The Decline of Over-Invested Transportation Networks

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Introduction
Transportation networks, like other markets, shrink over time when they become over-invested. Examples include the England canal system in the late 1800s and the railway network in the United States since 1920. Few studies, however, have been carried out to investigate the decline of transportation networks quantitatively.

This study develops a simulation model to describe the abandonment of weakest links in an over-invested transportation network over time. Network performance measures including total social welfare and network accessibility were computed throughout the degeneration process and different degeneration criteria were compared.

The study reveals the dynamics of the economic efficiency of a network during its decline phase and suggests how an efficient network topology can be obtained from a pre-specified over-invested infrastructure.

Models
The dynamics of a transportation network is implemented in our model as an iterative process incorporating five sequential component models. Instead of modeling the dynamics as an optimization problem solved by designers, this model simulates links as autonomous agents that collect revenue and upgrade/downgrade their supply independently. A degeneration process is added to remove the weakest link in the market for each time period. The framework of this model is illustrated as follows:

Performance Measurement
1. Welfare
The impact of the link abandonment on the economic efficiency of a network is indicated by the change of total social welfare from the preceding iteration, which adds up the change of total surplus enjoyed by travelers and total profit earned by roads.

2. Accessibility
Accessibility is measured as a function of the available opportunities moderated by a measure of impedance. This study adopts the typical form to measure accessibility by the denominator of the gravity model.

Results
The figure below illustrates the fluctuations of the cumulative change of total social welfare derived from Experiments A1-A3 on the 4X4 complete network, where Experiment A2 never starts a degeneration process, Experiment A1 starts to degenerate after the network growth reaches equilibrium and terminates it when the minimally connected network is derived, and Experiment A3 starts degeneration at the same time while stops it when the cumulative change of total welfare peaks in A1.

The result of Experiment A1 suggests that degeneration can improve network efficiency by removing inefficient links at the beginning, but further degeneration will impair efficiency. The result of A3 suggests a way to avoid over-degeneration and to derive a relatively efficient network topology by tracing the change of network efficiency and stopping degeneration when the highest welfare is achieved.

Experiments also tested three plausible indicators to identify the weakest link(s): the link with the lowest speed, the link with the lowest through-traffic volume, and the link operated at the lowest benefit-cost ratio (B/C ratio). Three scenarios exhibit similar fluctuations of efficiency over time, showing that the efficient network topology have some “insensitivity” to different degeneration criteria.

Conclusion
- This study develops the degeneration model to simulate the decline of a transportation network as an iterative process and enables the measurement of network efficiency throughout the process.
- Experiments reveal that a turning point exists during the degeneration process regarding the change of economic efficiency, showing that if the degeneration process is stopped at the turning point, a relatively efficient network topology can be derived.
- Experiments also reveal that this efficient network topology has some insensitivity to different degeneration criteria.
- Not limited to describe the actual abandonment of links, degeneration can also represent an underdeveloped area where all point-to-point paths can be used, and some which are more valuable are made faster while others are abandoned over time. It can also be used as a model wherein a set of many potential network additions are considered and degeneration is used to winnow that set. Extensions and applications of the degeneration model will be examined in future studies.