NECESSITY OF EVALUATION OF VENTILATION CONTROL AND ITS FUTURE PROSPECT

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Abstract

The electric power consumption for tunnel ventilation is enormous, and the development of better control strategies is expected to reduce it. In this situation, it became necessary to establish an evaluation function of the tunnel ventilation control, which gives an objective parameter as a measure of the quality of ventilation control. The author discusses the basic concept of evaluation and proposes a simple form of an evaluation function. Further possibility of application of the function is also pointed out. As this problem is rather new, the prospect of future development of the evaluation function is discussed.

1. INTRODUCTION

The ventilation facilities of a tunnel is designed so that the concentration level of pollutants is kept below a prescribed value in a steady state under an expected traffic condition as well as under conditions of tunnel length, longitudinal grade etc. In the actual operation, however, the traffic never shows the design condition, but is less dense in most of the time. Hence the ventilation power is reduced by controlling the ventilators according to the traffic. The control is carried out by adjusting the number of operating fans and/or changing the blade angle or the rotational speed of the fans. As the subject of control, the tunnel ventilation contains large disturbances caused by the dispersion of emission, piston effect etc. by each vehicle, different from the control of the ordinary plant (imagine the thickness control of the steel rolling or photographic film). Therefore, it is difficult to keep the control object to be constant, but a large fluctuation of pollution concentration in the tunnel is inevitable, and the requirement to the control is limited to that the concentration does not violate the allowable level so often.

The ventilation facilities require a large amount of power for the operation. For example, for the ventilation of Kan-etsu Tunnel, a 11 km tunnel with longitudinal ventilation with 48 × 1.5 m jet fans, two vertical shafts, 5 electrostatic precipitator stations (EP), the ventilation power annually cost about 600 million yen (3.5 million pound), although a sophisticated regulator control algorithm was adopted[1]. It means that the quality of ventilation control plays a significant role in considering the relation of cost and performance of ventilation.

In recent years, the cutting edge technologies of control have been introduced into routine control of tunnel ventilation in Japan[2][3][4]. These technologies are mostly converted from the fields to which they have been successfully applied, but they do not seem to be confirmed yet, if suitable for tunnel ventilation. In order to confirm the validity of these algorithms objectively, there arose necessity to establish a measure of evaluating the performance (not the performance of ventilation but of control!). The measure is also expected to encourage the development of control algorithms which are truly suitable for tunnel ventilation, because the makers have clear standard to be achieved. The current paper aims at the discussion on the concept how to establish a measure of evaluation of ventilation control for tunnels and on its prospect for the practical application.

2. NECESSITY OF EVALUATION OF VENTILATION CONTROL

The routine control of tunnel ventilation is carried out either by an operator (a person) or by a machine (mostly computer). The control is in some cases based on the daily pattern of traffic, and in other cases on feed back of visibility or CO concentration. They are often combined. It often happens that a severely polluted situation occurs for a very short time, especially in a longitudinally ventilated tunnel (transitory pollution). This usually diminishes quickly, and it is not necessary for the controller to respond to it. If the control system is too nervous, it will react to these phenomena, which is subjected to a worse evaluation due to unnecessary power consumption.

The ventilation control is the action taken in order to reduce ventilation cost, while maintaining the circumstances in the tunnel. Therefore, it is possible to reduce cost if a worse circumstances is allowed, and for a better visibility condition, higher power consumption is inevitable. Keeping the tunnel circumstance and reduction of ventilation cost are thus contradictory, and it seems that an absolute measure is difficult to establish. However, the necessity of the measure for the objective evaluation of the performance of ventilation control is increasing in various aspect, which is to extract a concrete parameter out of ambiguity. The possible applications of the evaluation are discussed in the later section.

The evaluation should be conceptually based on the balance of the following two items;

1) how well the tunnel circumstances are kept,
2) how economically the ventilators are operated.

It cannot be judged that the control is carried out properly, when one of the two shows poor result, even when the other shows an excellent performance. A good control is achieved when the both are satisfactory. The evaluation function can be hence constructed as the summation of the two penalties in the following way. Penalty of pollution is imposed over the time period while the pollution level exceeds the prescribed value, and is not imposed when the air is clearer than that. The penalty of power is imposed on the excessive power to the necessary minimum corresponding to the traffic density. As the two penalties have generally different dimensions, a conversion parameter is multiplied. Before summing up the two, a weighting parameter is also multiplied, so that the importance is adjusted. Thus a unified value for evaluation will be obtained.

3. CONSTRUCTION OF EVALUATION FUNCTION

In the former section, it was explained that the evaluation function consists as the summation of penalties of pollution and power. As the current problem is still in a premature stage, the author will here show an example of the evaluation function in the simplest form. A function, which bears practical application, is not yet established, and how it can be achieved is discussed in the later section.

The penalty of pollution should vary between the situations in which the concentration of soot or CO is above the permissible level or below. If a nonlinear penalty function is defined as is shown in fig. 1, the penalty of pollution takes the form,

$$\pi_{poll} = \frac{1}{T}\int_0^T F(t)\,dt, \text{ where } F(t) = \begin{cases} 0 & \text{for } \tau \geq \tau_0 \\ 1-\tau/\tau_0 & \text{for } \tau < \tau_0 \end{cases}, \tag{1}$$

where π_{poll} is the penalty of pollution, τ the visibility, τ_0 the permissible level. In the current study, the discussion is limited to soot density and the pollution is expressed by visibility. In the case for other pollutant such as CO, the pollution is directly the concentration, and the similar formulation will be observed. According to the author's proposal, penalty is generally given as the mean value over a certain time period T, where T can be an appropriate constant between one hour and one year.

It is not reasonable to count directly the power consumed for ventilation as the penalty of power, because the penalty should not be imposed to the power which is inevitable for the traffic at the time. Although it is a difficult work to divide which part is necessary and which part is not, the proposal assumes that the necessary minimal power is proportional to the jth power of traffic density, which leads to

$$\pi_{power} = \frac{1}{T}\int_0^T \left\{ \frac{P(t)}{P_0} - \left(\frac{N}{N_0}\right)^j \right\} dt. \tag{2}$$

π_{power} is the penalty of power, P the power consumption for ventilation, P_0 the power of total installation for ventilation, j the index in the range of 2 to 3. N is the traffic density averaged over a certain period of an hour or so, N_0 the design value of traffic density. If one considers on the soot density, N and N_0 should be better taken for the one of Diesel vehicles.

The unification process to combine the above two penalties is done under consideration of following two;

1)conversion of dimension and

2)weighting.

In the case of above formulation, the two penalties happen to be non-dimensional, but it is usually necessary to be in a same dimension before being summed up. In addition, significance of the terms are necessary to be determined in terms of weighting parameter. The final form of the evaluation function is thus expressed as

$$\pi_{total} = a\,\pi_{poll} + (1-a)\,b\,\pi_{power}, \tag{3}$$

in which a is the weighting parameter $(0 \leq a \leq 1)$ and b denotes the conversion coefficient between the two different quantity in different physical dimensions.

There are obstacles in applying the above defined evaluation function to the actual tunnel. One is that the measurement system is not always arranged suitably for the application of the evaluation function, and another is that the actual tunnel does not have the reproductivity in traffic etc., which may lead to inconvenience in evaluating the behavior of the function. For the purpose of considering the evaluation function in the beginning stage as it is, it is more convenient to improve or observe the behavior of the function through numerical experiment in terms of simulator, rather than applying to actual tunnels. In numerical simulations, a slightest difference of the result can be identified as is solely caused by the difference of the control. In the last report, some of the sample calculation is presented and discussed[5], in which different target values are applied to the same control logic.

When one tries to apply a tentative evaluation function to an actual tunnel, a careful consideration is needed. The controller, a machine or a human being, does not perform his/her job supposing that it is evaluated in the way the function defines. It means that the function should be informed to the controller beforehand in order to avoid the judgment to be unfair. The evaluation function is rather the one, which should be presented as the specification at the placement of the order. It is the definition how the performance of the controller is evaluated. Before now, there have been no such clear definition, which may have lead to confusion. It helps the understanding between both sides of the placer and receiver of the order for construction of the controller. This is the ultimate role of the evaluation function.

4. POSSIBLE APPLICATION OF THE EVALUATION FUNCTION

Once an evaluation function is properly established, it can be applied in various purposes such as followings.

(1) Evaluation of the performance of a control software (algorithm): The automatic control of tunnel ventilation is one of the difficult problems among plant controls, because the system contains large amount of disturbances such as piston effect or discharge of the vehicles. On the other hand, a rather wide fluctuation is permitted so long as the pollution level seldom violates the limit. In recent years, sophisticated algorithms, such as AI or fuzzy controls, are introduced into this field, and the necessity of the objective evaluation of these control is increasing.

(2) Evaluation of the scale and performance of the controller: The effect of the limitation of speed and capacity of the controlling computer to the performance of control can be evaluated.

(3) Evaluation of pattern control: When the ventilators are controlled by temporal traffic pattern, the evaluation of the result can advice improvement of the pattern or combination with feed back operation.

(4) Comparison of performance by a human and by a machine: Through comparison between the performance by a human and by a machine (a computer), we learn advantages and disadvantages of the operation by human beings, which might be possible to give hint toward a better algorithm to be installed into the computer.

(5) Transient performance of the ventilators: The effect of the transient performance of the ventilators, such as swiftness of response, can be evaluated.

(6) Evaluation of the interval of control: It is generally considered that a too small control

interval can cause instability due to the characteristic of a long tunnel, in that it takes time until the change of ventilation operation induces its effect. According to the recent improvement of the measurement, however, it can be possible to introduce new concept in this field, and it is evaluated by the evaluation function.

(7) Evaluation of the layout and accuracy of sensors: How the layout and accuracy of traffic sensors, visibility meters, CO meters etc. affect the performance of control can be evaluated. A possibility can be estimated, if a better control is achieved by an additional installation of sensor(s). The data measured by sensors are usually smoothed in order to eliminate fluctuation, and the effect of the time constant of the smoothing on the control performance can be evaluated.

By establishing an evaluation function, such variety of problems can be evaluated, mostly by means of numerical simulation. When it happens that different results of evaluation are obtained by the same control algorithm applied to two different tunnels, it can be understood either that the degree of difficulty of control varies according to tunnels, or that the compatibility of control algorithm to each tunnel is different. This can be caused by variety of reasons such as traffic condition, longitudinal gradient etc. An ultimately ideal evaluation function would be the one which gives stable evaluations for various tunnels, taking above matters into account. Until achieving this level, the evaluation function have to experience a lot of improvement from now on.

5. FUTURE PROSPECT OF THE EVALUATION FUNCTION

Discussions are made on how to construct an evaluation function and its possible applications. One of the problems to be solved for the improvement of the simple function presented in the former section is the generalization of the evaluation function. It is the problem if a function is applicable to tunnels with different length and different traffic density. The problem does not lie in the adjustment of the form or the coefficients of the function to the tunnels, but it is related to the degree of difficulty in control and the evaluation should be done how it is coped with it.

The improvement of the function essential for practical application is to add an extra term with regard to the life of machines to the penalties of pollution and power. Too often on-off operation of jet fans affects to shorten their lives. Larger fans receive severer heat load, and longer time interval is required until the next start after a stop. Change of the blade angles of variable pitch fans, on the contrary, impose much less load on the life of the machines. Unfavorable operation should receive penalty according to its degree.

It was already discussed on the effect of traffic density on the penalty, in which excessive power to the traffic get penalty by eq. (2). One has to consider if it is properly evaluated by eqs. (1), (2) and (3) in the following two cases:

(1) Traffic density is extremely low, and no (very few) ventilator(s) is operated.

(2) Traffic density is very heavy, and the permissible level of pollution is not maintained with all the fans in operation.

A consideration is also necessary when a 'demand power' is set below the full facilities, in which a non-linear penalty is appropriate.

In a longitudinal ventilation system, the degree of difficulty is largely different between the cases in which the vehicles come into the tunnel with a constant distance and the ones come in clusters. The fluctuation of traffic should be, therefore, properly taken into account in the evaluation function, when it works as 'excuse' to increase the necessary minimal power.

6. CONCLUSION

The necessity of the evaluation of routine control of tunnel ventilation is discussed with its future prospects. The author has been roused attention on the issue for more than 15 years in Japan, and the importance begins to be recognized in recent years. But there is no discussion outside Japan yet, according to what the author hears, presumably because the electric power is less expensive in Europe and America. However, there is no doubt that the time comes in the near future, when the mankind has to struggle to reduce power consumption as much as possible, probably due to increasing CO_2 concentration. The current topic is a difficult problem, and it is recommended to begin the study at this moment and to refine evaluation functions, which can be used for various purposes.

References

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Nomenclature

a	[–]	Weighting parameter.
b	[*]	Conversion parameter.
N	[1/h]	Traffic density.
N_0	[1/h]	Design traffic density.
P	[W]	Power for ventilation (function of time).

P_0	[W]	Total power of the ventilation facilities.
t	[s]	Time.
T	[s]	Reference time period in which values are averaged.
π_{poll}	[–]	Averaged penalty on pollution.
π_{power}	[–]	Averaged penalty on power consumption.
π_{total}	[–]	Summation of two penalties with weighting parameters.
τ	[–]	Visibility of 100 m distance.
τ_0	[–]	Allowable limit of visibility.

* The unit is not fixed.

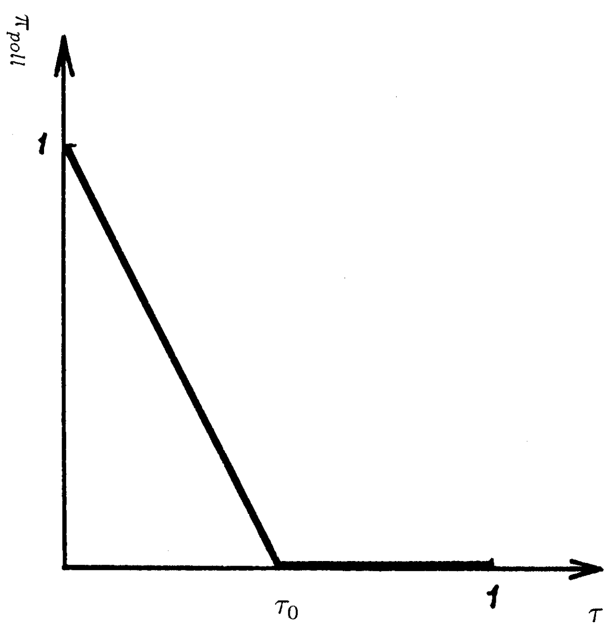

Figure 1: Penalty function of pollution