The ventilation system and emergency simulation of the Shinjuku Tunnel

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1 INTRODUCTION

In order to provide an efficient traffic operation in large urban areas, to construction of a road network based on circular and radial routes can play an important role. For this reason, the Metropolitan Expressway Public Corporation is constructing the Central Circular Shinjuku Route (Shinjuku Route). The main part of the Shinjuku Route consists of an 11km long tunnel fully justified. In order to provide an efficient traffic operation in large urban areas, to construction of a road network based on circular and radial routes can play an important role. For this reason, the Metropolitan Expressway Public Corporation is constructing the Central Circular Shinjuku Route (Shinjuku Route). The main part of the Shinjuku Route consists of an 11km long tunnel structure with heavy traffic (Shinjuku Tunnel). The tubes for each direction are separate tunnels located under a local road. The exit and entrance ramps are combined in a single tube causing complex air exchange at these merge and branch parts. Based on these considerations, it was decided to operate a transverse ventilation system in this tunnel.

Especially in the light of the accidents in the Mont Blanc Tunnel and the Tauern Tunnel, it was deemed important to investigate how a suitable evacuation environment can be secured at times of tunnel fire. In addition, it is necessary to limit costs for power supply, by the use of a suitable ventilation control at normal traffic situations. In order to investigate a suitable control for this complex ventilation system of the Shinjuku Tunnel, a calculation model was established, based on nodes and links. This theory can also be applied for other types of complex tunnel structures, and requires short calculation time. Investigation was carried out concerning the controllability of the longitudinal flow velocity with complex transverse ventilation systems, based on feedback control algorithms introduced by Mizuno [1]. These algorithms are based on the concept of so called imbalance operation, in which exhaustion and fresh air flow are artificially differentiated.

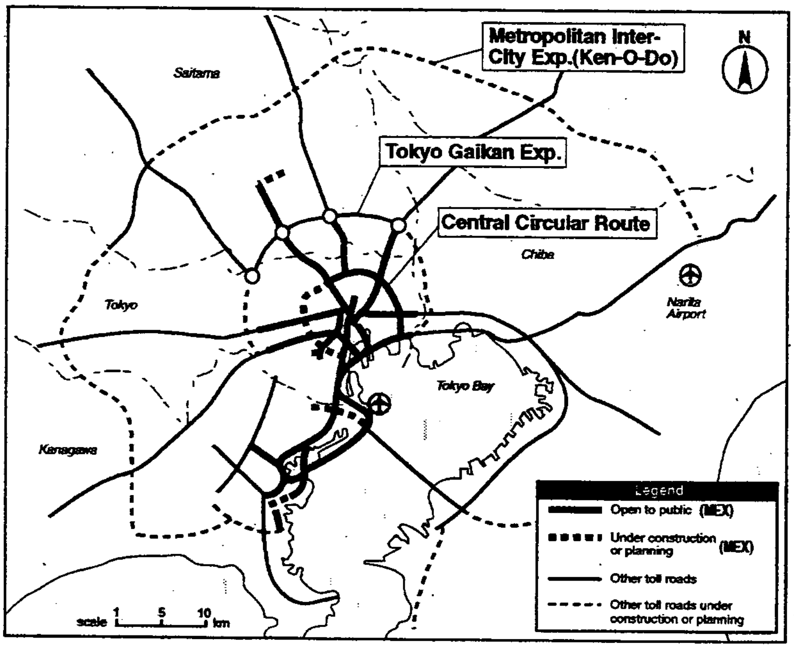

Figure 1. 3 Circular Routes in the Metropolitan Area

2 OUTLINE OF THE SHINJUKU TUNNEL

A road network based on well-balanced radial and circular routes can play an important role to provide an efficient traffic operation in metropolitan areas. Especially circular routes have a significant function to increase the choice of trips or to ease traffic concentration.

In the Tokyo Metropolitan Area, 3 circular routes are being implemented since the 1960's, including the Metropolitan Inter-City Expressway (Ken-O-Do), the Tokyo Gaikan Expressway and the Central Circular Route. At present, however, only 20% of these roads have been completed, meaning a delay when comparing with other cities that started constructing circular routes at the same time as Tokyo, such as London (99%) and Paris (74%).

Metropolitan Expressway Public Corporation is responsible for the inner most of the 3 circular routes, the Central Circular Route (Figure 1).

2.1 Outline of Metropolitan Expressway network

The total present length of the Metropolitan Expressway network is 281 km. The network plays a key role as traffic artery that supports the urban and economic activities in the area, having a traffic volume of 1.15 million vehicles per day, and providing route for 40% of the goods transport through the metropolitan area.

On the other hand, the delay in implementation is causing traffic jams due to lack of capacity, and the traffic congestion volume (i.e. the product of congestion length and time) saw a peak in 1990. The ongoing implementation of the network and bottleneck measures carried out to further ease traffic congestion, have resulted in a reduction to half of the congestion volume during peak hours in 1998, but traffic congestion at the radial routes into the city center have not reduced. This is caused by congestion at the Inner City Link (C1), with traffic volume of

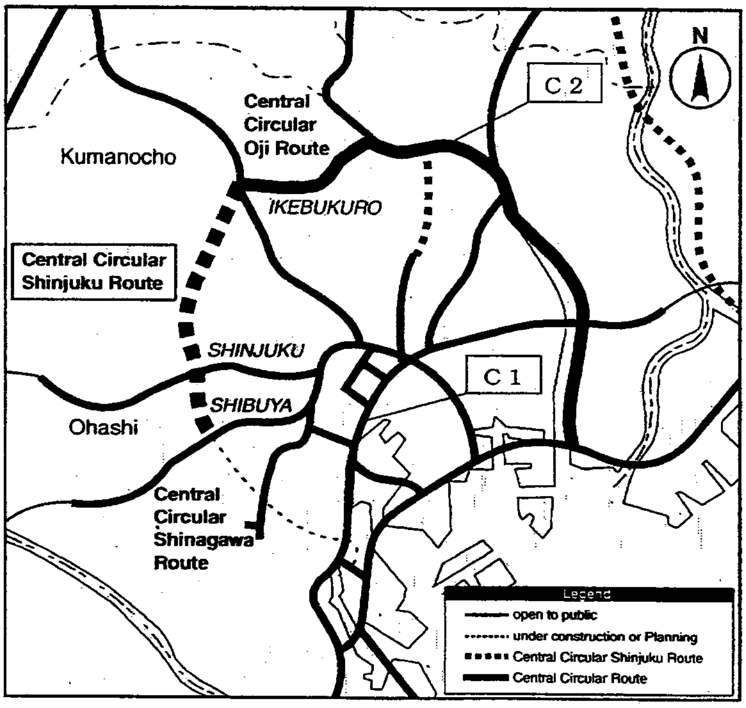

Figure 2. Outline of the Central Circular Route

460,000 vehicles per day, whereas 270,000 vehicles or 60% are through traffic not having the city center as its final purpose.

The Central Circular Route (C2) will play a role to divert and spread the through traffic, in order to provide a well-balanced road network in the Metropolitan Area, and largely alleviate congestion. With a radius of 8km from the heart of Tokyo, the total length of the Central Circular Route (Figure 2) is about 46km, of which 26km are in operation. The remaining 20km consist of the Shinjuku Route (11km, under construction at the moment) and the Shinagawa Route (9km, in planning).

2.2 Outline of the Shinjuku Route

The Shinjuku Route, L=11km, is an expressway with 2 traffic lanes in each direction and a design velocity of 60km/h. The main part of the route consists of a tunnel construction, based on air quality and noise considerations. Being an intercity tunnel, the route has a large number of access routes to local roads, and the length between ramps is relatively short. In total the route will include 6 ramps to local roads and 2 junctions to existing radial routes.

The tunnel operates a transverse ventilation system, which is based its complex structure due to the branch and merge sections. In total there are 9 ventilation stations, of which 7 are located at positions with limited space, and all facilities and equipment are installed in underground structures and only have the ventilation shaft as connection to the ground level. The other 2 ventilation stations are constructed above ground (Figure 3).

In addition to the eastern part of the Central Circular Route which is in operation at the moment, the completion of the Shinjuku Route, planned in 2007, will mean completion of

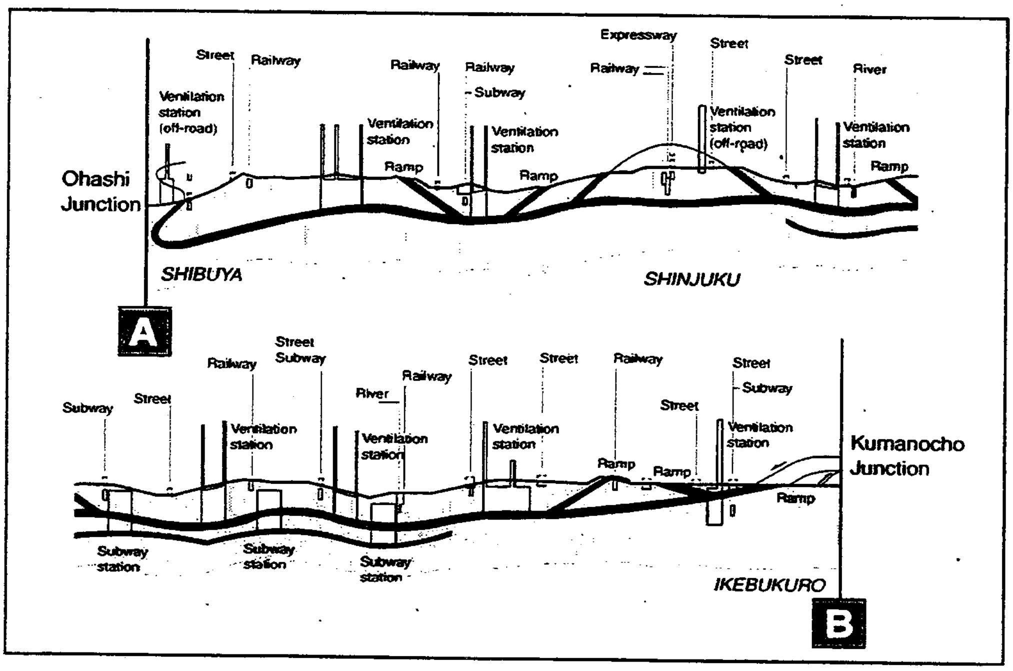

Figure 3. Outline of the Shinjuku Route

80% of the Central Circular Route. It is objected that through traffic concentrating in the heart of Tokyo at the moment is diverted to the Shinjuku Route, resulting in a more efficient operation of the Metropolitan road network.

2.3 Outline of Shinjuku Tunnel Ventilation

Tunnel ventilation is installed in order to prevent influence by polluted matter from traffic exhaust gas to tunnel users and maintenance personnel, and to ensure necessary visibility for safe and comfortable passage through the tunnel. Furthermore, in case of tunnel fire, the ventilation system can be operated such that a safe evacuation environment is ensured and the firefight activities by the fire brigade is supported.

In order to achieve these purposes, the Shinjuku Tunnel will apply a transverse ventilation system to ensure a stable tunnel environment within the complex air movements due to the multiple ramps and junctions in the tunnel. In addition, the area surrounding the Shinjuku Tunnel consists of a large number of dwelling houses requiring suitable environmental considerations, and it was decided to apply a point extraction near the tunnel portals, in order to control exhaust gas emission from the tunnel portals. With in total 9 ventilation stations, an overall ventilation capacity of 8,000 m^3/s is planned. Because the main part of the tunnel is constructed with the shield method, it was decided to make use of the space under the road surface as ventilation ducts. The structure is based on flues, for the first time in Japan (Figure 4).

Due to the large number of ventilation equipment and capacity, a high energy-consumption is expected. Therefore, investigations are carried out to include fresh air income through the tunnel entrance due to traffic piston, normally not considered in transverse ventilation systems, and it is necessary to investigate a suitable ventilation operation system that controls the longitudinal flow velocity by balancing the extraction and supply volume.

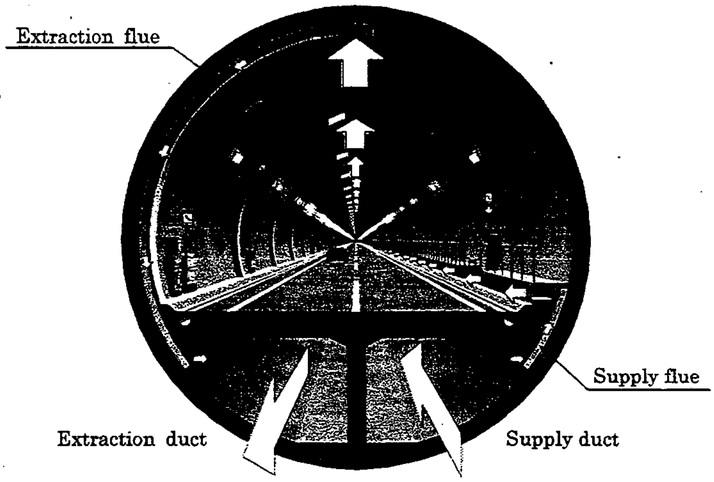

Figure 4. Cross section of Shinjuku Tunnel

2.4 Ventilation operation during tunnel fire accidents

In the first stage of a tunnel fire it is important to efficiently extract smoke to save lives, supply information to drivers to ensure a safe evacuation environment, and guide tunnel users through the emergency exits to safe areas.

Furthermore, investigations are carried out about ventilation operation and structural fire protection, in order to enable immediate rescue and fire fight activities by fire brigade. The ventilation operation in the first phase of a tunnel fire will be dependent on the traffic conditions at the time of fire outbreak. In case of congestion, tunnel users will be present both upstream and downstream of the fire, and the longitudinal flow velocity is planned to be kept as close as possible to 0m/s, and extract the smoke while maintaining the smoke stratification (Figure 5). In case of normal traffic conditions, the tunnel users will be present upstream the fire and the ventilation operation is such that smoke flows in the direction of the downstream side of the fire (Figure 6).

The ventilation operation in the later phase, when the fire brigade is carrying out fire fight activities from the upstream side of the fire, is planned such that smoke flows in the direction of the downstream side, and is thus the same as the initial phase ventilation operation in case of normal traffic conditions.

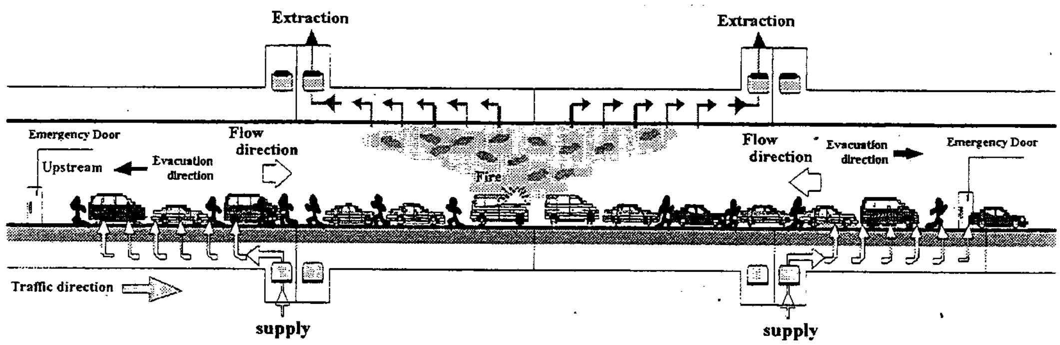

Figure 5. Fire ventilation operation in case of congestion

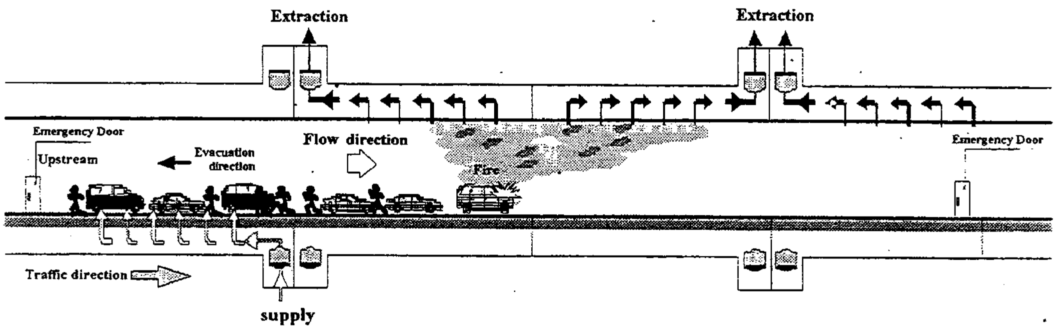

Figure 6. Fire ventilation operation during normal traffic conditions

In all cases, in case of transverse ventilation it is important to control the longitudinal flow velocity. Especially in case of fire, the control of the longitudinal flow velocity is important in order to maintain safe evacuation environment.

2.5 Necessity to control the longitudinal flow velocity with transverse ventilation

It was considered necessary to secure the evacuation environment for tunnel users (initial phase) and to support the fire brigade (later phase) in case of tunnel fire.

Therefore it was decided necessary to control the longitudinal flow velocity with the planned transverse ventilation system.

It was decided necessary to operate a cost efficient ventilation system that includes the traffic piston action, in order to limit costs for power consumption. Below an outline is given of investigation to control the longitudinal flow velocity with the transverse ventilation system planned for the Shinjuku Tunnel.

3 DESCRIPTION OF THE SIMULATOR

3.1 Equation of motion for longitudinal flow per unit section

The equation of motion for longitudinal flow per infinitesimal section dx is given [2] as

$$dm\left\{\frac{\partial V_r}{\partial t}+2V_r\frac{\partial V_r}{\partial x}-V_r\frac{\xi_b q_{in}-\xi_e q_{out}}{A_r}\right\}=-\frac{\partial p}{\partial x}dxA_r+dF_r+dF_t, \tag{3.1}$$

where $dm=\rho A_r dx$. In the following, we assume the coefficients are as follows. The momentum brought into the traffic room by the fresh air is assumed to be zero; thus, $\xi_b=0$. Whereas the exhaust air is supposed to flow out with the momentum based on the mean velocity, yielding $\xi_e=1$. Thus equation (3.1) becomes,

$$dm\left\{\frac{\partial V_r}{\partial t}+2V_r\frac{\partial V_r}{\partial x}+V_r\frac{\xi_e q_{out}}{A_r}\right\}=-\frac{\partial p}{\partial x}dxA_r+dF_r+dF_t. \tag{3.2}$$

Furthermore, by assuming q_{in} and q_{out} to be uniform in a section, V_r can be formulated as a first degree equation of x as

$$V_r=V_{r\alpha}+\frac{q_{in}-q_{out}}{A_r}x. \tag{3.3}$$

By integrating equation (3.2) over the total section based on equation (3.3), adding F_j and F_e, the following equation is obtained. This is the equation of motion that controls the longitudinal flow in one section. In the following considerations, the flow velocity $V_{r\alpha}$ at the start of a section is taken as the representative longitudinal flow velocity of that section.

$$\begin{aligned}m\frac{\partial V_{r\alpha}}{\partial t}&=-m\frac{1}{2A_r}\frac{d}{dt}(Q_{in}-Q_{out})-A_r\rho\left(V_{r\beta}^2-V_{r\alpha}^2\right)\\&\quad-m\frac{1}{2}\frac{q_{out}}{A_r}\left(V_{r\beta}+V_{r\alpha}\right)+F_r+F_t+F_j+F_e+A_r\left(p_\alpha-p_\beta\right)\end{aligned}, \tag{3.4}$$

or

$$m\frac{dV_{r\alpha}}{dt}=f+A_r(p_\alpha-p_\beta). \tag{3.5}$$

This is the equation of motion that controls the longitudinal flow in one section. Here the following applies

$$f\equiv+F_r+F_t+F_j+F_e+F_{trans}. \tag{3.6}$$

Also F_{trans} is the force exerted from transverse ventilation,

$$F_{trans}=-m\frac{1}{2A_r}\frac{d}{dt}(Q_{in}-Q_{out})-A_r\rho\left(V_{r\beta}^2-V_{r\alpha}^2\right)-m\frac{1}{2}\frac{q_{out}}{A_r}\left(V_{r\beta}+V_{r\alpha}\right). \tag{3.7}$$

Defining,

$$\Delta V_r\equiv\frac{Q_{in}-Q_{out}}{A_r}, \tag{3.8}$$

and substituting $x=L$ in to equation 3.3, the continuity equation is express in a differential form,

$$\frac{dV_{r\beta}}{dt}=\frac{dV_{r\alpha}}{dt}+\frac{d}{dt}\Delta V_r. \tag{3.9}$$

3.2 Ventilation forces

The ventilation forces on the right hand side of equation (3.4) are expressed as follows.

3.2.1 *Wall friction*

The wall friction is expressed as in equation (3.11).

$$F_r = \int_0^L dF = \int_0^L \left\{ -A_r \lambda \frac{dx}{D_r} \frac{\rho}{2} |V_r(x)| V_r(x) \right\} \tag{3.10}$$

$$= \int_0^L \left\{ -A_r \lambda \frac{dx}{D_r} \frac{\rho}{2} \left| V_{r\alpha} + \frac{q_{in} - q_{out}}{A_r} \right| \left(V_{r\alpha} + \frac{q_{in} - q_{out}}{A_r} \right) \right\}. \tag{3.11}$$

Because the integration function is of the second degree, it can be solved analytically. On the other hand, the symbols need to be addressed and the absoluteness symbols need to be removed.

3.2.2 *Traffic piston force*

The traffic piston action is expressed as:

$$F_t = \int_0^L dF_{t+} + \int_0^L dF_{-}. \tag{3.12}$$

Here, the piston action of the traffic moving from α to β is

$$F_{t+} = \int_0^L dF_{+} = \int_0^L A_m \frac{\rho}{2} n_{+} \left| \{V_{t+} - V_r(x)\} \right| \{V_{t+} - V_r(x)\} dx. \tag{3.13}$$

The piston action of the traffic in the opposite direction can also be expressed similarly.

3.2.3 *Ventilation action by Jet fans*

The ventilation action by Jet fans is expressed as

$$F_j = n_j \rho V_j^2 A_j \left(1 - \frac{V_r}{V_j} \right). \tag{3.14}$$

3.2.4 *Entrance loss*

The entrance loss is expressed in equation (3.15) in case of air inflow from the start point,

$$F_e = -A_r (1 + \zeta_e) \frac{\rho}{2} V_{r\alpha}^2. \tag{3.15}$$

Also, In case air inflow from the end point, the loss is expressed similarly. Otherwise $F_e = 0$.

3.3 Calculation model for complex ventilation systems

In order to carry out calculation for complex ventilation systems, an analysis method is used based on graph representation of the tunnel structure using nodes and links.

With the graph theory a general calculation model for road tunnels consisting of multiple structures has been realized. Additionally, based on the equation of continuity and the equation of motion concerning the longitudinal flow the pressure at branch and merge points is derived, and a continuous condition equation for longitudinal flow is derived.

3.3.1 Representation of nodes and links

Figure 7 shows an example of a network model based on nodes and links, in order to obtain a general model of the tunnel structure. Nodes and links are defined as follows:

node with known pressure: tunnel portals, shafts openings, etc.
node with unknown pressure: ventilation openings within tunnel, branch and merge sections and shafts.
links: tunnel and shaft sections with node α as start point and node β as end point.

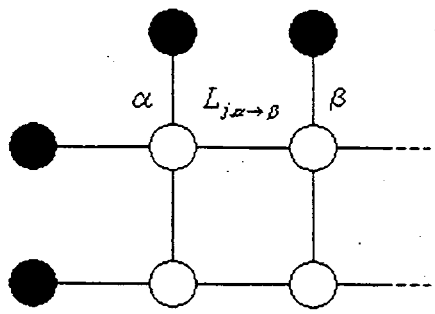

Figure 7. Representation of nodes and links

Furthermore, numbers are attached to each node and link, and velocity and traffic at each link is positive from start point to end point.

3.3.2 Connection matrix

In order to apply the represented network of nodes and links to the calculation model, information is necessary about which node is connected to which link. Therefore, a connection matrix is produced, with values 1, -1 or 0 to represent the relation between links and nodes. $\mathbf{S}_1$ shows the connection relation between links and nodes with unknown pressure, $\mathbf{S}_2$ shows the connection relation between nodes and links with known pressure, and $\mathbf{S}_3$ is the matrix describing the connection between the link and its end point, which is necessary to allow the possibility of the velocity difference between the start and the end point.

Connection matrix $\mathbf{S}_1 : n_L \times n_N$

$$s_{1i,j} = \begin{cases} 1 & \text{if link } i \text{ is connected to node } j \text{ as the start point} \\ -1 & \text{if link } i \text{ is connected to node } j \text{ as the end point} \\ 0 & otherwise \end{cases}$$

Connection matrix $\mathbf{S}_2 : n_L \times n_{N0}$

$$s_{2i,j} = \begin{cases} 1 & \text{if link } i \text{ is connected to node } j \text{ as the start point} \\ -1 & \text{if link } i \text{ is connected to node } j \text{ as the end point}. \\ 0 & otherwise \end{cases}$$

Connection matrix $\mathbf{S}_3 : n_L \times n_N$

$$s_{1i,j} = \begin{cases} -1 & \text{if link } i \text{ is connected to node } j \text{ as the end point} \\ 0 & otherwise \end{cases}$$

3.3.3 Pressure at merge and branch section

The flow volume preservation at merge and branch section is described as

$$\mathbf{S}_1^T \mathbf{A}_r \mathbf{V}_r + \mathbf{S}_3^T \mathbf{A}_r \Delta\mathbf{V}_r = \mathbf{0} \qquad ,(3.16)$$

where

$$\mathbf{V}_r \equiv [V_{r1}, V_{r2}, \cdots, V_{rnL}]^T ,$$

$$\Delta\mathbf{V}_r \equiv [\Delta V_{r1}, \Delta V_{r2}, \cdots, \Delta V_{rnL}]^T .$$

Differentiating with time it gives

$$\mathbf{S}_1^T \mathbf{A}_r \frac{d\mathbf{V}_r}{dt} + \mathbf{S}_3^T \mathbf{A}_r \frac{d\Delta\mathbf{V}_r}{dt} = \mathbf{0} \qquad .(3.17)$$

When representing equation (3.5) with vectors, the equation of motion of the tunnel air is as given

$$\frac{d\mathbf{V}_r}{dt} = \mathbf{m}^{-1}\left(\mathbf{f}(\mathbf{V}_r) + \mathbf{A}_r \mathbf{S}_2 \mathbf{p}_{out} + \mathbf{A}_r \mathbf{S}_1 \mathbf{p}_{in}\right) \qquad .(3.18)$$

$$\mathbf{f}(\mathbf{V}_r) \equiv [f(V_{r1}), f(V_{r2}), \cdots, f(V_{rnL})]^T :$$

$$\mathbf{m} \equiv \mathrm{diag}[m_1, m_2, \cdots, m_{nL}]^T$$

$$\mathbf{p}_{in} \equiv [p_{in1}, p_{in2}, \cdots, p_{in\,nN}]^T$$

$$\mathbf{p}_{out} \equiv [p_{out1}, p_{out2}, \cdots, p_{out\,n0}]^T$$

$$\mathbf{A}_r \equiv diag[A_{r1}, A_{r2}, \cdots, A_{rnL}]^T$$

(3.17) and (3.18) for $\mathbf{p}_{in}$ gives

$$\mathbf{p}_{in} = -\boldsymbol{\psi}_{in}^{-1}\boldsymbol{\psi}_{out}\mathbf{p}_{out} - \boldsymbol{\psi}_{in}^{-1}\boldsymbol{\Gamma}\mathbf{f}(\mathbf{V}_r) - \boldsymbol{\psi}_{in}^{-1}\mathbf{S}_3^T\mathbf{A}_r\frac{d\Delta\mathbf{V}_r}{dt} . \qquad (3.19)$$

$$\boldsymbol{\psi}_{out} \equiv \mathbf{S}_1^T \mathbf{m}^{-1} \mathbf{A}_r^2 \mathbf{S}_2 .$$

$$\boldsymbol{\psi}_{in} \equiv \mathbf{S}_1^T \mathbf{m}^{-1} \mathbf{A}_r^2 \mathbf{S}_1 .$$

$$\boldsymbol{\Gamma} \equiv \mathbf{S}_1^T \mathbf{m}^{-1} \mathbf{A}_r$$

3.3.4 Equation of motion for complex ventilation systems

Substituting $\mathbf{p}_{in}$ of equation (3.19) in the equation of motion (3.18) gives equation (3.20).

$$\mathbf{m}\frac{d\mathbf{V}}{dt} = \mathbf{f}(\mathbf{V}_r) + (\mathbf{A}_r\mathbf{S}_1)^{-1}\left\{-\boldsymbol{\psi}_{in}^{-1}\boldsymbol{\psi}_{out}\mathbf{p}_{out} - \boldsymbol{\psi}_{in}^{-1}\boldsymbol{\Gamma}\mathbf{f}(\mathbf{V}_r) - \boldsymbol{\psi}_{in}^{-1}\mathbf{S}_3^T\mathbf{A}_r\frac{d\Delta\mathbf{V}_r}{dt}\right\} + \mathbf{A}_r\mathbf{S}_2\mathbf{p}_{out} \qquad .(3.20)$$

Using Euler forward difference, the representative longitudinal flow velocity is derived.

4 STUDY OF EMERGENCY VENTILATION BY SIMULATION

This section describes the emergency ventilation in case of tunnel fire. The behavior of air flow is important in order to ensure safe evacuation environment. Simulations were carried out in order to verify the possibilities of a feedback control to maintain the longitudinal flow in line with the objected values.

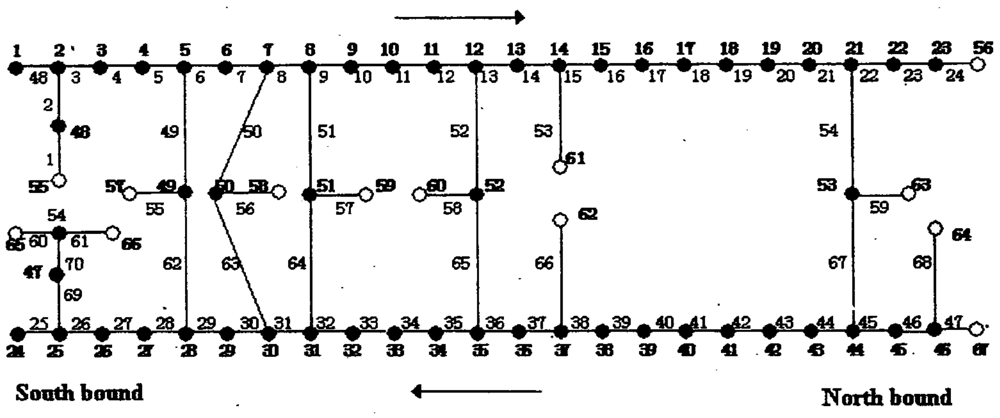

Figure 8. Network model for Shinjuku Tunnel

4.1 Ventilation system

Simulation is carried out with Shinjuku Tunnel as model and following conditions for case of emergency. First of all the network model based on nodes and links is shown in Figure 8. The flow rate of transverse ventilation at each section is calculated based on ordinary ventilation analysis.

Sections close to a branch, such as Link 6, are easily influenced by other links and are presumed to be disadvantageous in terms of longitudinal flow control. On the other hand, the longitudinal flow of relatively long sections without branch or merge parts, such as Link 18, is presumably easy to control. Therefore, the simulation results of accidents in these two sections are shown.

4.2 Simulation scenario

The simulation scenario is shown as follows.

- The congestion start at t = .1:40(min.) 350m ahead.
- The accident occurs at t = 0:00 (min.).
- The accident results in a fire at t = 1:00(min.).
- The fire is recognized at t = 3:00(min.). The tunnel entrance is closed to traffic, and the emergency ventilation control is started to maintain a 0m/s flow velocity.

Fire caused by accident occurs, which is recognized within 2 minutes. After the start of control, the longitudinal flow at the accident site is limited, thereby limiting smoke spread and maintaining the evacuation environment.

4.3 Characteristics of longitudinal flow

This section describes the characteristics of longitudinal flow in terms of flow velocity control. Based on simulation of emergency ventilation control, the possibilities to maintain the longitudinal flow velocity at 0m/s is verified. With a representative section including many

	Upstream (link 3-4)		Object control section (link 5-6)		Downstream (link 7-13)		Other links	
	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust
Case1	100%	25%	0%	100%	25%	100%	25%	25%
Case2	25%	100%	0%	100%	100%	25%	25%	25%

Table 1. Ventilation operation after the accident

branch and merge parts, the characteristics for links 5 and 6 are described, as they are presumed to be disadvantageous for the longitudinal flow control. Figure 9 shows which feedback control can be applied, using the characteristics of longitudinal flow in case the ventilation fans are operated as shown in Table 4.1 after the accidents occurs (t = 3:00 min.). Additionally, the control of the section upstream and downstream the object control section have a degree of flexibility, and their patterns are decided as shown in Table 1.

Figure 9 shows the flow velocity change for case 1 (upper limit) and case 2 (lower limit). These results show the range of feedback control for case 1 and case 2. Because this range includes 0m/s, it was concluded that a feedback control to maintain 0m/s is possible after the accidents to 3:40 min..

4.4 Feedback control for longitudinal flow

Basic idea of the controlling logic is the so called "imbalance operation of ventilation", with which the longitudinal air flow can be brought to a certain target value in a transverse system. A simple example: if you want to reduce the air flow, you would increase the fresh air in the downstream sections, while increase the exhaustion in the upstream sections. The difference of fresh air supply and exhaustion is defined as

$$\Delta Q \equiv Q_{in} - Q_{out} \tag{4.1}$$

at each section. According to the difference of the air flow velocity to the target value, ΔQ in

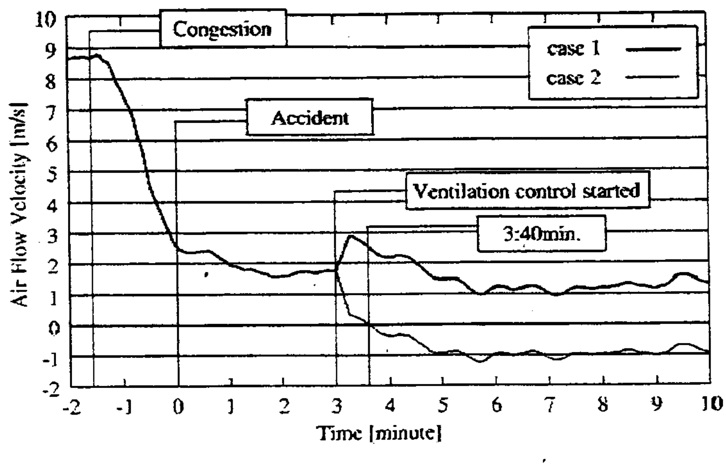

Figure 9. Characteristics of longitudinal flow

the upstream sections are calculated as

$$\Delta Q^{T+1} = \Delta Q^{T} - K(V_a - V_0), \tag{4.2}$$

and the one in the downstream sections takes negative value. The superscript T and $T+1$ denote sequence of control period.

4.5 Simulation of emergency control

4.5.1 Accident in the link 6

• Ventilation operation pattern

	Upstream (link 3-4)		Object control section (link 5-6)		Downstream (link 7-13)		Other links	
	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust
case3	Imbalanced operation	Imbalanced operation	0%	100%	Imbalanced operation	Imbalanced operation	25%	25%

Table 2. Ventilation operation pattern

• Control pattern
Control cycle 10 sec.

• Traffic control
The tunnel is closed in both directions 3 minutes after accident occurrence. The average traffic velocity is 60km/h before the accident.

• Ventilation equipment specifications
The required time to operate the ventilation equipment from 0% to 100% is 60 sec. The minimum output ratio is 25%.

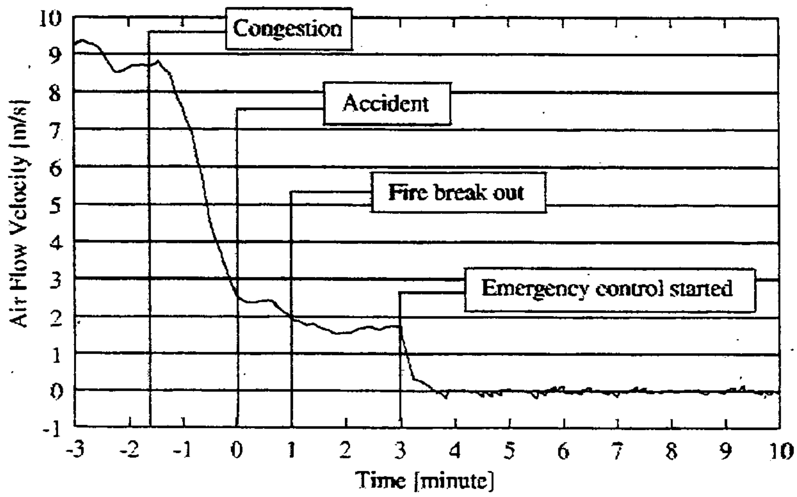

Figure 10. Change in time of longitudinal flow velocity for link 6

4.5.2 *Simulation results*

After congestion occurrence the traffic piston action decreases, and at the time of accident occurrence the longitudinal flow velocity reduces to about 2m/s. The longitudinal flow velocity reaches the object value 30 seconds after start of the ventilation control for 0m/s flow velocity. Also after that, the flow velocity remains at about 0m/s. (Figure10)

4.5.3 *Accident in the link 18*

• Ventilation operation pattern

	Upstream (link 14-17)		Object control section (link 18)		Downstream (link 19-21)		Other links	
	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust
case3	Imba-lanced operation	Imba-lanced operation	0%	100%	Imba-lanced operation	Imba-lanced operation	25%	25%

Table 3. Ventilation operation pattern

• Control pattern

Control cycle 10 sec.

• Traffic control

The tunnel is closed in both directions 3 minutes after accident occurrence. The average traffic velocity is 60km/h.

• Ventilation equipment specifications

The required time to operate the ventilation equipment from 0% to 100% is 60 sec.
The minimum ratio is 25%.

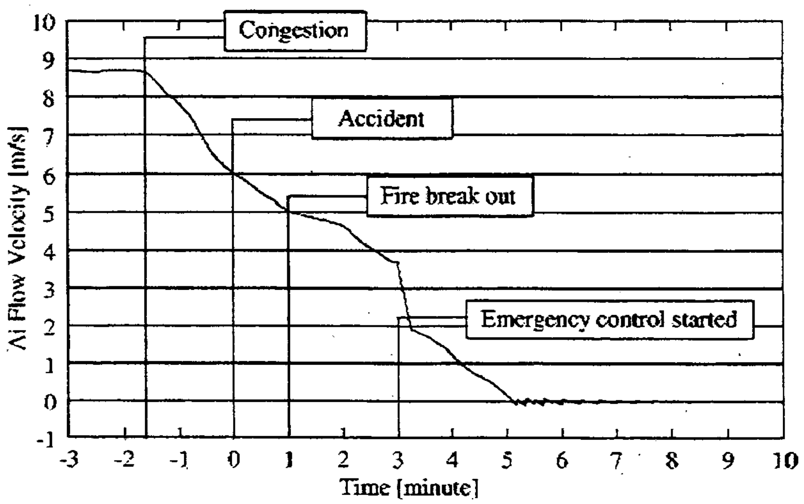

Figure 11. Change in time of longitudinal flow velocity for link 18

4.5.4 Simulation results

After start of the ventilation control for 0m/s the object value in 2 minutes. This is because the traffic piston action works longer after the tunnel is closed to traffic, as the distance of the entrance is further away than that in the case for l ink 6. (Figure 11)

5 CONCLUSIONS

In order to investigate a suitable control for the complex transverse ventilation systems, a calculation model was established, based on nodes and links. Simulation were, it was carried out the controllability of the longitudinal flow velocity with complex transverse ventilation systems, based on feedback control algorithms.

The simulation results show that for the Shinjuku Tunnel a flow velocity of 0m/s is reached 4 minutes after fire occurrence in the worst case, and this value can be maintained in a stable manner after that point of time. Therefore it is considered that by keeping the flow velocity at 0m/s during the initial stage when the fire size has not increased, it is possible to extract smoke while keeping it stratified along the ceiling, thereby securing the evacuation environment for tunnel users.

Based on these results, it is necessary to clarify the development of heat and smoke during tunnel fire accidents, and to confirm the evacuation environment for tunnel users, and investigate a suitable ventilation control during normal traffic conditions. In addition, in order to construct tunnels that suitably reflects the results of this investigation, it is necessary to implement a high performance feedback ventilation control, and investigate the distribution of sensors such as air flow velocity and direction meters, as well as defining suitable control logics.

The simulation results are going to be compared with the on-site experiment, when the Shinjuku Tunnel is completed. There are also several comparisons to validate the simulation model, such as the one at the Higashiyama Tunnel, conducted early this year.

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NOMENCLATURE

A_j	: area of jet fan outlet[m²]
A_m	: equivalent frontal projection area of vehicles[m²]
A_r	: cross section of tunnel[m²]
D_r	: hydraulic diameter of tunnel[m]
F_e	: entrance loss force[N]
F_j	: jet fan ventilation force[N]
F_r	: wall friction force[N]
F_t	: traffic piston action[N]
F_{trans}	: longitudinal force by transverse ventilation[N]
K	: control gain[s/m]
L	: section length[m]
m	: air mass[kg]
n_j	: number of jet fans
n_L	: total number of links
n_N	: total number of nodes in tunnel
n_{No}	: total number of nodes at tunnel facing outside
n	: traffic volume per unit length[veh/m·s]
p_{in}	: pressure of node in tunnel[Pa]
p_{out}	: pressure of node at portal[Pa]
q_{in}	: supply flow volume per unit length[m³/s·m]
q_{out}	: exhaust flow volume per unit length[m³/s·m]
Q_{in}	: supply flow volume[m³/s]
Q_{out}	: exhaust flow volume[m³/s]
$S_{1\,i,j}$	: connection matrix of nodes in tunnel
$S_{2\,i,j}$	: connection matrix of nodes at portal
$S_{3\,i,j}$	: connection matrix of nodes and end of link
t	: time[s]
T	: time step of control
V_a	: airflow velocity at the point of accident [m/s]
V_j	: jet fan flow velocity[m/s]
V_r	: representative longitudinal flow velocity[m/s]
ΔV_r	: velocity difference between start and end of link[m/s]
ΔV_0	: target value of V_r [m/s]
x	: distance from start of section[m]
λ	: wall friction loss coefficient
ρ	: air density[kg/m³]
ξ_b	: supply momentum coefficient

ξ_e	: exhaust momentum coefficient
ζ_e	: entrance loss coefficient

Subscript

α	: start of section
β	: end of section
+	: direction of traffic (downstream)
-	: direction of traffic (upstream)
i	: link number
j	: node number