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Extending the Link Transmission Model with general concave fundamental diagrams and capacity drops

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Kinematic wave theory consists of two main equations: the conservation of vehicles and the equilibrium flow-density relationship. Assuming that each traffic state along a road at each point in time is an equilibrium state, these combine into a single partial differential equation for the propagation of traffic along a network link. Newell (1993) proposed a solution scheme using cumulative numbers of vehicles as the primary variable, which later led to the development of the Link Transmission Model (Yperman, 2007). Daganzo (2005) implicitly shows that for triangular fundamental diagrams, this model indeed leads to the correct solution.

This requirement of triangular fundamental diagrams is restrictive. Firstly, it imposes the speed in subcritical traffic to be constant instead of more realistically, depending on the traffic density. Secondly, it impedes any discontinuity between the free-flow capacity and the queue discharge rate, i.e. a capacity drop. We therefore extend the Link Transmission Model to handle arbitrary concave fundamental diagrams, optionally including capacity drops. The resulting model, which converges to kinematic wave theory if there is no capacity drop, can be used in a network simulation and features both standing queues and moving jams.

Building upon the proofs in Daganzo, we derive a finite set of space-time paths that form an exact solution network for continuous concave fundamental diagrams. This solution method is more general than those proposed by Yperman for piecewise-linear diagrams and Gentile (2010) for continuously-differentiable diagrams and better at reproducing acceleration fans or rarefaction waves.

We further extend this model to include capacity drops. By applying a node model without memory effects and using inverted-lambda style fundamental diagrams, we permit the head of a queue to move upstream. We ensure that the queue discharge rates before and after a discontinuity in an inhomogeneous road are both taken into account.