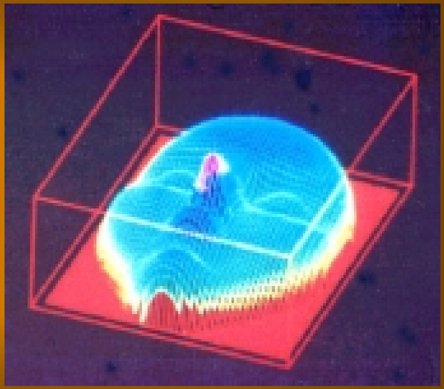
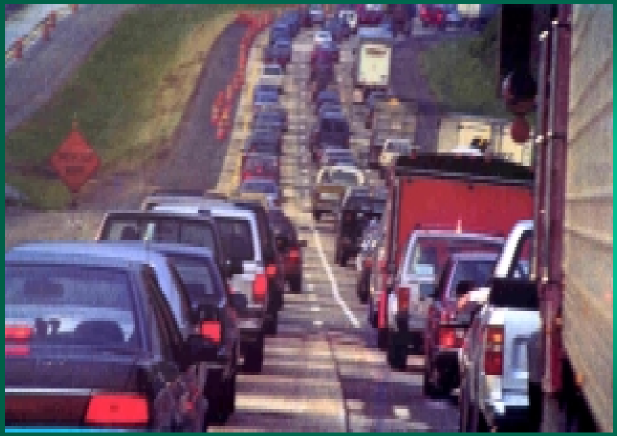
Applications of the Fuzzy Intelligent Systems

Z. Dong, Department of Mechanical Engineering, University of Victoria

Automated CNC Tool Path Generation in Sculptured Surface Machining

- Intelligent Rough Machining of Sculptured Parts
- Optimal Tool Path Generation for 3½½-Axis CNC Machining





Dynamic Traffic Control

- Dynamic Traffic Control for Signalized Highways
- Real-time Traffic Contra-flow Operation at George Massey Tunnel

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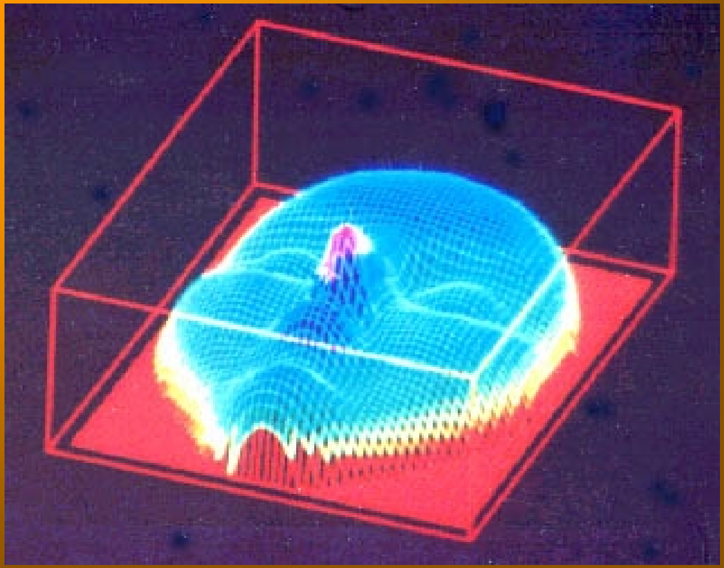
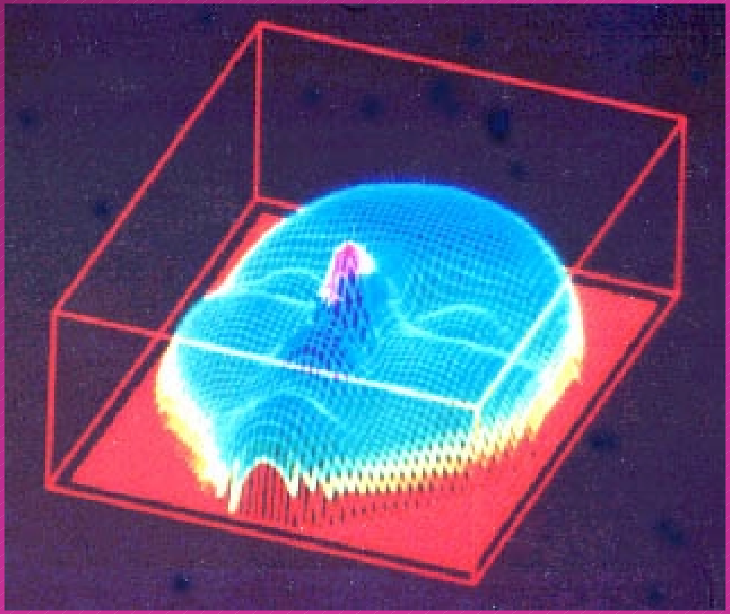


Intelligent Rough Machining of Sculptured Parts for Maximum Productivity



H. Lee, Z. Dong and G.W. Vickers

A Project Supported by the Natural Science and Engineering Research Council of Canada

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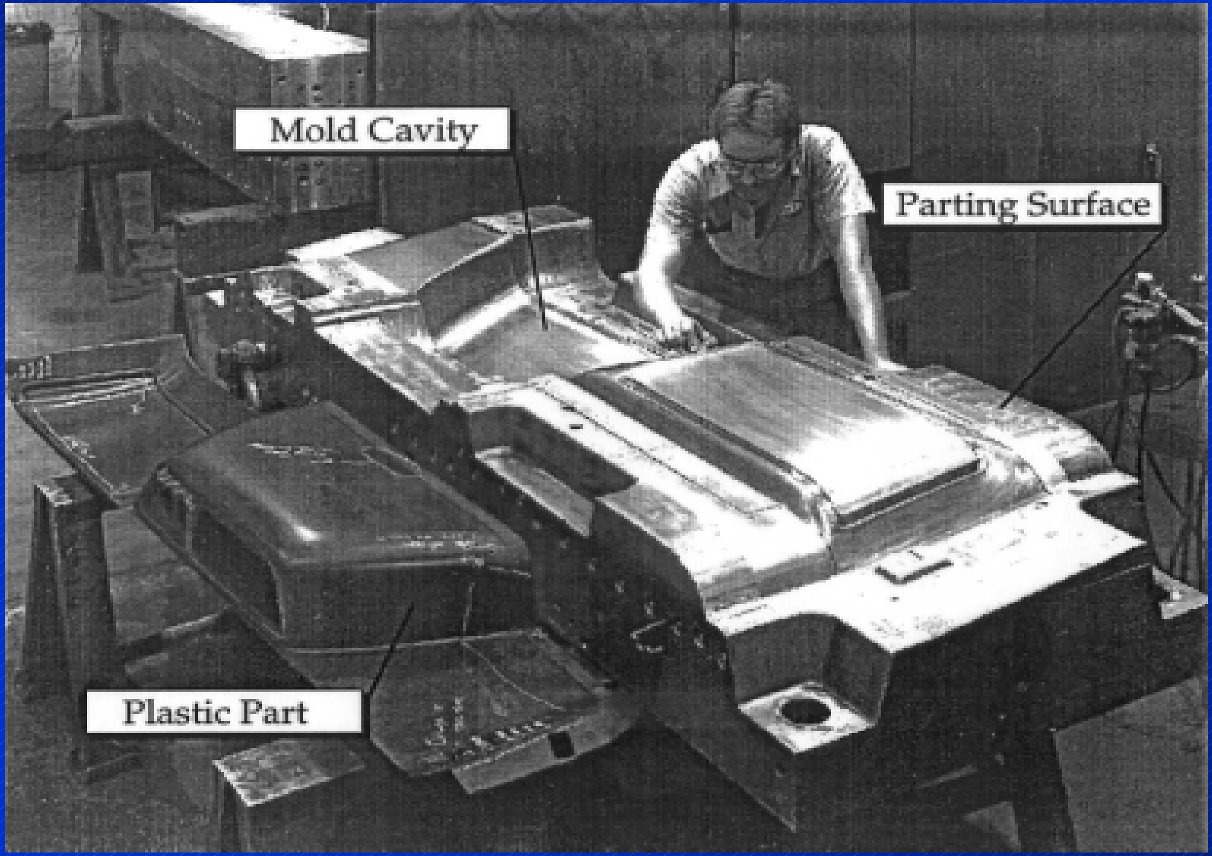
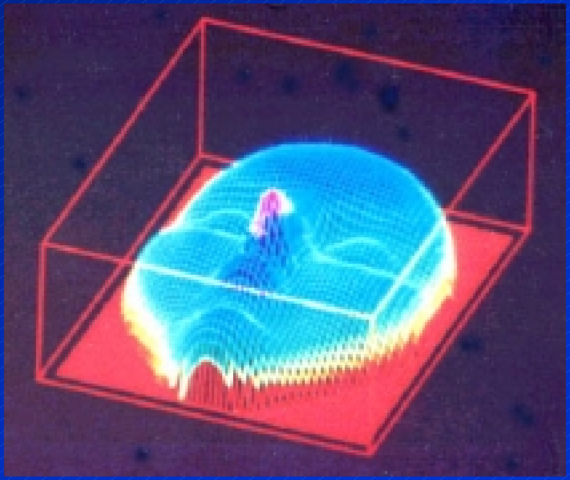
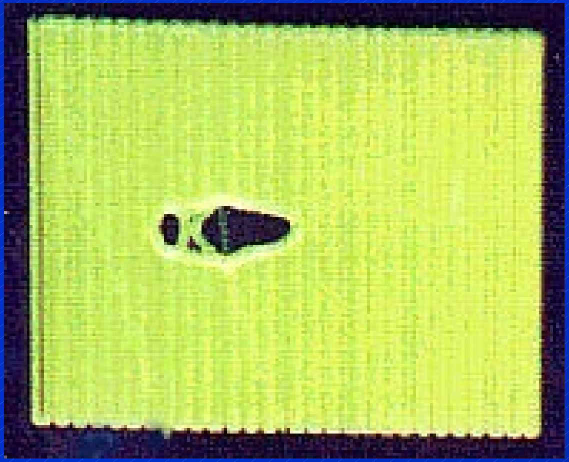
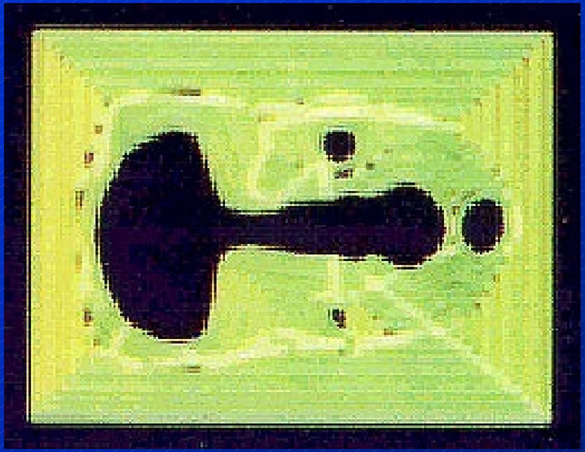
Rough and Finish Machining of Dies and Injection Molds



2 1/2D Rough Machining







Intelligent Rough Machining of Sculptured Parts

- **Objective**

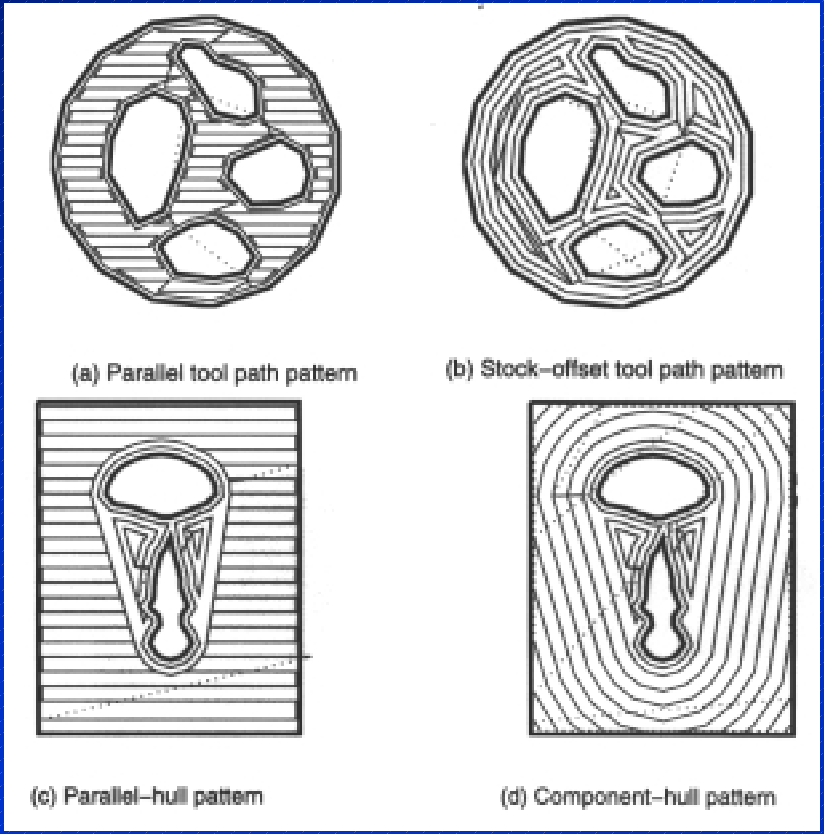
  Minimize machining time given part geometry, material and machining constraints

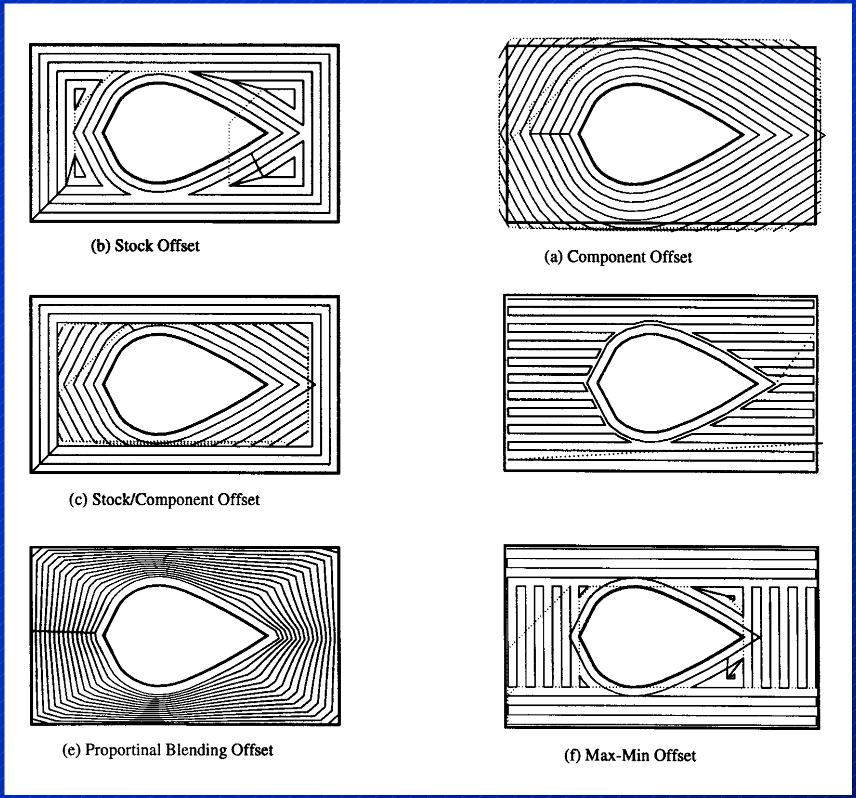
- **Scope of Study**
  - Identification of Optimal Machining Strategy Based on Part Geometry

    Optimal Tool Path Patterns for 2 ½ D Machining
  - Identification of Optimal Machining Parameters

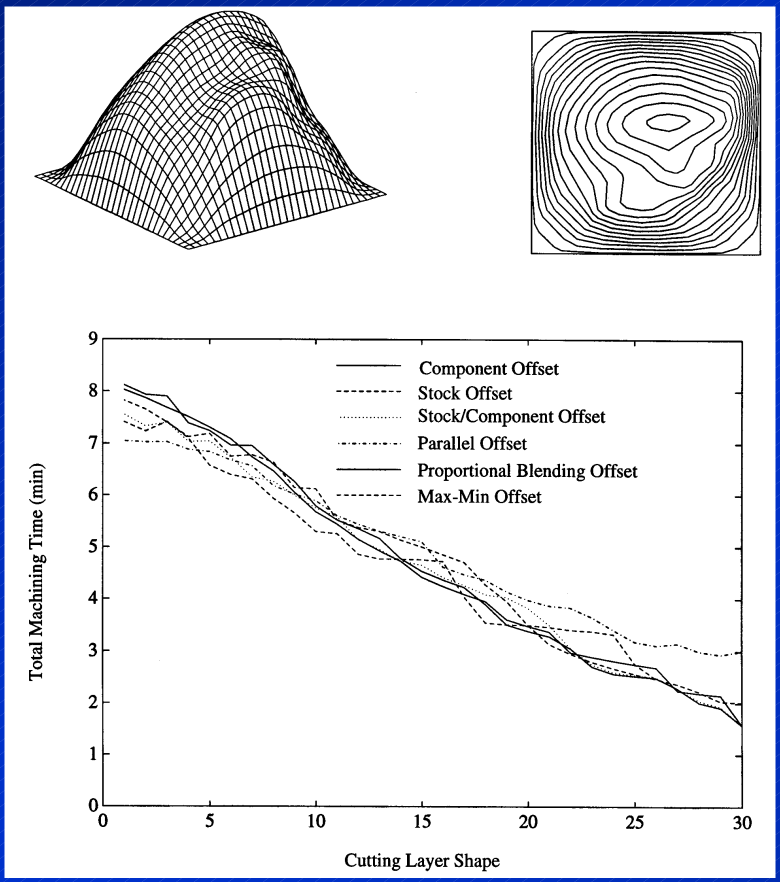
    Feed-rate, Depth and Width of Cut, Number of Cutting Layers

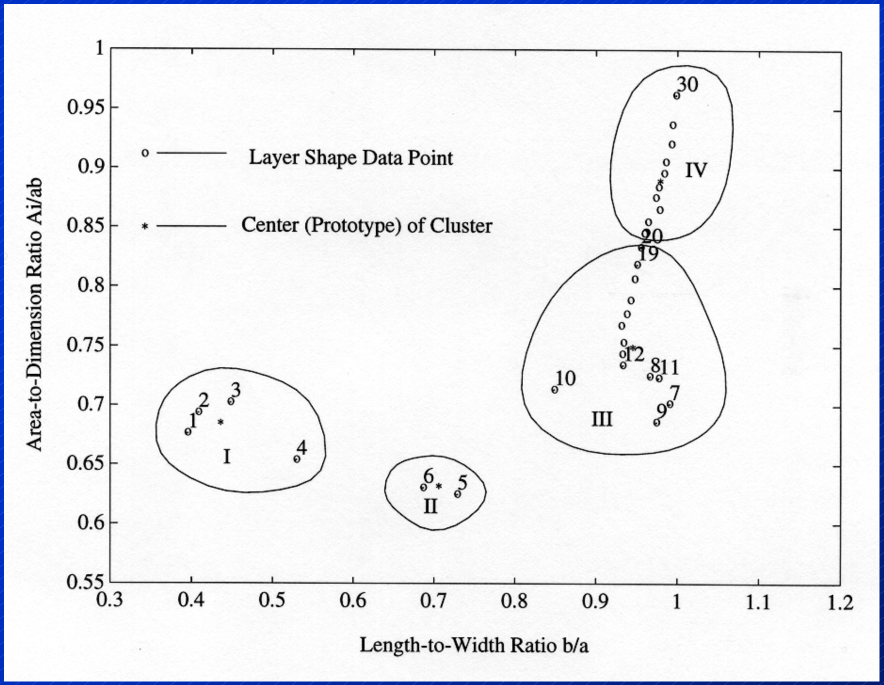
Various Feasible Tool Path Patterns in 2 ½ D CNC Machining





Clustering of Cutting Layers in Identifying the Optimal Tool Path Patterns





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Identification of Optimal Tool Path Patterns

- Alternatives
  - Clustering all possible cross-section shapes
  - Clustering all cutting layers of a given part
- Fuzzy Variables and Function
  - Fuzzy parameters: length/width ratio, island/stock area ratio, etc.
  - Fuzzy Measure: tool path length (machining time)
- Benefits
  - Around 15 % of machining time reduction
  - Automation in tool path pattern selection

Machining Parameter Optimization

Objective Function:

$$\min_{X} \; T = T_c + T_m + T_u + T_d \frac{T_c}{T_l} \approx T_c + T_m$$

$$= \sum_{1}^{N} t_{ci} + \sum_{1}^{N} t_{mi} = \sum_{i=1}^{N} \sum_{j=1}^{n_{ci}} \frac{l_{cij}}{f_{cij}} + \sum_{i=1}^{N} \sum_{k=1}^{n_{mi}} \frac{l_{mik}}{f_{mik}}$$

Design Variables:

$$X = \{ N, f_i, d_i, d_{c,i}, P_i \;\; {\scriptstyle (i\,=\,1,\ldots N)}; \;\; S_p(x,y,z), S_s(x,y,z) \}^T$$

Machine and Process Constraints:

$$0 \le F_{T,i}(\phi) = K_T a h_i(\phi) \le F_{T,max}$$

$$0 \le F_{R,i}(\phi) = K_T K_R a h_i(\phi) \le F_{R,max}$$

...

Geometry Constraints:

$$\sum_{i=1}^{N} d_i = H$$

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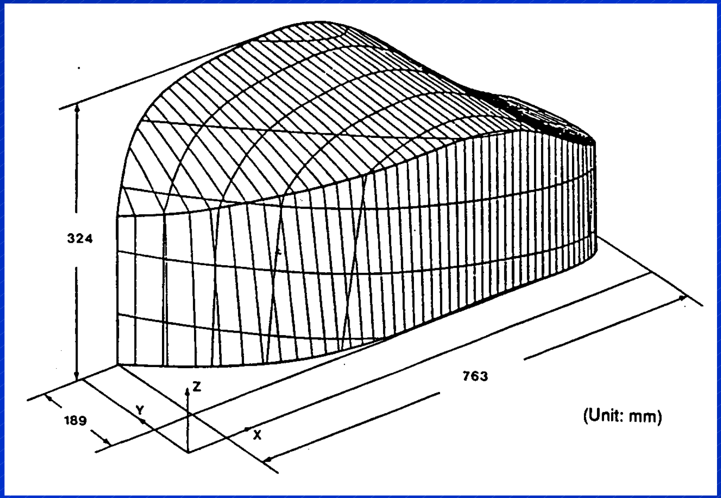
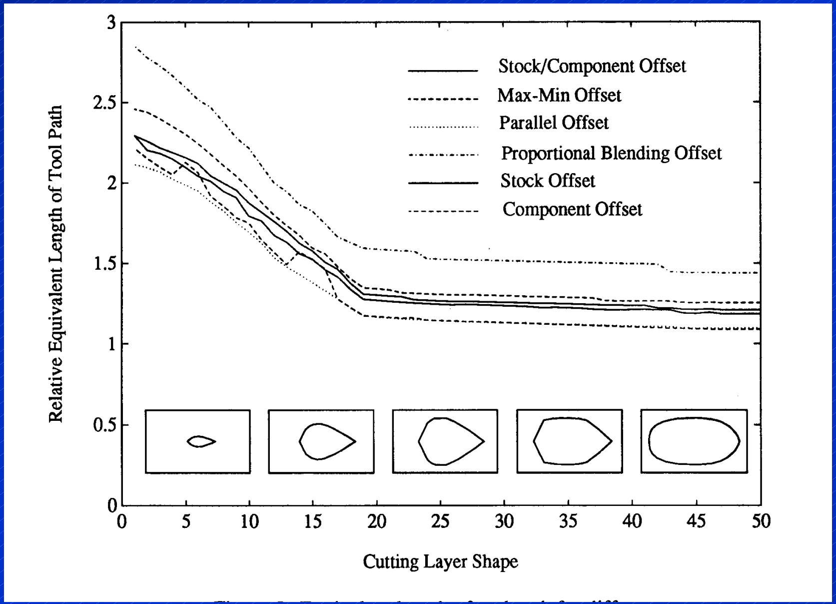
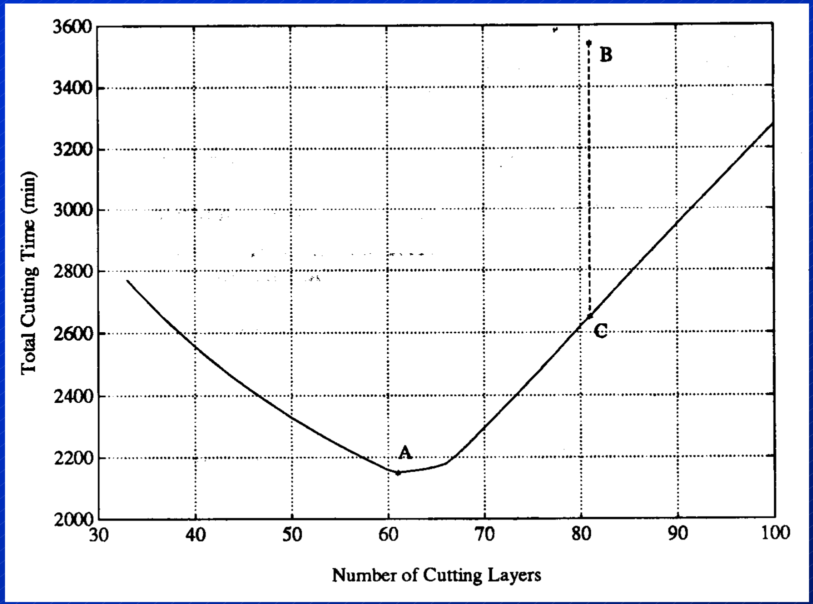
Test Results

Higher Productivity with Reduced Machining Time:

- vs. Manual Planning: 39%
- vs. Adaptive Control: 25%







Summary

- **Two Aspects and Two Methods**
  - Identification of Optimal Machining Strategy Based on Part Geometry
    - ~ Optimal Tool Path Patterns for 2 ½ D Machining (Fuzzy Intelligent System)
  - Identification of Optimal Machining Parameters
    - ~ Feed-rate, Depth and Width of Cut, Number of Cutting Layers (Math Modeling and Numerical Optimization)
- **Machining Time Reduction and Automation (Benefits)**
  - Machining Strategy Optimization (15%)
  - Machining Parameter Optimization (45%)

Automated Optimal 3½½-Axis CNC Tool Path Generation for Machining Sculptured Parts Using Fuzzy Pattern Clustering

Z. Chen, Z. Dong and G.W. Vickers

Advanced Manufacturing Lab.

Dept of Mechanical Engineering

Supported by NSERC

(Please see the other poster for details.)

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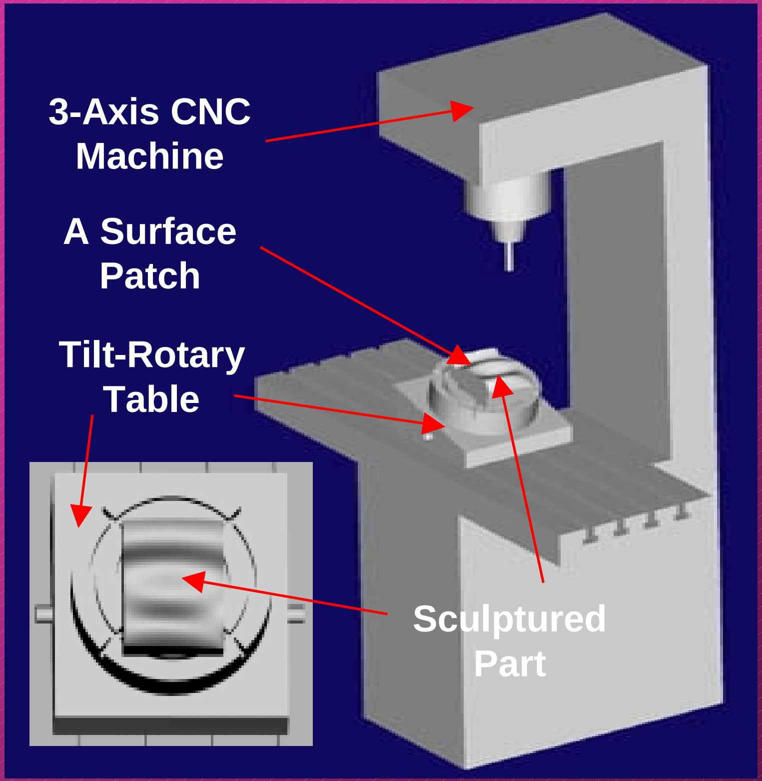


3½½-Axis VS. 5-Axis CNC Machining

3½½-Axis CNC Machining

- Discrete Translation and Rotation
- Reorientation for Better Machining Set-up
- Rigid and Less Chatter
- Lower Investment and Cheaper Maintenance
- Automatic and Optimal Tool Path Planning

5-Axis CNC Machining

- Synchronized Translation and Rotation
- Flexible Machining and One-time set-up
- Less Rigid and Prone Chatter
- Higher Costs and Expensive Operating
- Difficult to Generate Tool Path

Sculptured Surface Expression

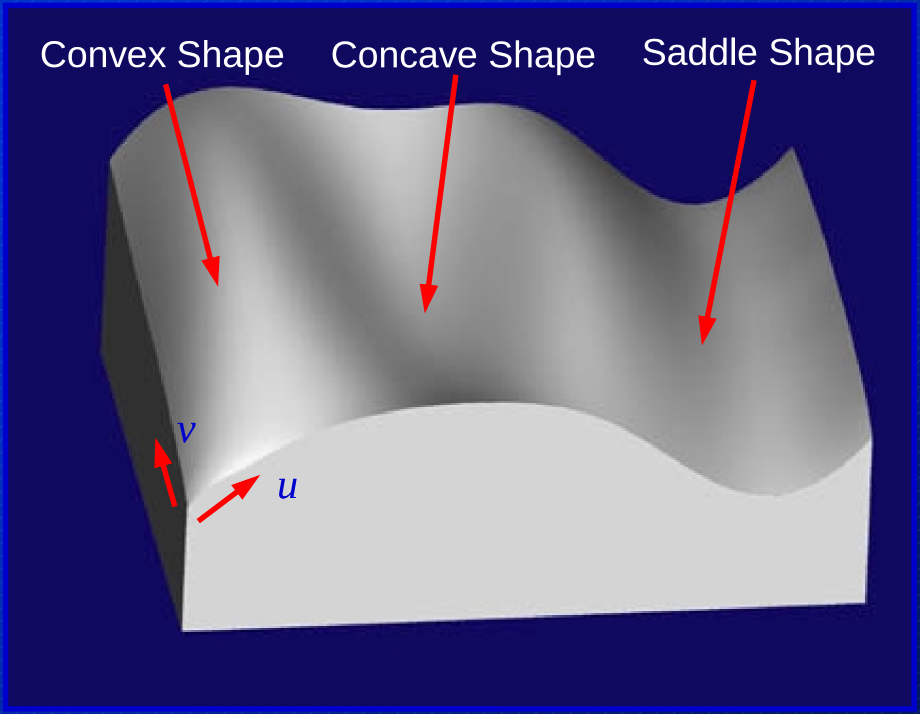
To digitize the surface feature, *shape and machinability*, surface expression is needed. Non-Uniform Rational B-Spline (NURBS) surface is often used.

- **NURBS Surface Expression**

$$\mathbf{S}(u,v)=\sum_{i=1}^{n+1}\sum_{j=1}^{m+1}\mathbf{C}_{i,j}\cdot \mathrm{N}_{i.k}(u)\cdot \mathrm{N}_{j,k}(v)$$

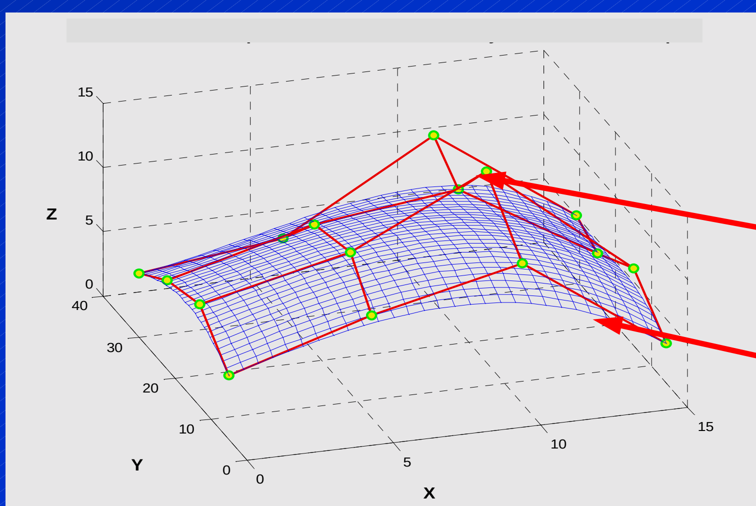
$$u_{\min}\le u\le u_{\max},\ v_{\min}\le v\le v_{\max}$$

- **Surface Shape Types**
  - **Convex**
  - **Concave**
  - **Saddle**



Hierarchical Data Structure

- Surface Grid Points
  - Convex
    - Accessible & No Gouging
    - Inaccessible / Gouging
  - Concave
    - Accessible & No Gouging
    - Inaccessible / Gouging
  - Saddle
    - Accessible & No Gouging
    - Inaccessible / Gouging



An Example Sculptured Surface

Control Polyhedron (4 X 4)

Grid Points of A NURBS Surface

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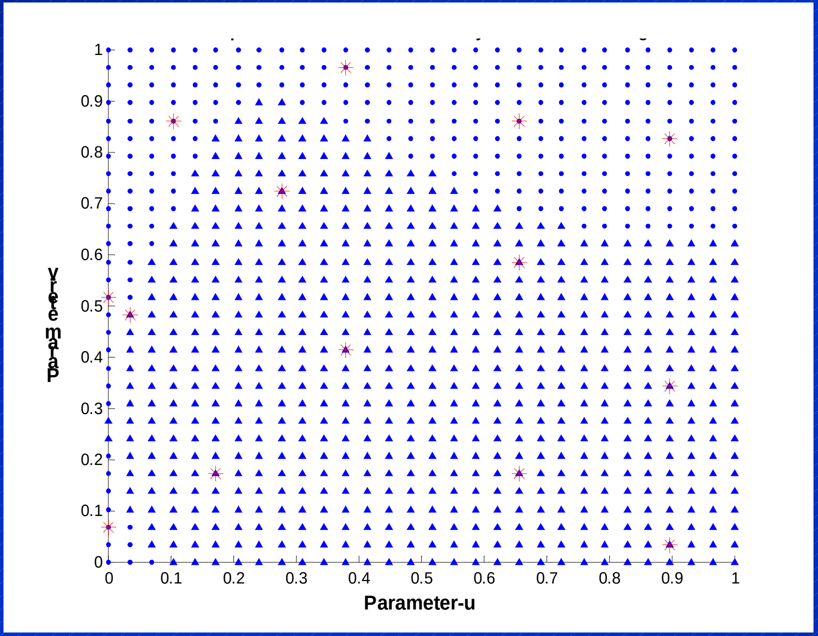
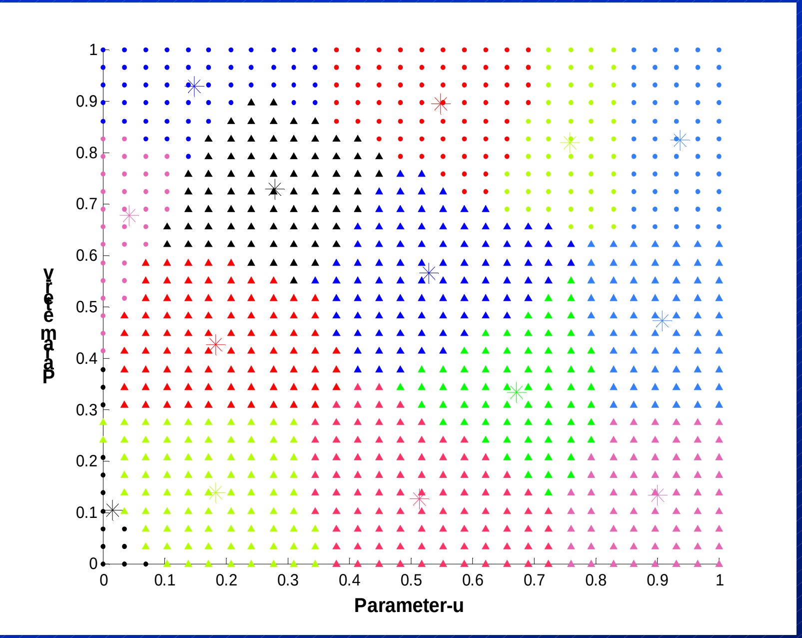
Fuzzy Pattern Clustering of Surface Points

- Subtractive Fuzzy Clustering
  - Input: Grid Points of A Surface Shape (i.e. Accessible Convex)
  - Output: The Number of Cluster Centers and Their Locations
- Fuzzy C-Means Clustering
  - Input:
    - Grid Points of A Surface Shape (i.e. Accessible Convex)
    - The Number of Cluster Centers and Their Locations
  - Output:
    - Optimized Number of Clusters
    - Locations of the Cluster Centers

Subtractive Fuzzy Clustering on Points of the NURBS Surface

Fuzzy C-Means Clustering on Points of the NURBS Surface





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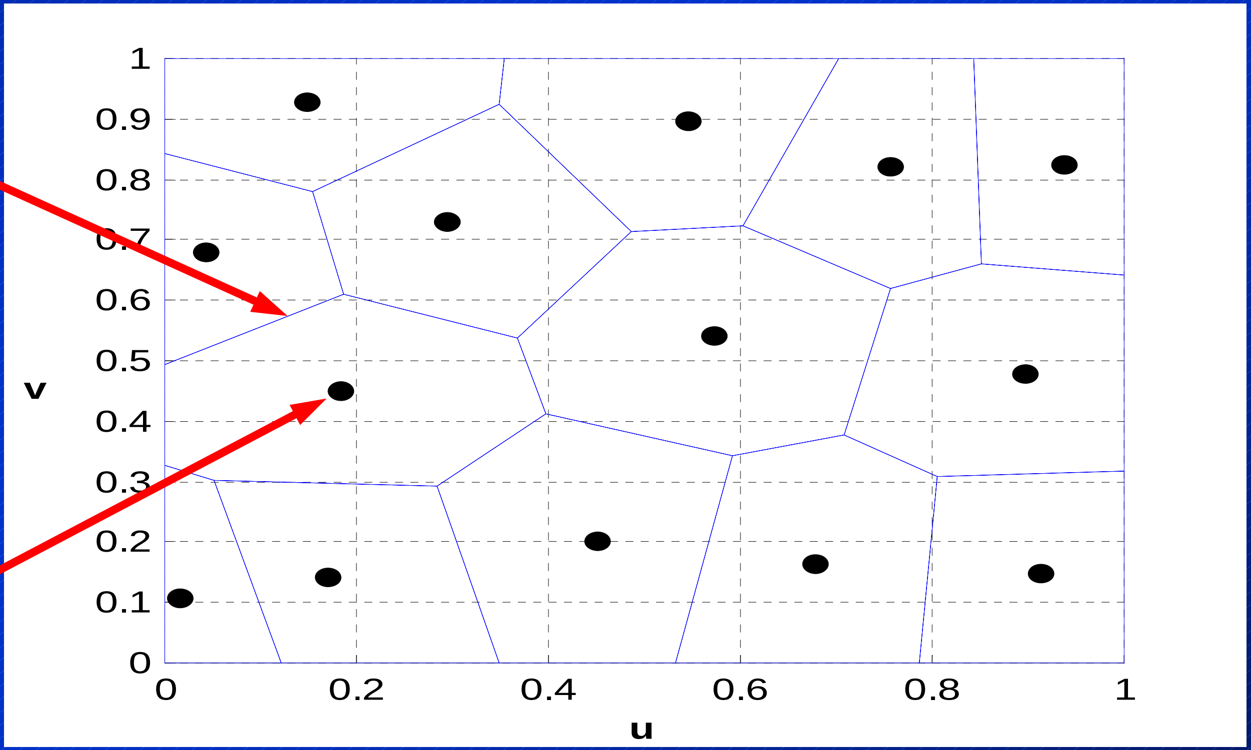
Voronoi Diagram of the Surface Patch Boundaries

Surface Patch Boundaries

Cluster Center of Surface Patch



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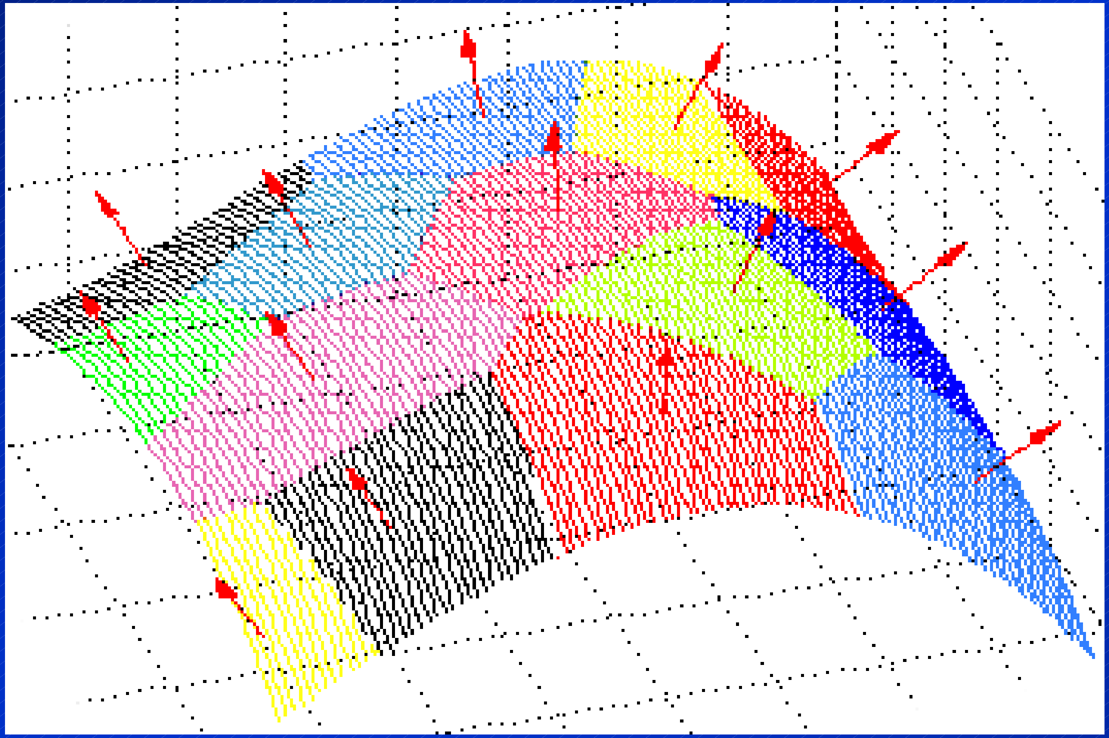
Automatically Generated Optimal Tool Paths



Shown in the Figure:

- Surface Patches
- Surface Normal of the Cluster Centers
- Iso-parameter Tool Paths for Each Surface Patch

Five-axis Machining on Low-cost, 3-axis CNC Machine

Better Surface Quality and Higher Productivity

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Dynamic Traffic Control

- Dynamic Traffic Control for Signalized Highways

- Real-time Traffic Contra-flow Operation at George Massey Tunnel

Dynamic Traffic Signal Control Using A Self-learning Fuzzy-neural Intelligent System

J. Wu and Z. Dong

Supported by Ministry of Transportation and Highways of British Columbia
and Institute for Robotics and Intelligent Systems

University of Victoria, B.C. Canada

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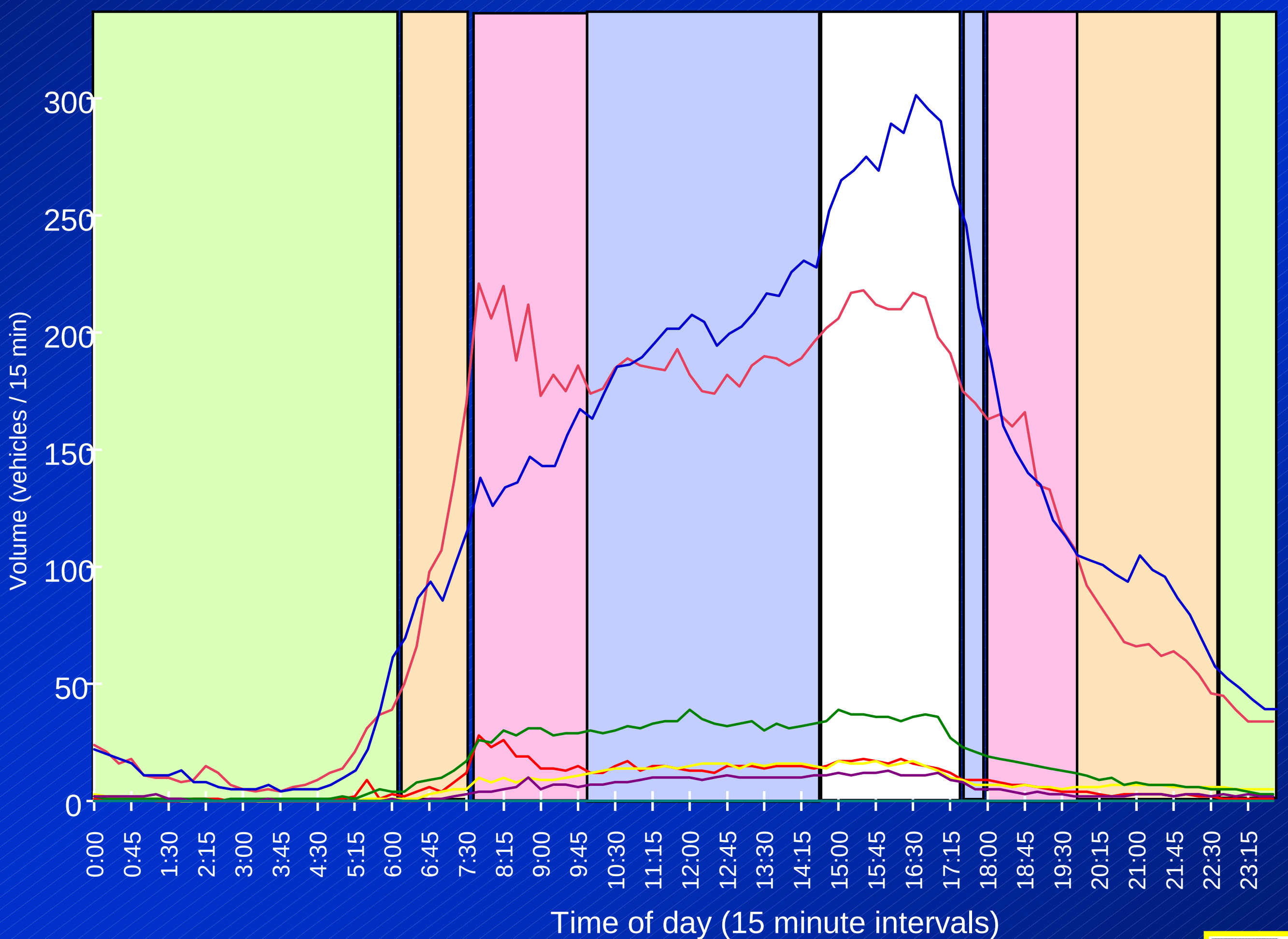
Major Obstacles for Dynamic Traffic Control

- Complexity of the traffic system and traffic flow conditions
- Real-time traffic control
- Self-learning and adaptability
- Implementation

Traffic Demands on Trans Canada Highway
in Duncan Area



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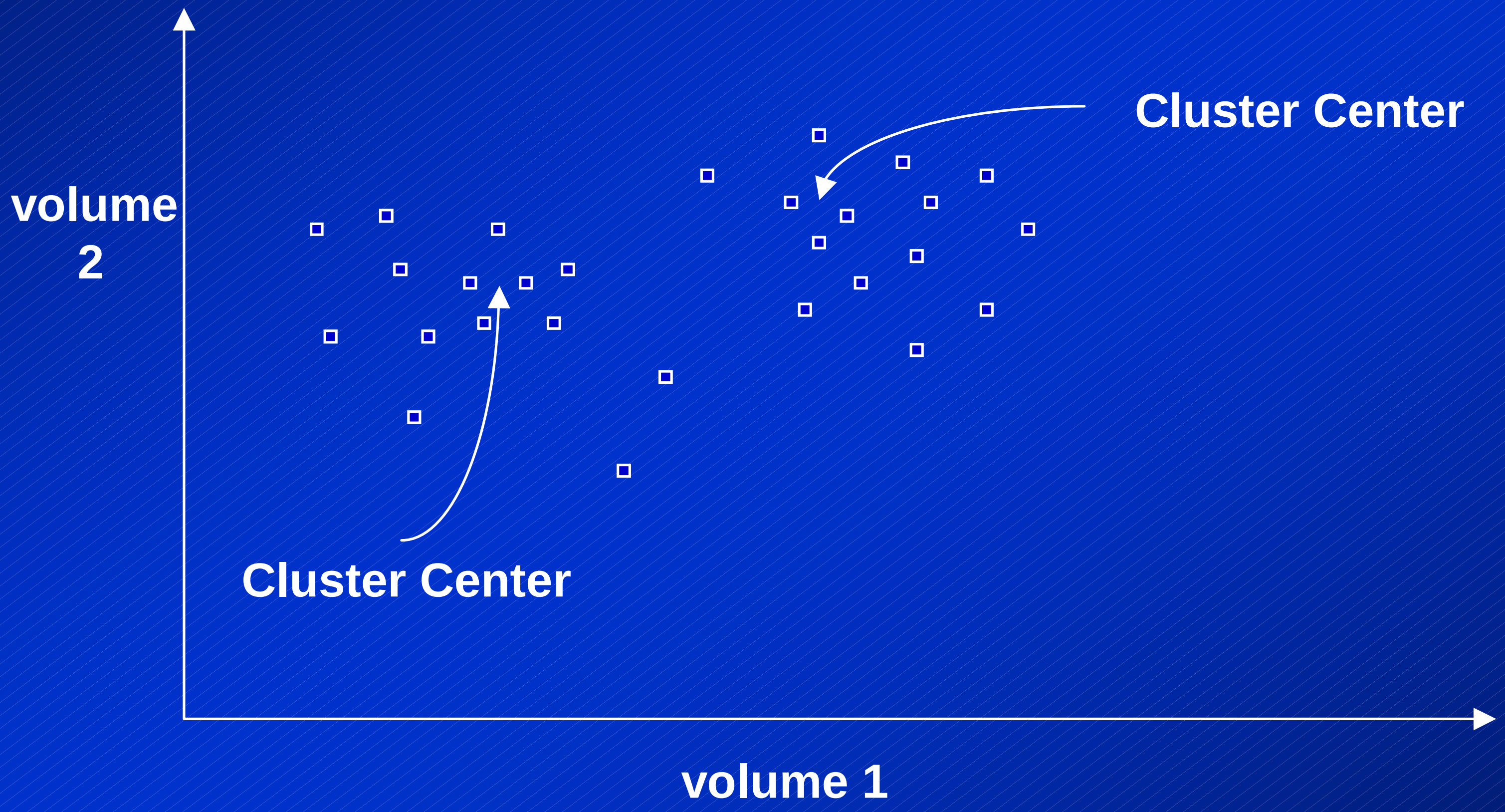
Traffic Volumes in the Traffic State Space



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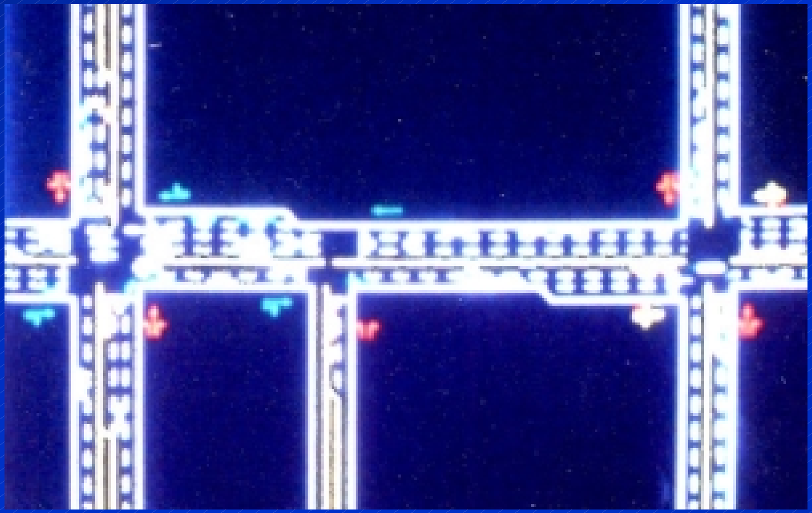
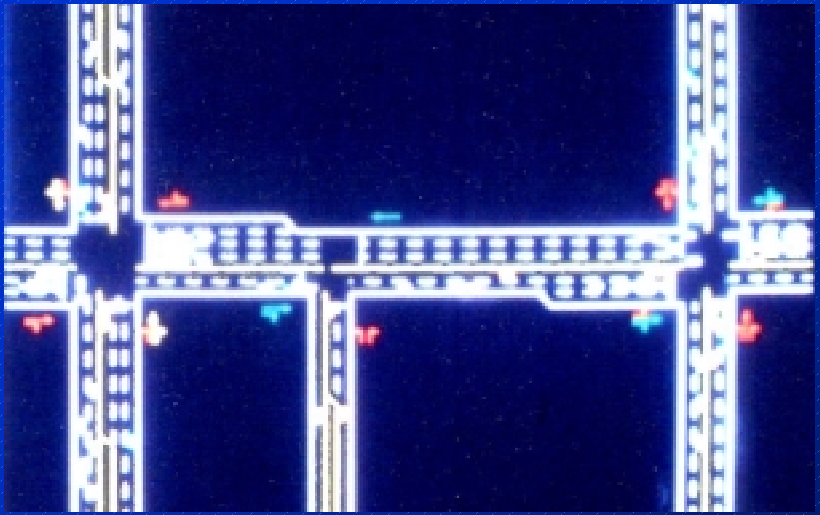
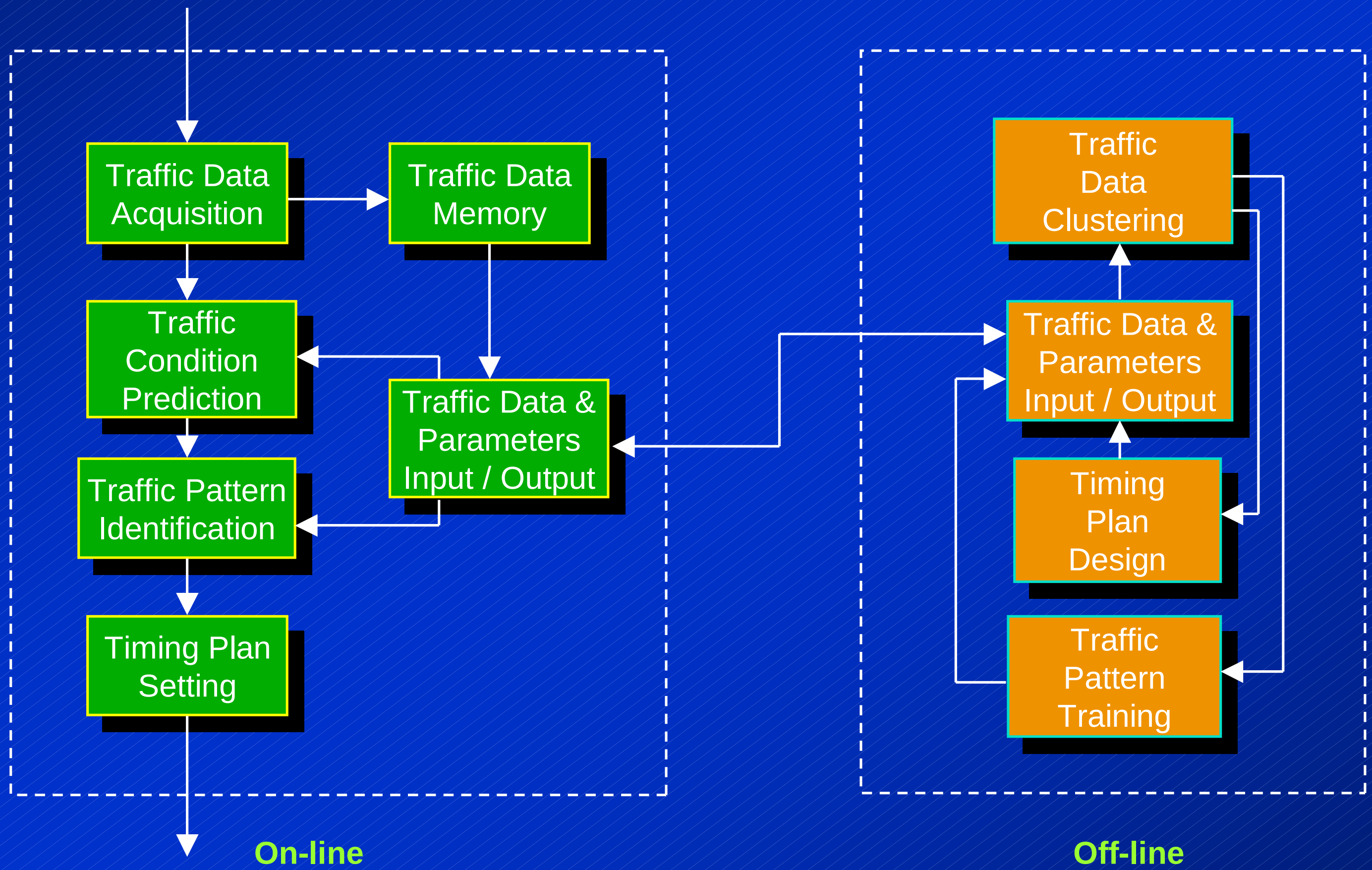
Traffic Timing Plan Design

- Transyt - 7F   (minimizing total delay)
- Passer III (maximizing bandwidth)

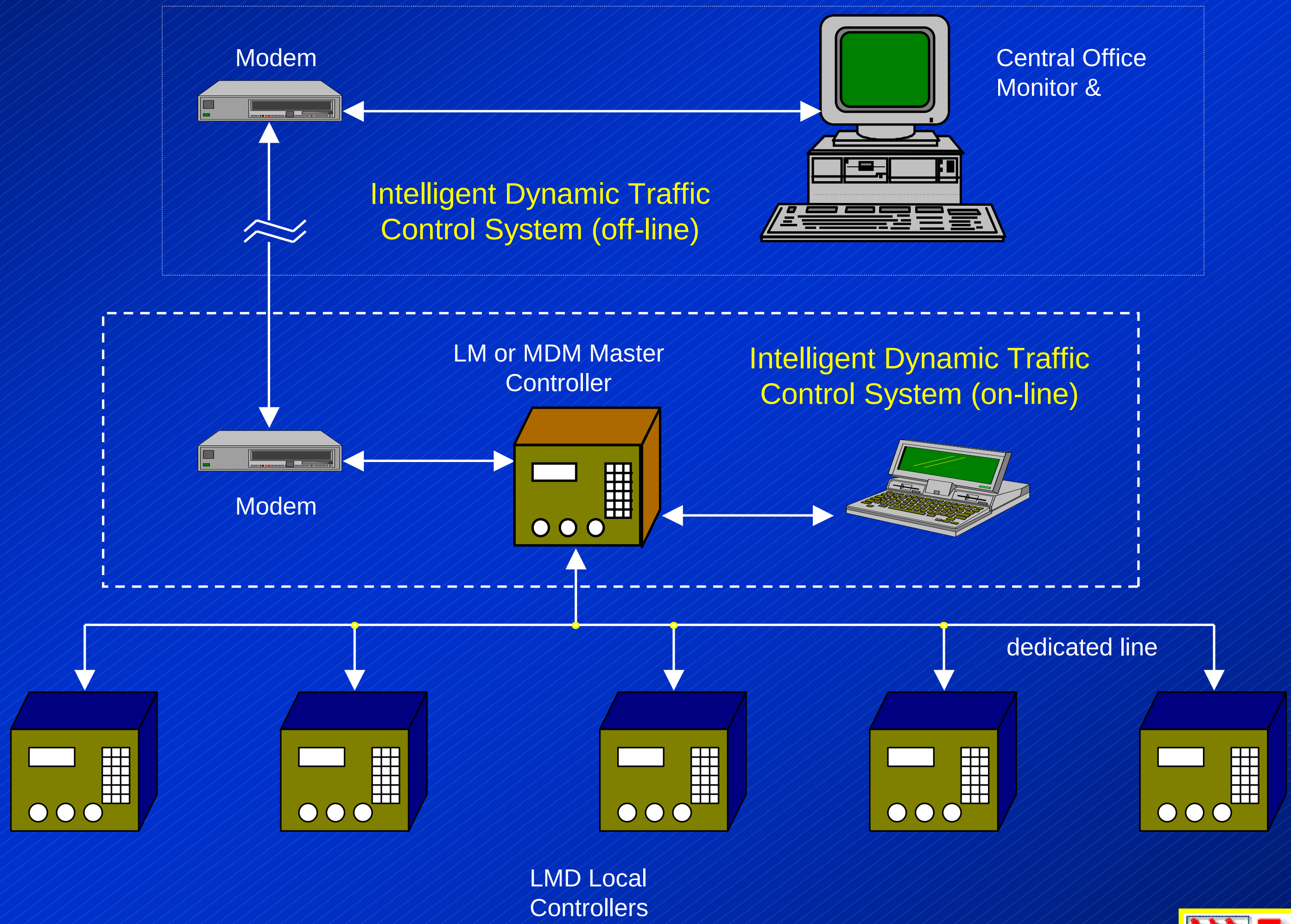




Intelligent Dynamic Traffic Control System Structure (software)



Intelligent Dynamic Traffic Control System



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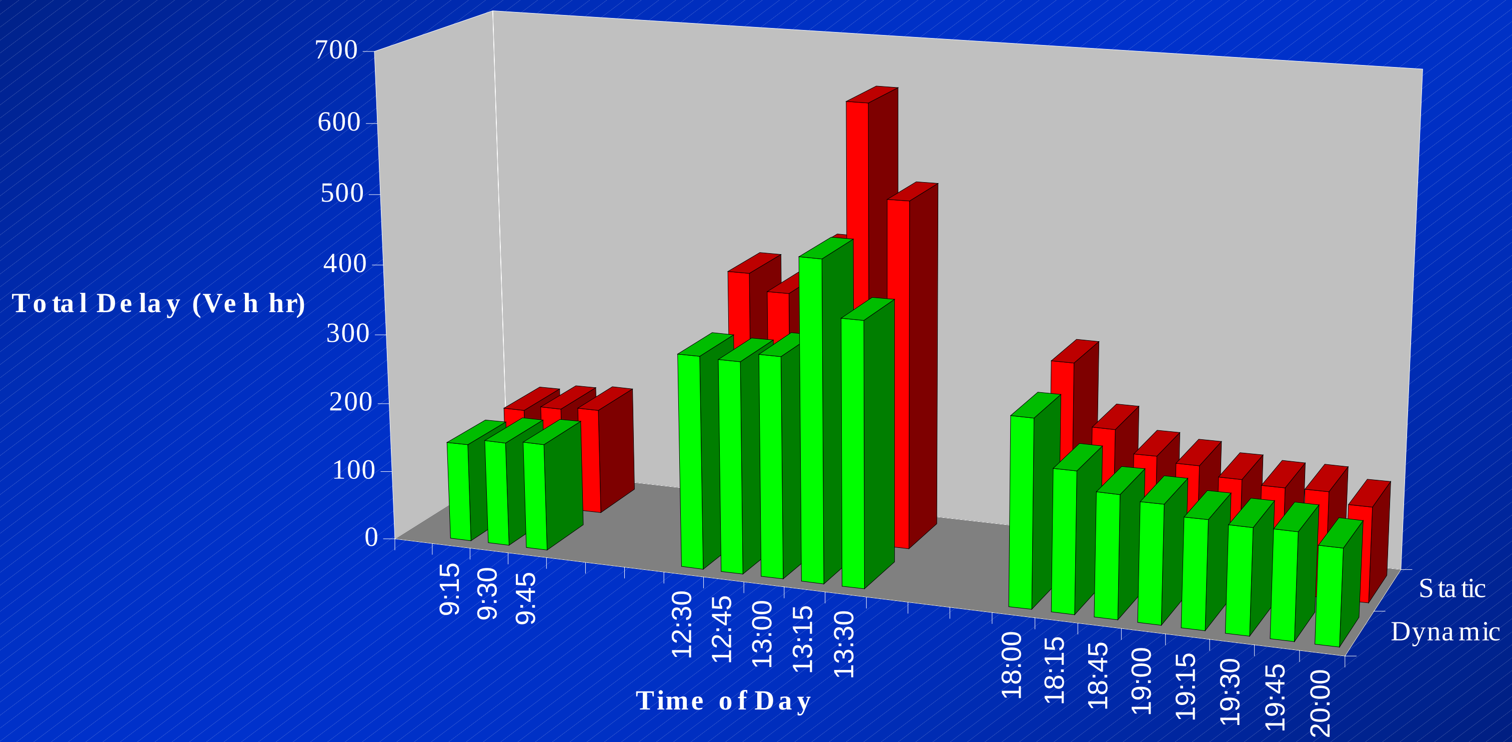
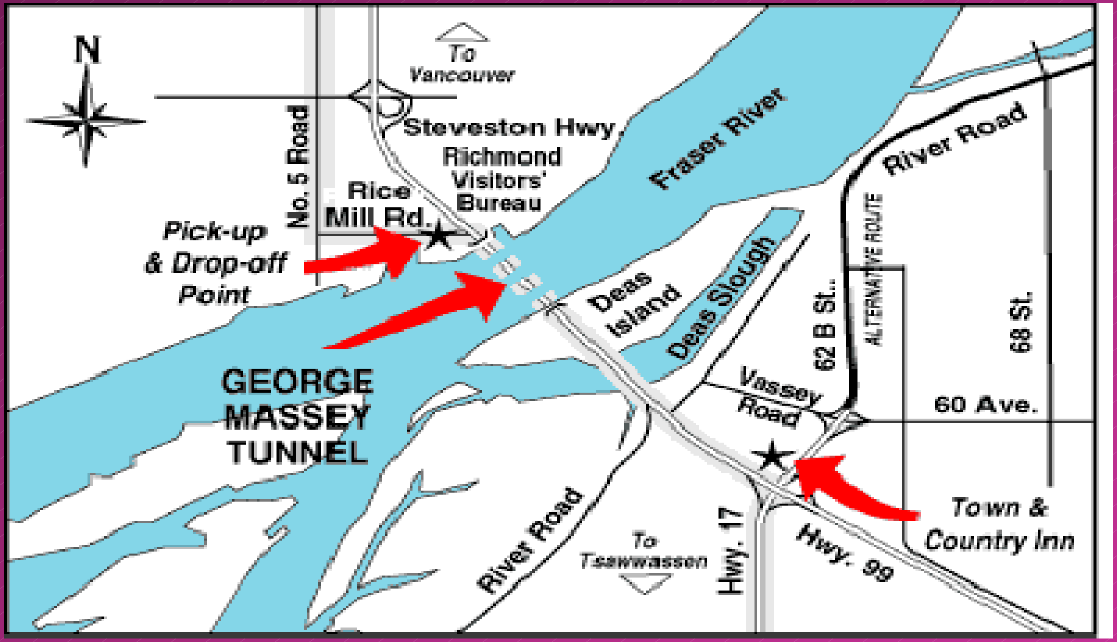
Total Delay of Static and Dynamic Traffic Control



Average Total Traffic Delay Reduction: 5~30%

Real-time Traffic Contra-flow Operation Using Artificial Neural Network, Fuzzy Pattern Recognition and Delay Minimization



D. Xue and Z. Dong

Supported by Ministry of Transportation and Highways of British Columbia

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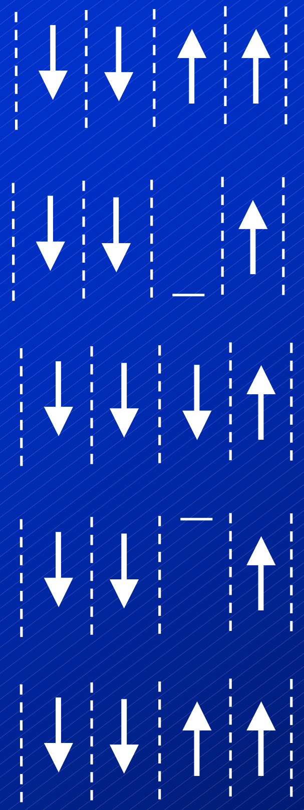
Research Problem

- **Traffic Problems:**
  - Tunnels and bridges are often bottlenecks of a traffic system.
  - Traffic demands from the opposite directions vary periodically.

    ⟹ Contra-flow Operations
- **Contra-flow Control Problem:**
  - Lane switch leads to a temporary capability loss.
  - Difficult to accurately predict future traffic demand.
  - Difficult to handle constantly changing traffic conditions.

A Contra-flow Operation Cycle

- Closing the selected contra-flow lane to clear up the traffic on this lane;
- Opening the contra-flow lane in the opposite direction;
- Closing the contra-flow lane when the traffic peak hours are over; and,
- Re-opening the traffic lane to its normal state.



Traffic Demand Prediction by Pattern Matching

A Traffic Pattern:

$P_i = (P_{i1}, \dots, P_{ip})$ $(i = 1, \dots, c)$

Sample every 5 min for 7 hrs:

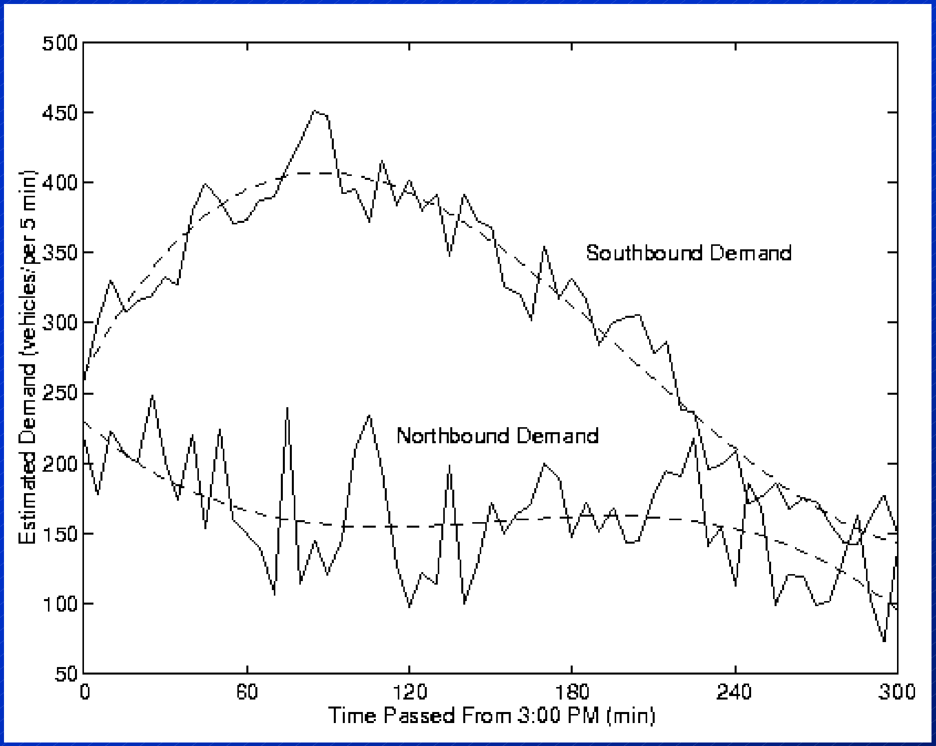
$p = 1 + 7 \times 60/5 = 85$ *samples*

Collected Traffic Data:

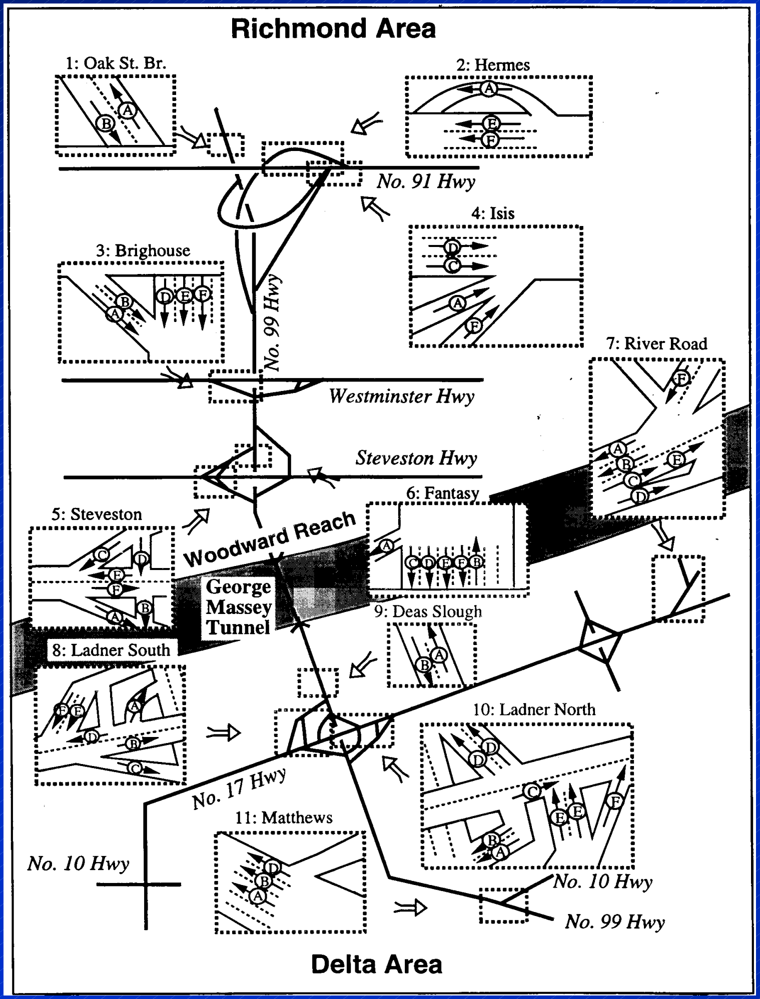
$D = (D_1, \dots, D_q)$ $(q < p)$

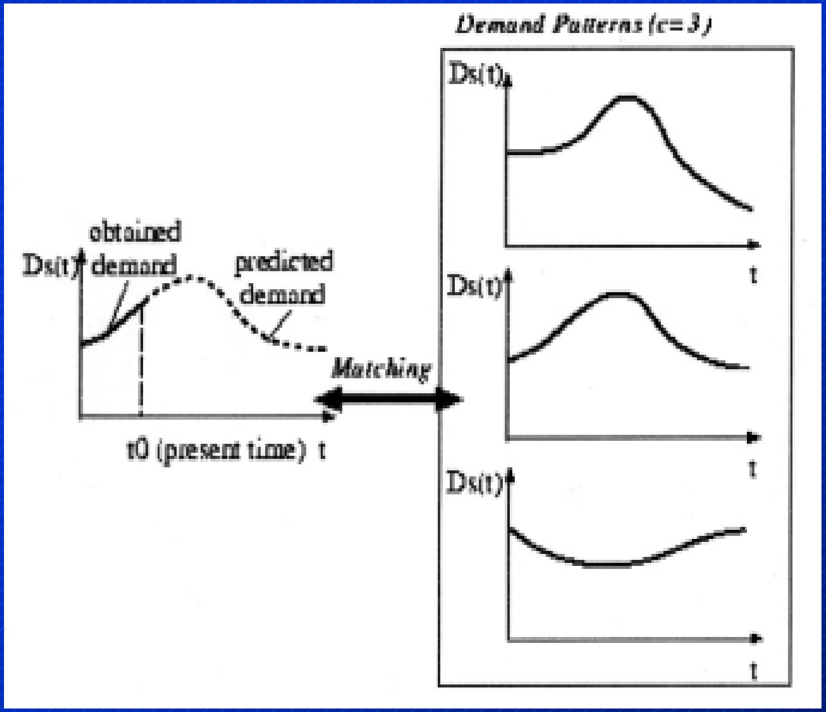
Similarity Measure:

Distance (D, P_i)



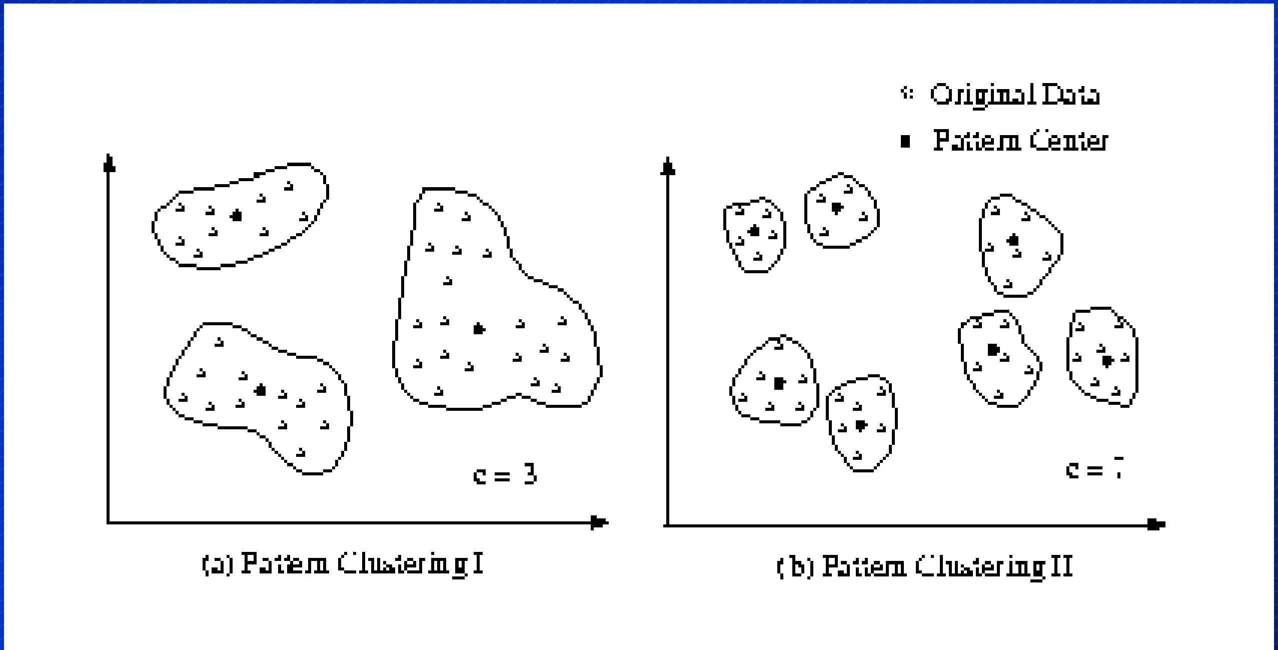
Two Challenging Tasks



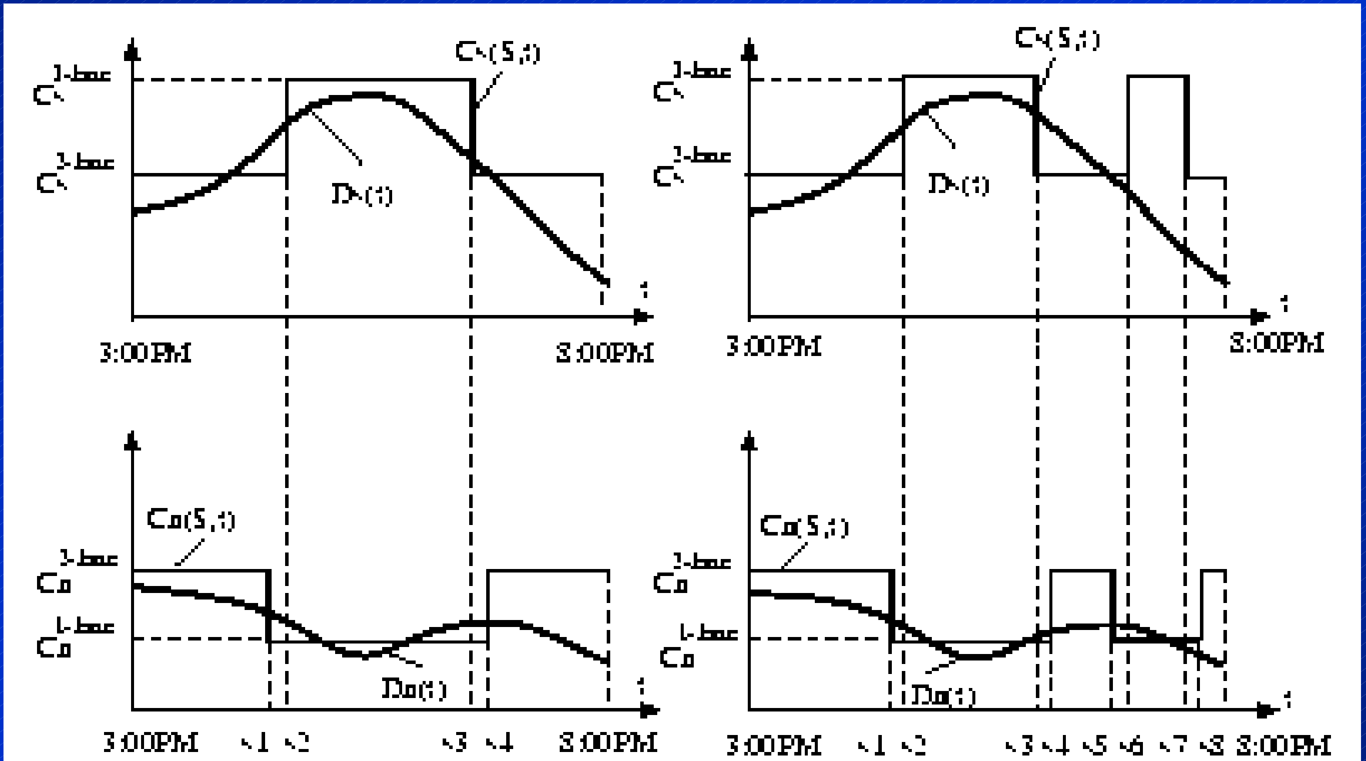


Hierarchical Pattern Representation and Matching

- Improving search efficiency
- Utilizing available heuristics: Mon-Thur, Fri, Weekends/holidays



Traffic Demands and Capacities at the Tunnel Site



(a) One-Shift Contraflow Control (b) Two-Shift Contraflow Control

Traffic Delay Reduction

Table 3: Traffic Delay Measures for Different Schedules

Fixed-time Schedule	2163
On-line Schedule	1416
The Optimal Schedule	948
Improvement of On-line Schedule	34%
Total Room for Improvement	56%

(Unit of Delay: Vehicle-hours)

Proposed System Implemented by the MOT since 1996.

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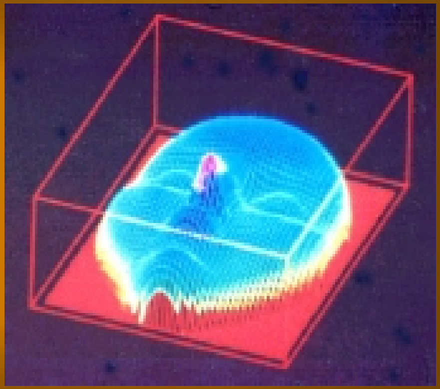

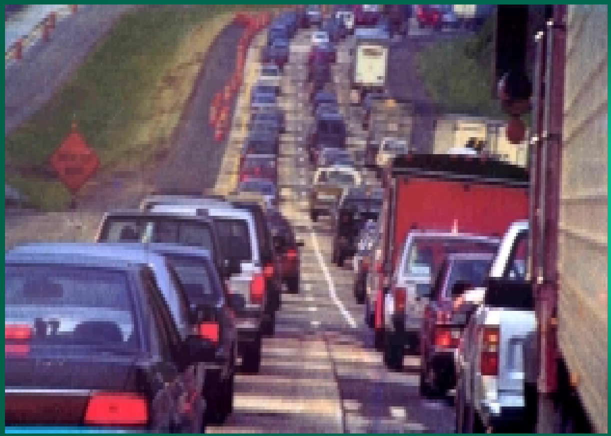

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