Chapter 1
Intelligence in Transportation Infrastructures via Model-Based Predictive Control

R.R. Negenborn and H. Hellendoorn

Abstract In this chapter we discuss similarities and differences between transportation infrastructures like power, road traffic, and water infrastructures, and present such infrastructures in a generic framework. We discuss from a generic point of view what type of control structures can be used to control such generic infrastructures, and explain what in particular makes intelligent infrastructures intelligent. We hereby especially focus on the conceptual ideas of model predictive control, both in centralized, single-agent control structures, and in distributed, multi-agent control structures. The need for more intelligence in infrastructures is then illustrated for three types of infrastructures: power, road, and water infrastructures.
1.1 Transportation infrastructures

Transportation infrastructures, like power distribution networks [27], traffic and transportation systems [12], water distribution networks [7], logistic operations networks [28], etc., (see Figures 1.1–1.3) are the cornerstones of our modern society. A smooth, efficient, reliable, and safe operation of these systems is of huge importance for the economic growth, the environment, and the quality of life, not only when the systems are pressed to the limits of their performance, but also under regular operating conditions. Recent examples illustrate this. E.g., the problems in the USA and Canada [44], Italy [42], Denmark and Sweden [16], The Netherlands, Germany, Belgium, and France [43], and many other countries [36] due to power outages have shown that as power network operation gets closer to its limits, small disturbances in heavily loaded lines can lead to large black-outs causing not only huge economic losses, but also mobility problems as trains and metros may not be able to operate. Also, as road traffic operation gets closer to its limits, unexpected situations in road traffic networks can lead to heavy congestion. Not only the huge traffic congestion after incidents such as bomb alerts are examples of this, also the almost daily road-traffic jams due to accidents illustrate this convincingly.

Expanding the physical infrastructure of these networks could help to relieve the issues in transportation networks, although at extremely high costs. As alternative to spending this money on building new infrastructure, it is worth spending effort on investigating improved use of the existing infrastructure by employing intelligent control techniques that combine state-of-the-art techniques from fields like systems and control engineering [4], optimization [6], and multi-agent systems [47], with domain-specific knowledge.

The examples of networks just mentioned are only some particular types of networks within the much larger class of transportation networks. Common to transportation networks is that at a generic level they can be seen as a set of nodes, representing the components or elements of the network, and interconnections between these nodes. In addition, transportation networks have some sort of commodity, that is brought into the network at source nodes, that flows over links to sink nodes, and that is influenced in its way of flowing over the network by elements inside the network, as illustrated in Figure 1.4. Other characteristics that are common to transportation networks are:

- they typically span a large geographical area;
- they have a modular structure consisting of many subsystems;
- they have many actuators and sensors;
- they have dynamics evolving over different time scales.

In addition to this, transportation networks often contain both continuous (e.g., flow evolution) and discrete dynamics (e.g., on and off switching), and can therefore also be referred to as hybrid systems [45]. This mixture of characteristics makes that transportation networks can show extremely complex dynamics.