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INTELLIGENT CONTROL OF COMMERCIAL VEHICLES BRAKING SYSTEM FUNCTION

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ABSTRACT – Ever-increasing demands in term of responsiveness and control are being made on system for brake and chassis management in commercial vehicles. Electronic Braking System (EBS) introduced in commercial vehicles providing rapid brake response and release for every single wheel of commercial vehicles according to the driver's demands. EBS ability for electronically monitoring and controlling of the index pressures between the proportional relay valve (front axle), axle modulator (rear axle) and trailer control valve has been used in this paper for introducing a new adaptive control strategy for the braking forces distribution of commercial vehicles. Implementation, here proposed, intelligent control strategy has be done by artificial intelligence technology based on neural network control. The main benefit of the proposed intelligent control strategy is that future decisions related to the control of braking systems are based on the developed neural model of braking system operation of commercial vehicle.

INTRODUCTION

Braking systems of commercial vehicles were always given the highest importance concerning safety issues and in particular active safety. Due to different design and load characteristics of these vehicles, different performance of their braking system especially related to different wheel brakes and their tribological behaviour are the main reasons why the operation of their braking systems should be constantly monitored and controlled depending on the driver's demands and the adhesion characteristics between tyres and road (1,2). Inappropriate braking of these vehicles may cause heavy accidents due to relatively longer stopping distances and higher energy output of brakes particularly in the case of vehicle combinations.

Ever-increasing demands in term of responsiveness and control are being made on system for brake and chassis management in commercial vehicles (3). The traditional medium used for brake system (compressed air) can be now controlled with the speed and precision offered by modern electronic abilities. Electronic Braking System (EBS) introduced in commercial vehicles providing rapid brake response and release for every single wheel according to the driver's demands.

The extremely rapid response time provided by the electronic control can be used for crucially shortening the braking distance by introducing advanced control of braking system operation. The control of commercial vehicle's braking system operation is related not only to vehicle speed but also to lateral acceleration together with the yaw moment control and significantly reducing the possibilities of the vehicle rolling over. Obviously, such a complex task imposed to the control of braking system can not be based on the driver abilities and need to be done independently of the driver. That is why a control program in EBS operation should be permanently improved.

EBS offers possibilities for further innovative solutions for controlling of braking systems performance of commercial vehicles. A need to improve braking performance of commercial vehicles simultaneously with resolving the problem of the vehicle combination braking compatibility leads to better control of the most relevant disturbing factors. An improved EBS braking forces management would certainly enable to reach the given task. The advanced strategy for the braking force management, proposed here, is based on intelligent controlling of the braking forces distribution between the front and rear axle of power-driven vehicle and/or between towing/trailer combination and/or between tractor/semi-trailer combination. Intelligent control of braking system operation can be considered as a critical point for further improving of commercial vehicles braking systems operation and active safety in general.

IMPROVING OF EBS CONTROL FUNCTIONS

From figure 1 (tractor for semi-trailer) it can be seen the principles of the EBS operation. The brake signal transmitter is used to generate electrical and pneumatic signals according to driver demands. The brake pedal’s travel measured is interpreted as the index retardation and converted by the central module into the index pressures for the front and rear axle. The index deceleration increases progressively with the amount of pedal travel. The axle modulator reads and controls the brake pressures of the wheel brakes on both sides of the rear axle. The signal received form the brake signal transmitter determines the vehicle intended retardation. Together with the wheel speed measured by the wheel speed sensors, the intended retardation is the input signal for EBS control, which uses these readings to establish the index pressure values for the front and rear axel, and the trailer control valve (4,5,6).

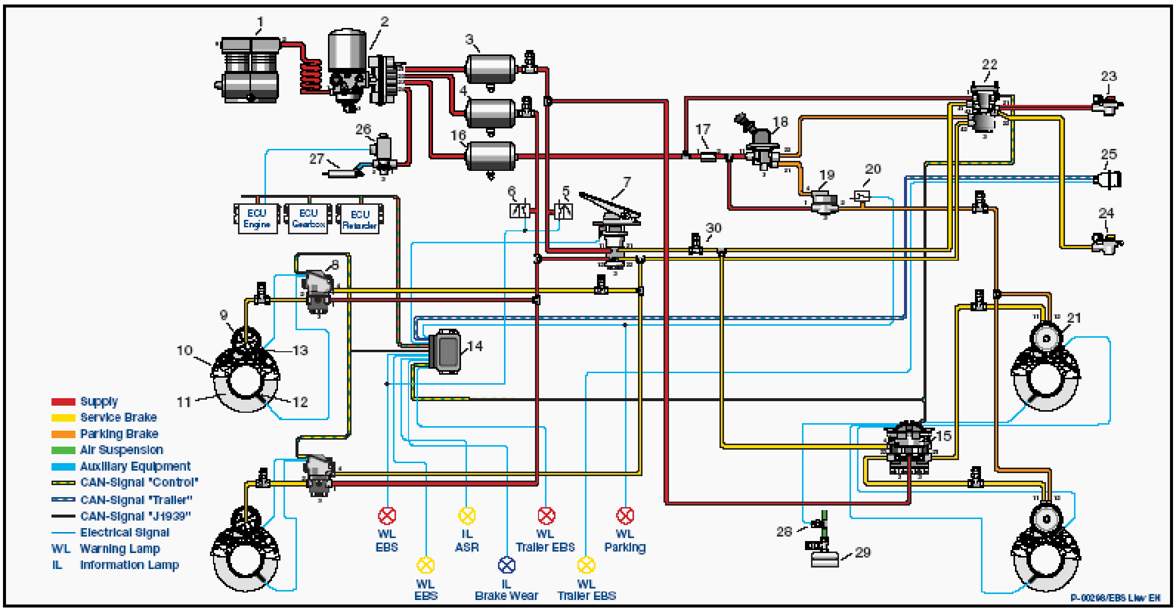

Figure 1. EBS of commercial vehicle- an example

Therefore, the proportional relay valve is controlled by ECU for application of the front brakes providing the braking rate line of front circuit (figure 2, service braking). Similarly, the rear brakes application is controlled by rear axle modulator providing braking rate line of rear circuit (figure 2, service braking). It can be seen from figure 2 that braking rates realized by front and rear circuits determining the total service braking rate line of the vehicle. The control of service braking rates line of the tractors’ can be considered as the most important factor in the braking system operation particularly from the adhesion utilization curves and compatibility requirements point of view (figure 2). That is why, a special attention should be paid to the strategy for controlling of the front/rear braking rate lines of the tractor and their synchronization with the braking rate line of semi-trailer in this case, see figure 2. The same strategy could be used in the case of the towing vehicle -trailer combination.

Obviously, because the braking pressures are computed individually for both the tractor/semi-trailer or towing/trailer combination not only power-driven vehicles but also at the same time semi-trailer's (trailer) braking system operation can be controlled. The EBS trailer module is designed to control the brake cylinders pressures for each side and communicates with tractor or towing vehicle via special trailer interface. If the deceleration of the trailer lies in the middle of the band prescribed by ECE R13 Annex 10 no coupling force occurs. If the trailer deviates from the middle band position, the motor vehicle ECU will perceive this by means of retardation control portion of the program and will adjust the trailer's actuating pressure accordingly.

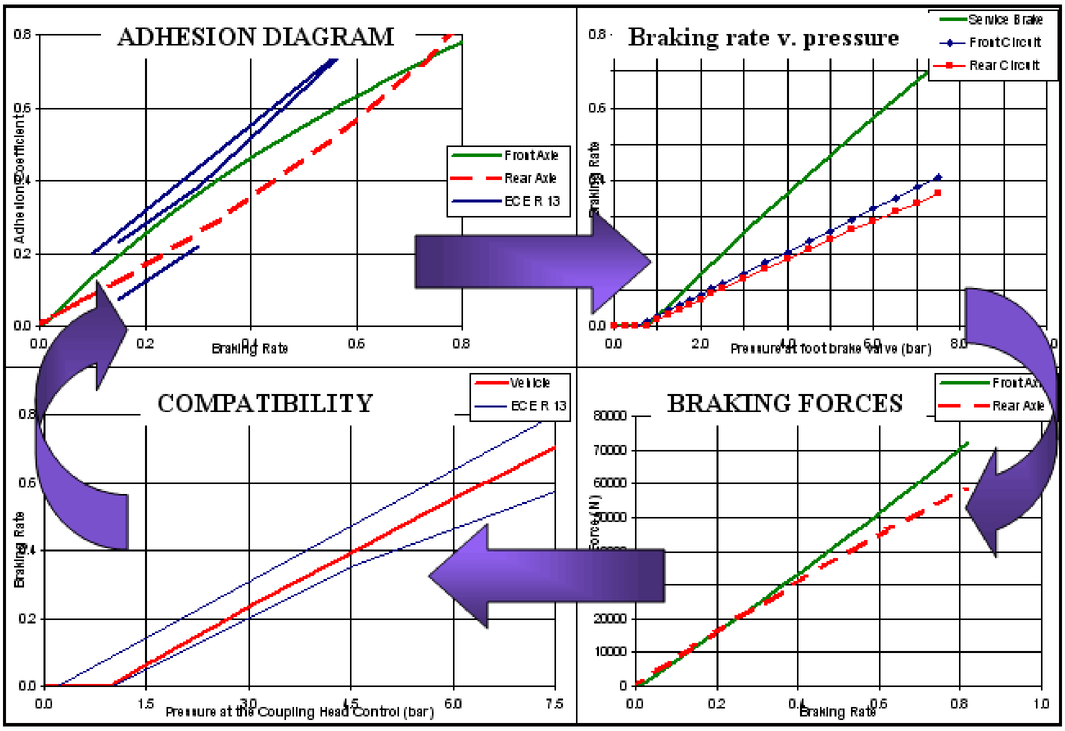

Figure 2. Requirements imposed to the braking system of power-driven vehicle-laden condition

Braking systems of road vehicles depends on a hierarchy, as shown in figure 3: subsystems (two independent service braking systems, emergency braking system, parking braking system), assemblies (control, transmission, wheel brakes, for example), subassemblies (calliper including brake piston), and components (brake rotor which may be drum or disc depending on the brake kind and type, friction material which may be brake pad or brake lining, and brake control device, which may be wheel cylinder, etc.).

Regarding aforementioned complexity of braking system's structure, according to figure 3, the overall performance of braking system interrelates with performance of its subsystems and parts. The problem related to the control of braking system operation is primarily determined by the fact that the braking system performance are significantly affected by brakes operation i.e. friction pairs (drum/rotor-friction material) characteristics. That is why, the real braking system performance of commercial vehicles can be significantly changed by different friction material characteristics, for example, than those illustrated on figure 2, due to a number mutually opposed requirements imposed to friction material (figure 3).

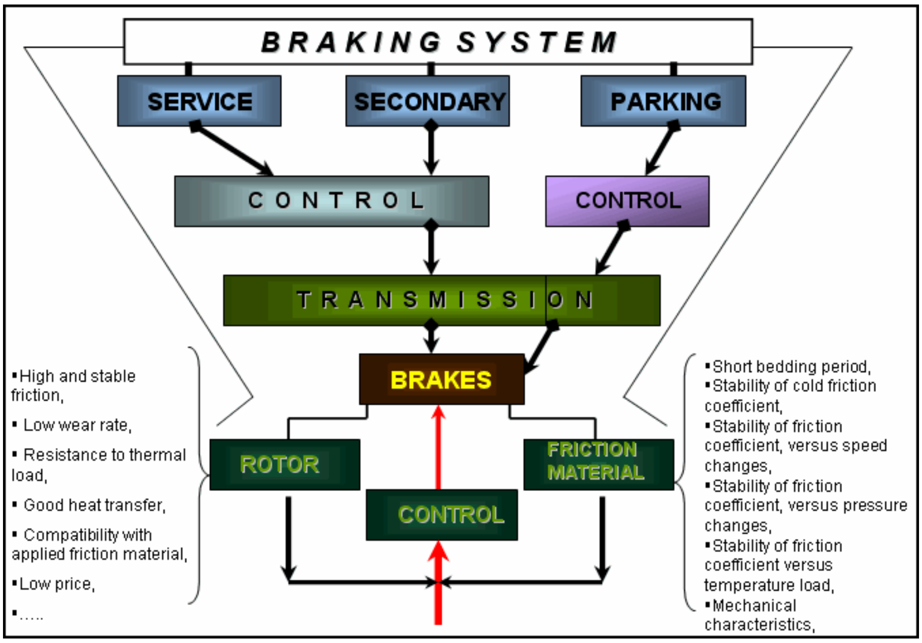

Figure 3. Interrelation of performance of braking system, its subsystem, and parts

Therefore, only improvement of the transmission part of the braking system operation by introducing EBS, the problem of braking system controlling cannot be successfully solved. That is why, EBS controlling function abilities could be better used for improving the braking performance of power-driven vehicle or tractor/semi-trailer combination or towing vehicle in combination with the trailer. This improvement is related to introduction of the new intelligent EBS function for advanced braking force distribution based on monitoring, identification, and adaptive controlling of braking system performance of commercial vehicles.

INTELLIGENT CONTROL OF BRAKING SYSTEM

From figure 4 can be seen a new strategy for intelligent controlling of the braking system performance explained for the case of the tractor/semi-trailer combination. This strategy is based on establishing the unique target function of braking rates line versus pressure at the foot brake valve or coupling head pressure for both laden and unladen conditions of the vehicle combination. It is evident, from figure 4 (laden condition), that the target function of braking rates line can be differently set up depending on load of vehicle combination and indented deceleration selected by the driver. In this case, the target function of braking rates line corresponding to the upper limit of the semi-trailer according to Annex 10 ECE R13 (7).

This target function can be used for controlling the both braking systems (tractor and its semi-trailer) at any load conditions. The upper limit of the semi-trailer in laden condition is chosen as a solution satisfying both load states and at the same time offers the maximum possible braking performance. Based on such set up target function, the appropriate index pressures for the proportional relay valve (front axle of tractor), axle modulator (rear axle of tractor) and trailer control valve (three axles of semi-trailer) should be calculated on such way to simultaneously provide that partial decelerations of tractor and its semi-trailer become identical (compatibility condition) and the target braking rates line is fulfilled. This strategy comprises three different controls ranges: (i) wear control range, (ii) normal braking range, and (iii) panic control range.

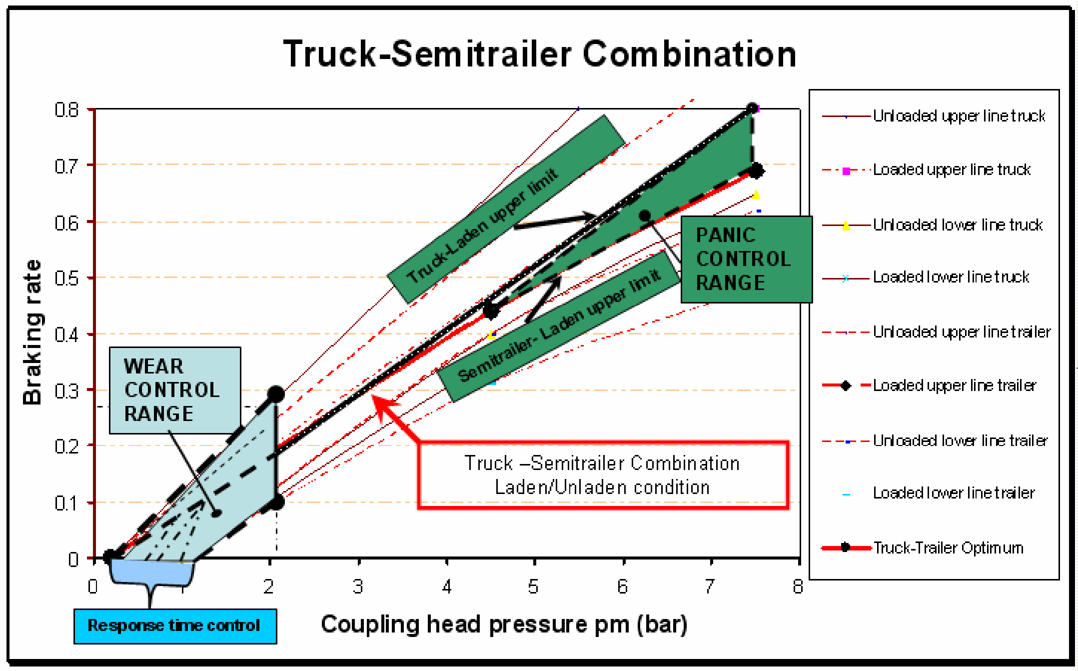

Figure 4. The target function set up for tractor and its semi trailer-laden condition

In the wear control range, for the index pressures which correspond to values not more than two bars, the wear balance of the brakes friction linings of the tractor and its semi-trailer would be achieved by selecting of the appropriate pressure line applications of brakes, on the each axle of the vehicle combination. In this range, the set up target function would not be considered because partial decelerations of the vehicle combination would be allowed to be changed in the marked area of the wear control range.

During normal braking, the braking systems operation of vehicle combination would be forced to fulfil predefined target function (semi-trailer upper limit-laden condition). According to figure 4, the index pressures selected by control module need to be computed on such way to provide identical partial decelerations of vehicle combination that are known in advance (target function) for the specific operation condition (vehicle combination speed, wanted deceleration by driver) irrespective of the load state. Computation of the index pressure values for the front and rear axle of towing vehicle and for axles of semi-trailer (trailer) would be based on the separate neural models of the front and rear brake's circuit operation of the tractor as well as neural model of semi-trailer brakes operation which are developed by monitoring and identification of their operation for different driving conditions.

Control strategy for normal braking could be changed according to acceleration of the brake signal transmitter in the case of panic braking. Here proposed braking strategy would be able to recognize panic situation and to change the target function of the tractor braking system operation (see figure 4). In the panic situation the both braking systems (tractor and its semi-trailer) would be forced to offer the maximum of its performance because the target function of the tractor would be changed from the upper limit of the semi trailer (laden condition) to the upper limit for tractor (laden condition). According to that, the index pressure values for the tractor's front and rear brakes application would be adjusted to the new (panic) braking rate function. The semi-trailer braking system performance would be controlled according to previously set up target function on the upper limit of the semi-trailer for laden condition. Furthermore, the response time of the both braking systems will be also adjusted simultaneously with changing of the towing vehicle braking strategy.

Here proposed, intelligent control strategies for the tractor/semi-trailer braking systems operation could be done by artificial intelligence technology based on neural network control. The neural network control has great potential since artificial neural network are built on a firm mathematical foundation that includes versatile and well-understood mathematical tools (8-14). That is why, in this paper artificial neural networks are used as one of the key elements in the design of controllers supposed to control tractor/semi-trailer braking performance according to developed neural models of the tractor/semi-trailer's brakes operations (figure 5).

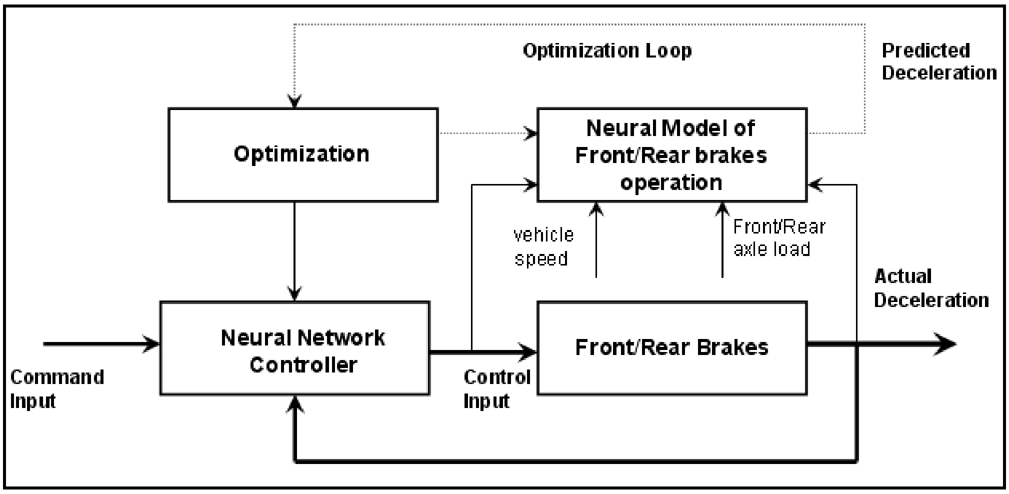

Figure 5. Neural modelling of the tractor's front/rear brakes operation

There are typically two steps involved when using neural networks for controlling: (i) system identification and (ii) control design (8). In the system identification stage, neural models of the tractor's front and rear brakes operation would be developed as well as neural model of semi-trailer brakes operation. In the control design stage, the developed neural models would be used for the tractor/semi-trailer braking systems controller designing. The neural models of the brakes operation serve to predict future behaviour of the brakes versus different operating regimes including the input signal from the driver and the selected index pressures see figure 5. On the other hand, the braking system controller based its function on this model in order to select control input at every sampling instant using the updated information from the monitored braking system variables.

Therefore, any tractor/semi-trailer braking systems action would be used for modelling i.e. neural network training in order to establish functional relationship between inputs and outputs shown on figure 5. After certain number of brakes applications, artificial neural network would be able to make prediction related to the tractor's front/rear brakes and semi-trailer's brakes performance (decelerations) versus actual operating conditions (selected the index of pressure, vehicle speed measured by speed sensors, and load carried at that time measured by axle load sensors). The benefit of this approach is that this prediction can be constantly evaluated and eventually corrected by neural network controller according to the real deceleration values for different disturbing influences (changes of the friction coefficient for different operation conditions, for instance).

From figure 6 can be seen difference between the target braking rate lines of the tractor's front and rear brake circuits, which are determined by previously adopted the unique target function of braking rates line based on the tractor/semi-trailer combination characteristics, versus real ones. It is obvious that real tractor/semi-trailer's braking performance (braking rates), for the specific usage conditions, deviate from the target ones. That is why, the neural models of the braking systems operation (see fig. 6.) would be able to provide possibilities for their intelligent controlling. Based on the models of the tractor/semi-trailer's brake's behaviour the neural network controller could be able to make selection of control input (the index pressure values) for the axles of tractor/semi trailer on such way to provide that partial decelerations of vehicle combination corresponding to the actual target function.

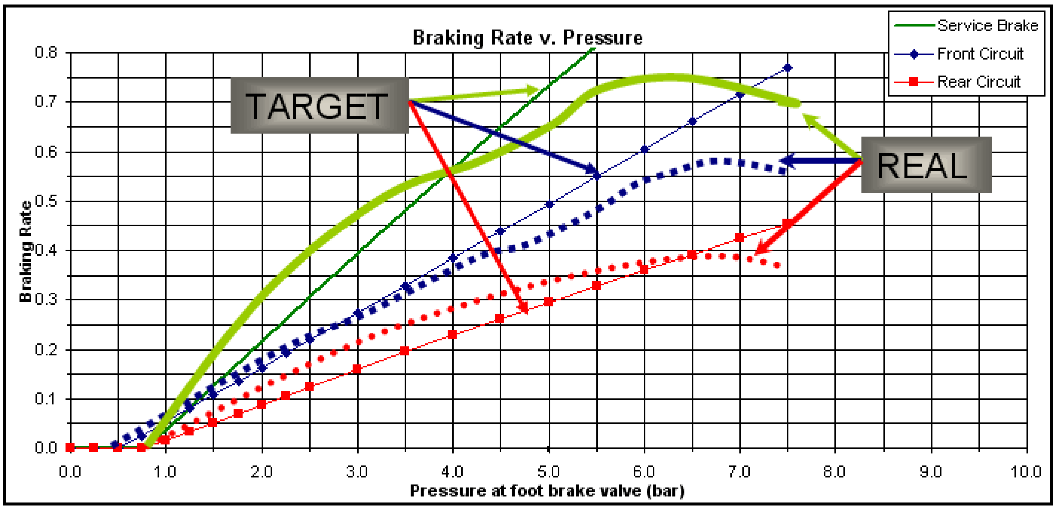

Figure 6. The tractor's target functions of braking rate lines versus real ones

CONCLUSIONS

The modelling of the braking system operation using variables which are constantly monitored by EBS during braking (driver deceleration demands, the index pressures, actual load carried by axle load sensor, vehicle combination speed by speed sensors, and actual deceleration by speed sensors) for establishing input/output relationship can be used for improving the control of braking system of commercial vehicle. According to proposed strategy for the braking systems controlling, the basic precondition is related to establishing the upper and lower limits for the both load state of power-driven vehicle or tractor/semi-trailer or towing/trailer combination. The upper and lower limits depend on mass of vehicle or vehicle combination, its wheelbase, and height of centre of gravity. That is why, it is important that intelligent braking system automatically recognize these vehicle's characteristics. It can be done using information from wheel speed sensors. Based on this information, the target function or braking strategy can be selected according to the actual braking situation initiated by the driver and the tractor/semi-trailer load conditions.

Intelligent Control of braking systems of commercial vehicles would be an "add-on" system, and its application does not impose any restriction concerning existing ESP devices already used in vehicles. It has a task to enable solution to the problem of the better control of braking system operation in a more accurate way then it was the case now a day, by means of over-taking responsibility for controlling the braking systems operation of the power-driven vehicle or tractor/semi-trailer or towing/trailer combinations.

The main benefit of the proposed intelligent control strategy is that future decisions related to the braking systems control are based on the neural models of the braking systems operation obtained as a result of real braking system operation in different braking regimes. That is why the control inputs (the index pressures) for the front and rear axles of the towing vehicle as well as coupling head pressure for the trailer vehicle could be adjusted for different operating condition offering the maximum capabilities of the braking systems function in the three different control ranges: (i) normal braking, (ii) wear control, and (iii) panic braking.

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