USING QUALITY CONTROL CHARTS TO SEGMENT ROAD SURFACE CONDITION DATA

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Outline

- Segmentation as a classification tool
- Current strategies for segmenting road surface condition pavement condition data
- Limitations of the current segmentation methods
- Fundamental concepts of quality control charts and application as a segmentation method
- Compare results of c-chart segmentation with previous segmentation methods

Introduction

- Many elements of road condition data are collected periodically at the network-level, for example IRI, friction, FWD, rut depth.
- This data drives the selection of maintenance and rehabilitation strategies and the extent of each treatment
- With the growth in stored data, there is a need to identify homogeneous and consistent condition-based subsections
- A network could be segmented dynamically into homogeneous subsections which have statistically-uniform properties using one or several condition data elements

Segmentation strategies

Several approaches exist for classifying condition data.

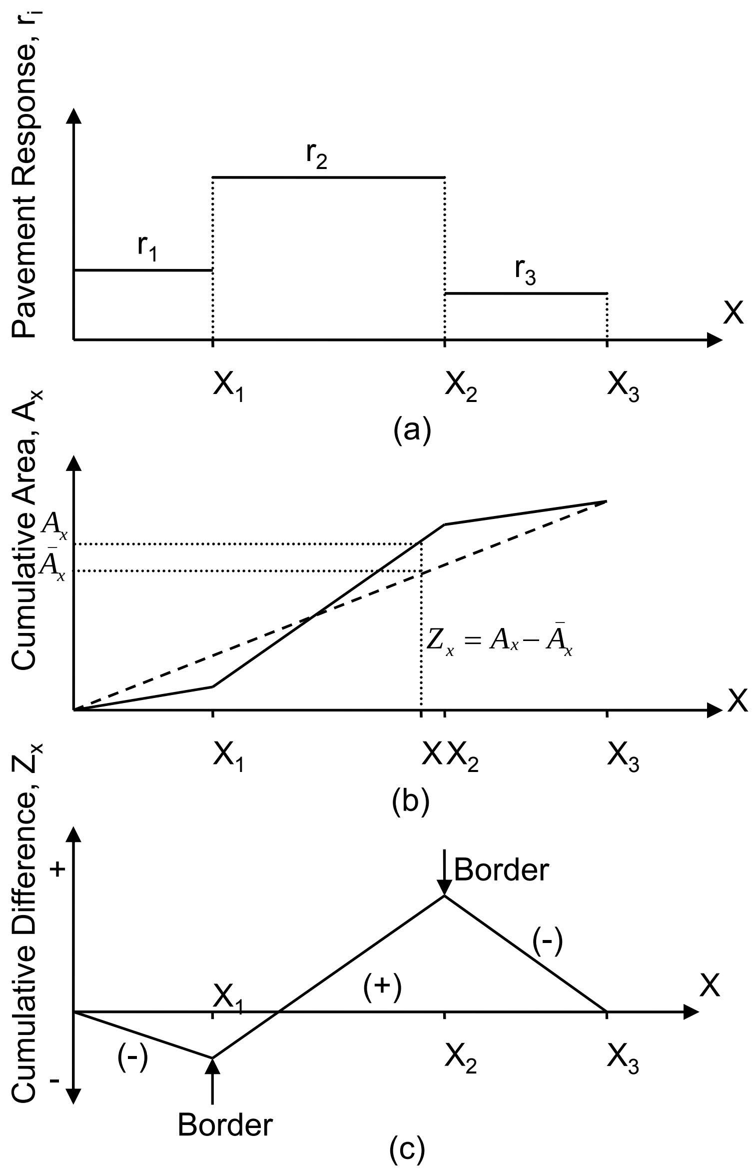
Four methods will be discussed:

1. Cumulative Difference Approach (CDA)
2. Absolute Difference Approach (ADA)
3. Classification and Regression Trees (CART)
4. Quality Control Charts (C-Chart)

Important to note that there is no unique or final solution.

Solutions are recursive and adaptable. Additional criteria are required to terminate the process.

The cumulative difference approach (CDA)

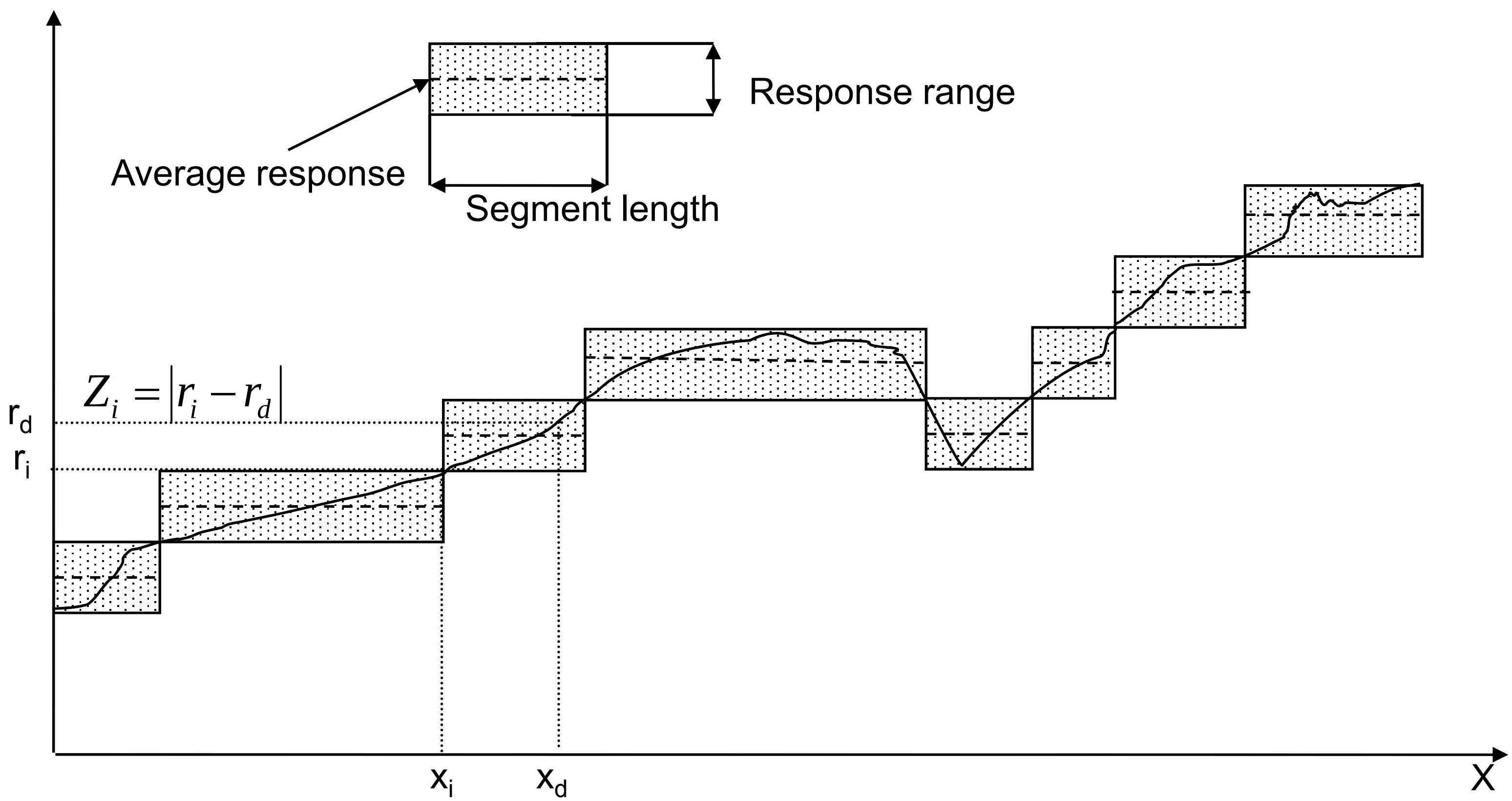


(a) Response

(b) Cumulative Area

(c) Cumulative Differences

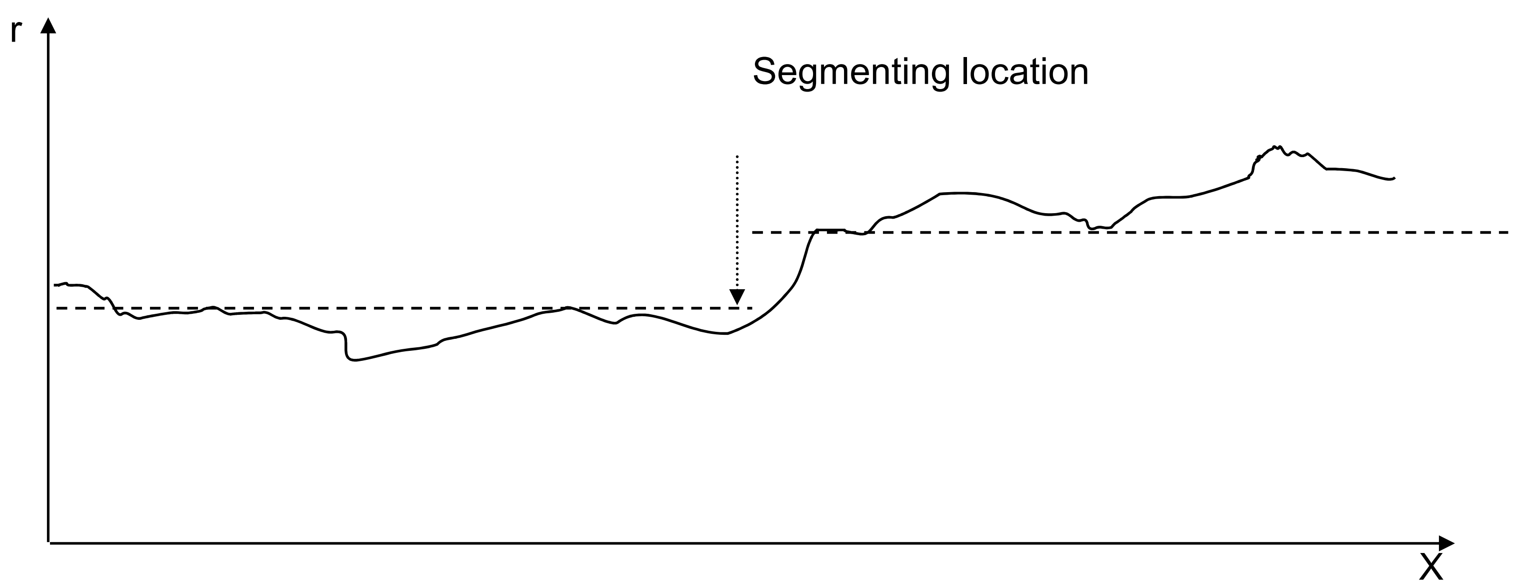
The absolute difference approach (ADA)



The absolute difference approach

Classification and regression trees (CART)

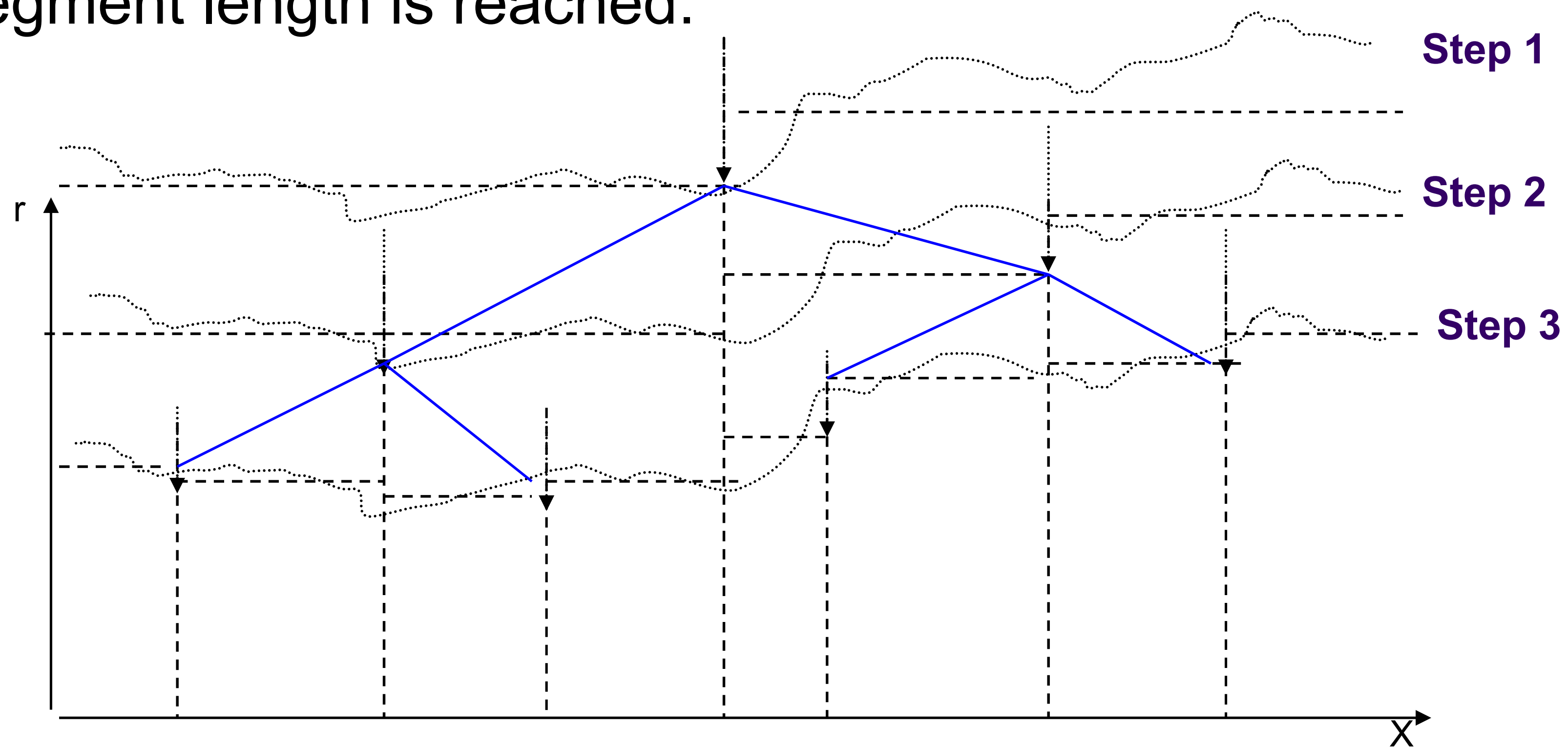
Each data set is divided into two homogeneous subsections by locating the position where the sum of the squared differences between the data in each segment and the corresponding mean of each segment is minimized.



Exhaustive search for dividing the data set into two homogeneous subsections

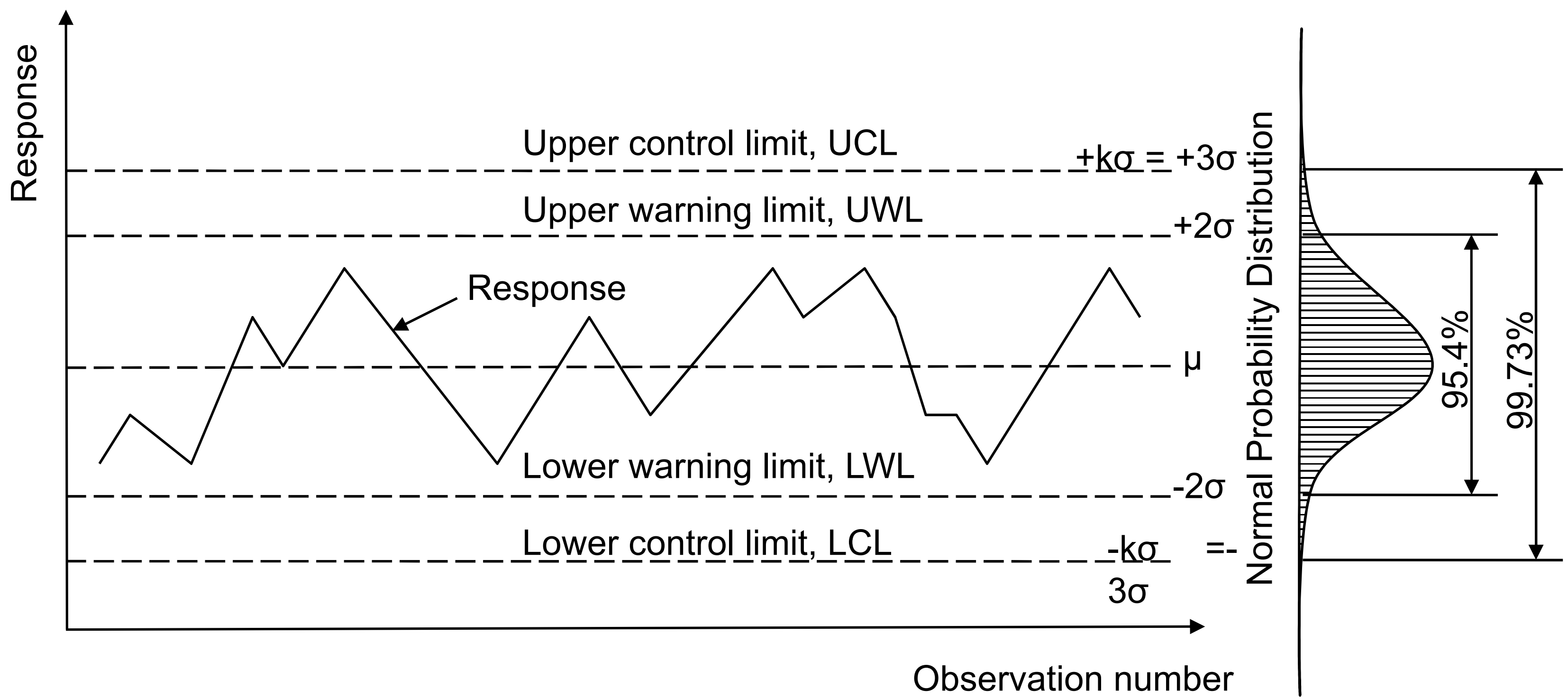
Classification and regression trees (CART)

The procedure is applied recursively to each segment until a maximum number of segments or a minimum segment length is reached.



Regression tree for eight delineated sections

Control chart approach (C-Chart)



Typical control chart showing warning limits (±2σ) and control limits (±3σ)

General model for control chart

The centreline CL, the upper control limit UCL, and the lower control limit LCL are:

$$UCL = \mu + \mathrm{k}\sigma$$

$$CL = \mu$$

$$LCL = \mu - \mathrm{k}\sigma$$

where k is the distance of the control limit from the centreline expressed in standard deviation unit.

The outer limits are usually at 3σ and the inner limits, usually at 2σ

Estimating mean and standard deviation from segment data

Mean and st. deviation are estimated from segment data
Must be recalculated with the addition of each data point to the segment

Estimate of mean

$$\hat{\mu} = \bar{r}$$

$\hat{\mu}$ = estimate of mean for current segment
$\bar{r}$ = average of responses in current segment

Estimate of variance

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{n} r_i^2 - n\bar{r}^2}{n-1}$$

r_i = response value

$\hat{\sigma}^2$ = estimate of variance for current segment

n = number of response points (i) in current segment

Modifying c-chart control limits using response range

St. deviation of a segment can be too large for practical applications

Control limits can be assigned to not exceed a desired (practical) target range:

$$UCL = \hat{\mu} + c$$

$$LCL = \hat{\mu} - c$$

c is the minimum of the $3\hat{\sigma}$ in the segment and 0.5 r_{range}

C-chart delineation algorithm

1. Proceed from the fifth data sample from the start of the segment to allow for a reasonable initial estimate of the statistical parameters

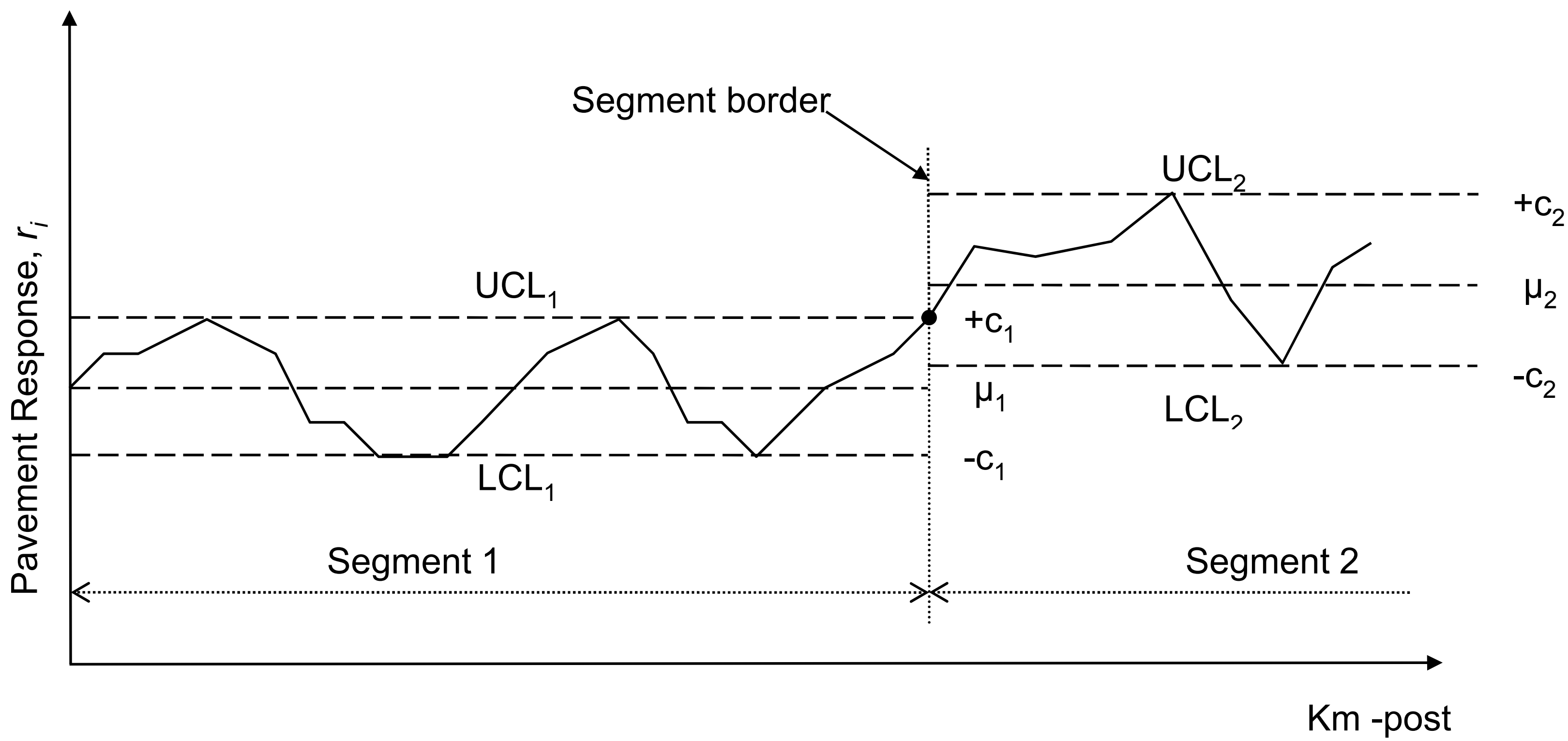
2. On adding each new data sample, the estimated mean and variance of the segment are calculated based on data from start of segment up to the tested sample.

3. The lower of $3\hat{\sigma}$ and 0.5 r_{range} are used to establish and update the control limits.

4. A new segment is started when the tested data sample falls outside the control limits.

5. The process continues until all profile data is segmented

Segmentation using c-chart approach

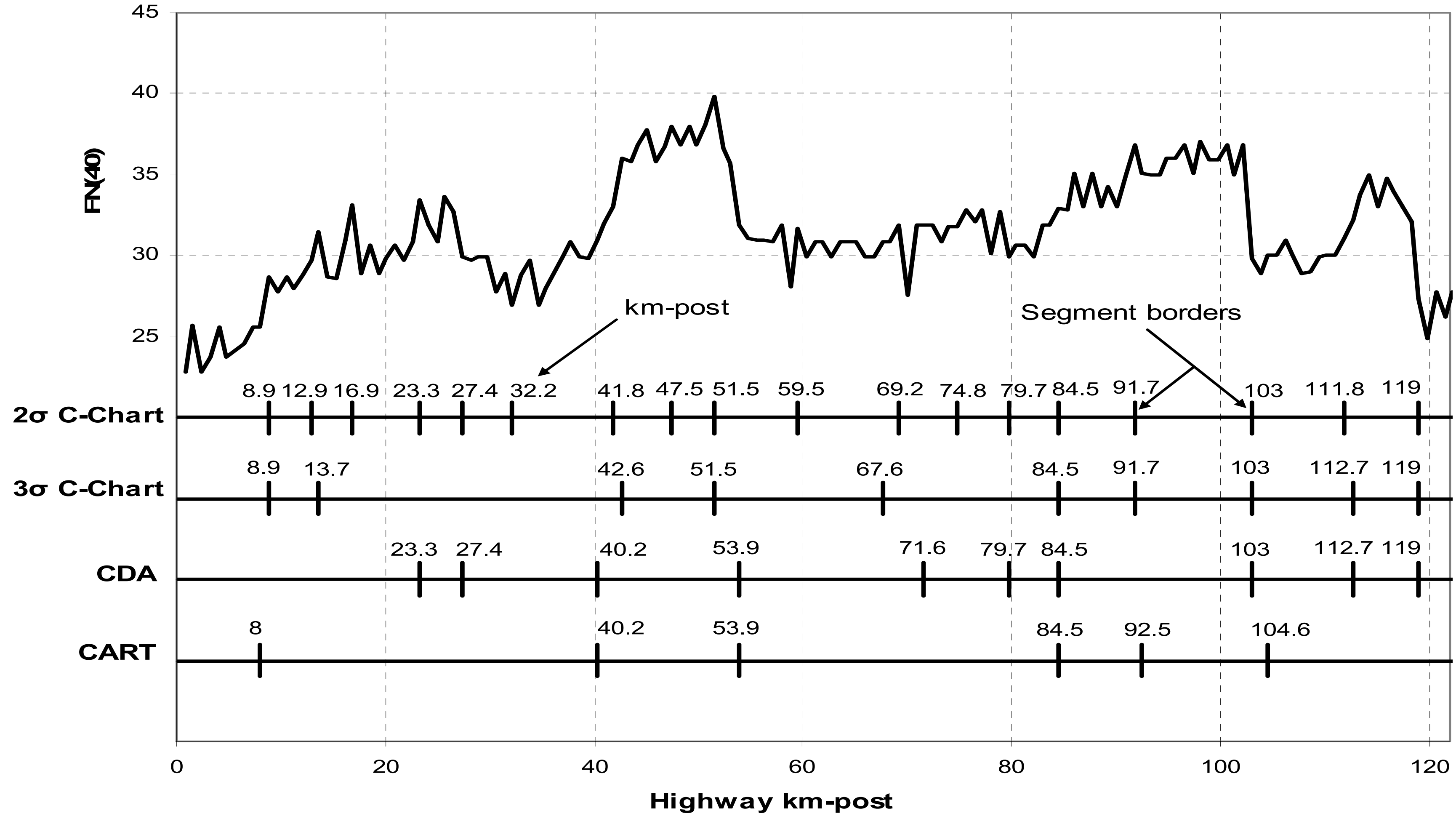


Identification of homogeneous segments using c-chart approach

Comparison of segmentation methods

Segmentation Method	Characteristic			
	Segmentation Criterion	Minimum number of segments	Final number of segments	Segment range
CDA	Diversion from mean of entire profile	Two	Unlimited	Not specified
ADA	Target range	One	Unlimited	Predetermined
CART	Minimum sum of squared error	Two	Predetermined	Unlimited
C-Chart	Standard deviation	One	Unlimited	Optional

The AASHTO Example



Delineating a Friction Number profile using various methods

The sum of squared errors (SSE)

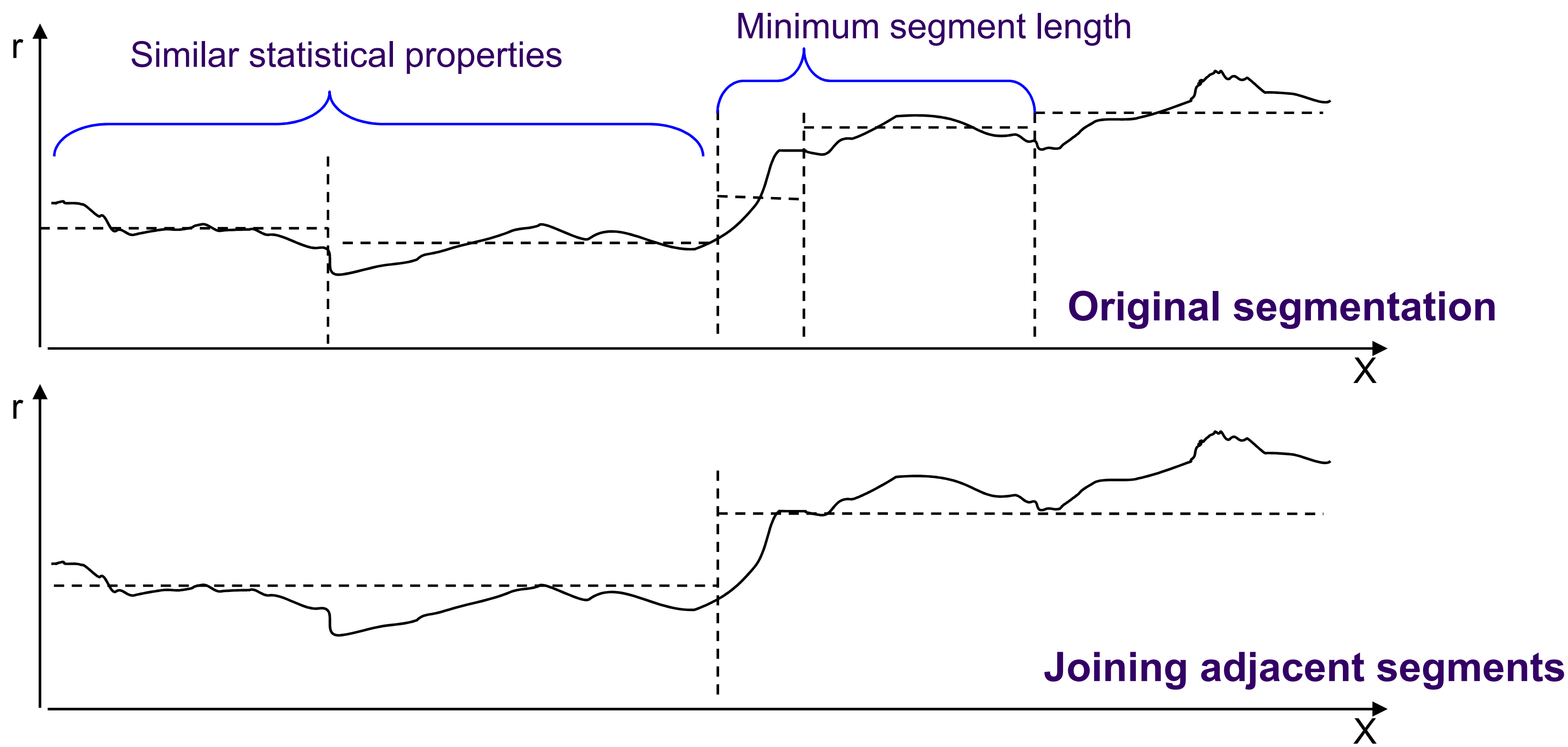
Comparison of sum of squared errors (SSE) using three segmentation methods

Segmentation Method	SSE [FN(40)]	Number of subsections
CDA	521	11
CART	431	7
2σ C-Chart	264	19
3σ C-Chart	331	11

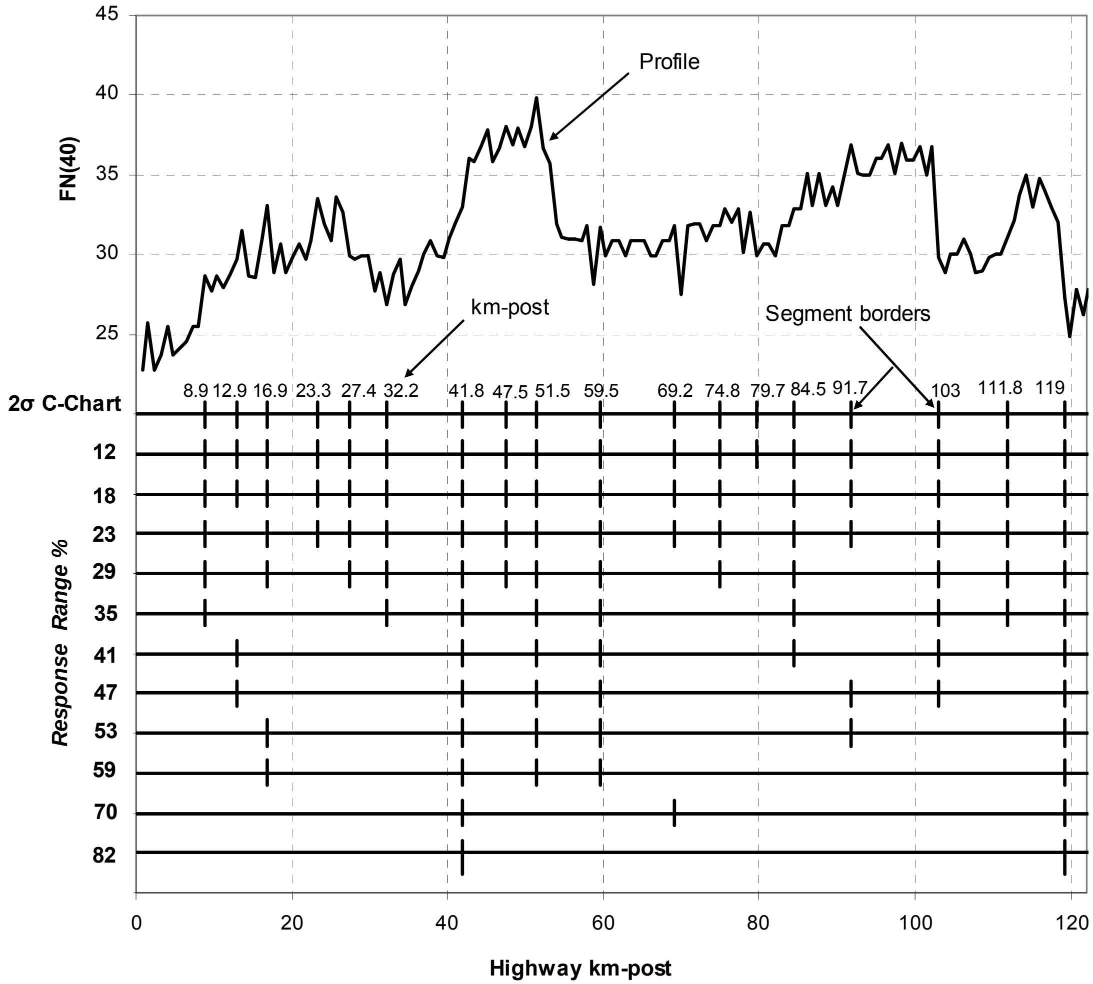
Joining of adjacent segments

If two adjacent segments have similar statistical properties, joining should be examined.

Joining is performed if the resulting (joined) segment is considered uniform.



Joining of adjacent segments



Joining of adjacent segments generated by 2σ c-chart method using various response ranges

Joining of adjacent segments

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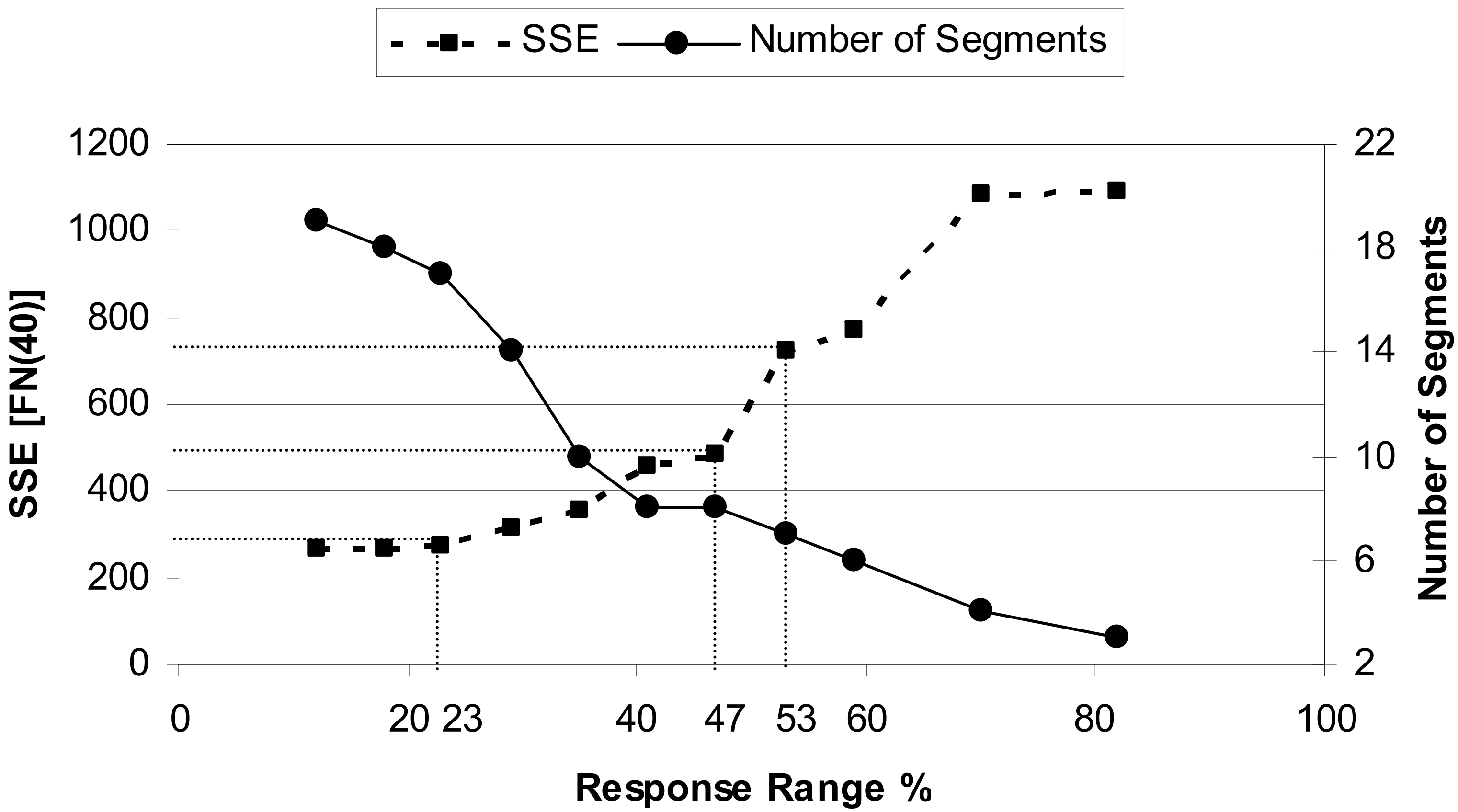

Relationship of sum of squared errors (SSE) and number of joined segments to response range

Limitations

- No clear winner. Selection of a segmentation method should be based on the type of data and the quality of information to be extracted.
- No unique or perfect answer. The lowest SEE is when each segment contains exactly one sample and the mean of the entire section is not affected by segmentation.
- Process can be “nearsighted” if it cannot recognize brief disturbances
- It is important to strike a balance between approximation of a condition in a uniform subsection and the details provided by higher resolution data.

Conclusions and recommendations

- Segmentation allows for the extraction of uniform homogeneous sections.
- Several available methods for segmenting road condition data are presented.
- C-chart can be employed as a segmentation tool and selecting a practical target range provides additional control over the solution.
- The AASHTO example was used to demonstrate the various methods.

Conclusions and recommendations

- The main advantage of the c-chart approach is that it is an autonomous process that does not require prior knowledge of the statistical characteristics of the data.

- If the characteristics of data are known, additional criteria such as target range can be incorporated to improve the segmentation

- Segmentation tools and criteria should be tuned to achieve the desired solution

Thank You