2. Literature Review This chapter provides an overview of the academic and institutional research related to this thesis, prior to presenting the methods used for measuring port capacity and evaluating investment decisions under uncertainty, respectively, in Chapter 3. This literature review will, first, summarize past approaches for measuring port capacity generally, followed by a review of approaches for measuring capacity across the individual components (anchorage, waterway, terminal quay, terminal yard, and intermodal links) that comprise a port system. Second, the literature review will present previous methods utilized to evaluate port infrastructure investments. To reiterate, please note that the primary methodologies – Lagoudis & Rice's methodology for port capacity measurement and de Neufville & Scholtes's methodology for evaluating investment strategies under uncertainty – developed from past research and applied in this thesis, are introduced and described in Chapter 3.

2.1 Port System Capacity Research exists that addresses general performance and capacity measurement across a port system; however, much of the research is focused on container terminals. A recent study on the state of the U.S. port system and its preparedness for the effects of the Panama Canal expansion describes the components of a port 22 system, the factors influencing capacity, and the measurement of port utilization (U.S. Ports and Inland Waterways Modernization, 2012). Other maritime experts describe a port system and its operations (Stopford, 1997), as well as the measurement of port performance (Fourgeaud, 2000). One study applies a supply chain management approach identifying a port system's flows (physical cargo, payment, information, and capital) as well as factors related to measuring port capacity (Bichou & Gray, 2004). More specifically, previous studies have addressed capacity measurement across a port system's components: anchorage, waterway, terminal quay/berth, terminal yard, and intermodal links to rail and road. The following summarizes select studies for each of these components, in the direction of inbound cargo.

2.1.1 Anchorage Past studies have investigated anchorage capacity from different perspectives. Berg-Andreassen examined the economic impact of anchorage capacity using both a mathematical model based on queuing theory and scenario planning, and applying them to anchorage data for the Mississippi River (Berg-Andreassen & Prokopowicz, 1992). Mathematical models based on queuing theory were also used to study efficient loading/unloading at the anchorage-ship-berth link of a port system (Zrnić, Dragović, & Radmilović, 1999). More recently, anchorage capacity and utilization was measured on the basis of anchorage location through the development of two computer-based simulation models – Maximum Hole Degree First (MHDF) and Wallpack MHDF – that suggest a method for improving utilization at the anchorage component (Huang, Hsu, & He, 2011). 23

2.1.2 Waterway Research related to the waterway component (i.e., river or canal serving the port) has primarily been focused on Europe, where inland waterways are a widely-used conduit for transporting cargo to and from the continent's hinterland. One study evaluated waterway capacity using numerical models based on both queuing theory and statistical forecasts to estimate delays caused by locks along inland waterways (Dai & Schonfeld, 1998). Another study examined waterway congestion caused by interruptions along the Strait of Istanbul with the use of a queuing model (Ulusçu & Altiok, 2009). The economic impact of vessel delays related to waterway depth was investigated for the waterway serving the Port of Antwerp (Veldman, Bückmann, & Saitua). Two additional studies focused on government policy of inland waterway transport for continental European nations (Seindenfus, 1994), with one study arguing that the UK government should align its waterway policy with that of continental Europe (Burn, 1984).

2.1.3 Terminal Quay A port system's sea-side and land-side activities meet at the terminal quay/berth, where cargo is loaded/unloaded from the vessel to the terminal yard. A number of studies measured the efficient use of quay cranes and berth utilization at the terminal quays of container terminals. One study investigated cost and time inefficiencies through the use of a simulation model, with the Pusan container terminal in Korea as a case study (Dragović, Park, &

Radmilović, 2006). A second study analyzed the scheduling of berths and quay cranes concurrently using a twophase integer programming model (Park & Kim, 2003). A third study developed 24 heuristics based on a genetic algorithm to determine optimal berth schedules and quay crane allocations (Imai, Chen, Nishimura, & Papadimitriou, 2008). Finally, a fourth study evaluated the delays resulting from quay crane breakdowns using Markov theory and cost analysis (Mennis, Lagoudis, Platis, & Nikitakos, 2008).