road is in poor condition.

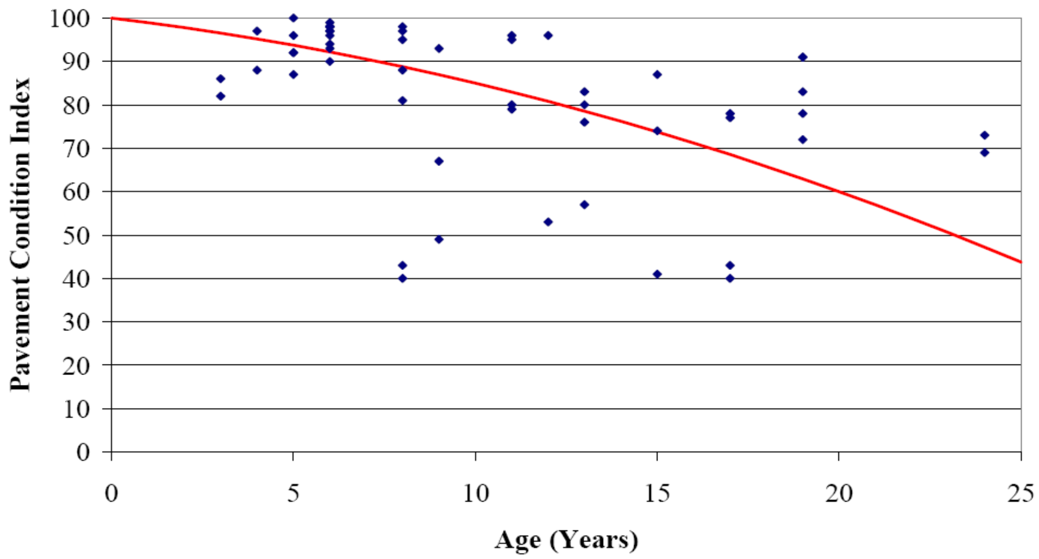


Figure 2-3 PCI vary with age - Other countries

Source: (Flores, Montoliu, & Bustamante, 2016)

3. METHODOLOGY

3.1 Population Of The Study

Under Maganeguma rural road development project there has been constructed more than 3000 km of cumulative length of interlocking block paved roads. This included road segment packages. The value of a project package varies from 0.5 mil LKR to 2 mil LKR. As this population is vast and it spread over every corner of the island, Gampaha district was selected for our research study.

There are several important reasons to select Gampaha as our base district. This district located in wet zone, which can be, consider as moderate condition. It has second largest population after Colombo. As a result, more vehicles use these roads. Roads in Gampaha district will be revealed average condition of wear and tear of interlocking block paved roads. However, three secretariats were selected for the study, as it was convenient for data collection.

Table 3-1 Block Paved Roads

Year	Concrete Block Paving (km)	Total Length (km)
2009	0.62	1,996.83
2010	170.76	854.54
2011	540.27	553.30
2012	629.05	635.38
2013	638.99	638.99
2014	684.97	687.49
2015	311.96	456.60
2016	45.70	87.64

Source: (Maganeguma development, 2018)

3.2 Sample of The Population

Minimum number of samples needed to be inspected was determined by following equation.

$$n = \frac{Ns^2}{(\left(\frac{e^2}{4}\right)(N-1) + s^2)}$$

e = margin for mistakes in calculating the segment PCI; generally, e=±5 PCI points; s = standard deviation of the PCI (one sample unit to another sample inside the section.

At the time of first performing the inspection the**'s'** value (standard deviation) is assumed to be **10** for interlocking concrete block pavements

N = count of all samples in the section (here Gampaha district CBP sections).

$$n = \frac{521\ x\ 10^2}{\{\left(\frac{5^2}{4}\right)(521-1) + 10^2\}}$$

n = 15.5

Alternative to above method table given in distress manual can be adopted for determine the number of sample units. According to the manual if there are more than forty samples in the section only 10 percent of samples over 40 sample units 10 percent of sample units needed to be surveyed.

In our research we surveyed 50 roads sections. It is intended to compare the results with the values obtained in study done in North America. That study was conducted base on 48 samples and it was decided to this survey should be extended to similar number of samples (50 samples).

3.3 Sampling Techniques

Sampling of road segments for survey was done by considering several factors. First all locations were put in to geographical map of Gampaha district. Then select three divisional secretaries, which is convenient for collecting data. Gampaha, Mahara and Attanagalle were selected as divisional secretariat divisions. There were average number of road projects in above three divisions with compared to other divisions in Gampaha district. Then sample locations were selected. When selecting the samples considered about usage of the traffic condition and convenient of surveying. However all the sample selections were done merely examine the locations through the map. Due to uncertainty of locations, higher number of roads was identified in initial stage for the survey. As an example, 11 sections were selected in Kalagedihena area but only five were surveyed. It was random selection by the surveyor. If one road has several concrete blocks paved road segments which were laid under separate projects, then they were count as separate samples.

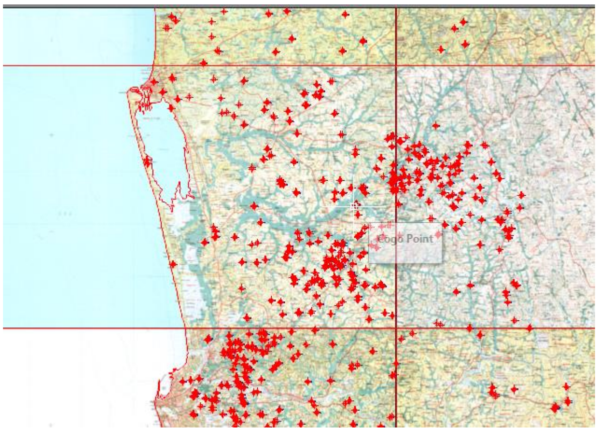


Figure 3-1 Paved Roads in Gampaha & Colombo districts

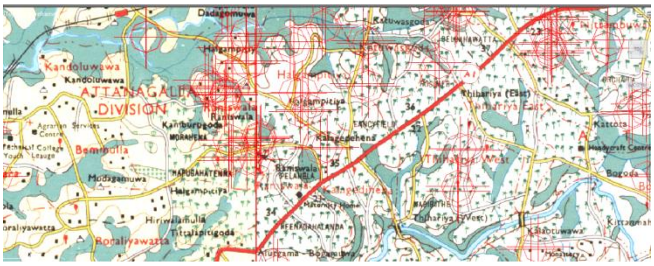


Figure 3-2 Close up of GPS Data

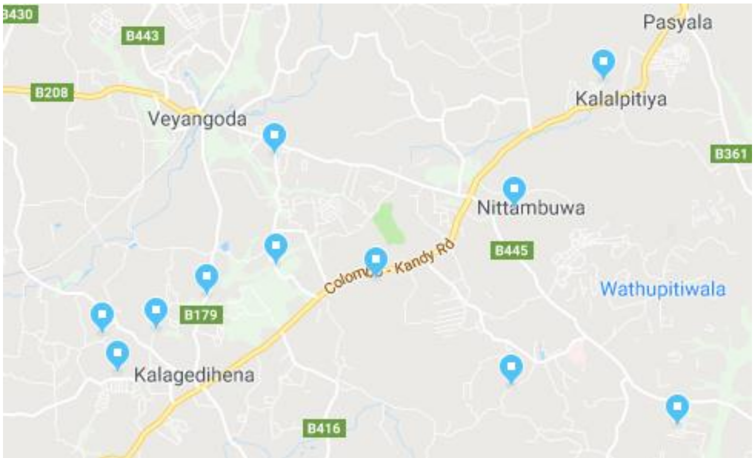


Figure 3-3 Road location added to Google Maps

3.4 Instrument for Data Collection

The method use for data collection was field surveying. The data collection was carried out according to the Data sheet which is annex 1. This data sheet prepared according to interlocking concrete pavement distress manual. Main aim of this data sheet was collect data for calculating pavement condition index. Apart from the data in this sheet photographs were taken of the roads and GPS location was recorded. The data sheet designed by the researcher as the survey can be repeated if needed. First did pilot survey on five samples and identified common distresses in interlocking block paved roads. It was understood that the distresses we found are more similar to distresses state in the distress manual. Therefore, the distress types and numbers extracted from distress manual.

This data sheet has two sections,

1. Information about the sample.

Road: the name of the road and section. Most of the roads dose not named as they were access roads to resident areas. The chain age of the sample starting point has recorded for future reference.

Date: the date of survey carried out.

Section: if the same road had surveyed for several samples it was state here.

Sample unit: number given for the sample by researcher. This numbering issued as first surveyed roads got least value number.

Surveyed by: surveyor or inspector's name.

Sample area: surface area of the sample. Most of the samples were around 150 square meters but some are larger than 250 square meters. If the road had only one block paved section and it was considered as one sample without considering area. However, as the PCI value calculated based on intensity, size of the sample was not affected significantly.

2. Data about distresses.

There are eleven common distresses identified in the distress manual. In pilot survey it was found that these distresses would be covered most of the distresses in Sri Lankan roads. Hence, it was decided to consider the same distresses account for our survey also.

The data collected in tabular manner with five main columns.

Distress and severity: This column was filled with the distress number which has given in the data sheet and the severity level as low (L), medium (M) and high (H). The severity was decided base on the guidelines given in the distress manual.

Quantity: Here is recorded the area or linear length of the identified distress. In Edge Restraint (103) was the only distress that is measured by linear meters, rest of distresses measured in square meters. Sometimes same distress with similar severity was found in separate locations. They were recorded separately under same row.

Total / Density: These columns include summation of distress quantity and percentage of distresses from total area. Density of Edge Restrain (103) calculated base on length of the road.

Deduct value: This value obtain based on the graphs given in the distresses manual. This column was not filled in the field.

Sketch: This is one of most vital information in this data sheet. Here we marked each distress location and label it with distress number and severity. The sketch would be useful for future references or recheck PCI values.

Notes: Special comments and observations could be stated there.

3.5 Distress Severity Measurement

After identification of distresses on pavement it is crucial to measure severity. The quantity was determined base of affected area. As the final deduct value dominated by level of severity it is needed to adopt a method which would use universally. Also the method shall be depend on quantitative values rather than surveyors' judgment.

Distress manual published by ICPI have given comprehensive guideline for obtain severity.

This is sample for distress severity measurement for **Depressions (102).**

If an area of the pavement's elevation is lower than surrounding level, that area is identify as depression. This is cause due to underlying sub grade or granular base settlements. Settlements can be found frequently over utility cuts and adjacent to road hardware. According to the manual, depression causes roughness, when raining happens water stagnates on these depression areas and can cause hydroplaning of vehicles.

It is not reliable to identify depression mere visual examination. Low severity depression is difficult to be detected by visual inspection. Straight edge of 3m is used with proper technique to detecting depressions with reasonable reliability.

Further the manual given guidelines to identify and measure each severity of depression.

Severity Levels:

Table 3-2 Severity levels of Depression

Severity Level	Maximum Depth of Depression
Low	5 – 15 mm [0.2 to 0.6 inches]
Medium	15 – 30 mm [0.6 to 1.2 inches]
High	> 30 mm [1.2 inches]

Figure 3-4 Sample distress (High severity)


Figure 3-6 Sample distress (Medium severity)


Figure 3-5 Sample distress (Low severity)

3.6 Method of Data Collection

First, identify location of the sample road segment with help of map. The map was marked with all road segments as red marks with start and end points. Then visit the field for surveying. As measuring tools we used were 30m tape, 0.3m straight edge and 3m length straight aluminium hollow box rod.

We went to the location and walk through the road section and visual inspect the road surface. Basic information was recorded such as road name. Here we could record abnormalities such as concrete mixed on top of the surface in space provide for notes in data sheet. Then sample length was selected. According to manual measuring wheel needed to use for measurements but we used 30m tape which is not convenient as wheel but not affect accuracy. The sample length was selected around 50m of length and start and end points were marked on the surface. After that identified each distress type and drew it in the sketch of data sheet afterward named them with relevant distress number and severity level. Then measure each distress separately. The aluminium rod used to make out Depressions (102), Faulting (105), Heave (106) and Rutting (111).

Distress type and severity was decided based on Interlocking Pavement Distress Manual published by ICPI.

If one particular location has more than one distress, then each one had recorded separately. We were always careful to identifying and recording the most of distress types, severity as well as density in the sample units, measuring for linear dimensions and spot-checking vertical deformations with the straight edge. It was spend 20 to 30 minutes for inspection of one sample.

3.7 Method of Data Analysis

PCI value calculation

- Deduct value- this value obtain using Deduct Curves, which are annexed in the Distress Manual. First select the graph for relevant distress type and find deduct value by severity curve and distress density.
- Total Deduct Value (TDV)- summation of all deduct values for particular sample.
- If there are deduct values which greater than 10% of TDV, it is needed to be corrected. The correction curves have been supplied with the Distress Manual.
- Corrected Deduct Value (CDV) obtains from those curves.
- PCI=100-CDV, final Pavement Condition Index could be obtain.

<u>Model calculation of PCI</u>

Sample 01

Length = 50 m Width = 3 m Area = 150 m^2

Distresses data

Table 3-2 Modal calculation data

Distress type & Number	Affected Area or Length	Severity	Density
Damaged pavers-101	10	L	6.7%
Depression - 102	1	L	0.7%
Edge Restrain - 103	2.8	H	2.8%

Calculate deduct value for Edge Restrain

First selected the deduct curve relevant to Edge Restrain. Then the value was found for 2.8% with high severity.

Figure 3-7 Deduct curves for edge restrain

Source: (Applied Research Associates, Interlocking Concrete Block, 2007)

Deduct value for Edge restrain = 25

Similarly

Deduct value for Damaged pavers = 02

Deduct value for Depression = 04

Total deduct value =31

There are two individual deduct values greater than 2. Hence maximum corrected deduct value (CDV) needed to be found.

$$m = 1 + \frac{9}{98}\ x\ (100 - HDV) \leq 10$$

Where:

m = acceptable number of deducts with decimals (must be ≤ 10)

HDV = maximum individual deduct value

$$m = 1 + \frac{9}{98}\ x\ (100 - 25) \leq 10$$

m = 7.88 say m= 8

As m = 8, largest 8 deduct values consider. We have three deduct values. Therefore consider all three values.

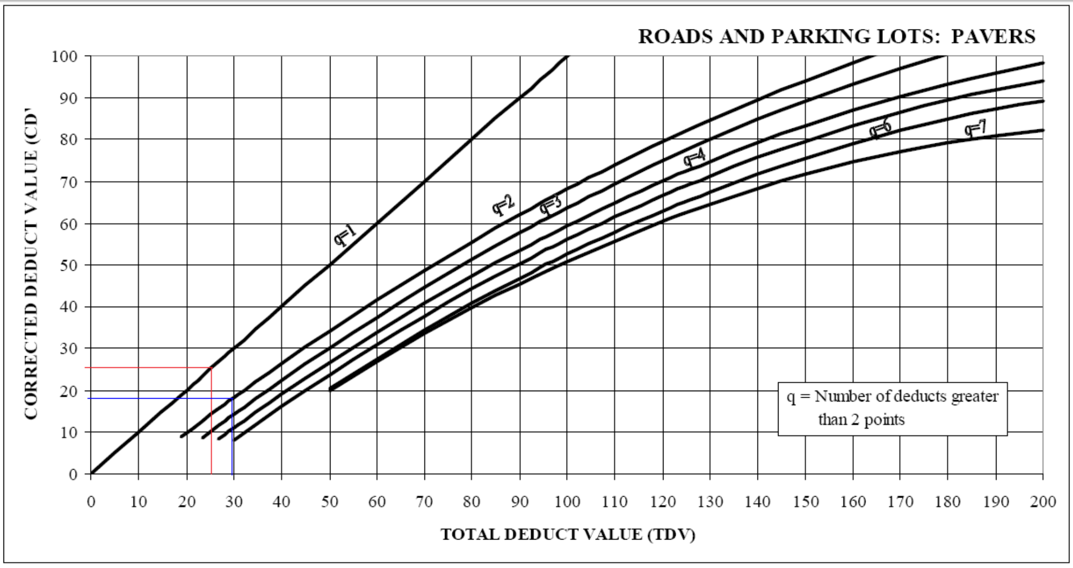


Figure 3-8 CDV curves

$q_1 = 2$ and TDV =25+4=29 => $CDV_1 = 18$

$q_2 = 1$ and TDV =25 => $CDV_2 = 25$

Maximum CDV (corrected deduct value) = 25

Hence;

$$\text{Pavement Condition Index} = 100 - CDV$$

$$= 100 - 25$$

$$= 75$$

Similarly PCI value should be calculate for each sample. (Annex 2)

4. OBSERVATIONS AND RESULTS

This chapter contains data gathered from survey and results. Here calculated PCI values have been organized and attempted to validate obtained PCI values. Then roughly observed the data set, yield general idea about distresses of blocks paved roads and overall level of service of the roads. Here data have been prepared into useable manner for further analysis.

4.1 Validation of Data

There was no any tool developed for calculate PCI value of concrete block paved pavements in our country. Therefore, the manual developed in North America has been adapted to this research. As this manual not been validate to Sri Lankan context, it would be prudent to check its' reliability and validity.

This validation procedure was carried out manually and compared these values with obtained PCI value. Firstly, along with collection data and taking measurements surveyor assigned a value in between 0-10 which 10 is considered the best. When this mark was assigning time, the valuators did not have clear idea about the PCI value of the sample. Hence, it is reasonable to assume the manual assigned value and PCI are independent from each other. Then calculated PCI value graphed verses ten times of manual value of the samples. The graph obtained is as follows,

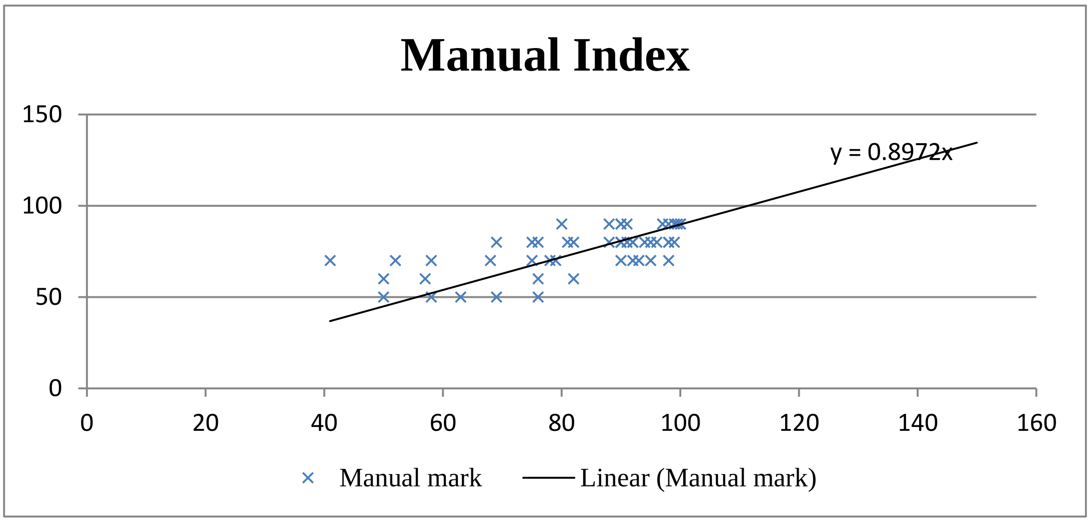


Figure 4-1 PCI vs Manual Index

By observing PCI vs Manual value graph, we can validate method of calculating PCI was reliable with actual situation. The Pearson's correlation of y=x line derived by MS Excel is 0.66 and the points of the graph cluster along the trend line. Even though the most of points are laid within 50-100 in manual and PCI scale. This is because of the data not vastly distributed.

4.2 PCI Values of the Survey

The sample road segments had been surveyed were in different level of conditions. It is necessary to have general image of how our data is being distributed and what are the top and bottom values. In order to illustrate data had been arranged descending order. Following graph gives general idea of PCI values. The legend shows in right of the graph is extract from the Distresses manual. This legend was referred from distress manual for interlocking concrete pavements.

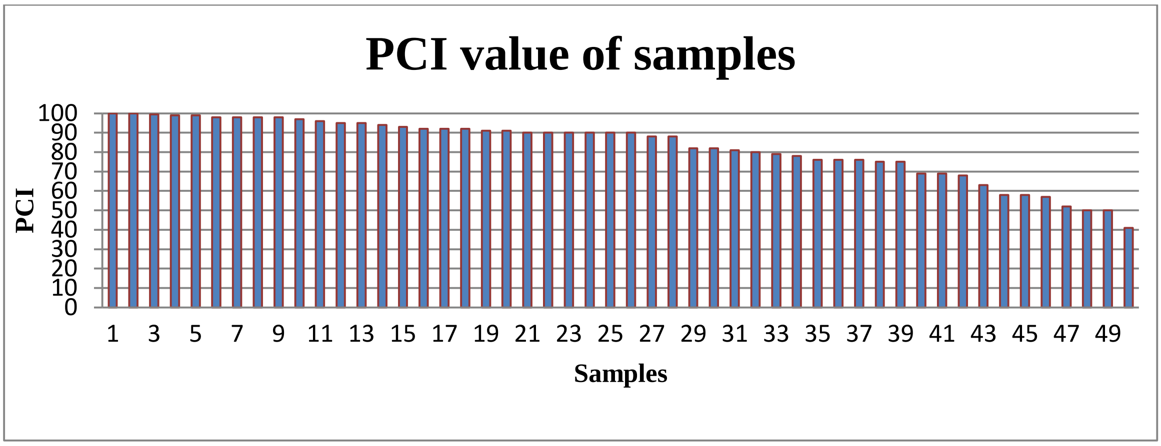


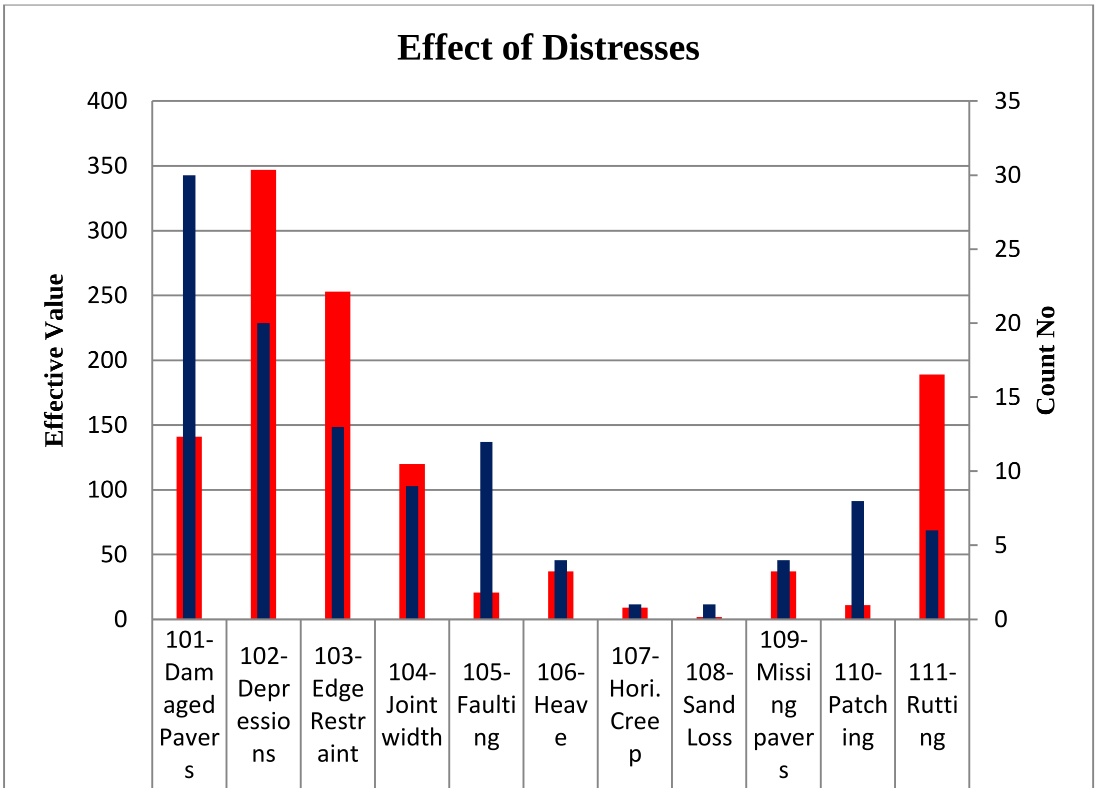
Figure 4-2 PCI variation of samples

According to the graph, 27 of samples (52%) are in excellent condition, 12 samples (24%) in very good condition, 7 (14%) and 5 (10%) in good and fair conditions respectively. There was no sample in poor, very poor or failed condition. Therefore, the all road segments were in functional stage when survey was carried out. It is worth to note that all these roads were aged between four to six years. Other than that, there are no out lairs or identifiable fraudulent values in the data set. Indeed this data can be use further analysis without omitting or modifying any sample and these

PCI values are practical as many literatures proves the life time of block paved pavement is more than six years.

4.3 Effect and occurrence of distresses

The Pavement Condition Index calculates based on eleven distresses types and severity. As each distresses data collect separately, occurrence of distress and effect on PCI value by each type can be illustrate as follows. Here thin blue column implies count of distress. In other words, number of times surveyors found that particular distress type. The deduct points due to each distress type is shown in thick brown column.



	101-Damaged Pavers	102-Depressions	103-Edge Restraint	104-Joint width	105-Faulting	106-Heave	107-Hori. Creep	108-Sand Loss	109-Missing pavers	110-Patching	111-Rutting
Effect	141	347	253	120	20.7	37	9	2	37	11.1	189
Count	30	20	13	9	12	4	1	1	4	8	6

Figure 4-3 Effect and Occurrences

For an example, 101-Damaged pavers had been found in 30 sample units and it deduct 141 points from all samples while 102-Depressions occurred in 20 road units although it deducted 347 points. That implies damaged pavers are more common but not significant effect on road condition with compared to depressions. The road maintainers target should be reduce distresses that are considerably affect road conditions. However some distresses were found rarely such as Heave (106), Horizontal Creep (107), sand loss (108) and Missing pavers (109). We could overlook these distress types as their effect also bare minimum.

4.4 PCI change with pavement aging.

The roads constructed in 2010, 2011 and 2012 were considered for the research. However, it was unable to get the exact date of road completed so it had to assume all roads built in single year had same number of days functioning.

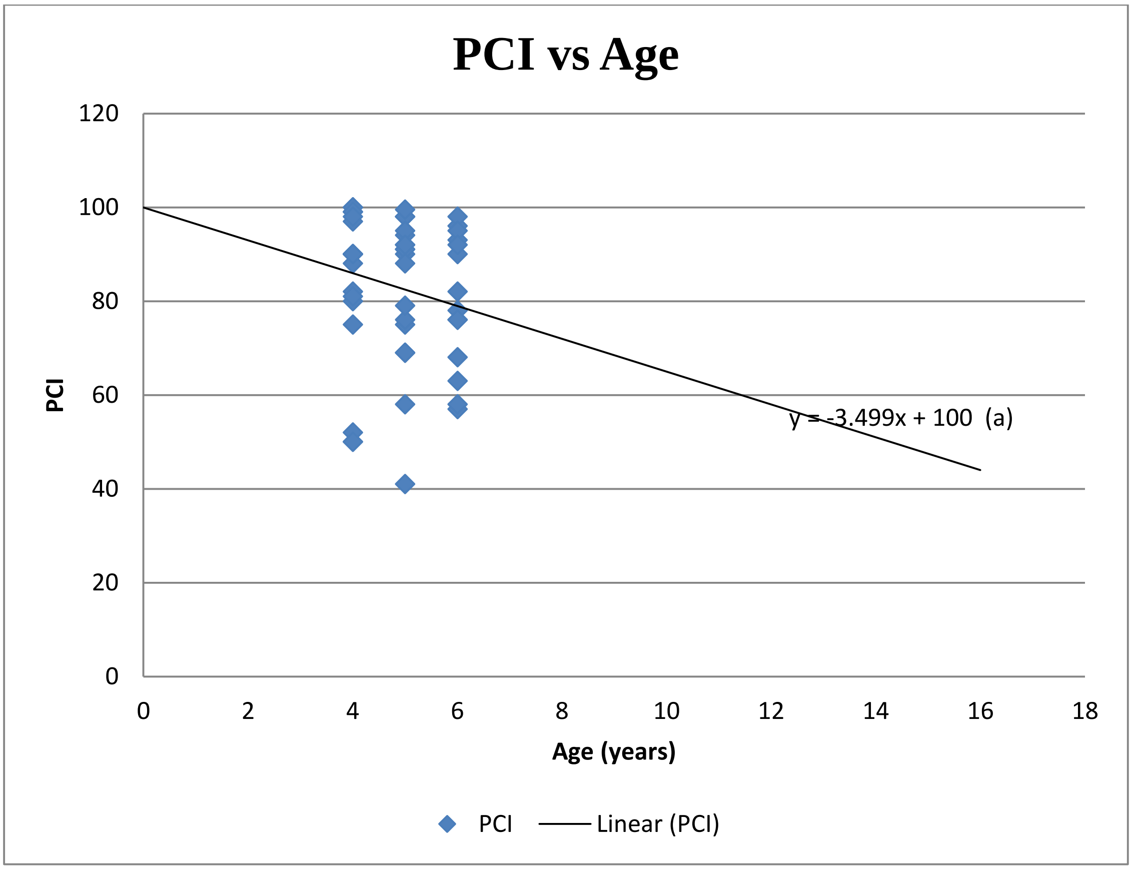


Figure 4-4 PCI vs Age

As this graph demonstrates, the points are very widely distributed. Y intersection is set to 100 PCI value by assuming that when road construction completed with 100 PCI value. However, this graph contain three years of data (4-6).This graph's trend line forecast that PCI value of the pavement would reach value 40 in the road aged 16 years. According PCI rating (Applied Research Associates, Interlocking Concrete Block, 2007) it could be considered as poor condition. Further than means pavement might be needed to rehabilitate. Although researched carried out in North America found their roads were become poor condition when they become more than 25 years of age. (Applied Research Associates, LIFE-CYCLE MANAGEMENT OF, 2008)

5. ANALYSIS AND DISCUSSION OF RESULTS

5.1 Rehabilitation cost

The roads need to repair and rehabilitate when the condition of pavement is damaged to the point, which road users could not travel comfortably. When considering rehabilitation process in concrete block paved roads, there are three type of rehabilitation programs can be done. Such as re-lay concrete blocks, reconstruct base with re-laying blocks and edge curb construction. The method uses for rehabilitation depend on type and severity of the distresses. If damaged pavers (101) happed then only relaying would be enough.

Cost for rehabilitation had been calculated by considering 2016 as the base year. The rates and values are taken from Maganeguma rural road project estimation for western province in 2016. Then rates had been modified to rehabilitation processes stated above three programs. Then generate reconstruction unit cost per square meter for each distress type. Removing damage paver cost has not included and reuse of older blocks was not considered. Following table summarized costing values for each distress type.

Table 5-1Rehabilitation cost

Distress		**Base**	**Edge**	**Paving**	**Rehab unit cost**
Cost per 1m^2 /1m reconstruct		474.1409	803.6352	2404.237	
101	Damaged pavers			1	**2404.24**
102	Depressions	1		1	**2878.38**
103	Edge Restraint		1	1	**3207.87**
104	Excessive Joint Width			1	**2404.24**
105	Faulting			1	**2404.24**
106	Heave	1		1	**2878.38**
107	Horizontal Creep	1		1	**2878.38**
108	Joint sand loss/Pumping			1	**2404.24**
109	Missing pavers			1	**2404.24**
110	Patching			1	**2404.24**
111	Rutting	1		1	**2878.38**

5.2 Relation between Rehabilitation cost and PCI value

After calculating PCI value next analytical part is obtain rehabilitation cost for each sample. The values derived from above table used for calculate rehabilitation cost. Here it was considered only the area or length of damaged; the severity did not take in to account. For instance, if 10 square meters of damaged pavers with lower severity and same area of damaged pavers with higher severity will be going to cost same amount of money.

Finally, rehabilitation cost graphed agents PCI value of the sample.

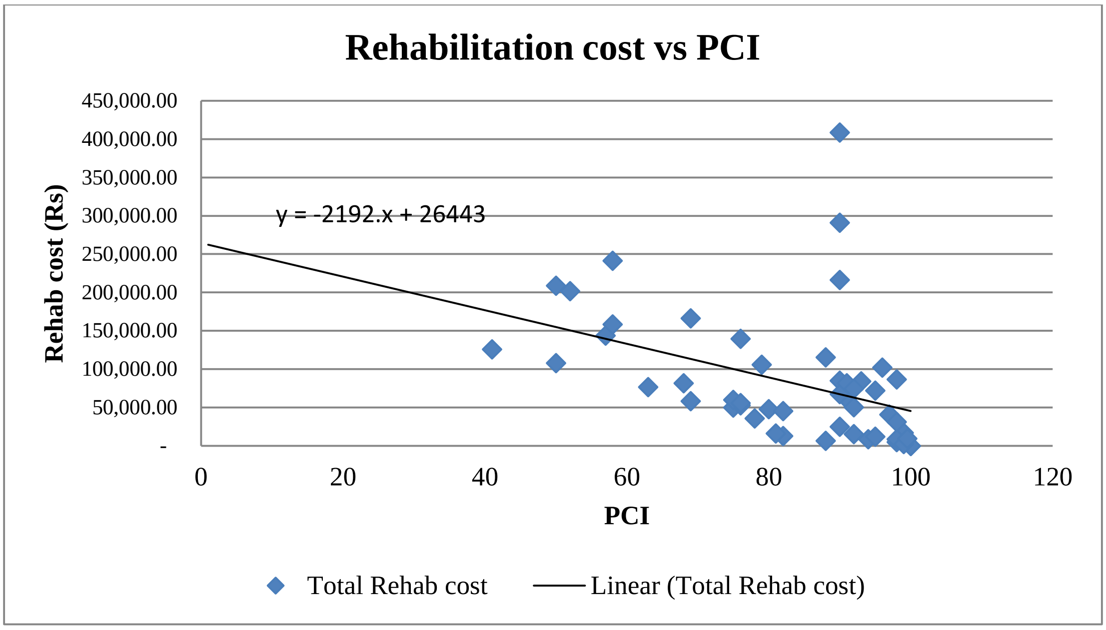


Figure 5-1 Rehabilitation cost vs PCI

Two trend lines have been generated using Excel as linear and second order polynomial. Rehabilitation cost increases with PCI value decreases, which is desirable.

y= -2192x+26443 ➔ (b)

There are three out liars could be identified. That is because these samples have large surface area with low severity damaged pavers.

The trend line equations of above two graphs were used for obtain new equation. There are two graphs due to linear and polynomial lines in Rehab cost agents PCI graph being used.

Using (a) and (b)

$$y = 7669x + 45234 \rightarrow \quad (c)$$

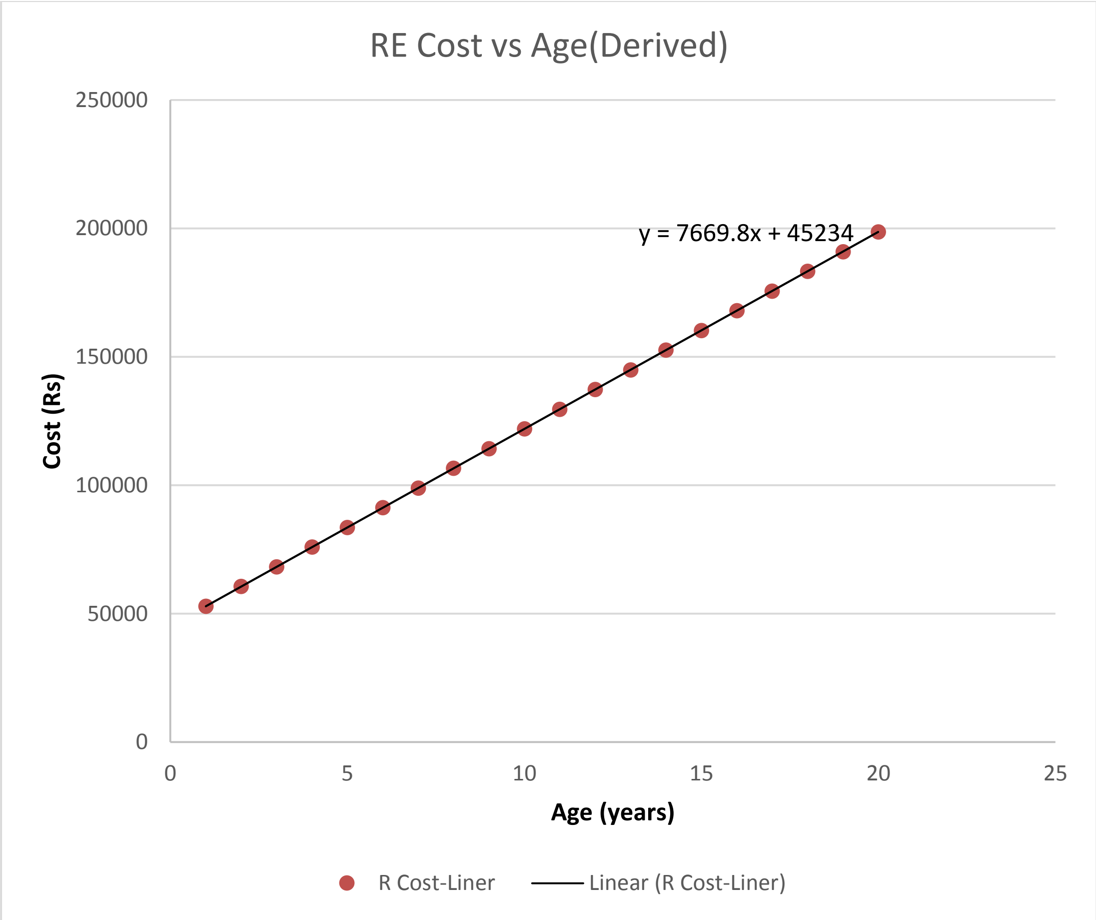


Figure 5-2 Total rehab cost vs Age - derived

This graph gives general idea about how much cost would need in future for rehabilitation. It will be useful situations where there are number of damaged roads segments and initially need to decide financial requirement without doing field survey.

5.3 Cumulative maintenance cost vs rehabilitation interval

Even graph 5.3 gives clear idea of rehabilitation cost we cannot decide extract when we should start rehabilitation process. The graph of rehabilitation cost vs time interval is drawn to find out when the most economical to initiate construction. The total rehabilitation cost is calculated for 20 years period. Said otherwise, if rehabilitation was carried out in certain time interval, cumulative value of the cost, at end of twenty years.

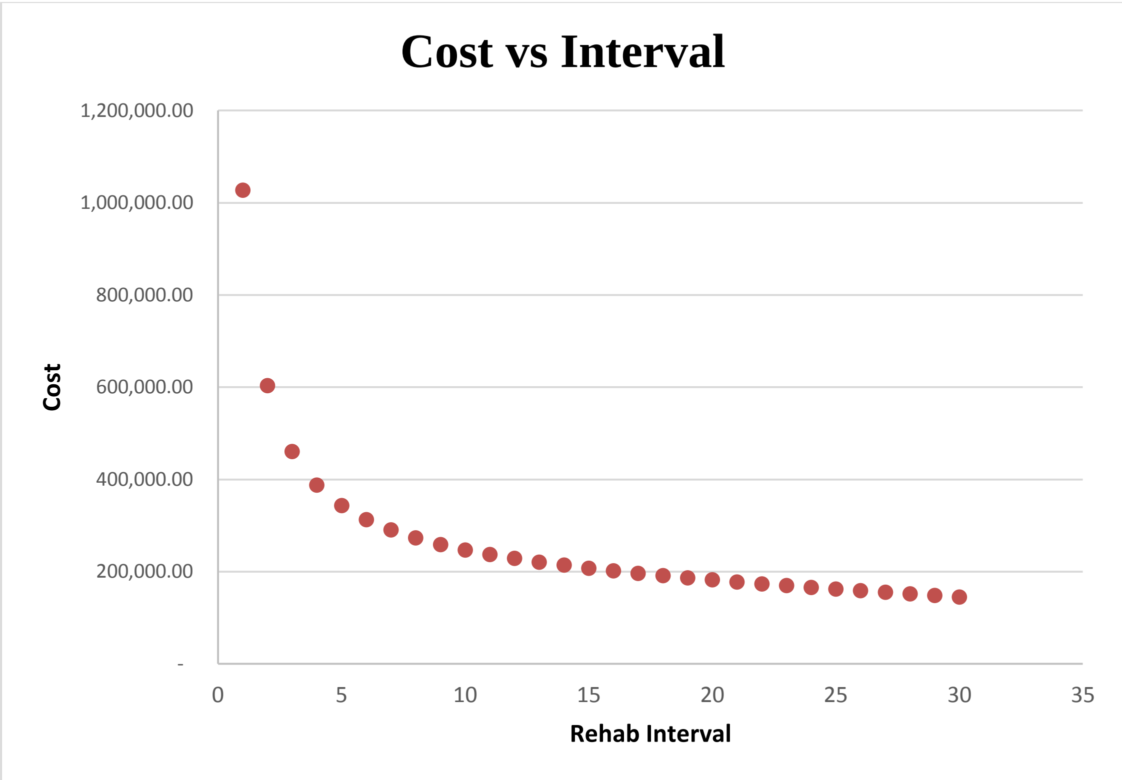


Figure 5-3 Total cost vs Rehabilitation interval

According to above graph 15 years of time interval would economical for periodic maintenance. The predicted value for reconstruction is around LKR 200 000.00 in 2016 value. This value is calculated for pavement of 150 m^2 of area that is about 50m long road section.

The oldest road section we surveyed was built in 2010, according to above graphs it would be rehabilitate at 2025. The actual cost at that time can be found out by present value method.

6. CONCLUSION

6.1 Overview and summary of the research study

Concrete block paving for rural and low traffic volume roads was introduced to Sri Lanka through Maganeguma Rural Road Development program. This program allocated financial aid and guided construction process of concrete block paving. Therefore construction supervision was carried out by local authorities such as Pradeshiya sabha and municipal council. Several road projects were supervised through RDA regional offices. However after construction was completed the road had been hand over to local authorities as they are the responsible institutes for rural roads. Anyway up to now there were no any maintenance was done to constructed road sections. Main intention of this research is find out the current condition of the older concrete block paved roads which is age more than four years. And analysis collected data to derive useful information that can help future when roads needed be rehabilitate.

The research study was designed as data survey research based on pavement condition index (PCI). The Maganeguma program covered all district in the island but it was impractical to survey all district. So the survey narrowed to three divisional secretariats in Gampaha district with theoretically sufficient sample size. The method of obtaining PCI value for each pavement type is different and there are more than one method for obtaining PCI due to several institutes publish distress manuals for PCI. However for block paved pavements there was not approved pavement distress manual for our country. Hence the distresses manual developed in North America has been used for this study. Sample selection was done based on Maganeguma data base. This data base contained GPS location, year of construction and other details relevant to every road segment construct under the program. After selecting samples, data collected to data sheet and calculate PCI according to distresses manual. Survey of one sample usually took twenty to thirty minutes.

Finally, data analysis carried out with intention of achieving research goals. Initially it was decided to confirm reliability of collected data. The PCI value verification was accomplished by compare obtained values with manual pavement rates. The result of this test was acceptable level. Hence further analysis was carried out. Then we generated couple of charts which illustrated nature of the pavement condition. This revealed all samples are in serviceable condition and no need of rehabilitation near future. In fact 90% of roads were in good, very good or excellent condition. Then again graphed with distresses types and it showed relationship between occurrence and effect of each distress type.

Then it was done the analysis work which is relevant to main research problem. Final aim of the research was obtaining economical time interval for periodic maintenance and expected cost for rehabilitation. This analysis was helped with PCI value, road construction year and costing data for concrete block paving work. As final outcome of the research, it was able to produced justifiable time interval for maintenance with cost value.

6.2 Conclusions

- The distresses manual developed for North America can be applicable to Sri Lankan conditions. The distresses in above manual covers almost all the distresses could be found in block paved roads. There were eleven distinguish distresses type in design manual and all distresses have been encountered during this research survey happened to be belong to identified distresses type. Some charts named 'deduct curves' were assisted to calculate PCI value. These curves derived according to effect of each distress type and severity. Consequently the curves are universal values and do not change with the location. Hence institute in our country can adapt to North American Distresses Manual for concrete block paving. Using such manual would be mitigate effect of subjectivity and improve uniformity when evaluate pavement condition. Currently there is not any practice to evaluate pavement condition any stage of pavement contraction. If we can does such evaluation at least end of the defect liability period it would be meaningful.
- The condition of the concrete block paved roads was remarkably better according to obtained PCI value. Even the roads selected as survey samples were older than six years of age, they perform better. None of these roads

were found with poor condition. This would be important finding with regard to compare block paving with other pavement methods. However the most affected distresses happened due to base failure therefore base improvement should be stressed out while construction is going on. Although there was declination of pavement condition with aging which is acceptable.

- Our main research problem was finding the most economical time interval for periodically maintenance. It was suggest 15 to 20 years would be better for such maintenance. This value was obtained based on the facts and finding of this research study. First fact was based on PCI vs Age graph. In that graph PCI value reach 40 when age is about 16 years. Last graph gave the second fact which is Total cost agents Rehabilitation time interval. Here it was showed us the cost had not varied much after 12 years of time interval. In conclusion if every fifteen years doing a pavement condition evaluation and taking necessary action to rectify distresses would be economical to road maintaining institute. Nevertheless carrying out rehabilitation shorter time interval would not be financially sensible while longer time period would be damaged pavement and unusable road pavements due to lack of maintenance.
- The cost for rehabilitation a road segment is depending on level of damaged happened to the pavement. However prior to conduct rigorous pavement condition evaluation it was needed to have rough idea about the cost needed for rehabilitation. For instant if there are hundreds of road sections and we need to allocate money for rehabilitation as provisional sums then we have to have some kind of norm value for cost of rehabilitation. According to total cost agents time interval graph, cost for rehabilitation 50 meters road segment was expected 200 000.00 LKR. This value was based on 2016 prices. Since these roads constructed in between 2010 to 2012 rehabilitation would be needed in 2025 onwards. Then the cost should be recalculated with reasonable interest rate. On the other hand this is a rough value.

6.3 Limitation of the study

This research data base was 50sample. Statistical the sample size is enough for statistical analysis. Although there are thousands of block paved roads in the island and generalizing fifty samples for all road might not give correct results. If it is possible the research could be redone with large sample size and find out whether the size affect the results.

Here we considered roads which are older than four years and the oldest samples were six years old. But the research results are highly depending on age of the roads. In fact we forecasted condition of fifteen years old roads base on six years old roads' pavement condition. However the oldest interlocking block paved roads available are six years old one and results are cannot compare to check whether the method was correct. Anyway this research is scientifically anticipation of pavement condition.

The samples used for survey belonged to three divisional secretariats which are adjacent to each other. That implied the weather condition and vehicular movements were similar in all samples. Nevertheless this area is recognized as wet zone with higher capacity of precipitation. The results could be difference in dry zone roads. Details about condition of the sub grade and method use to improve base had not been recorded. Hence assume all samples have same base condition. If we had that data it would be possible to find out relation between base condition and pavement condition with time.

There were two persons participate this survey as data collectors. Both of them have fair knowledge in road construction but had not experience in PCI value or any other pavement evaluation technique. There could be minor errors happen due to inexperience. The recommended equipment for long distance measurement was measuring wheel but here linen tape was used.

Above facts could be considered as limitations of our research but researcher try his best to overcome such difficulties.

6.4 Suggestions for Future Research

- This research is concentrated on concrete block paved roads in Gampaha district. Similar research could be repeated in other district and compare results with these results.
- Here anticipate pavement condition of 15-20 years of roads base on 4-6 years old road pavement data. If we can repeat this research after five years of time (2021) we can confirm these results are reliable or not.
- It was found value for reconstruction cost. In this research we assume all roads would be deteriorate same rate and all of them would be needed to rehabilitate once. Anyway actual situation is some roads depreciate faster than others. Hence if it is possible to find out the probability of depreciation we could generate more reliable cost value for rehabilitation. In other words, if there are 100 roads segments with 15 years old. 75% of them could be poor or worst condition, then allocations are needed only that group of roads. In this research it was assumed all roads it would need rehabilitation when they are 15 years old.
- Most of distresses coursed due to poor condition of road base. Therefore much attention should be put on base construction and quality control measures should be introduced while base is being constructed.

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INTERLOCKING CONCRETE BLOCK
ROADS AND PARKING LOTS
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

ROAD ______________________________ DATE ____________

SECTION ______________________________ SAMPLE UNIT ______

SURVEYED BY ____________________ SAMPLE AREA (sq m) [sq ft] _______

DISTRESS NUMBER AND TYPE

101 Damaged Pavers
102 Depressions
103 Edge Restraint
104 Excessive Joint Width
105 Faulting
106 Heave
107 Horizontal Creep
108 Joint Sand Loss/Pumping
109 Missing Pavers
110 Patching
111 Rutting

DISTRESS/ SEVERITY	QUANTITY					TOTAL	DENSITY %	DEDUCT VALUE

SKETCH

NOTES: ____

Annex 2

S.No	Area	101-Damaged Deduct Value	102-Depressio Deduct Value	103-Edge Restraint Deduct Value	104-Joint width Deduct Value	105-Faulting Deduct Value	106-Heave Deduct Value	107-Hori. Creep Deduct Value	108-Sand Loss Deduct Value	109-Missing Deduct Value	110-Patching Deduct Value	111-Rutting Deduct Value	Q (Entries)	TDV	CDV	PCI
1	150	2	4	25									3	31	25	75
2	140.0			2									1	2	2	98
3	192.0	3	10	5		1						6	5	25	10	90
4	156.8	2		9								9	3	20	9	91
5	134.4			18									1	18	18	82
6	156.8	1											1	1	1	99
7	162.0	1	23										2	24	24	76
8	147.9		6										1	6	6	94
9	153.0	2	8										2	10	8	92
10	150.0	4	3			1							3	8	4	96
11	156.6	10				5							2	15	10	90
12	139.2	4				7							2	11	7	93
13	150.0		20		2								2	22	20	80
14	150.0	3	50		16								3	69	50	50
15	108.0												0	0	0	100
16	115.2	3											1	3	3	97
17	120.0	2	31	10								50	4	93	59	41
18	140.0	4						9					2	13	9	91
19	33.8	2											1	2	2	98
20	159.5	15				1				30			3	46	31	69
21	150.0												0	0	0	100
22	153.0			19									1	19	19	81
23	180.0	1		24									2	25	25	75
24	153.0									1		42	2	43	43	57
25	112.8	8										32	2	40	32	68
26	150.0					1	22						2	23	22	78
27	156.0	2	24				7						3	33	24	76
28	165.3	2	42		15								3	59	42	58
29	139.2				5								1	5	5	95
30	92.4	10		31						4			3	45	31	69
31	147.0		28		40								2	68	48	52
32	196.0	10				2							2	12	10	90
33	154.0	10											1	10	10	90
34	156.0	10											1	10	10	90
35	139.2	6			6								2	12	12	88
36	180.0		5		18				2			50	4	75	50	50
37	246.0		10			0.1					0.1		3	10.2	10	90
38	180.0	1											1	1	1	99
39	135.0	1				1					2		3	4	2	98
40	114.0	5	13	20		1							4	39	21	79
41	124.0					0.5					0.5		2	1	0.5	99.5
42	174.0		8								0.5		2	8.5	8	92
43	284.0	2				0.1							2	2.1	2	98
44	225.0	8	12	36	10								4	66	37	63
45	112.5										5		1	5	5	95
46	156.0		8								1		2	9	8	92
47	153.0			12									1	12	12	88
48	238.0	7		42	8					2			4	59	42	58
49	150.0		18				4				1		3	23	18	82
50	150.0		24				4				1		3	29	24	76
TDV		141	347	253	120	20.7	37	9	2	37	11.1	189				
Count		30	20	13	9	12	4	1	1	4	8	6				