

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



# Improvement of Automatic Train Operation Using Enhanced Predictive Fuzzy Control Method

Mohammad Ali Sandidzadeh and Babak Shamszadeh  
*School of Railway Engineering, Iran University of Science and Technology  
Iran*

## 1. Introduction

Today traffic is one of the chief concerns in many countries and large cities. Development of public transportation is one of the key and vital solutions to this concern. Without paying enough attention to proper public transportation it becomes almost impossible to solve this issue. As a result, transportation is considered to be a development index throughout the world, and railway transportation is considered to be one of its most important and vital forms. Easy access, short waiting times, fast and comfortable trips, high safety and artistic design are all important factors in attracting more passengers to use public transportation. Recent public transportation systems move toward fully automatic operations with the least possible human interferences, so that a safer and more economic system is provided for passengers. Automatic Train Operation (ATO) plays an important role in this.

The most important role of ATO is controlling a train's movement between two stations. ATO strategy must be in such a way that it provides passenger comfort, accurate stop gap and energy saving while also adhering to the punctual schedule. Therefore the mentioned items are considered as evaluation indices of the control system. From a control point of view, ATO system has the following characteristics:

- The resolution of input data (such as velocity data) is low
- Attributes of control devices (such as brakes) are time-variant
- Route conditions such as gradient and altitude are functions of location. In other words, the power consumed in tractions and brakes alters according to the location of train.
- Evaluation indices of control system are multi-dimensional and include passenger comfort, safety, etc...

Provided that evaluation indices of control method are multi-dimensional and considering above mentioned attributes, we are facing a non-linear system with specific conditions and for controlling this system we need a suitable control method. One known method is to use PID controller to follow a target movement curve [9]. Other techniques include valuable works of Yasunobo et. al. that have created a suitable control method by means of a predictive fuzzy control which samples a skilled human operator's riding habits [1,2]. In

this method, a skilled operator's strategy for train movement is used. At first, the operator's strategy is extracted in forms of sentences and then by using fuzzy and predictive control this strategy is implemented. For this purpose, passenger riding comfort, trip time, energy saving, traceability of target curve and accurate stop gap indices are defined in forms of fuzzy membership functions. Driving strategies are written as fuzzy rules. Also by modeling the real system, necessary predictions are made.

In this paper, train movement control is divided into two phases. The first phase is called constant speed control which is from the start position of the train and continues up to the point where the train enters automatic stop zone. In this phase before reaching the mentioned point, the train goes into coasting mode and coasting point is selected smartly by ATO system according to line's situation. The second phase which is called automatic train stop control has responsibility of adjusting precise train velocity until the train accurately and completely stops.

## 2. Modeling the train and automatic train operation system

ATO is a sub-system of Automatic Train Control (ATC) system. Figure 1 shows ATO system structure and its sub-systems.

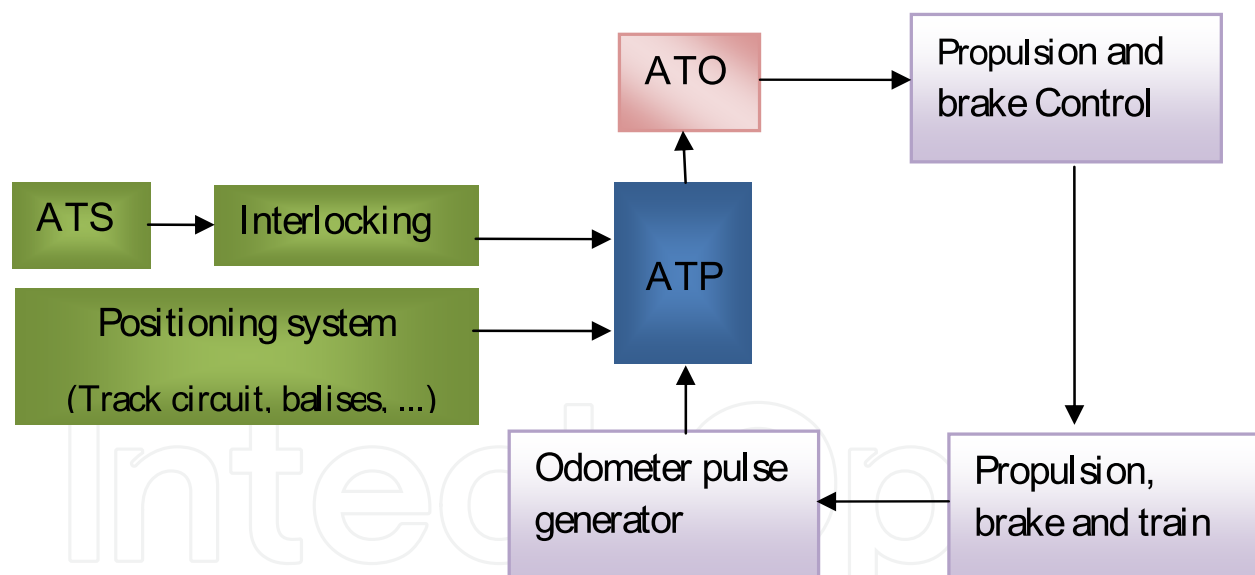


Fig. 1. ATO System Structure

According to figure 1, ATO inputs consist of:

- Distance pulses that come from speedometer or tacho-generator
- Train position marker detection signals that come from wayside equipments
- Supervisory commands that come from Automatic Train Supervision

A model of ATO system is presented in figure 2:

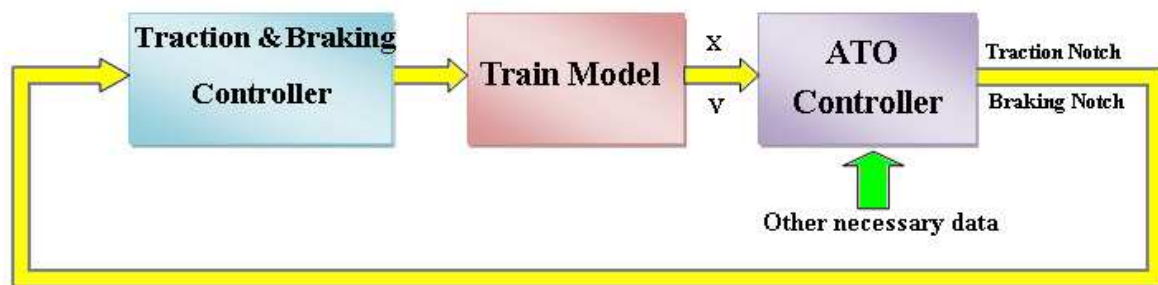


Fig. 2. Block Diagram of ATO System

Power control and brake control are respectively controlled via Power Notch and Brake Notch, which are discrete values and they create a precise force for proper train control. Today this discrete method is used in most control systems. Braking devices correct braking deceleration power in a way so that the brake notch can work without considering the train load. Even though there will be  $\pm 30\%$  error in real braking deceleration which is caused by the change in friction coefficient of brake pads, change in air pressure inside pipes, train weight change, etc... Train velocity is gained by the number of tachometer generator pulses during a sampling time. Usually the accuracy of tachometer generator pulses is about 10 cm and if sampling time is 1 ms then the speed detection error would be  $\pm 0.36$  km/h, which is a negligible fault [2]. The mentioned condition should be implemented in ATO and train model in order to replicate a good train dynamics [9].

Movement resistance according to Davis formula is  $A + BV + CV^2$  [kg/ton] in which velocity unit is kilometer per hour.  $A$  is related to the axle load,  $B$  to the quality of track and vehicle stability, and  $C$  is related to area, vehicle shape, surrounding air and the tunnel air. Grade resistance is  $mg \times \sin\theta$  and line gradient is in radians. Curve resistance is  $mg \times 10^{-3} \times k/r$  in which  $r$  is radius of line curve and  $k$  is a coefficient that depends on line width and is 750 m for a width of 1435 mm.

In this article voltage control method is used for traction motor rev control [4]. In this method the average voltage is altered by changing the ignition angle of thyristor, although to decrease the simulation time a multi-switch with various voltages is used. For braking system a pneumatic brake system is utilized. This braking system is useful for velocities lower than 100 km/h and has the ability of fully stopping the train. In this project, for the sake of simplicity, dynamic brake is omitted and pneumatic brake is equaled to resistive torque. A multi-switch with various resistive torques is used. Torques are defined and given values according to permitted brake decelerations.

Figure 3 represents train model simulation in MATLAB software environment which was used in this article. As it is shown in this figure, system inputs are voltage and torque that enter train model from power and braking controllers respectively. The resistive torque used in this simulation is gained from the total resistive torque divided by the number of traction motors. The simulation halts when train velocity becomes zero. To avoid increase in current at the moment of movement start, a resistance box is used to limit the current of traction (power) motors to the defined acceptable (1.5 times the nominal current) range.

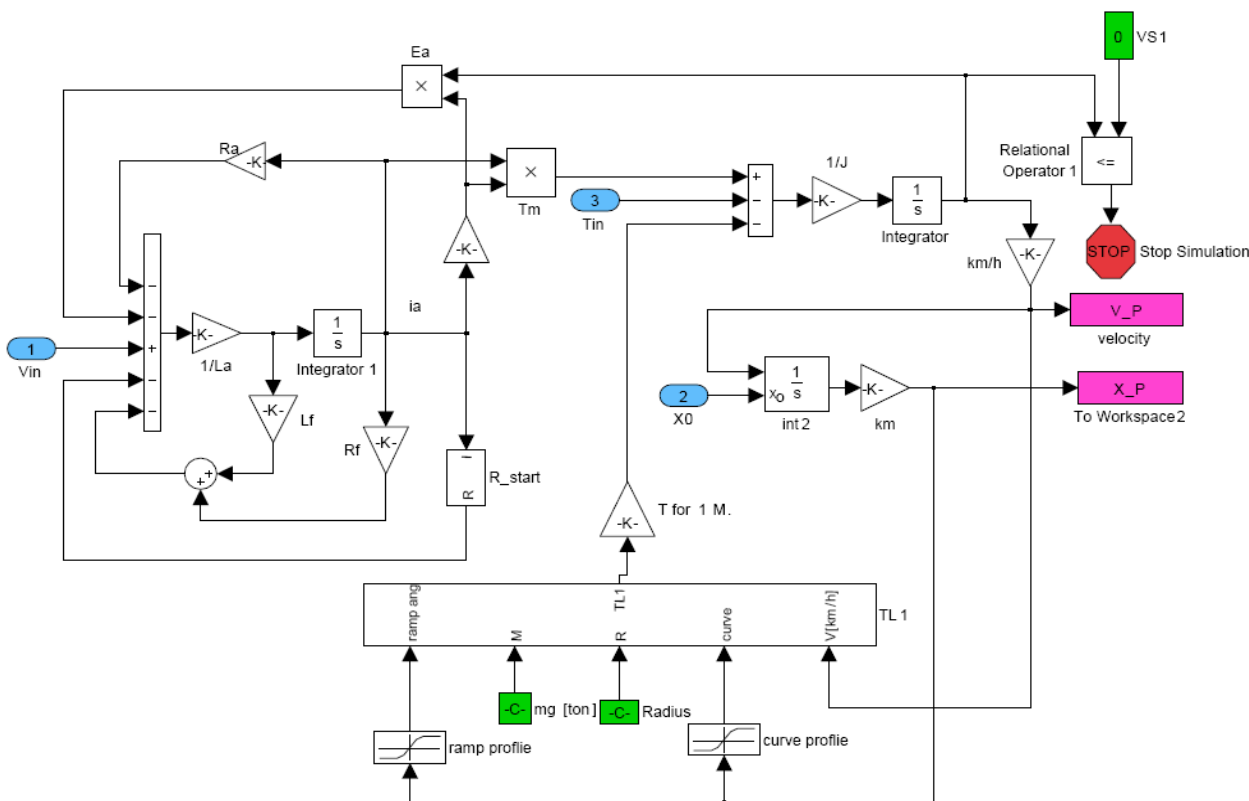


Fig. 3. Train Model Simulation

3. The proposed control method for ATO system

In this article a predictive fuzzy control method for Train Automatic Operation (ATO) is proposed. Predictive fuzzy control is a control strategy based on the system model that in each moment of sampling performs improved control action according to its current system state and simulation calculation of system model. The predictive fuzzy control has nothing to do with the mathematical model under control and this model can exist as linear, non-linear and even fuzzy model which is expressed with linguistic variable. In this article instead of having rules to improve the target function, simulation calculation of the controlled system and better estimation of the value of control rule are used [3]. In this control method, fuzzy control method and predictive control algorithm and also computer simulations are all mixed with each other to compose the predictive fuzzy control.

3.1 Fuzzy control

In 1965 Professor Zadeh proposed fuzzy logic theory in an article named “fuzzy sets”. Fuzzy control is the result of applying this theory to decision making [5]. The first application in industry was performed by Mamdani on a steam engine in 1974. Fuzzy control works like this: a control instruction like  $u^*$  based on predicted control rules  $R = \{R1, ..., Ri, ..., Rn\}$  is inferred from linguistic input variables  $\{x \text{ is } Ai \text{ and } y \text{ is } Bi\}$  using fuzzy inference engine. One example of these rules is this:

“If  $x$  is  $Ai$  and  $y$  is  $Bi$  then  $u$  is  $Ui$ ”

### 3.2 Predictive fuzzy control

Fuzzy control faces problems in systems that have a large delay time. To overcome this, predictive fuzzy is proposed. Just like other predictive controls, control action in predictive fuzzy control is based on predicting outputs of system.

Predictive fuzzy control is a control strategy based on system model that performs the optimum control action in each sampling time based on system's current condition and the calculations resulting from system model simulation. Predictive fuzzy control has nothing to do with the mathematical model under control, and this model can exist as linear, non-linear and even a fuzzy model expressed with linguistic variable.

In this control instead of having rules to optimize the target function, simulation calculations of the controlled system and estimation of the best amount of the control rule are utilized. In this control method, fuzzy control method and predictive control algorithm and also computer simulation are all put together according to figure 4 and create the predictive fuzzy control.

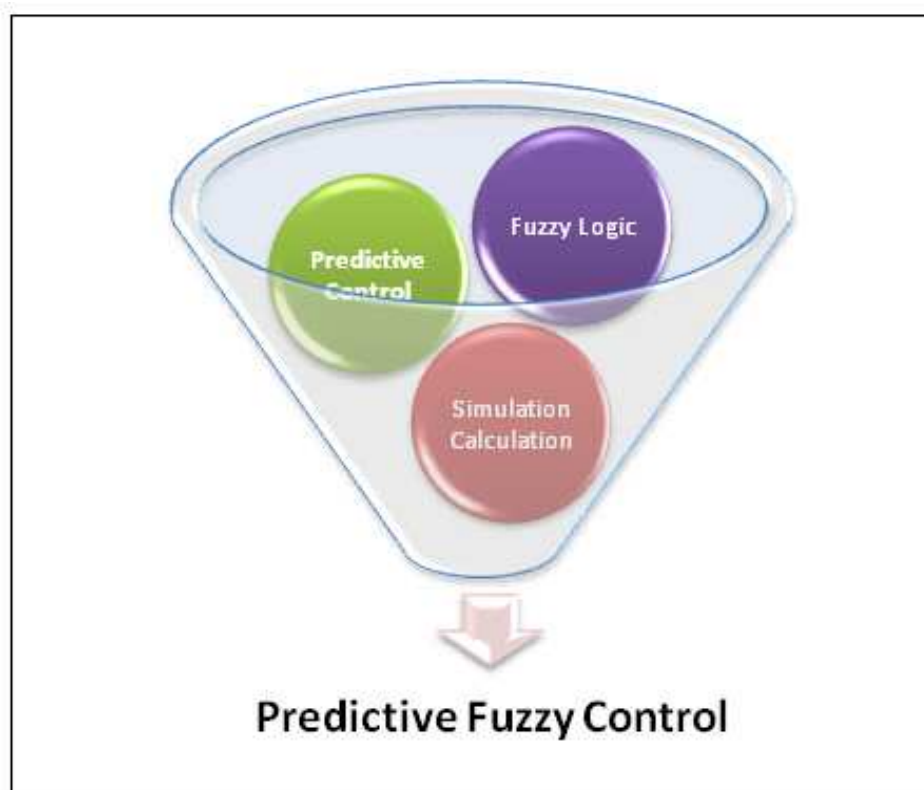


Fig. 4. Predictive Fuzzy Control System Structure

A skilled operator has extensive experience through his many experiments with system's operation and events, and he can satisfy system objectives via his high-level control method. With a small investigation on operator's control method we realized that he performs his control by predicting forthcoming system states and also by harnessing his extensive experience of the system. According to this, the predictive fuzzy control must calculate the next state of the system when selecting the control rule and propose this rule according to the next best state of the system.



This method is like this:

- Control rules  $R=\{R1,...,Rn\}$  are defined as :

$R_i$ : **If** ( $U$  is  $C_i \rightarrow x$  is  $A_i$  and  $y$  is  $B_i$ ), **Then**  $U$  is  $C_i$

- $C_i$  Control rules are selected based on the predictive results of  $(x, y)$  that show the highest probability.

Prediction of each evaluative amount  $(x, y)$  is based on the following:

*"Control instruction  $C_i$  includes control rule  $R_i$ . Control rule  $R_i$  is evaluated. As a result control instruction  $C_i$  of control rule  $R_i$  with the maximum evaluation value is selected."*

There is no inference or a non-fuzzy maker action in a fuzzy controller. The base of work is that after converting real variables in to fuzzy linguistic variables via Mamdani minimum, the weight of rules is resulted. The important thing in fuzzy rules is that each fuzzy rule is relegated to a real output. After giving weights to each rule, the output of the rule with the highest weight is selected as the output of the entire controller system.

#### 4. Applying improved predictive fuzzy to ATO

Description of effects of a human operator's strategy on system functionality, definition of the meanings of linguistic evaluation indices, definition of models for predicting system operation and conversion of a skilled human operator's linguistic strategies to fuzzy control rules, are parts of designing and implementing a predictive fuzzy controller.

A skilled human operator controls the train much better than the conventional controller of ATO. This is because the human operator thinks about different control system indices and evaluates them directly. Therefore if a proper control system is designed so that it can accurately understand and mimic the control operation strategy of a human operator, it would perform the control operations even better than a skilled human operator. This is due to higher accuracy of electronic measuring devices when compared to that of a human being and also their faster response rate to commands and faster system processing speed.

##### 4.1 Human operator strategies of train operation

Control rules based on below experience-based rules are selected in constant speed control and Automatic Train Stop control zones [1,2]:

- Constant Speed control (CSC) Zone rules:
  1. For safety, if train speed goes beyond the speed limit, brake command with the maximum force is selected.
  2. For energy saving, if coasting is allowed then coasting is continued.
  3. For shorter running time, if speed falls too much below the limit, power notch is selected.
  4. For passenger comfort, if train speed is in the predetermined permitted range, the control notch will not change.

5. For traceability of target curve, if notch is not changed and it becomes evident that train speed exceeds the permitted range, a  $\pm n$  notch is selected so that the train can accurately trace the target speed.
- Train Automatic Stop Control (TASC) Zone Rules:

The operator starts the TASC operation by detecting the TASC position marker which indicates the remaining distance to the target point. In this control mode the operator selects the control notch based on tentative control rules.

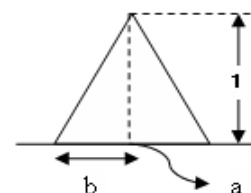
1. For passenger comfort when the train is in TASC zone, the control notch is not changed if the train stops in the predetermined permitted zone.
2. For minimizing running time and maximizing passenger ride comfort, when the train approaches the TASC zone the notch is changed from acceleration to deceleration by a small margin.
3. For accurate stop gap, when train is in the TASC zone and it becomes clear that it won't stop in the predetermined allowed zone, a  $\pm n$  notch is selected so that the train stops accurately at target position.

#### 4.2 Definition of linguistic evaluation indices

In this section ATO system evaluation indices are defined which include safety evaluation index, passenger comfort evaluation index, traceability of target function evaluation index, energy saving and also accurate stop gap evaluation indices. Required membership functions for defining indices are presented here:

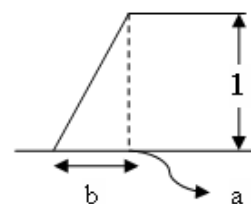
Tri\_mf  $\rightarrow$  Triangular function, which is defined by (a-b, a+b) region:

$$\text{Tri\_mf}(x,a,b) = \text{trimf}(x,[a-b, a, a+b]) \Rightarrow$$

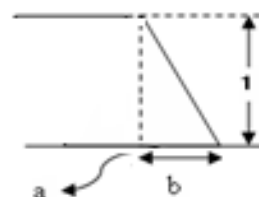


Half-triangular function, which makes values more than an equal to 1:

$$\text{Trir\_mf\_r}(x,a,b) = \text{trimf}(x,[a-b, a, \text{inf}]) \Rightarrow$$



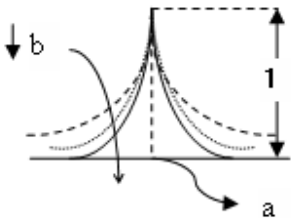
$$\text{Trir\_mf\_l}(x,a,b) = \text{trimf}(x,[-\text{inf}, a, a+b]) \Rightarrow$$





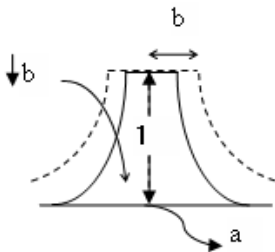
Dsig\_mf → Pyramidal function, which is defined by  $(-\infty,+\infty)$  region

$$Dsig\_mf(x,a,b) = 1 - 2 \times dsigmf(x,[b,a,0,0]) \Rightarrow$$



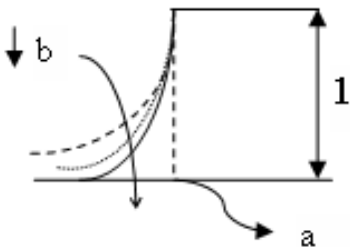
pi\_mf → Trapezoid function, which is defined by  $(-\infty,+\infty)$  region

$$pi\_mf(x,a,b) = pimf(x,[a-2b,a-b,a+b,a+2b]) \Rightarrow$$



S\_mf → Half-trapezoid function, which make values more than *an* equal to 1:

$$S\_mf(x,a,b) = smf(x,[a,a-b]) \Rightarrow$$



- **Safety evaluation index:** safety is calculated by the remaining time to danger or speed limit zone. Figure 5 shows the related defined membership functions :
- Danger (SB):  $\mu_{SB}(t_s) = Trir\_mf\_r(t_s,0,T_s)$
- Safe (SG):  $\mu_{SG}(t_s) = Trir\_mf\_l(t_s,T_s,T_s)$

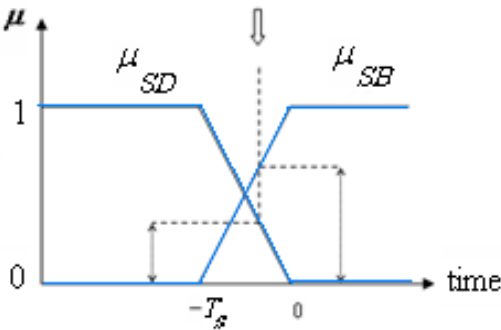


Fig. 5. Safety Index Membership Function

- **Passenger Riding Comfort performance indices:** Changing the notch frequently is associated with bad passenger riding comfort. Comfort is evaluated at  $N_{ch}$  steps and the time elapsed from the latest notch change  $t_{ch}$  :
  - Good passenger comfort (CG):  $\mu_{CG}(t_{ch}, N_{ch}) = S\_mf(t_{ch}, 1 + \frac{N_{ch}}{2}, \frac{N_{ch}}{2})$
  - Bad passenger comfort (CB):  $\mu_{CB}(t_{ch}, N_{ch}) = 1 - \mu_{CG}(t_{ch}, N_{ch})$

Figure 6 shows the passenger riding comfort performance index membership function.

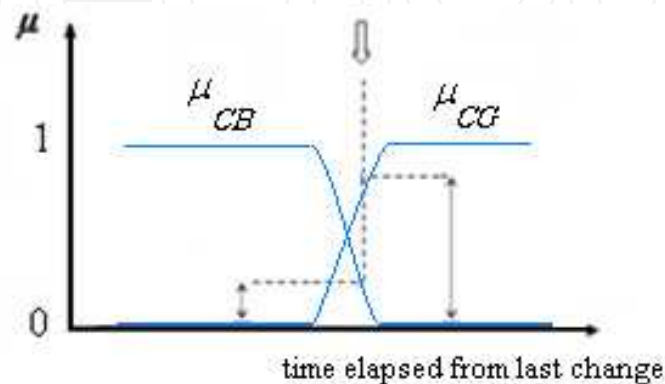


Fig. 6. Passenger Riding Comfort Performance Index Membership Function

The larger the notch change, the longer time it will take for the membership function of good passenger comfort to become 1. If the amount of notch change is 1 after  $\frac{1}{2}$  second passenger comfort weight becomes 1, and if notch change is 7 after 4.2 seconds passenger comfort weight becomes 1.

- **Evaluation Index of target curve traceability:** The difference between the predicted speed and the target speed is used for evaluating target curve traceability index.
  - Good Trace (TG):  $\mu_{TRG}(V_p(N_p)) = pi\_mf(V_p(N_p), V_t, 2)$
  - Accurate Trace (TA):  $\mu_{TRA}(V_p(N_p)) = Dsig\_mf(V_p(N_p), V_t, 2)$
  - Low speed trace (TL):  $\mu_{TL}(V_p(N_p)) = S\_mf(V_p(N_p), V_t / 2, V_t / 5)$

Figure 7 presents the index membership functions of the above evaluation.

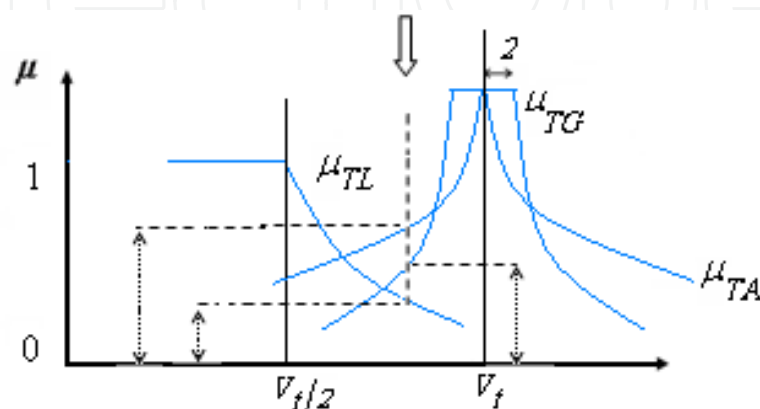


Fig. 7. Target Curve Traceability Index Membership Function

In a specific time, the position of future velocity is calculated based on the current  $\pm n$  notch selected. If the input notch is supposed to be without change, then a good traceability membership function with a predicted  $V_t$  and a predetermined tolerance of  $V_e$  is specified. Based on the selected  $n= \pm 1, 2,3N$  and speed predictions, accurate trace membership functions with similar  $V_t$  are resulted. Finally by collision of this function with target velocity, membership function with the highest weight is resulted. It is clear in figure 8 that selection of the input notch has the highest weight.

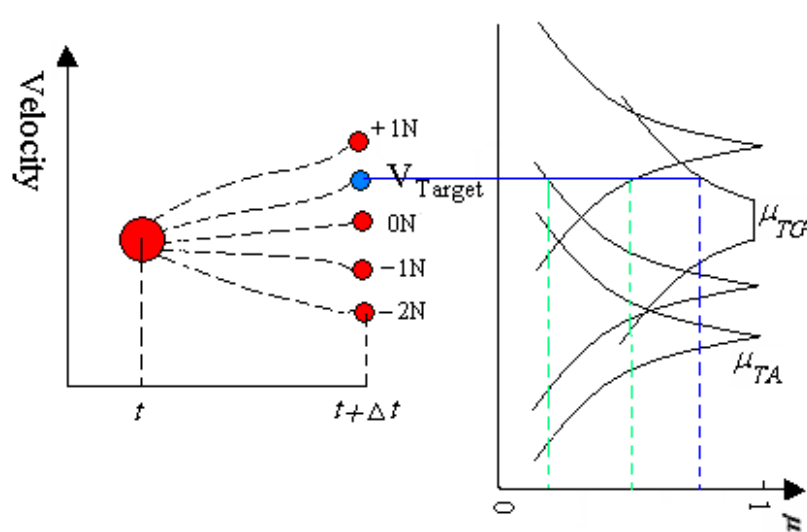


Fig. 8. Weight Of Membership Function In Target Curve Traceability Index

- **Accurate stop gap evaluation index:** Accurate stop evaluation index is defined by the difference between the predicted stop position and the stop target location.
  - Good Stop (STG) :  $\mu_{STG}(X_p(N_p)) = pi\_mf(X_p(N_p),V_t,30)$
  - Accurate Stop (STA):  $\mu_{STA}(X_p(N_p)) = Dsig\_mf(X_p(N_p),V_t,30)$

Figure 9 shows these membership functions mentioned above.

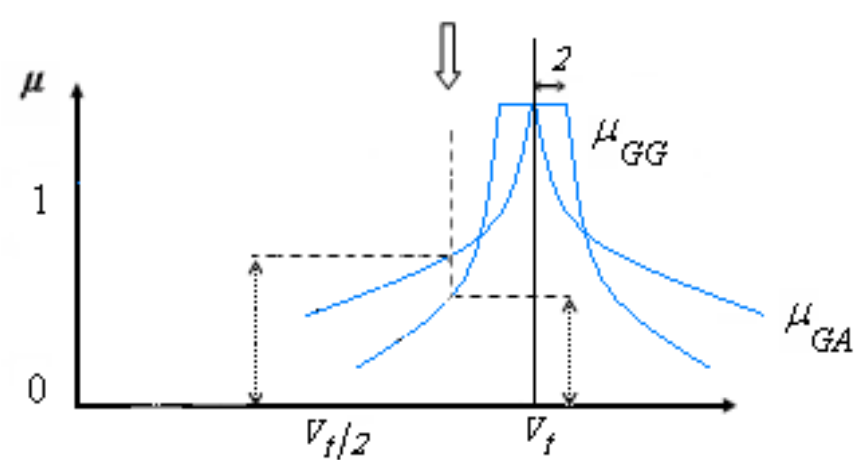


Fig. 9. Accurate Stop Gap Index Membership Function

In a specific time the control system predicts how target stop point changes by a  $\pm n$  change in the current notch. Based on the input notch, good stop membership function is predicted with  $X_t$  and a determined tolerance of 30cm is specified. Then for  $n = \pm 1, 2, 3N$  change from the current notch, accurate membership functions with similar predicted  $X_t$  are resulted. Finally weight of each membership function is resulted by colliding them with target position. It is clear from figure 10 that no change in the notch has the highest weight in membership functions and it is also visually clear that the most accurate stop gap is related to this choice.

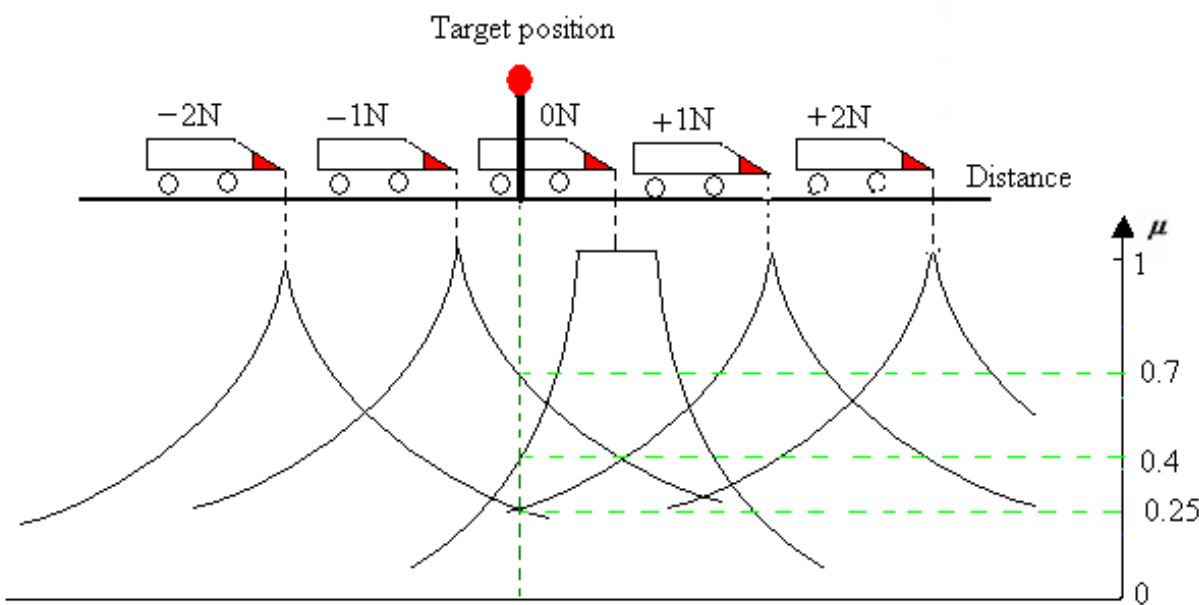


Fig. 10. Weight of Membership Function in Accurate Stop Index

4.3 Predictive model

As mentioned in previous parts, predictive fuzzy control system is based on predicting system behavior. For this purpose, a system model should be introduced that is capable of predicting system behavior with the desired accuracy. For modeling train dynamics, DC series traction motor and its resistive torque must be replicated. Each train is composed of a number of traction motors with analogous powers, and all motors should overcome the resistive torque imposed on the train. Resistive torque is gained by multiplying resistive forces by radius of wheel. The total external forces imposed on the train are calculated from movement resistance formulas (described in section 2). For modeling series DC traction motor we have to first calculate its mathematical relations. Required relations for modeling motor traction are as below:

$$E = K_a \phi_f \omega_m$$
$$V_a = E_a + (R_a + R_f) I_a + L_a \frac{dI_a}{dt} + \frac{d\lambda_f}{dt}$$

$$T_m = K_a \phi_f I_a = K_a K_f I_a^2$$

$$T_m - T_L = j \frac{dw}{dt}$$

Figure 11 represents train dynamics with DC series traction motors. From the technical characteristics of traction motors we have to fill in the undetermined items in system model. Besides, moment of inertia, radius of rotation, axis conversion coefficient, and etc should be added to the model to demonstrate system behavior properly. After modeling, the accuracy of the modeled system can be gained by experimenting on a real system.

Control system in CSC region predicts system behavior only for a few seconds, but in TASC zone system behavior up to a complete stop should be predicted. Therefore the accuracy of the predictive model should be in a way that the error tolerance of stop prediction with real error is in the acceptable range, so that the control system can perform properly based on gained results of the predictive model. In other words, if prediction results when compared to real results contain a huge error rate, then the control system loses its efficiency. In this article a train simulation model is presented in which the prediction results and the results of train dynamic simulation are in the acceptable error range.

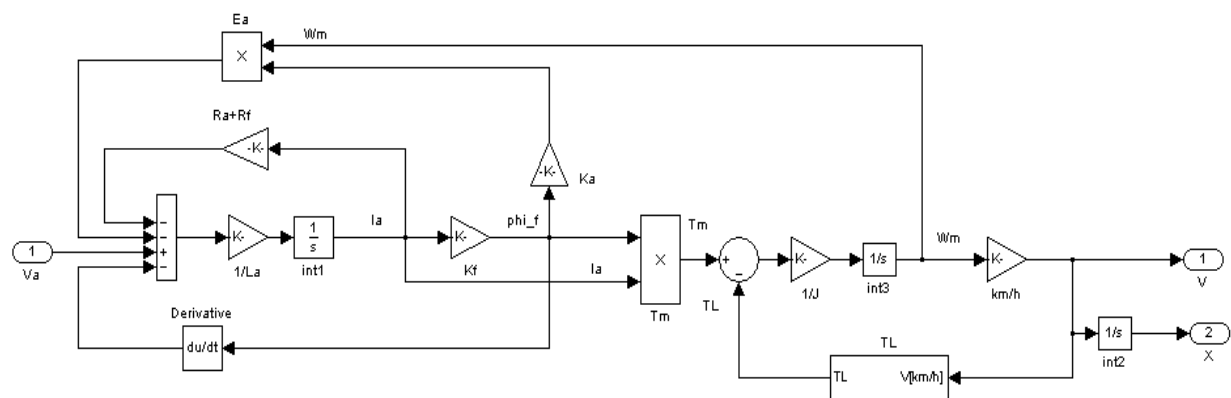


Fig. 11. A Model of Train for Prediction Traceability

4.4 Fuzzy Control Rules

DN is difference of notches, PN is power notch and BN is brake notch. The maximum power notch and brake notch is supposed to be 7 and 9 respectively. Safety evaluation index is *S*, comfort evaluation index is *C*, traceability evaluation index is *T*, and evaluation index of stop gap is represented by *ST*. Train movement strategy in constant speed control (CSC) zone is summarized in the following and figure 12 shows the fuzzy rules:

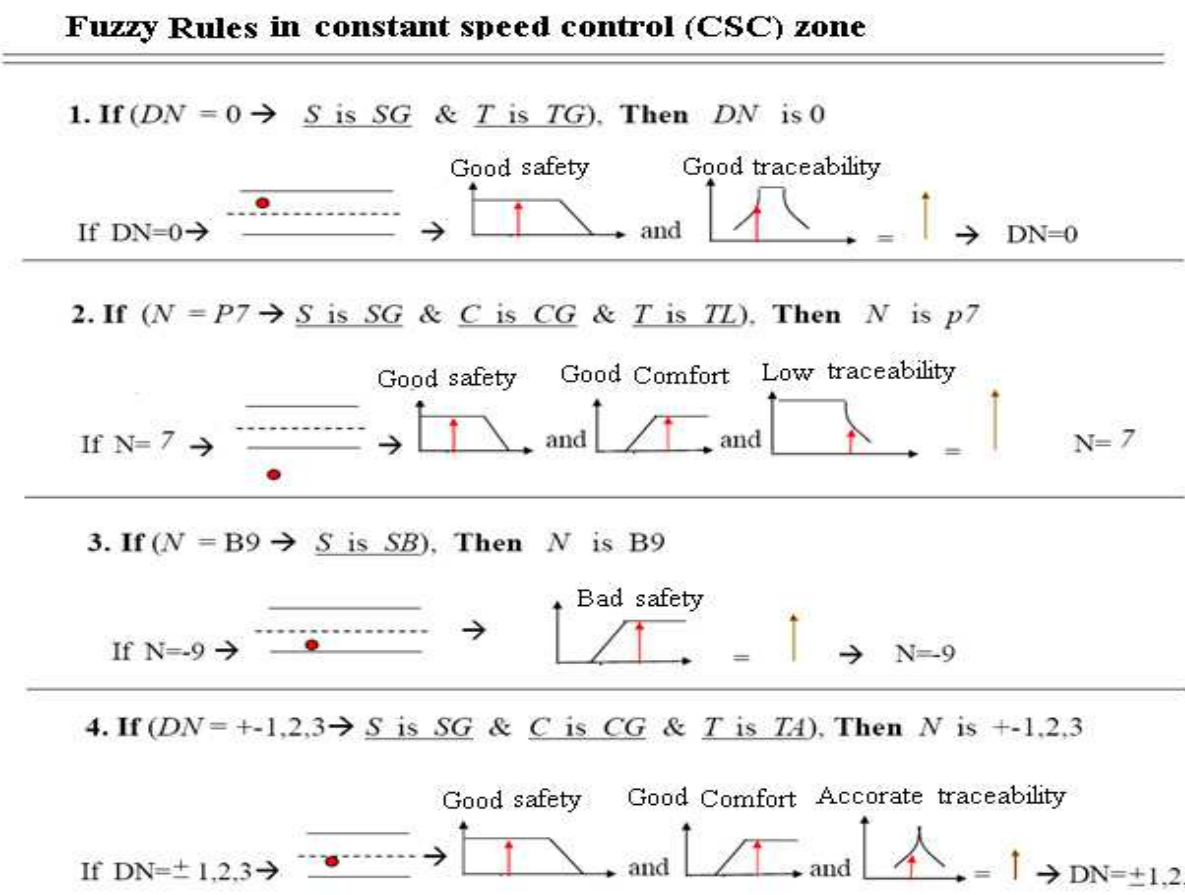


Fig. 12. Fuzzy Rules In CSC Zone

Train movement strategy in Train Automatic Stop Control (TASC) zone can be summarized by the following and figure 13 shows the rule base:

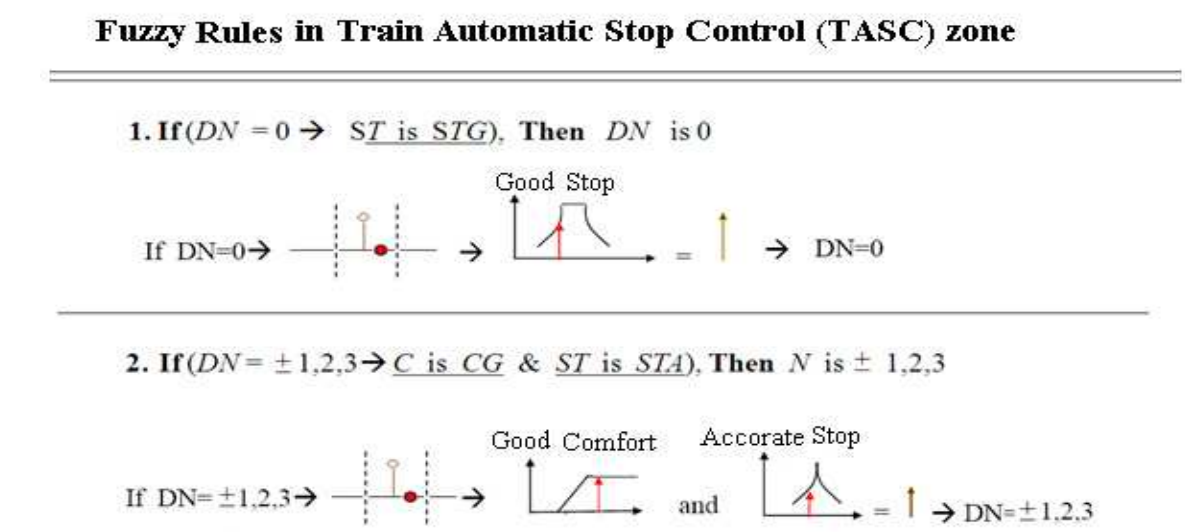


Fig. 13. Fuzzy Rules in TASC Zone

## 4.5 Techniques used for reducing energy consumption

One of the most important roles of ATO is reducing energy consumption. Different techniques are used for this purpose in all of which coasting is used for reducing consumed energy [6, 7, 8]. In this article two methods are used for reducing energy consumption which is presented in the following sections.

### 4.5.1 Using coasting in accurate stop gap zone

In Constant speed control (CSC) zone the control system always investigates a proper zone for coasting, and if all conditions are met then the control system smartly enters the accurate train stop gap (ATSC) zone. In accurate stop gap zone, control system calculates the proper situation for applying brakes up to a complete stop, and based on this the remaining time until braking zone ( $t_z$ ) is gained. Based on the gained time, the following three membership functions indicated in figure 14 are calculated:

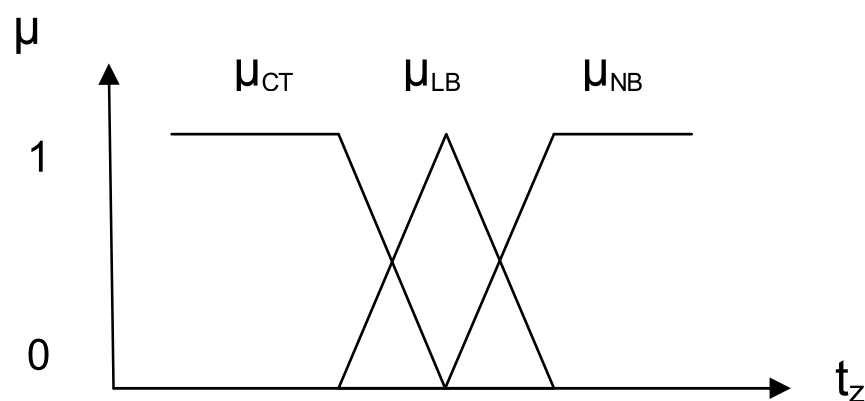


Fig. 14. Accurate Stop Gap Index Membership Function in ATSC Zone

- Coasting Time:  $Trir\_m\_l = F(t_z, 0, 1)$
- Low Brake Time:  $\mu_{LB} = Trir\_mf(t_z, -1, 1)$
- Normal Brake Time:  $\mu_{NB} = Trir\_m\_r(t_z, -2, 1)$

When the control system moves from constant speed control zone to accurate stop gap zone, coasting time membership function gains weight of 1 and the train moves in coasting mode until low braking is applied. Coasting time depends on two factors: One is the braking time and the other is the time control system moves from constant speed control zone to accurate stop gap zone. Based on route conditions and estimation of brake capability, control system calculates the braking point so that the train applies brakes with average deceleration. In this article the average deceleration is gained in the fifth notch. Therefore the time achieved for braking depends on route conditions and braking capabilities of train, and it is not changeable, though the second element can be changed by system designer.

In constant speed control zone, system conditions for moving into the stop zone are always supervises and investigated. In constant speed control zone, the control system predicts train speed conditions in the braking position with notch zero and smartly calculates the best point for entering the constant speed zone. Required conditions for entering constant speed zone are as follows:



1. 1- Train velocity in braking position is in a distinctive area of maximum velocity.
2. 2- Safety condition is acceptable while coasting
3. 3- Passenger riding comfort is convenient

As a result of using this method the control system always smartly and based on route conditions-before entering constant speed zone- moves in coasting mode. Due to the fact that there is less than %2 time increase in this technique, ATO will always use this method.

#### 4.5.2 Using coasting in constant speed control zone

If in constant speed control zone and by using coasting the train is kept in the permitted region, then for reducing energy consumption coasting is used. For this purpose energy saving membership function is represented like figure 15.

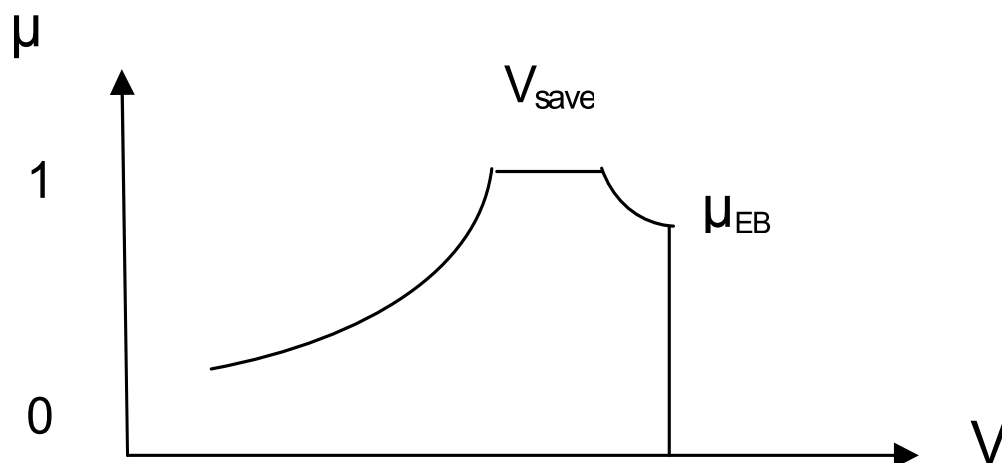


Fig. 15. Accurate Stop Gap Index Membership Function in CSC Zone

The amount of  $V_{save}$  represented above determines the amount of coasting. The more it increases, the higher coasting value becomes and energy consumption is reduced more. It should be noted that coasting increases the running time. Therefore there should be a balance between running time and coasting. It is better to define running time as a penalty function for energy saving, so that by taking the permitted running time into account, coasting is continued (previous methods). The problem with this method is that coasting is continued only until the time schedule allows it and it saves less energy when compared to the time coasting is used alongside the moving route. Therefore coasting level as a variable gives out different times and coasting level or  $V_{save}$  is selected according to the assumed time.

### 5. ATO system controller working method

In this method, the control system estimates the braking capability. By estimating the braking capability, accurate stop gap sensitivity to braking capability changes is reduced. Then control system indices that were introduced in the previous section are defined. Finally according to indices and energy saving conditions the best control rule in each part is gained, so that according to where the train is, rules relating to that location are extracted

and the relating notch is applied to power or braking control system as the output notch. The mentioned Procedure is executed each 100ms which is the sampling time.

Figure 16 shows the general diagram of predictive fuzzy control for ATO presented in this article. As it is exhibited in this figure, control system’s required inputs are fed into an s-function in which the control algorithm is written. Some inputs are used for predicting system dynamic and some others for defining indices. A coefficient for converting control region from CSC to ATSC is generated via a latch memory, so that the control system uses this coefficient to know in which region it has to operate.

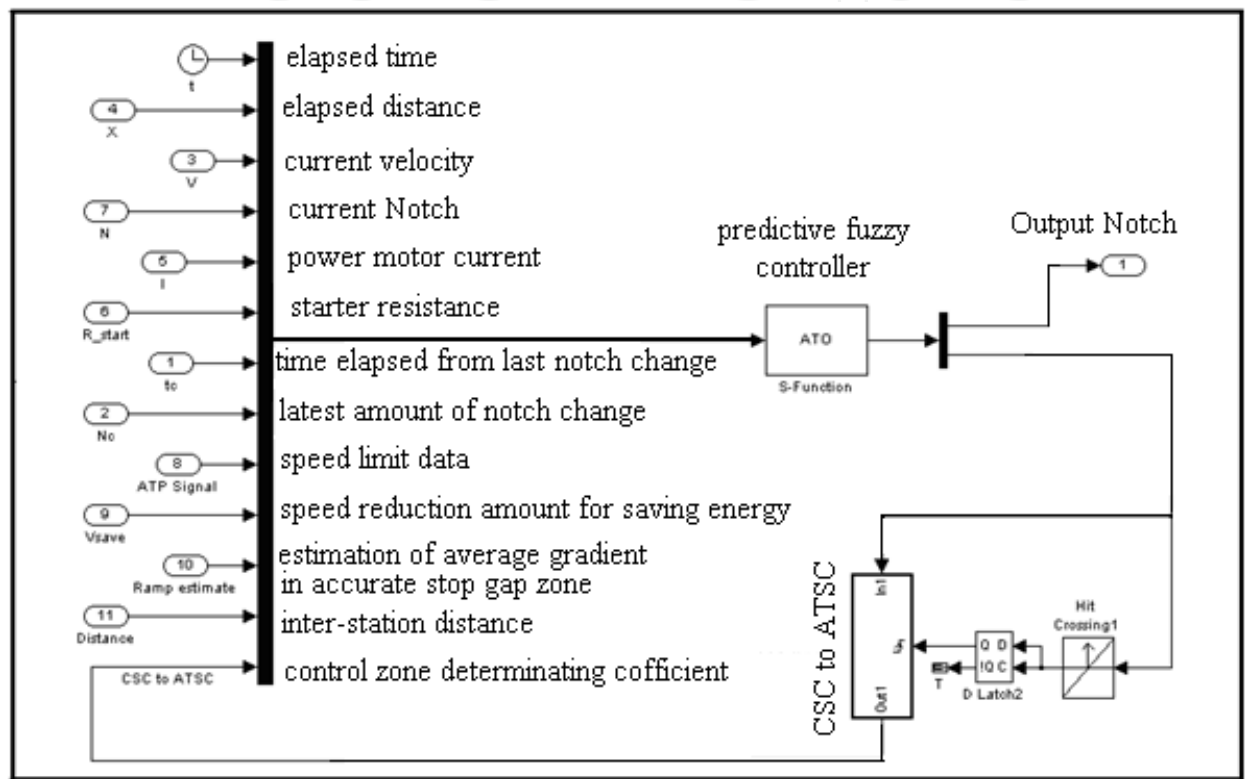


Fig. 16. General Diagram Of Predictive Fuzzy Control For ATO System

## 6. Simulations and results

In this part of this article ATO is simulated and is presented in a graphical simulator. Capabilities of improved predictive fuzzy control method are revealed in the next part.

### 6.1 Simulation assumptions

Train travel route is assumed to be a path between two stations with a distance of 1000 meters. Speed limit is assumed to be 40 km/h between distances of 550 and 650 meters. Curve radius is assumed to be 200 meters along the path. Gradient and altitude are assumed to be %2 and %5 respectively along the path. The assumptions considered in simulation are presented in Table 1.

Train weight	190 Tons
Movement Resistance	$1.97+0.016v+0.00084v^2$
Number of power notches	7 steps
Number of brake notches	9 steps
$B_m$ Maximum Brake Deceleration	min =3.6    km/h/s norm=5.14   km/h/s max =6.68   km/h/s

Table 1. Simulation Assumptions

6.2 Implementing the simulation

Figure 17 displays the simulation in a path with the length of 1000 meters. As it is shown, with the same velocity profile and route attributes, time and energy consumptions are both reduced compared to previous methods [1, 2]. In the previous method running time was 97 seconds and energy consumption was 0.65 KWh, however in this method time and energy consumptions are reduced by 1 second and %16 respectively, and this is because of the techniques introduced and explained in section 4-5 of this article.

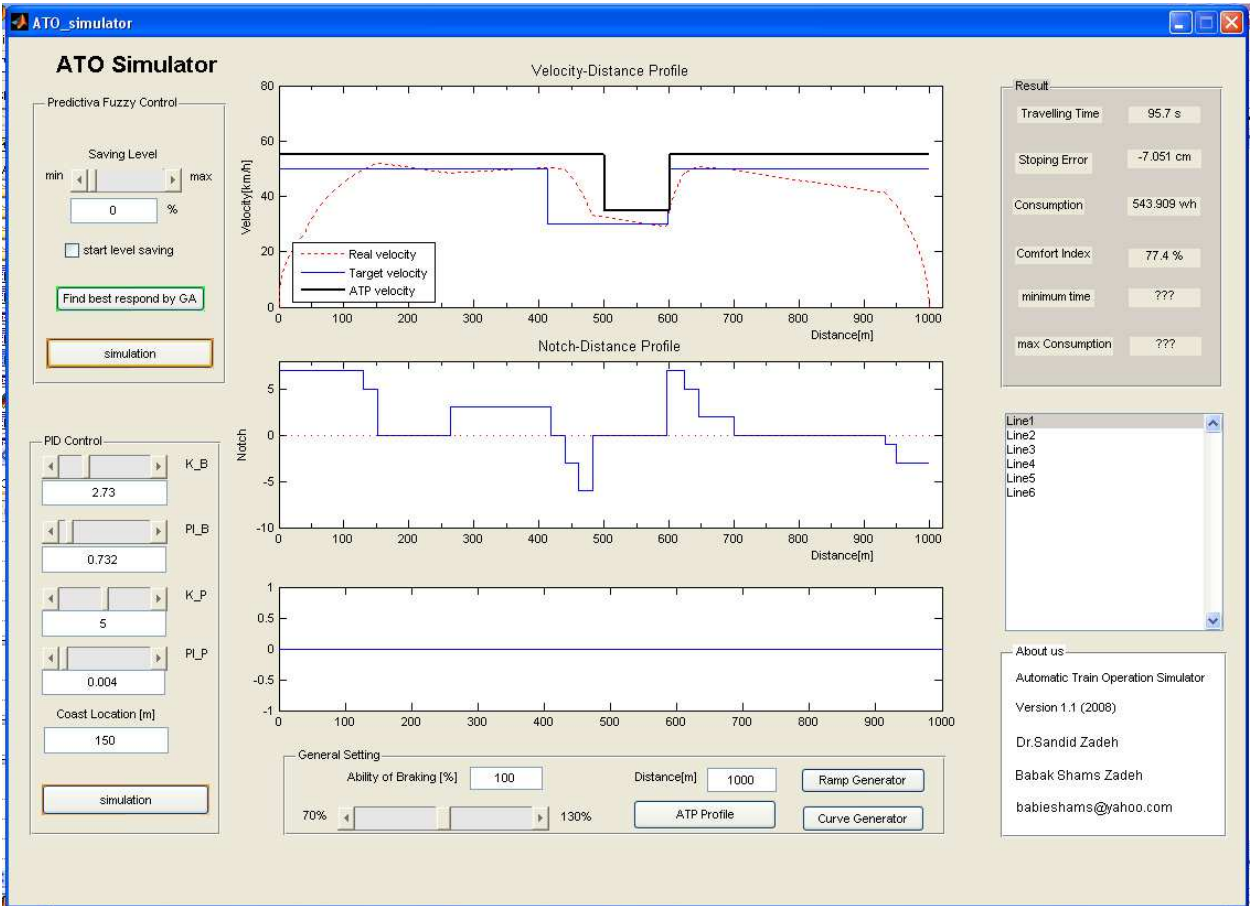


Fig. 17. Result of Simulation without Coasting Level in ATO Simulator

Table 2 also displays energy consumption based on coasting level (which is relevant to the increase in time), for a sampled line profile and velocity. As it is shown, in a slide with a small increase in time the amount of energy consumption increases significantly.

	Coasting Level %20		Coasting Level %40	
	Time Increase	Energy Consumption Reduction	Time Increase	Energy Consumption Reduction
- %5 inclination for movement path	0.2 seconds	%6.5	3.6 seconds	%18.6
+ %5 inclination for movement path	0.7 seconds	%1.8	2.9 seconds	%4.9

Table 2. Energy Consumption Based on Coasting Level

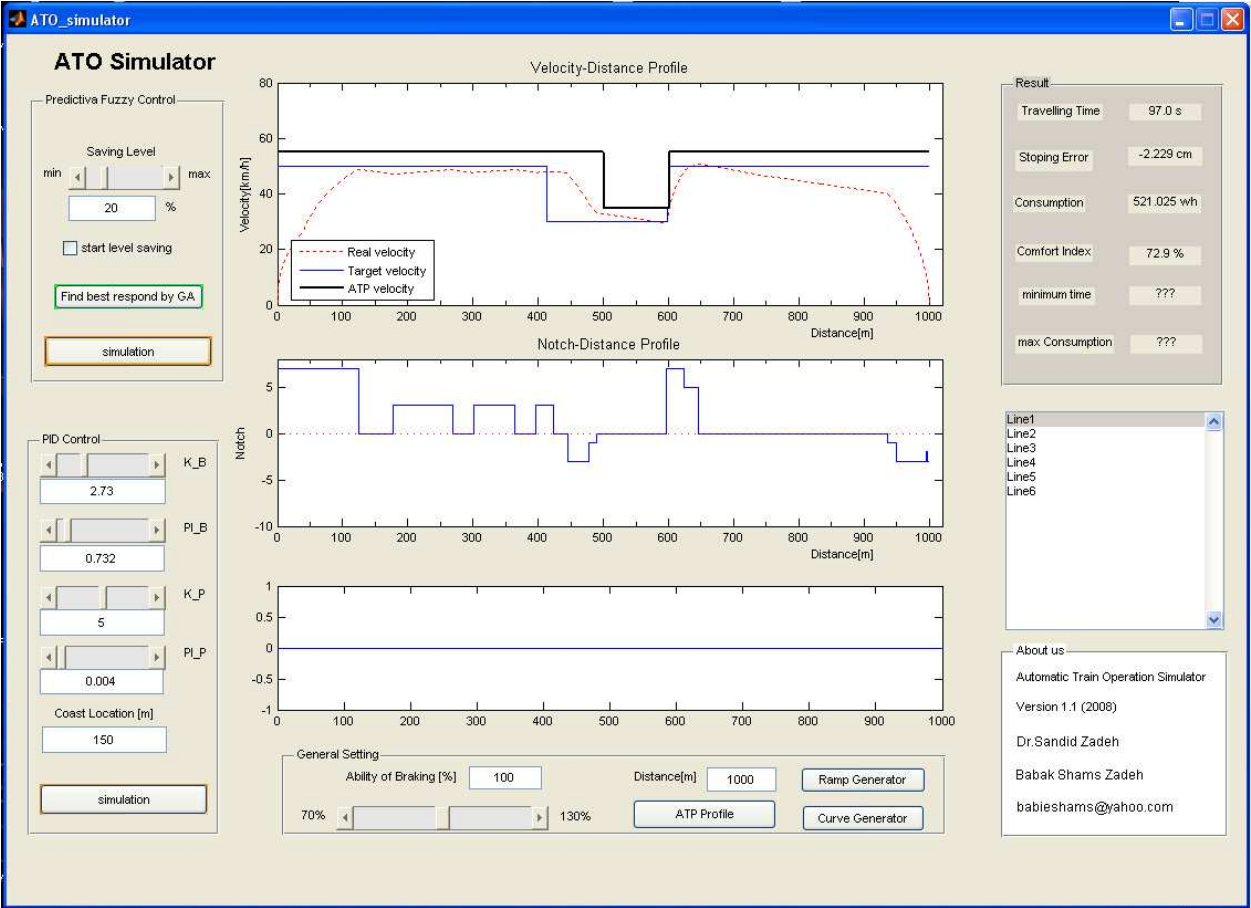


Fig. 18. Result of Simulation Based on Coasting Level in ATO Simulator

Therefore we can reach a convenient energy consumption rate by tuning the coasting level appropriately. Figure 18 clearly exhibits this fact. As it is displayed, running time is increased by 97 seconds, and energy consumption in comparison to similar methods is reduced by %20.

## 7. Conclusion

In this article, the predictive fuzzy control method has been implemented to automatic train control with new techniques for energy saving. As explained in this paper, the applied strategy of energy saving has two parts. The first part is in the zone of constant speed control (CSC), which regulates the coasting level in whole running of train in this region. This technique offers more energy saving in comparison to previous methods which use the coasting particularly in defined and permitted section of train running. In addition, considering the tradeoff between running time and coasting level, an optimized point with respect to running time and energy saving could be obtained which will be possible to be used in normal operation. The second part of applied strategy in this paper for energy saving is for train automatic stop control (TASC) which will improve the accurate stop, passenger comfort and energy saving by intelligent definition of TASC zone. By applying the above techniques and simulation, it is observed that the energy consumption is lower than previous suggested methods by other researchers e.g. 16% whereas more improvement in energy consumption could be gained by optimized regulation of coasting level and minor variation on running time. The results of simulation in this paper present the conclusion.

## 8. Acknowledgement

The authors express their thanks and appreciations to the School of Railway Engineering of Iran University of Science and Technology for their support to carry out this research. The same feelings will be applied to Tehran metro company for their data to do the simulation. The efforts of Mr. Hamed Zafari from Khatam Equipment & Development Company in Tehran are needed to be mentioned and appreciated for his cooperation to present this paper in English language.

## 9. References

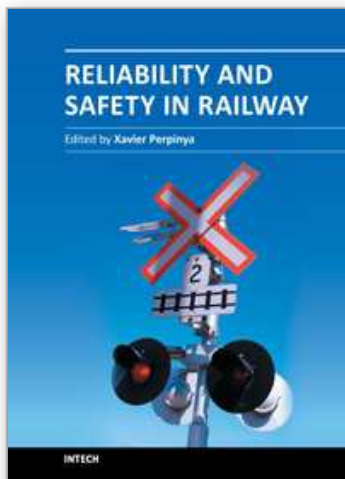
- [1] S. Yasunobu et al, Fuzzy Control for Automatic Train Operation System, 4<sup>th</sup> IFAC/IFIP/IFRS int. Conf. on Transportation Systems, (1983), 39-45.
- [2] S.Yasunobu & S. Miamoto. & H. Ihara, Application of Predictive Fuzzy Control to Automatic Train Operation Controller, Proc. Of IECON , (1984), 657-682.
- [3] S.Yasunobu, A fuzzy control for automatic stop control, Trans. of the society of instrument and control engineers Vol E-2, No. 1 , 1/9,2002.
- [4] F. Xiaoyun , J. Junbo, L. Zhi, The Research of Fuzzy Predicting and Its Application in Train's Automatic Control, IEEE Trans. SMC-3-1, 2000, 28-44
- [5] L.A. Zadeh, Outline of a new approach to the Analysis of Complex System and Description Processes, IEEE Trans. SMC-3-1, (1973) 28-44
- [6] G. Horwood and D. Kearney and Z. Nedic , A fuzzy controller using floating membership function for the braking of a long haul train , first International Conference on Knowledge-Based Intelligent Electronic System, Australia, 1997
- [7] K.K. Wong. T.K. HO, Coast control for mass rapid transit railways with searching methods, IEE Proceedings-Electrical Power Applications, Vol. 151(3), 2004, 365-376.

- [8] B. Mellit , G. Goodman, N.B. Ramabukwella, Optimization of Chopper Equipment for Minimizing Energy Consumption in Rapid Transit System, IEE conference Railway in the electronic age, London,1981, 34-41
- [9] Fujikura, Nohomi, Yasunobu et.al, Automatic Train Operation Method, The Proceedings of The Inst.of Electrical Engineers of Japan, 1977, 2205-2206

IntechOpen

IntechOpen





## **Reliability and Safety in Railway**

Edited by Dr. Xavier Perpinya

ISBN 978-953-51-0451-3

Hard cover, 418 pages

**Publisher** InTech

**Published online** 30, March, 2012

**Published in print edition** March, 2012

In railway applications, performance studies are fundamental to increase the lifetime of railway systems. One of their main goals is verifying whether their working conditions are reliable and safety. This task not only takes into account the analysis of the whole traction chain, but also requires ensuring that the railway infrastructure is properly working. Therefore, several tests for detecting any dysfunctions on their proper operation have been developed. This book covers this topic, introducing the reader to railway traction fundamentals, providing some ideas on safety and reliability issues, and experimental approaches to detect any of these dysfunctions. The objective of the book is to serve as a valuable reference for students, educators, scientists, faculty members, researchers, and engineers.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Mohammad Ali Sandidzadeh and Babak Shamszadeh (2012). Improvement of Automatic Train Operation Using Enhanced Predictive Fuzzy Control Method, Reliability and Safety in Railway, Dr. Xavier Perpinya (Ed.), ISBN: 978-953-51-0451-3, InTech, Available from: <http://www.intechopen.com/books/reliability-and-safety-in-railway/improvement-of-automatic-train-operation-using-enhanced-predictive-fuzzy-control-method>

**INTech**  
open science | open minds

### **InTech Europe**

University Campus STeP Ri  
Slavka Krautzeka 83/A  
51000 Rijeka, Croatia  
Phone: +385 (51) 770 447  
Fax: +385 (51) 686 166  
[www.intechopen.com](http://www.intechopen.com)

### **InTech China**

Unit 405, Office Block, Hotel Equatorial Shanghai  
No.65, Yan An Road (West), Shanghai, 200040, China  
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元  
Phone: +86-21-62489820  
Fax: +86-21-62489821



© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](https://creativecommons.org/licenses/by/3.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

IntechOpen

IntechOpen