# *Evolutionary Algorithms + Domain Knowledge = Real-World Evolutionary Computation*

## *Using Knowledge and Reasoning to Control Search and Vice-versa*

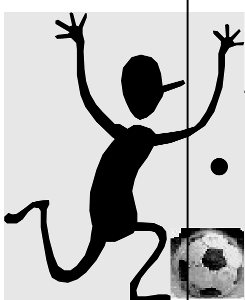
**Piero P. Bonissone**

**GE Global Research Center**

**bonissone@crd.ge.com**

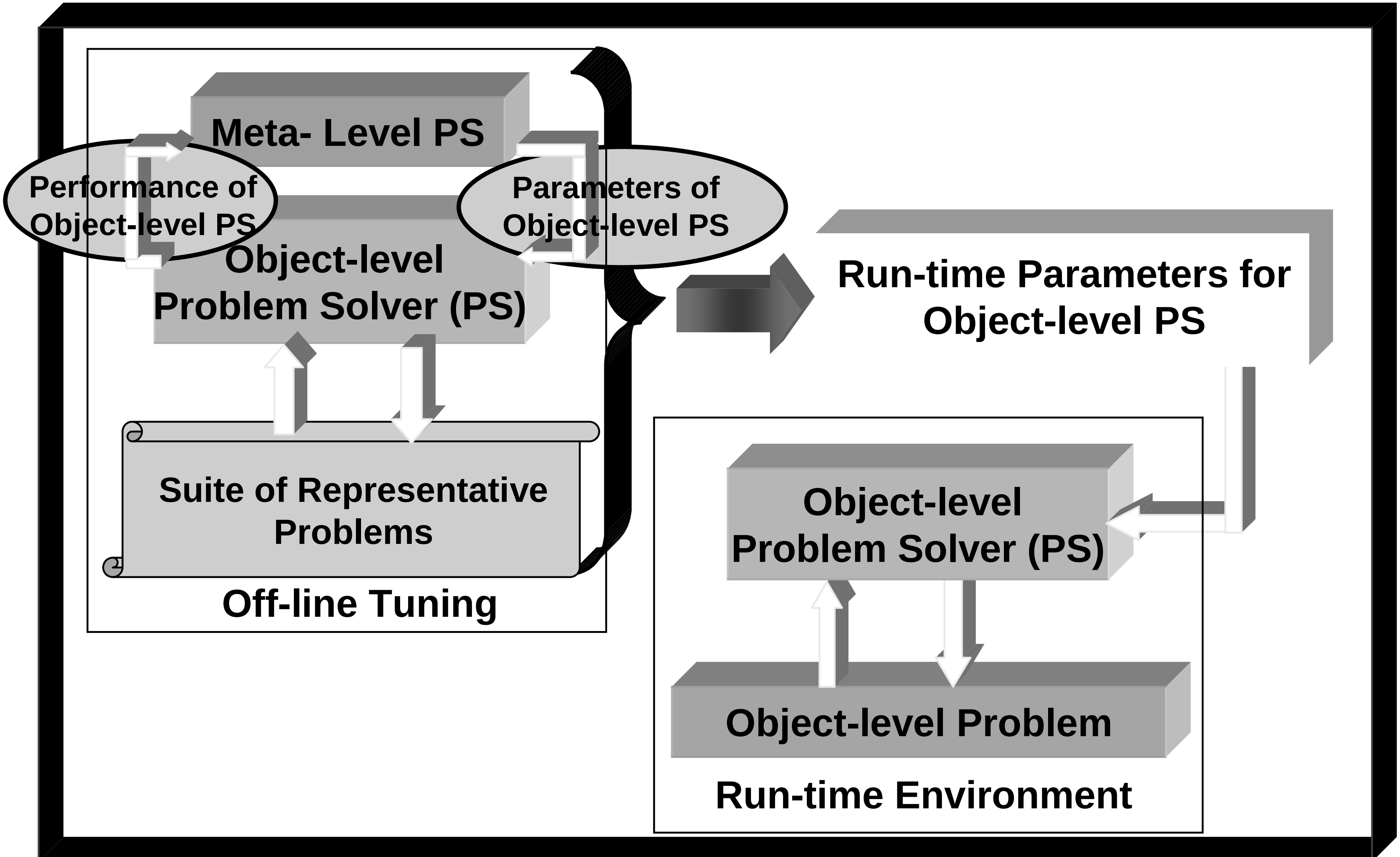
# NFL, Meta-Heuristics & Hybrid SC: Outline

- The NFL
- Tuning or Controlling the Object-Level Problem Solver (PS) with Meta-Heuristics
- Soft Computing Overview
  - SC Components: PR, FL, NN, EA
- Using SC to implement the Meta-Heuristics: Modeling with FL and EA

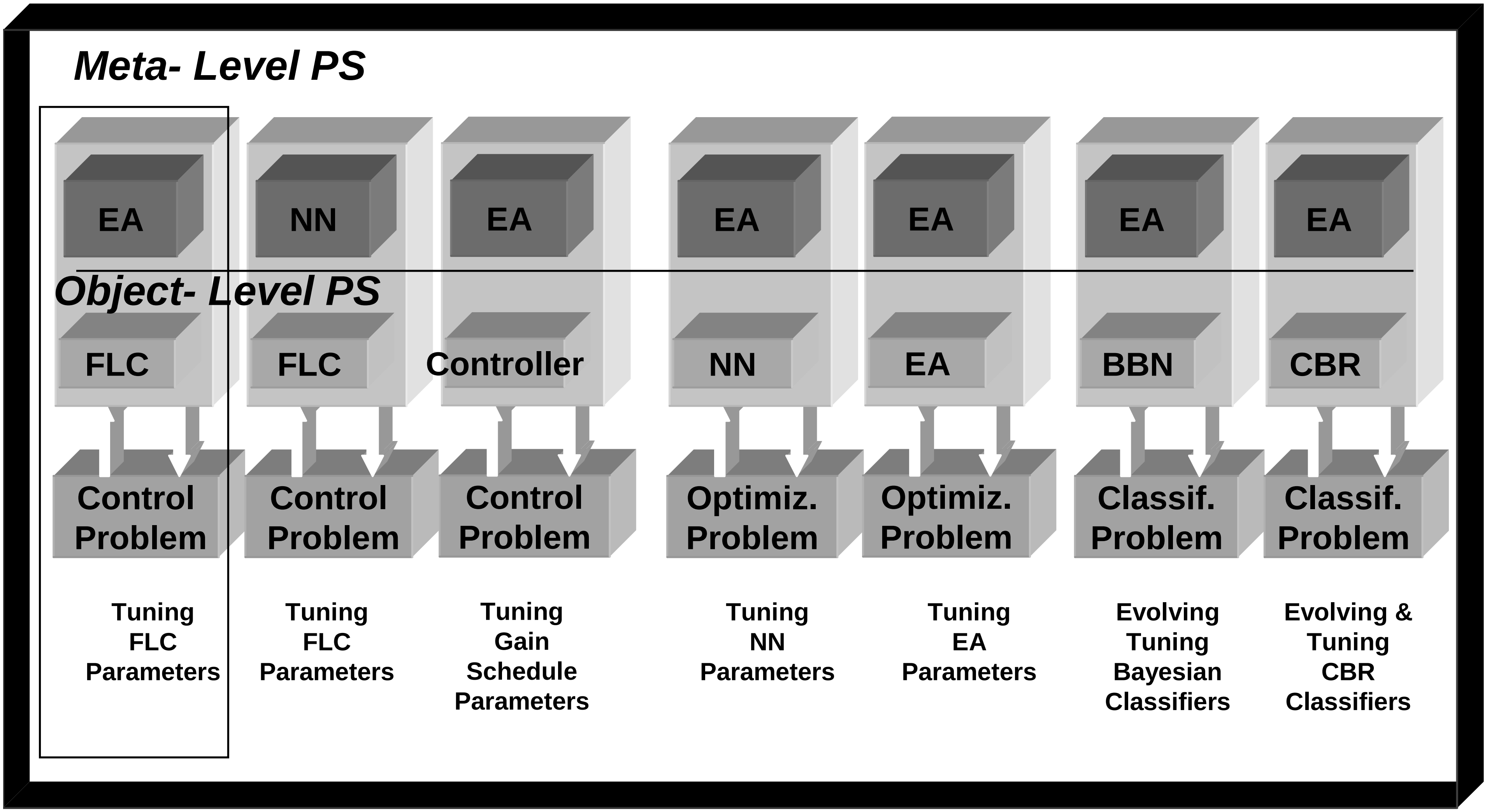


- **Example of Hybrid SC Systems at GE**
  - **FLC Parameter Tuning by EA**
  - FLR and F-CBR Parameter Tuning by EA
  - EA Parameter Setting (by EA) or Control (by FL)
- Conclusions

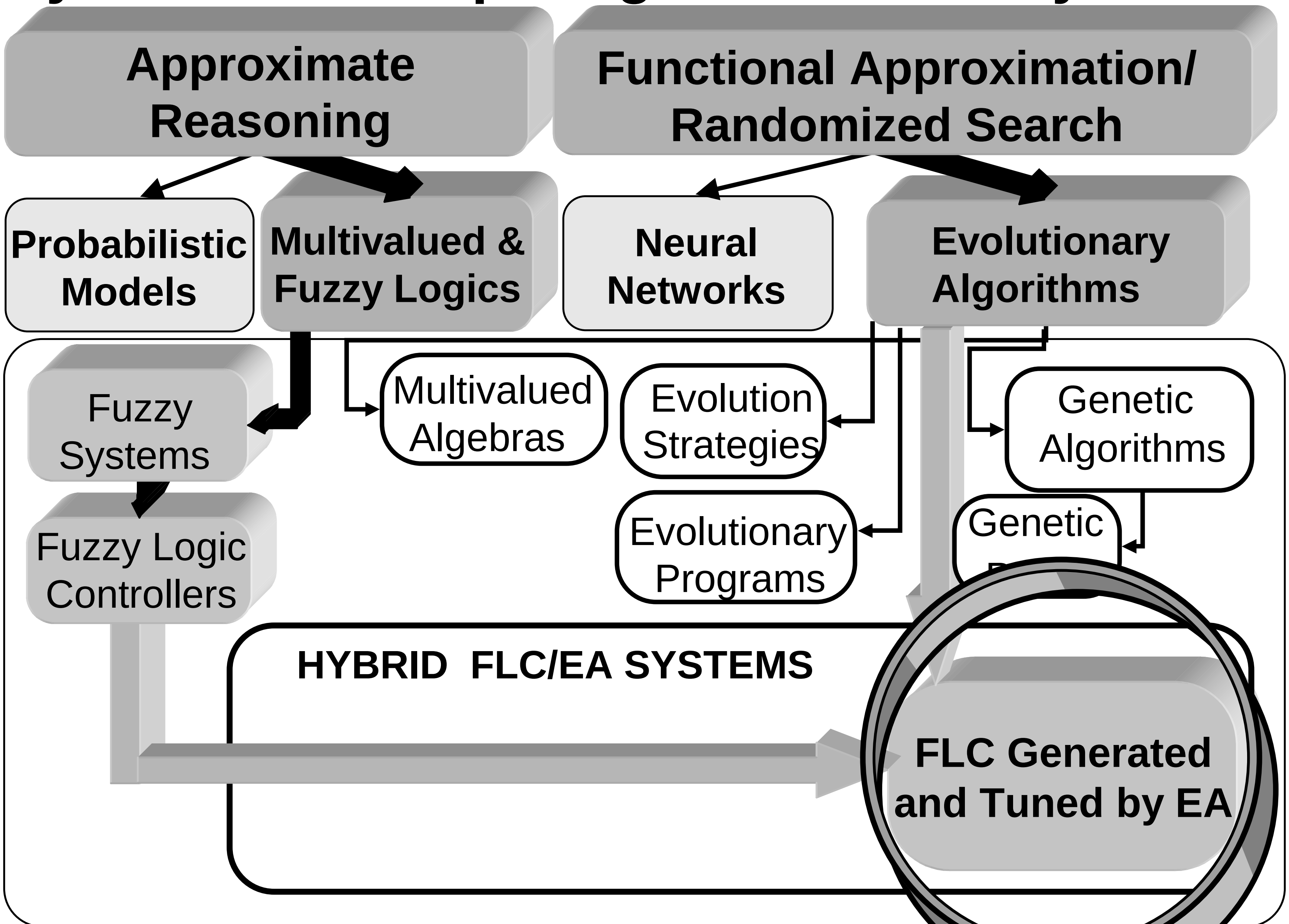
# Off-line Meta-Heuristics



# Examples of Off-line Meta-heuristics



# Hybrid Soft Computing: FLC Tuned by EAs



# FLC Tuned by EA - Outline

- Components & Historical Approaches
- Application to Automatic Train Handling (ATH)
- Solution Architecture
- Analysis of Results
- Remarks

# FL Controllers Tuned by EAs

- **FLC**
  - **FLC = KB + Inference Engine (with Defuzz.)**
  - **KB parameters:**
    - » Scaling factors (SF)
    - » Membership Functions (MF)
    - » Rule set (RS)
- **EA**
  - Encoding: binary or real-valued
  - Chromosome: string or table
  - Fitness function: Sum quadratic errors, entropy
  - Operators: one-point crossover, max-min arithmetical crossover, point-radius crossover.

# FL Controllers tuned by EAs (cont.)

- **Historical Approaches:**
  - **Karr 91-93:**
    - » Chromosome = concatenation of all termsets.
    - » Each value in a termset was represented by 3 binary-encoded parameters.
  - **Lee & Takagi 93:**
    - » Chromosome = 1 TSK rule (LHS: memb. fnct. RHS pol.)
    - » Binary encoding of 3-parameter repr. of each term
  - **Surman et al: 93:**
    - » Fitness function with added entropy term describing number of activated rules

# FL Controllers tuned by EAs (cont.)

- **Historical Approaches (cont.):**
  - **Kinzel et al. 94:**
    - » Chromosome = Rule Table
    - » Point-radius crossover changing 3x3 rule window (similar to a two-point crossover for string representation)
    - » Order of tuning:
      - – Initialize rulebase according to heuristics
      - – Apply GAs to find best rule table
      - – Tune membership function of best rule set
  - **Herrera et al. 95:**
    - » Chromosome = concatenation of all rules
    - » Real-valued encoding, Max-min arithmetical crossover

# SC in Train Handling: An Example

- **Problem Description:** ***Automated Train Handling***
  - **Control a massive, distributed system with little sensor information**
  - **Freight trains consist of several hundred heavy railcars connected by couplers (train length up to two miles)**
  - **Couplers have a dead zone and a hydraulically damped spring, causing railcars to move relative to each other and train length to change by 50 – 100 ft.**
  - **The position of the cars and couplers cannot be electronically sensed**

# SC in Train Handling: An Example

- **Solution Requirements**
  - An automated system has to satisfy multiple goals:
    - Tracking a velocity reference (defined over distance) to enforce speed limits and respect the train schedule
    - Providing a degree of train-handling uniformity across all crews
    - Operating the train in fuel-efficient regimes
    - Maintaining a smooth ride by avoiding sudden accelerations or brake applications (slack control)

**Multi-body regulation problem,
subject to proper slack management,
without sensors for most of the state**

# SC in Train Handling: An Example

- **Description of Our Approach**
  - Use a Velocity Profile externally generated (using classical optimization or Evolutionary Algorithms)
  - Use a Fuzzy Logic Control (FLC) to track the velocity reference (Fuzzy PI Control)
  - Use an Evolutionary Algorithms to tune the FLC parameters to minimize velocity tracking error and number of throttle changes
  - Implement control actions with fuzzy rule set to maintain slack control

# FLC tuned by EAs: Our Approach

- **Chromosome (real-valued encoding)**
  - Chr. 1 = Scaling factors;
  - Chr. 2 = Termsets;
  - Chr. 3 = Rules (not used)
- **Order of tuning (as in Zheng '92):**
  - Initialize rulebase with standard PI structure and termsets with uniformly distributed terms
  - Apply EAs to find best scaling factors
  - Apply EAs to find best termsets
  - Apply EAs to find best rule set (not used)
- **Transition from large to small granularity**

# FLC Sensitivity to Parameter Changes

**Changing a Scaling Factor**

| X1 | | | X2 | | |
|---|---|---|---|---|---|
| | *Very Low* | *Low* | *Medium* | *High* | *Very High* |
| *Very Low* | PH | PH | PM | PL | ZE |
| *Low* | PH | PM | PL | ZE | NL |
| *Medium* | PM | PL | ZE | NL | NM |
| *High* | PL | ZE | NL | NM | NH |
| *Very High* | ZE | NL | NM | NH | NH |

**Changing a Term in X1**

| X1 | | | X2 | | |
|---|---|---|---|---|---|
| | *Very Low* | *Low* | *Medium* | *High* | *Very High* |
| *Very Low* | PH | PH | PM | PL | ZE |
| *Low* | PH | PM | PL | ZE | NL |
| *Medium* | PM | PL | ZE | NL | NM |
| *High* | PL | ZE | NL | NM | NH |
| *Very High* | ZE | NL | NM | NH | NH |

**Changing a Rule**

| X1 | | | X2 | | |
|---|---|---|---|---|---|
| | *Very Low* | *Low* | *Medium* | *High* | *Very High* |
| *Very Low* | PH | PH | PM | PL | ZE |
| *Low* | PH | PM | PL | ZE | NL |
| *Medium* | PM | PL | ZE | NL | NM |
| *High* | PL | ZE | NL | NM | NH |
| *Very High* | ZE | NL | NM | NH | NH |

# Architecture: Modules, Fitness Funct.

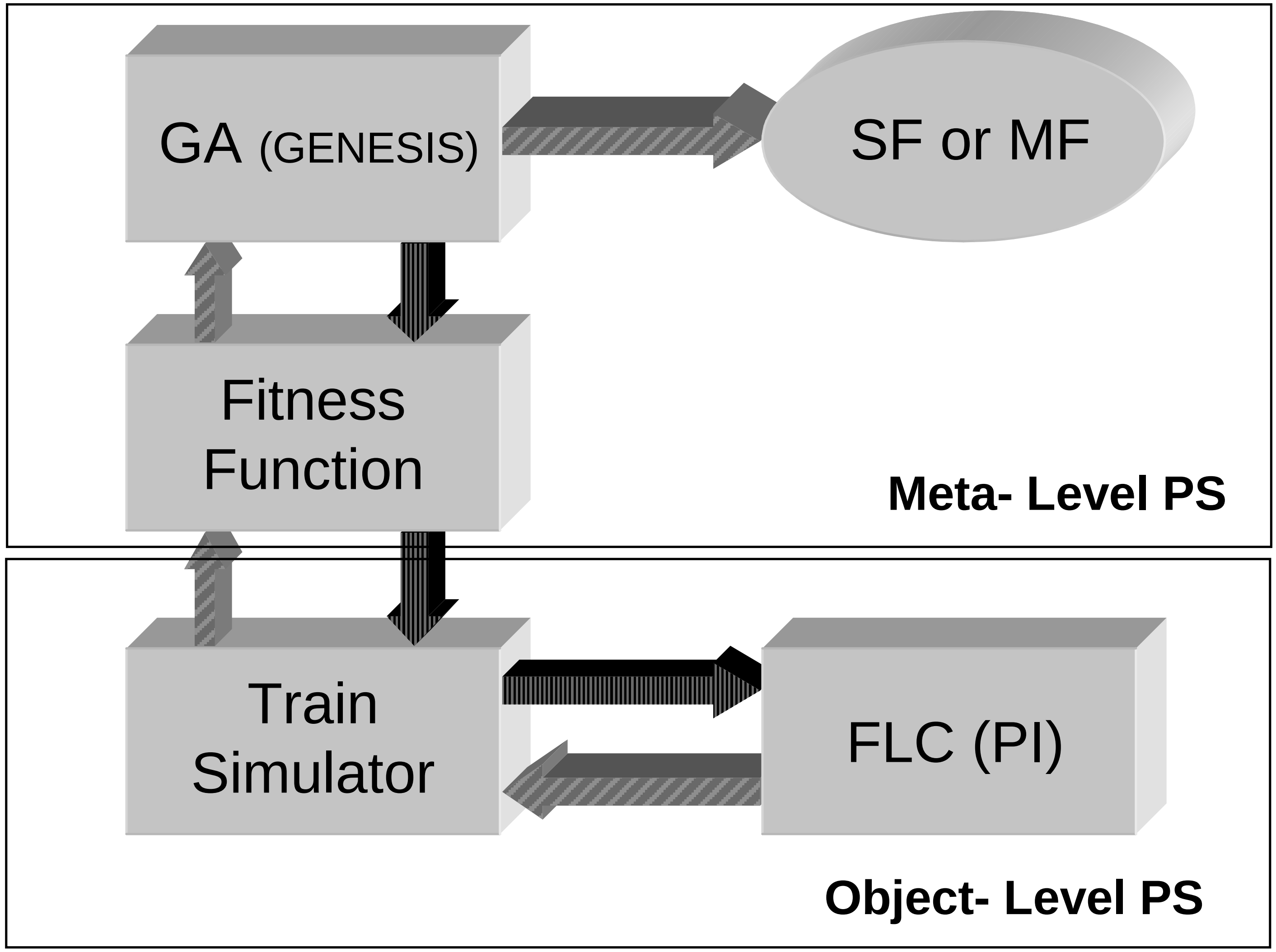
- **Architecture**
  - EA: pop.size=50; P(cross)=.6; P(mut)=.001
  - Three Types of fitness functions
  - Train Simulator: NSTD (STD+TEM)
  - Fuzzy PI (Ke, Kedot, K$\Delta$u)
- **Fitness functions ($f_1$, $f_2$, $f_3$)**

$$f_1 = \min\left(\sum_i |notch_i - notch_{(i-1)}| + |dynbrake_i - dynbrake_{(i-1)}|\right)$$

$$f_2 = \min\left(\sum_i |v_i - v_i^d|\right)$$

$$f_3 = \min\left(w_1 \frac{\sum_i |notch_i - notch_{(i-1)}|}{K_1} + w_2 \frac{(\sum_i |v_i - v_i^d|)}{K_2}\right.$$

# FLC tuned by GAs



# Experiment Design

- 12 test (4 for each fitness function)
  - Initial SF with initial MF;
  - EA tuned SF with Initial MF
  - Initial SF with EA tuned MF;
  - EA tuned SF with EA tuned MF
- Train Simulation:
  - 14 miles long flat track
  - 1 uniformly heavy train with 100 cars and 4 locomotives
  - Analytically computed velocity profile

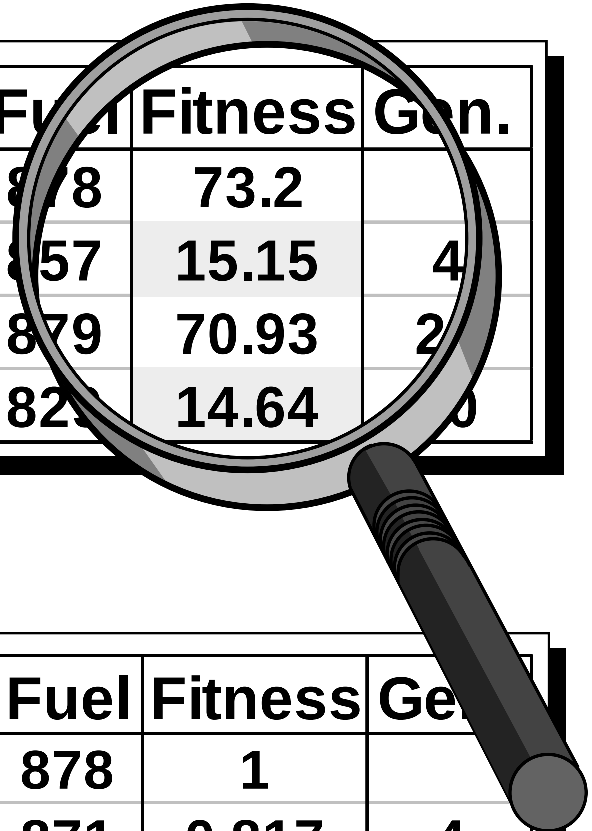
# Experiment Design

- **Representation:**
  - **SF: 3 floating point values for Ke, Kedot, K$\Delta$u**
  - **MF (21-9) = 12 values**
    - » 21 parameters: [($Left_i$ ,$Center_i$ , $Right_i$ ) for i=1, ..., 7]
    - » 9 dependent values: [($Left_i$ = $Right_{(i+1)}$) for i=1, ..., 6]
      + [$Center_1$= $Center_7$]+[$Right_1$ = $Left_7$ = 0]
  - **Constraints to maintain 0.5 terms overlap, for best interpolation**

# Experiments Results

- **Experiment Results with $f_1$**

| Description | Time | Journey | Fuel | Fitness | Gen. |
|---|---|---|---|---|---|
| Initial SF; Initial MF | 26.5 | 14.26 | 878 | 73.2 | |
| EA tuned SF; Initial MF | 27.8 | 14.21 | 857 | 15.15 | 4 |
| Initial SF; EA tuned MF | 26.00 | 14.18 | 879 | 70.93 | 2[illegible] |
| EA tuned SF; EA tuned MF | 28.3 | 14.12 | 82[illegible] | 14.64 | [illegible]0 |



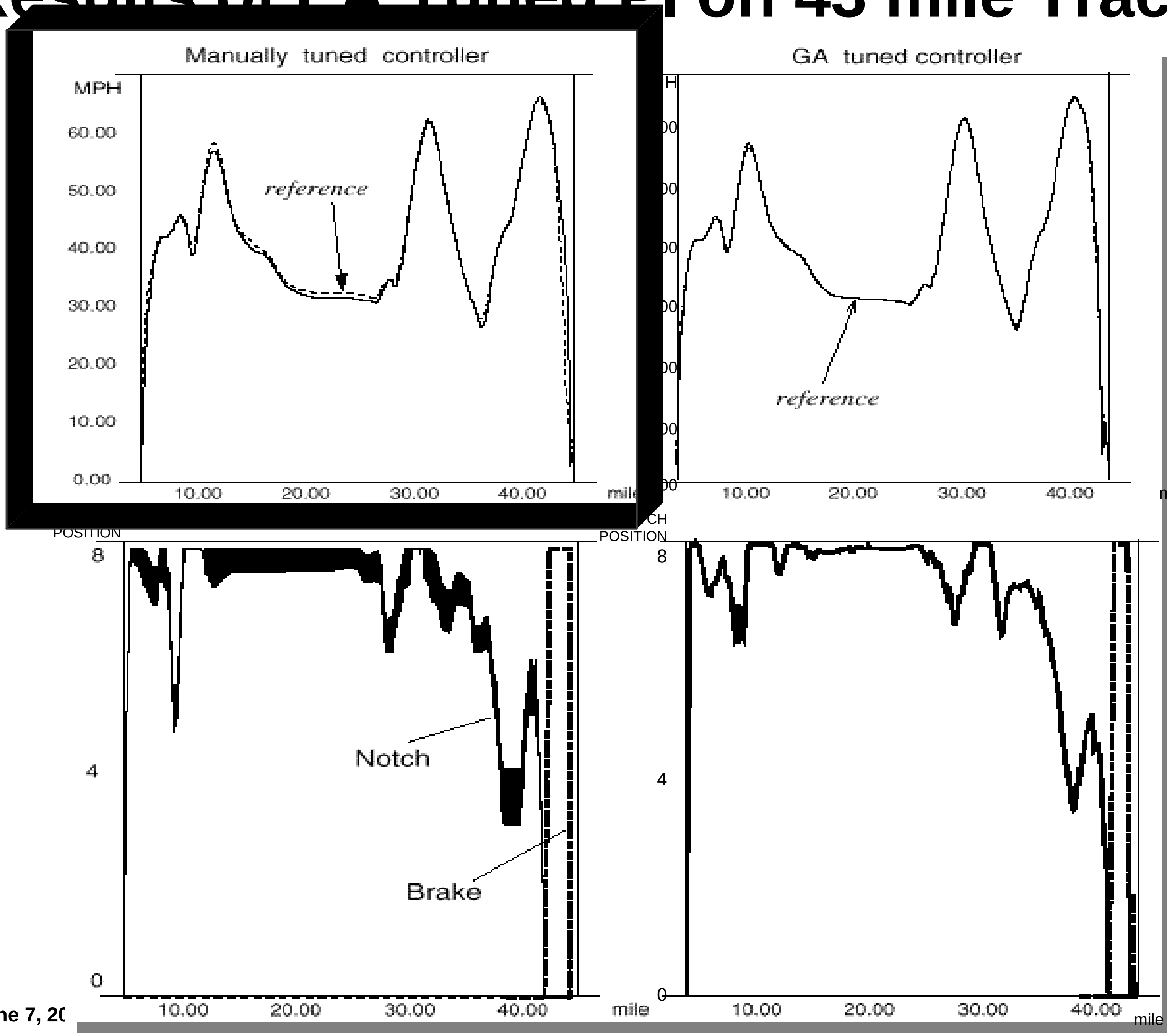
- **Experiment Results with $f_3$**

| Description | Time | Journey | Fuel | Fitness | Gen. |
|---|---|---|---|---|---|
| Initial SF; Initial MF | 26.5 | 14.26 | 878 | 1 | |
| EA tuned SF; Initial MF | 27.2 | 14.35 | 871 | 0.817 | 4 |
| Initial SF; EA tuned MF | 26.26 | 14.18 | 871 | 0.942 | 20 |
| EA tuned SF; EA tuned MF | 27.3 | 14.35 | 872 | 0.817 | 10 |

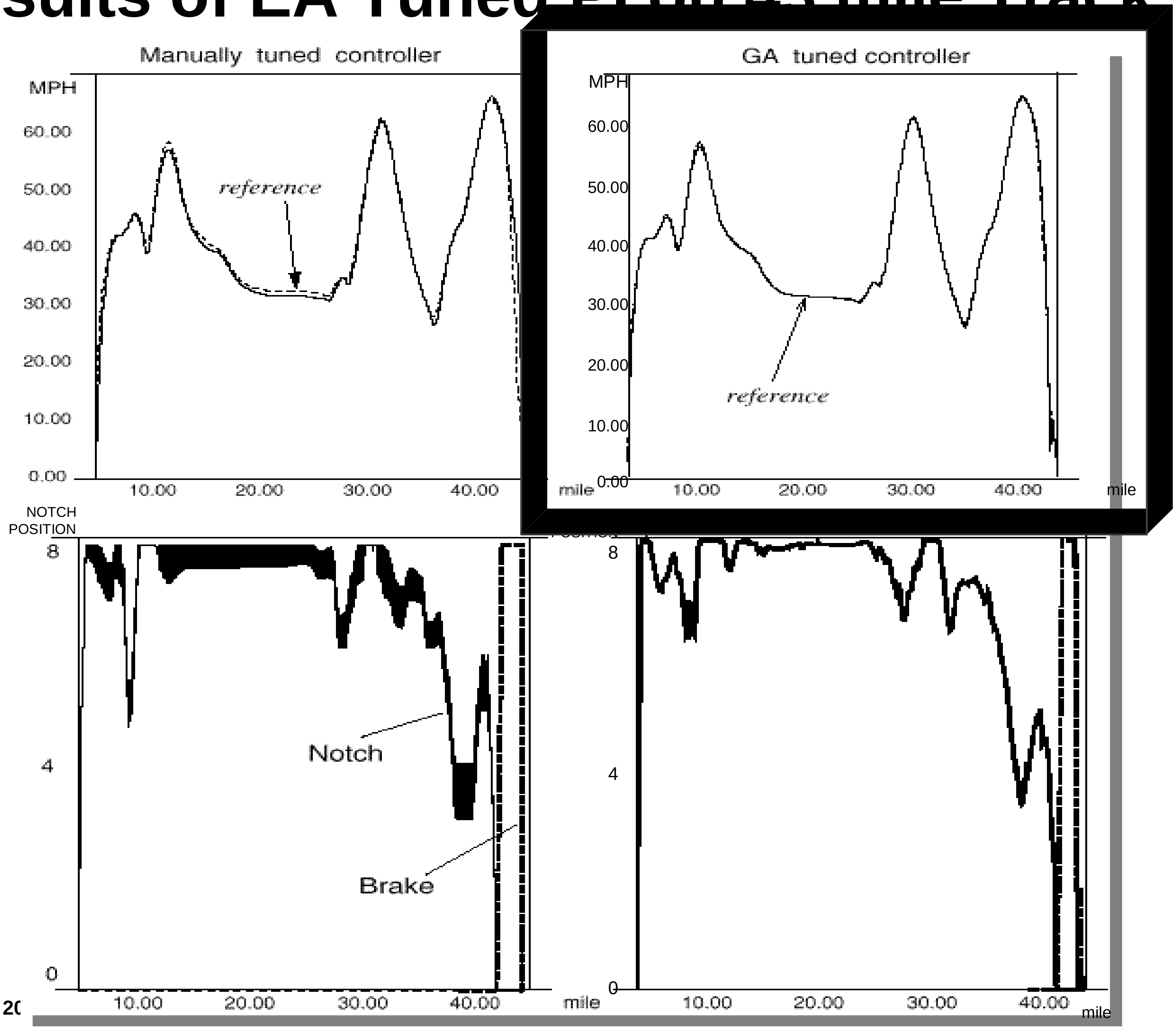
# Tuning of FLC with EA: Remarks

- Verified tuning order proposed by Zheng (92)
  - » SF tuning: major impact
  - » MF tuning: minor impact
  - » RS tuning: almost no impact
- For both f1 and f3, fuel minimization is implicitly derived from throttle jockeying minimization
- Complex fitness function (requiring simulation run - 23 sec for each chromosome evaluation) limited trials number - with no apparent impact
- Successfully tested on simulated 43 mile long track with altitude excursions
  - » (Selkirk, NY->Framingham, MA)

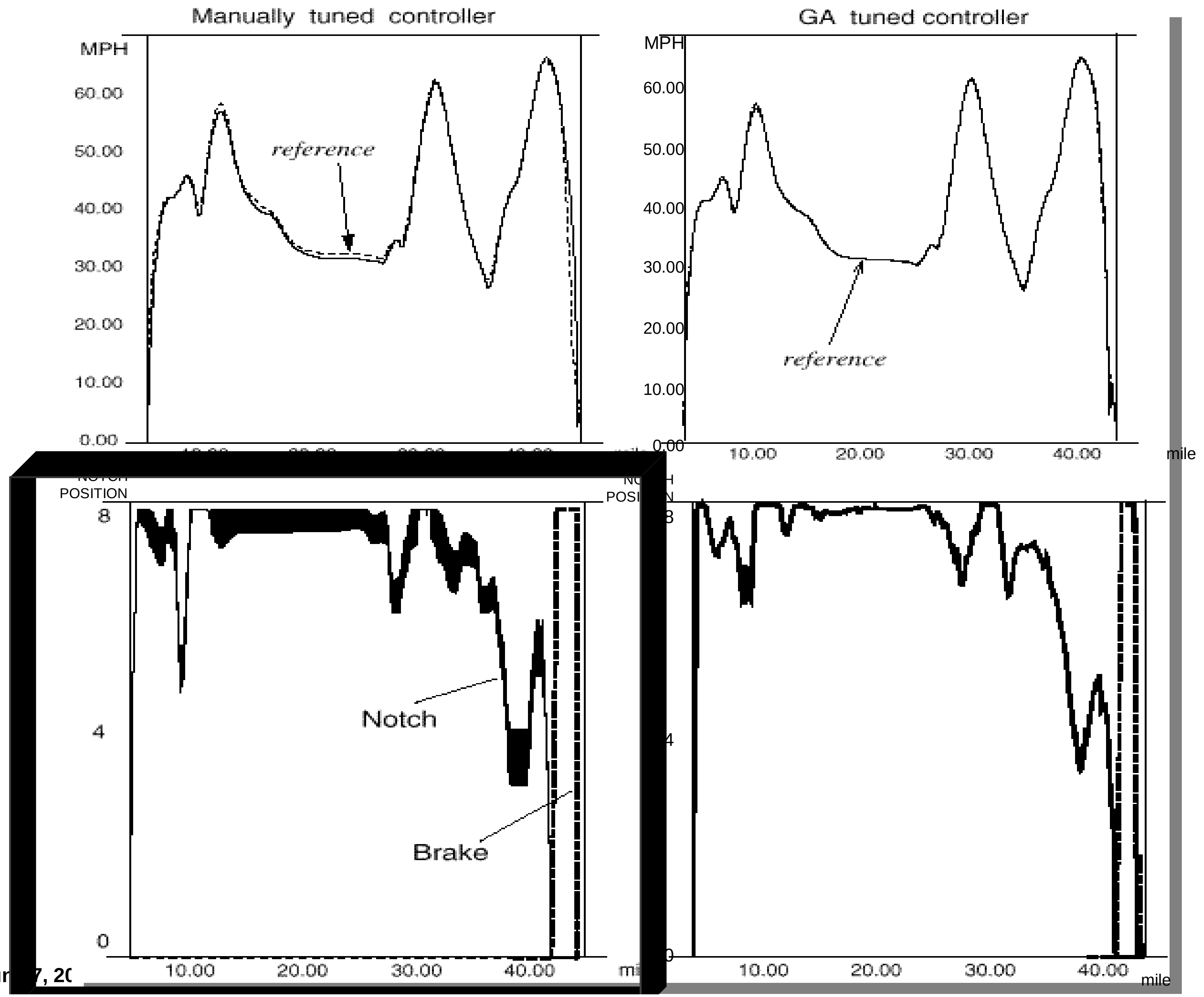
# Results of EA Tuned PI on 43 mile Track



# Results of EA Tuned PI on 43 mile Track



# Results of EA Tuned PI on 43 mile Track



# Results of EA Tuned PI on 43 mile Track