# Jan Šulc PhD Thesis' Review

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## Relevance

The subject of controlling the air quality in tunnels is an important issue for the three obvious reasons: (i) health considerations towards the users of the tunnel in terms of noise and air quality, thus the personnel working in the tunnels, the users of the tunnel, thus the car / truck / bus drivers and the people who living in the nearer neighbourhood of the air-exhausts and tunnel entrances. (ii) exception handling, such as accidents, power interruption or the like and (iii) power consumption and maintenance, thus mainly operating costs.

Control is essential for operating tunnels.

## Completion

The following were given as the objectives (citation):

1. *Provide suitable conditions for evacuation and emergency operations during fire.*
2. *Ensure the desired IEQ (Indoor Environmental Quality), i.e. to keep concentrations of exhaust gases (mainly NO x , CO and opacity) below defined limit values.*
3. *Reduce the impact of pollution on the ambient environment (especially in the case of city tunnels).*
4. *Minimize electricity costs for the running ventilation.*

The objectives correspond with the main reasons for controlling a tunnel. All aspects are comprehensively covered by the project work as reported in the thesis and the published papers.

Control is model-based. The models here being flow in conducts of different geometry and branching. Chapter 3 provides the basic theoretical background associated with computational fluid dynamics.

## Methods

### Bernoulli approach

The first paper uses the Bernoulli equation to design controllers. The theory could have started from a dynamic energy balance assuming negligible change of the internal energy, which would have lead to the model eventually being used as taken from the literature. It includes the friction term, changes in the geometry of the ducts but initially not the branching. The associated literature review is comprehensive including the fire dynamics, which are of obvious importance, but also effect of stack, wind dynamics, fans, as well as friction. Finally the sectioning and branching is being considered extending the model to capture the more complex structure beyond the straight one-entry-one-exit tunnels.

The main contribution is here not the controller itself, but the adaptation of the control policy to the complex geometry of the tunnel and the tuning to the operation mode including the emergency situation.

### PID controller design

The second paper focuses on the fire emergency situation and the constraint control of air flow. Based on the model method discussed in the first paper, PID controllers are designed using Skogestad's SIMC rule.The rules are based on a two-stage procedure. The first state is the identification of a first or second-order linear input/output model, which can also be the result of model reduction applied to a higher-order model. The second stage is a pole-placement design, which is often not mentioned but hidden in the "formula". Also in this paper.

### Optimisation

This paper focuses on the air quality control. The operation of the tunnel is classified into different states:

i. no ventilation needed, natural ventilation is sufficient caused by traffic movement and wind;

ii. above threshold of NOx asking for ventilation;

iii. NOx leaking out of the ramps asking for ventilation to use these ramps as air supply thus reverse the flow.

The approach is model based, using the models derived in the first paper. Optimisation is done in a special "block" implementing on-line optimisation using logic-based rules. The implementation is hierarchical, combining logic supervisory control that provides the optimal input for the underlying local tunnel control. The cost function aims at minimising power whilst meeting the impose the desired airflow. A state-machine in the form of a state diagram depicts the event-driven information flow and the consequent actions taken. The results are validated using the tunnel data.

## Main results

The thesis covers the subject excellently, both for the typical operations as well as the exceptions. Whilst the normal operations have been verified, one must say "fortunately" the exception state has not occurred in real time, at least based on the reporting.

The operation of the tunnel is significantly improved by the implemented control structure and policy. Thus a very successful project where theory was applied to a large-scale complex process of vital interest to the society.

## For the future

I would think that the main improvements can be gained by more detailed modelling and possibly by incorporating more measurements. The modelling of airflow is the first main challenge. The ducts are complex-structured, geometry is non-trivial and exhaust locations are constraint.
A series of significant disturbances are adding complexity if one wants to further improve, namely secondary effects of moving vehicles pushing air, wind with changing directions and velocity, latter not only affecting the airflow in the ducts directly, but also indirectly by changing the pressures at the exhaust locations. Improvements require faster control and thus more detailed models, more measurements and also tighter control of the fan system.

## Scientific achievements

The main achievement is the handling of the complexity. The individual parts are probably not in itself significant, but the sum definitely is.

## Conclusion and Recommenation

The thesis is both of scientific and practical relevance. A well taken opportunity to apply control technology to a society-relevant domain, namely tunnel air conditioning control.

The thesis is well structured and even though it is to a large extent a collection of three papers, well written, well organised and balanced. The introduction provides the overview and the papers the details.

The thesis stands excellently in the light of international research standards and is as such recommended to be approved for the PhD defence.

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