CHAPTER 9

THE 'EXTERNAL ECONOMY': NETWORKS AND TRADE

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INTRODUCTION

Previous chapters have referred to the social life of local communities and their subsistence economy, but without active social and exchange networks it is unlikely that urban life would have been able to develop. Algaze (2008: 93) underscores the importance of trade in the development of Mesopotamian civilization, arguing that urbanization is much more likely to be caused by an increase in long-distance exchange than the reverse. Much has been written on the subject of trade and exchange in prehistory and early state societies, as well as to what degree these processes were embedded within society (Snell 1997; Hudson and Levine 1996; Schloen 2001; Crawford 2013). Rather than review this body of scholarship, this chapter outlines the types of networks that linked social groups within all levels of ancient Near Eastern society. It also highlights some of the fundamental differences between the networks of northern and southern Mesopotamia, and how they have been incorporated within simulations.

Networks form an essential infrastructure that underlies individual sustenance and social development. There is now a large and expanding literature on the mathematical properties of networks (Watts 1999; Strogatz 2001; Brughman 2012), but rather than examine these formally, here we outline how networks relate to patterns of everyday life in the ancient Near East. The elements that form these networks range from those at a very local level, such as paths which link homes with fields, to long distance routes, linking cities or far off lands. They can range from informal paths made by a single individual walking through the grass to canals clearly visible through the landscape and deliberately dug and maintained through an immense investment of labor. They may also exist only in a traveler's knowledge, such as the routes of ships across the sea, where no trace is left of their passing. The elements can also coincide, as is the case with canals, with irrigation needs and other non-transportation based functions. Yet as diverse as these interconnected elements of networks may be, they are all critical for modeling the dynamics of action beyond mere static locations (Branting 2004; 2007).

Even more diverse than the form that these network elements take are the ranges of commodities that are moved over them. They can be physical things, items carried by hand or by hoof, such as copper ingots, textiles, clothes, or small but valuable prestige items such as cylinder seals. They can be bulk goods hauled by cart or barge, such as loads of grain or vessels of wine. They can be things transporting themselves such as human travelers, or plow teams, or herds of animals. As noted by Adam Smith (1776):

> 'Live cattle are, perhaps, the only commodity of which the transportation is more expensive by sea than by land. By land they carry themselves to market. By sea, not only the cattle, but their food and their water too, must be carried at no small expense and inconveniency.'

At the same time there is a wealth of non-physical items that are transported over these networks. These can be verbal communications, knowledge, ideas, or even disease. In the case of information networks, it can be argued that the flow of information is one of the main factors that contributed to the growth and development of the later territorial empires.

At any given time some of these diverse commodities and communications will pass one another along the road, moving from their place of origin to a temporary or permanent destination. Each will travel by its own means or mechanisms, based on factors such as shipment size, cost, or speed. These factors will, in turn, be predicated on attributes of the commodities and communications themselves such as their weight, cumbersomeness, level of secrecy, or by the level of need for those at the destination to receive them. Each means and mechanism requires variously trained or untrained individuals to take or accompany them from place to place. These individuals are necessary for navigating the physical and social spaces through which these networks pass. They may be required to pay tolls, negotiate social or political interactions along the way, repair conveyances, or provide security from theft; all to ensure that the commodities and communications reach their intended destinations.

SOCIAL NETWORKS AND PREHISTORIC COMMUNITIES.

Each of the networks simulated within ENKIMDU were probably built upon much earlier forms of social networks. These come in many forms, but some sociologists recognize three basic 'circles' of personal networks (Watkins 2008: 151-52; Gamble 1998; 1999; Turner & Maryanski 1991):

- The intimate network with which we have day-to-day contact. Usually around 20 people whom we see most often.
- The extended network, with which we have occasional dealings, usually amounting to some 100-400 people up to a maximum of 1000.
- A global network of people who might be categorized as 'others' but with whom occasional transactions may be negotiated either at first hand or through an intermediary. In present day small-scale societies these may amount to some 2500 people.

According to Gamble (1999), in the earlier Palaeolithic personal networks were mainly of the first group, whereas in the Upper Palaeolithic and thereafter there is evidence for extended networks. Watkins has elaborated on this by suggesting that, in the Epi-Palaeolithic both intimate and extended networks came together, although the geographical extent of such networks may have been reduced (Watkins 2008: 152). Moreover, the ability to develop large, strong and durable co-residential communities, as well as regional and supra-regional networks appears to be a phenomenon of the early Holocene and the earliest Neolithic of southwest Asia (Watkins 2008: 164-165).

Within these interaction spheres information flow and exchange of goods was increased, carried across networks operated both within settlements and communities and among them (Watkins 2008: 162). In other words, the communities under consideration by MASS must have already been able to build upon pre-existing complex and well developed networks of communication and transportation.

REGIONAL NETWORKS

Two very different models of networks have been incorporated within the simulations, reflecting typical differences in landscape and transportation between the northern and southern regions of Mesopotamia. The northern model is structured around land-based transportation networks, built up around settlements practicing rain-fed agriculture as their primary means of subsistence, augmented by an extensive system of mobile pastoralism. By contrast, the southern model is largely structured around canal and channel-based transportation networks, built up principally around settlements practicing irrigated agriculture, though mobile pastoralism is also present. These canals and channels provide for both water-based and land-based modes of transportation. The latter probably included tow paths along the banks of the canals or routes running parallel to the channels or canals, since crossing such a water feature in the absence of a bridge can be a major impediment.

The Northern Network

The northern network is structured upon elements of land-based transportation, both within the catchment of the villages and across the landscape between villages. Although by the Early Bronze Age, some parts of the region may have utilized riverine transportation, the focus of the northern model is on land-based transportation.

Geometry of the Northern Network

The foundation for the geometry of the northern network has been the broad linear depressions which we refer to as hollow ways by analogy to similar features in Britain. Hollow ways in northern Mesopotamia were noted opportunistically by Poidebard (1934) in his pioneering aerial work in the 1920s but only came under systematic observation in the 1950s by Van Liere and Lauffray (1954-55). Subsequently they have been recognized and mapped in northern Iraq and the middle Euphrates (Wilkinson 1993; Wilkinson & Tucker 1995). With the availability of CORONA images, it has been possible to map some 6000 kilometers of pre-modern hollow ways in the Upper Khabur basin and adjacent areas (Fig. 9.1; Ur 2003; Ur 2009).

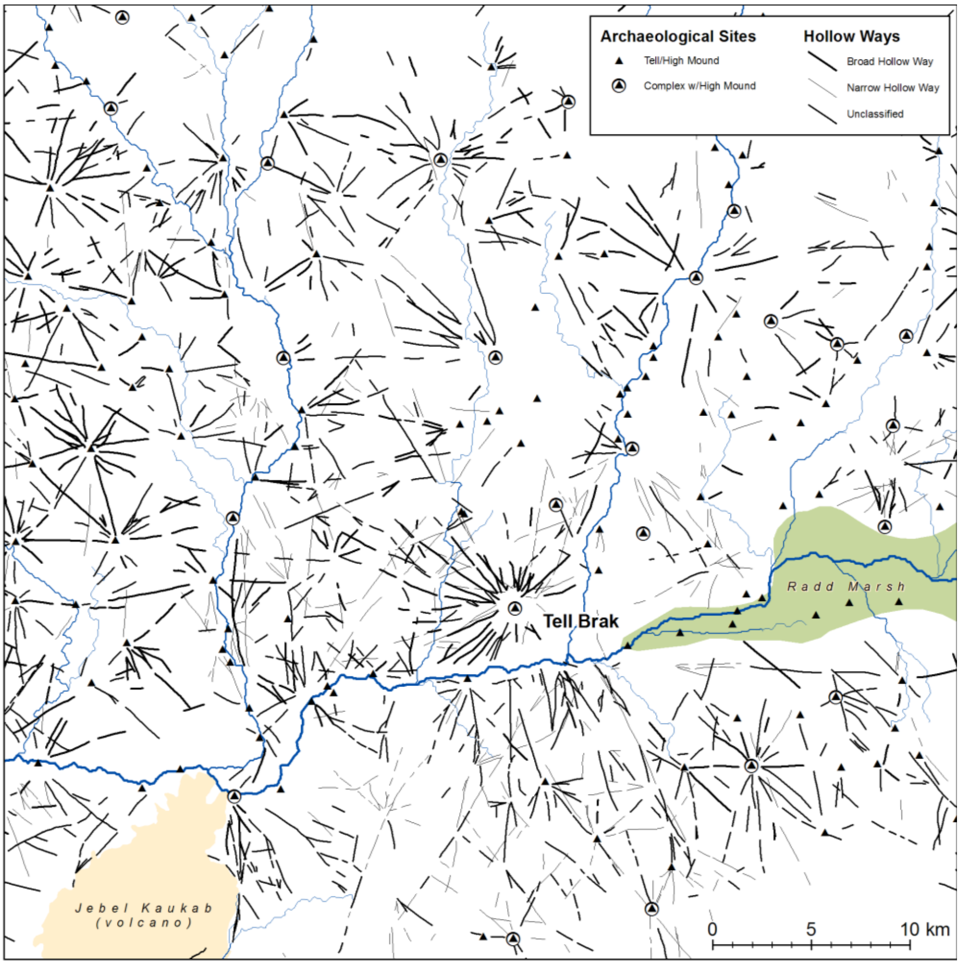

Fig. 9.1 Hollow ways in the area of Tell Brak (J.A. Ur).

When they retain topographic expression, hollow ways are generally 50-100 meters wide and between 0.50-1 meter deep (Ur 2010: 82-83). Because of this weak topographic imprint, they are difficult to recognize on the ground; all of the above studies have relied on remote sensing (aerial photographs and satellite imagery) or high resolution topographic maps. Many hollow ways are no longer depressed at all but rather are apparent as soil or crop marks. The buried surfaces of these features still retain moisture disproportionately to the surrounding soils and therefore have darker soils or denser vegetation growth (Wilkinson 2003: fig. 6.12; Fig. 9.2). But other hollow ways that run parallel to the natural slope of the basin have become even further inscribed, as they now act to channel surface runoff (Wilkinson 1993: 557-558).

The close association of broad hollow ways with Bronze Age tells was already recognized by Van Liere and Lauffray (1954-55), and has been confirmed and fine-tuned by more recent studies employing intensive ground control and developed ceramic chronologies. In the surveyed regions around Tell al-Hawa, Tell Beydar, Brak and Hamoukar, hollow ways are closely associated with multi-period tell sites with large later third millennium components (Wilkinson & Tucker 1995; Ur & Wilkinson 2008; Ur 2010).

Fig. 9.2 Hollow way to the northwest of Tell Brak (Syria) indicated by the dark vegetation in the far centre (photo by T.J. Wilkinson).

Despite one alternative interpretation (McClellan *et al*. 2000), hollow ways are best interpreted as the surviving traces of the track-ways which conveyed humans, animals, and wheeled vehicles between settlements, fields and pasture (Wilkinson 1993; Ur 2003). This movement disturbed the soil structure in two ways. In the dry season, disturbed sediments were removed by winds; in the wet season, the track surface was susceptible to 'hydrocompaction' (Tsoar & Yekutieli 1992) as well as overland flow. Although European hollow ways were sometimes excavated to remove animal dung (Taylor 1979:145-146), the depressed form of northern Mesopotamian features was an entirely unintentional result of the processes of deflation, runoff and 'hydrocompaction' (Wilkinson *et al.* 2010).

With these assumptions, the spatial patterning of hollow ways can be used to reconstruct the later third millennium subsistence economy as discussed in Chapter 5. In terms of patterning, features can be classified into two general groups. A small subset of hollow ways runs between sites, most often in a straight alignment. These tracks would have carried people and animals between neighboring settlements for trade and social activities. In addition, the majority of longer-distance travel would also have been routed along longer distance tracks that linked settlements or ran through the countryside (Sallaberger & Ur 2004: 69-70; see below).

The Political and Social Landscape

It is common to assume that the most efficient human pathways followed through the landscape are those that utilized valleys and other topographically expedient routes. Whereas valleys constrain human movements along them there is a tendency to avoid the rough ground and high places. Moreover, where the terrain is gentle and even flat, as is the case in most of Upper and Lower Mesopotamia, progress would appear to have been relatively easy, because apart from the occasional natural or artificial channel, there was little to impede progress. However, Ebla texts from the 24th century BC imply that for official parties, safe passage required negotiation or the consent of the king. Hence in the case of the territories of Ebla, Assur and Abarsal the text requests safe passage or unimpeded access through the area, by river and overland[1] (Sollberger 1980: 137-47; Pettinato 1991: 233-34; Wattenmaker 2009: 119-20).

This implies that without such permissions or agreements, it would have been difficult to pass through these territories. An equivalent situation is evident to anyone who has adhered to traditional modes of movement through parts of Syria and Arabia where there is some degree of local autonomy. In such cases it is usually courteous, and frequently in the interest of personal safety, to visit the local headman or ruler to obtain permission to pass through his territory. Although such courtesies are increasingly rare today, they must have been common in the ancient past, unless there was a strong regional or imperial administration in place, and even then passage through an area was not unrestricted.

This dilemma is indicated diagrammatically on Figure 9.3, which shows a number of settlements (in black) with their surrounding notional territories (broken lines) as well as the intended route of travel from Settlement A to Settlement B. Because the intended line of path cuts through a number of territories, it would have been politically expedient as well as safer to visit the settlement of the chief of each territory, as appropriate (i.e. the zig-zag path). This principle does not set out any hard and fast guaranteed route, but it illustrates, that unless the traveller has guaranteed rights of passage the most expedient route will frequently be more circuitous than any 'least cost pathway.' Of course, these more sinuous pathways would have been contingent upon local political circumstances with the result that over long periods of time route systems could have varied considerably.

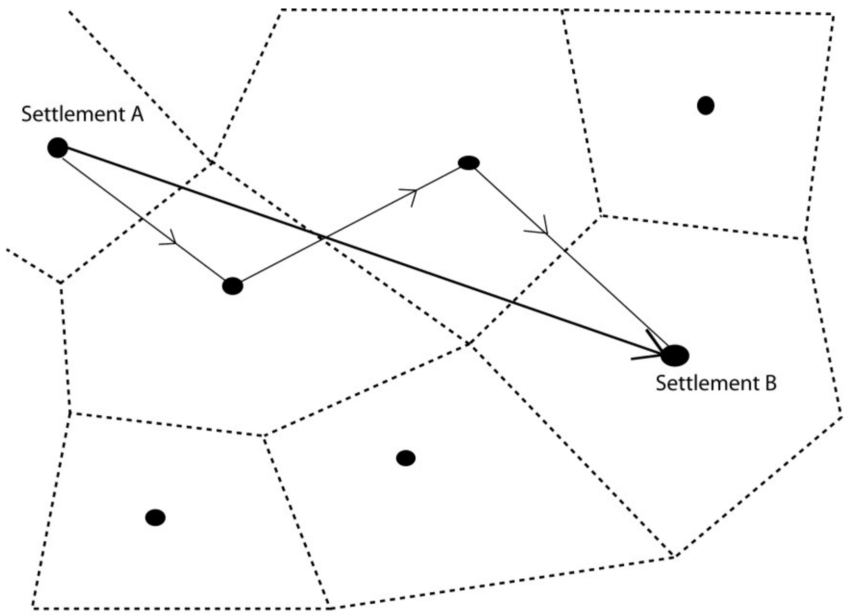

Fig. 9.3 Diagram indicating a likely passageway through a social -political landscape (T.J. Wilkinson).

[1] MEE 1 1859, Pettinato 1991: 229-240; also TM.75.G.2420, Sollberger 1980.

Conveyances and Commodities on the Northern Network

As mentioned above, long-distance trade in the north extends back to at least the late Epi-Palaeolithic. Already in the fifth millennium BC obsidian from Anatolia and mussels from the Indian Ocean are attested in greater Mesopotamia (Leemans 1972-1975: 77; Khalidi *et al.* 2009). Evidence for more extensive trade, particularly with the south, is found in the subsequent Ubaid period (Oates & Oates 2004: 181). After a decline in these north-south relations and the Uruk expansion, which set up colonies especially along trade routes in the north, large-scale trade is thought to have been based primarily in the south (Algaze 2008: 93-99). Much of this trade was extensive sea-trade with the Indus valley and other areas to the east. Following the collapse of the Indus civilization and the abandonment of sites in southern Babylonia, the major centers of international trade shifted north to the Mediterranean coast, Syria, and northern Iraq until the end of the Bronze Age.

By far the most important means of transport by land were humans and pack animals, particularly over rough terrain. Humans were often used as carriers for shorter distances, and as messenger for longer distances. Where goods were transported over longer distances, pack animals or wagons were used. The donkey, by far the most commonly used, could carry between 45 and 90 kilograms, 20 to 24 kilometers per day (Streck 2007: 301, with bibliography; cf. Moorey 1994: 12). Unlike the onager, donkeys could be ridden and were more often than any other animal (Weszeli 2007: 304). Mules were also used, having the ability to carry up to 77 kilograms, roughly 32 kilometers per day (Moorey 1994: 12). Onagers are usually considered untamable and were primarily used for stud purposes. As demonstrated by Juris Zarins (1976: 431-432), the standard value for a donkey in the Ur III period was around 5 shekels silver (= 41.67 gram). One (tamable) donkey-onager hybrid was roughly four times as valuable as a regular donkey (Zarins 1976: 463), and they were clearly considered prestige items in Upper Mesopotamia, for example, at Beydar, Ebla and Brak, in the third millennium. Horses, attested since the Ur III period, were seldom used as pack animals unless speed was of particular concern. Camels present a special case, with evidence for their presence attested by at least the third millennium (Steinkeller 2007: 218-219; n. 16) and possible evidence suggesting domestication by the early second millennium (Wapnish 1997). However, because arguments for full domestication in these earlier periods are inconclusive, camels have not been incorporated into the MASS model.

Caravans of humans and pack animals could grow to a huge size during the Ottoman period. Such caravans could include hundreds, if not thousands, of donkeys. However, in the Old Assyrian period caravans were much smaller, usually less than 10 with upwards of 20 being exceptional (Larsen 1976: 103; Veenhof 1972: 70-76). Depending on their size and the difficulty of the terrain, caravans could cover anywhere from 13 to 35 kilometers per day, as attested in Anatolia. Be it transport by human or animal, rest houses and sources of drinking water were absolutely essential. For the north, first millennium sources attest rest stops every 30 kilometers or so where fresh animals could be obtained (Streck 2007: 302).

Where the terrain allows, the sledge or wagon was also used for the transport of goods. Very little is known about the use of the sledge, though there is both graphic and archaeological evidence for it (Salonen 1951: 79-80). The wagon clearly developed from the sledge. Akkadian sources, in particular, distinguish wagons used for the transport of goods from chariots, or wagons used for riding (Salonen 1951: 23). The former were four-wheeled vehicles pulled by oxen or asses (Salonen 1951: 29-31); the latter could have two- or four-wheels and were pulled primarily by donkeys, mules or, in later times, horses. Cuneiform records provide extensive evidence for the various parts of these vehicles. One key development to both vehicles was the introduction of lighter-weight, spoked wheels (vs. solid-disc wheels) at the beginning of the second millennium B.C. (Crouwel 2007: 218).

The range of commodities found in the north is far too extensive to treat in detail here. Wood, stone, wool and textiles were the primary exports to the south. Of these, wool and textiles were supplementary because large amounts of both were also produced in the south (McCorriston 1997; Algaze 2008: 77-92). Copper, tin, and precious metals, along with precious and semi-precious stones, were the primary imports, coming primarily from Anatolia, Iran, and Afghanistan. Much trade in Upper Mesopotamia may be regarded as 'throughput trade' because the region was situated between mineral-rich Anatolia and the urban centers of Mesopotamia. Perhaps the most emblematic trade network in the north is attested in tablets from the site of Kültepe, ancient Kanesh (Larsen 1976). The activities described in these texts illustrate just how extensive and tightly organized trade networks could be.

The Southern Network

The southern communication networks were structured primarily upon elements of water-based transportation, namely along canals and channels needed for irrigation agriculture, and which were drawn from the Tigris and Euphrates. Alongside the canals, elements of land-based transportation can also be found, in the paths that run beside and between various canals. Yet the major focus of the southern model is on its unique water-based transportation.

Geometry of the Southern Network

The framework of the irrigation systems along with their geographic and morphological differences provides a basis for our modeling of ancient settlement systems in southern Mesopotamia. The channel system, both artificial and natural (see Chapter 2), provided a complex network of routes that acted as thoroughfares along both the NW-SE axis of Mesopotamia, and to some degree orthogonal to that axis as well. The anastomosing channels formed branching systems that allowed secondary routes to diverge and lead to other regions. In southern Mesopotamia, because the main settlements have developed along rivers or canals, the communication routes actually connect the main cities. This was in marked contrast to many of the hollow way routes of northern Mesopotamia which, as noted above, frequently linked the settlements to the agricultural or pastoral resources rather than settlements and towns. In other words, the northern routes tended to perpetuate the subsistence economy, whereas the networks of the south linked both the main towns and cities and were capable of transporting bulk products, rather in the manner of modern motorways (Fig. 9.4). In terms of social and political interactions, it is also likely that northern towns and cities could have been more autonomous, whereas those of the south were more interdependent, with greater potential to either interfere or cooperate with their peers up or downstream. The potential for growth, conflict or decline was therefore greater in the south than the north.

Fig. 9.4 Bulk transport of reeds by boat in early 20th century Iraq (Photo V 009, courtesy of Gertrude Bell Archives, Newcastle upon Tyne).

Irrigation was based upon gravity flow, which benefited from the channels being raised upon levees above the irrigated fields (Chapters 2 and 4), but in cases where the channel was not raised, from at least the Middle Bronze Age irrigators developed systems of water lifting devices, such as the *dalia* (i.e. *shaduf*) or water sweep (Oleson 2000: 189; 222). In fact, iconographic representations of the *dalia* being used in the irrigation of Mesopotamian gardens can be found on cylinder seals already from the late Early Dynastic period (Selz 2001: 47, n. 38 with figs. 4 and 5). Potentially problematic for riverine transport would have been the presence of temporary dams and water-diversion devices at the head of canals which would have either restricted movement or contributed bottle necks in the transportation network. Silting of channels was a second potential problem, one that required investment of labor to clean many of the channels from time to time. Consequently, although the channel networks held manifest advantages for communication, they should not be assumed to have been perfect.

In the south, land-based transportation networks had to contend with the rivers and canals that supplied the framework for water-based transportation, but which also provided an impediment to land-based travel. Rivers could be crossed at fords, with ferries, or by constructing bridges (Streck 2007: 302). Several Assyrian and Babylonian kings are known to have built bridges from trees during military campaigns and, in cities, from stone (Müller 1938). Given the extent of the canal network in the south, bridges were a common feature on a smaller scale as well, with many of the weirs and canal regulators serving this function, depending on the traffic. There is very little documentation for formalized roads outside of cities, though the banks of the canal would serve as an appropriate path for travel or for towing boats.

The network of channels points to another aspect of the 'Mesopotamian Advantage' that the south held over the north. Most of the major, and arguably more successful, settlements in the south developed on the major channels that functioned as thoroughfares. This access to these thoroughfares contributed to the further growth of those cities (see Chapter 14). Moreover, water for domestic and animal use, for irrigation and for transport, was all combined within the same source, namely the channels and canals. In the north, not only were the overland transport routes less efficient, and had to contend with the problems of a 'high friction' social landscape as discussed above, but also transport functions, domestic supply and water for animals were separated.

Conveyances and Commodities on the Southern Network

Given the importance of canals and channels in the southern network, it is not surprising that water transportation predominated. In fact, in the bilingual Sumerian-Akkadian lexical series ḪAR-ra = *ḫubullu*, tablet IV, lines 256-353, we encounter almost one hundred different terms for boats and ships (Landsberger 1957: 173-180). Despite this wealth of terminology much less is known about the nature of the early Mesopotamian vessels used for the transport of goods along the channels. The numerous representations of river vessels found on seals and seal impressions from the third millennium BC are, in general, too stylized to provide any detailed information on their structure and appearance. We do know that most were likely wooden constructions with little or no reed components. This contrasts with reed boats for maritime use which are well known from the fourth and third millennium in the Persian Gulf.

By the Ur III period more is known about these river vessels thanks to a group of texts from Umma, which describe the construction of different boats and ships. Information provided includes capacities for the vessels along with the various materials used in their construction. These materials, in addition to various wooden elements such as planks and nails, include up to four different types of bitumen or petroleum tar for caulking the hull and fish oil for preserving the wood from rot (Widell 2009).

From the sizable corpus of Ur III texts, we know of 23 different volume capacities of boats, ranging from 1 gur (0.3 cubic meters) to 360 gur (108 cubic meters). The most common boat on the rivers and canals of Mesopotamia in the late third millennium was the 60-gur (roughly 20 cubic meters) boat, accounting for 80.1% of all recorded commodities transported by water. Other frequently recorded vessels on Mesopotamian waterways included the 10-gur boat (3 cubic meters), the 20- (6 cubic meters), 30- (9 cubic meters) and 40-gur

(12 cubic meters) boats, as well as the large 120-gur boat (roughly 40 cubic meters; Fig. 9.5). Rough estimates of the maximum lengths of the vessels can be arrived at through calculations of the number of wooden ribs documented in the texts, as compared with traditional river vessels from the area of Iraq in the early twentieth century. According to these calculations 3, 9, 18 and 36 cubic meter capacity ships measured a corresponding maximum of 6, 8, 11 and 14 meters in length. Combining these two calculations of capacity and length it can be seen that roughly 86% of the boats mentioned in the Ur III texts were 11 meters or more in length.

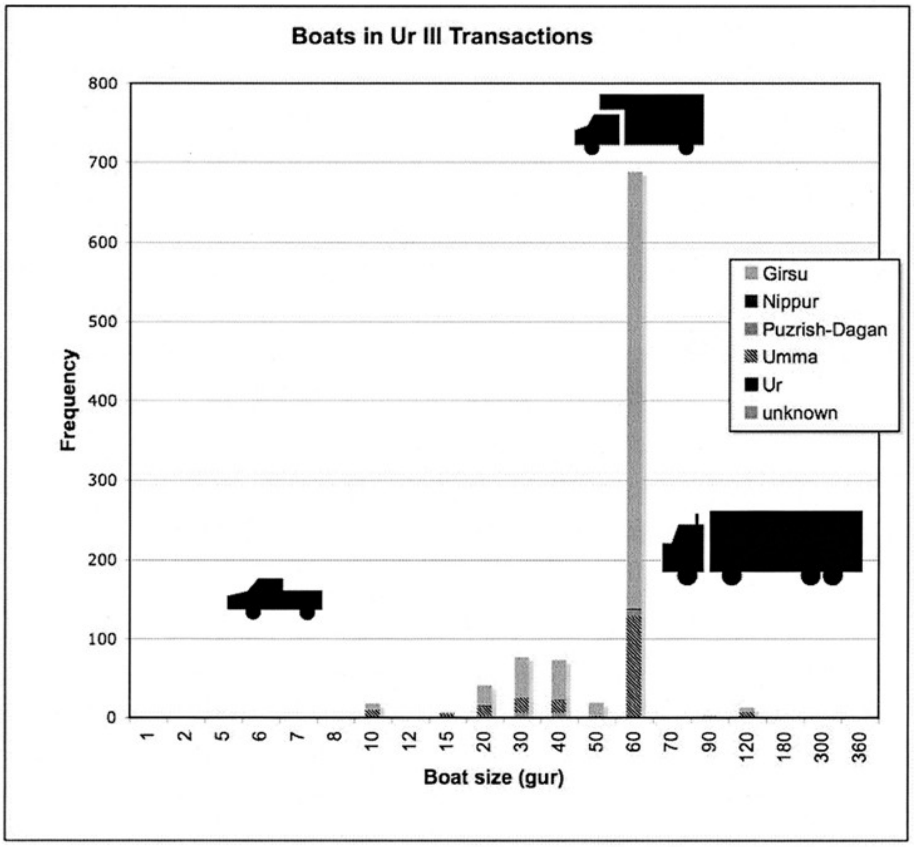

Fig. 9.5 The range of boat sizes known from Ur III texts (by M. Widell).

The vessels were moved using a variety of means, depending on the size of the boat and the direction it was traveling. As seen in texts and in representations, boats could be towed, floated downstream, or moved with paddles and poles. Towing rates for such vessels were around 15 km per day and rarely exceeded 20 km per day even along stretches without intervening bridges or other obstructions (Steinkeller 2001: 59, n. 156). Floating, paddling, or punting with poles would have resulted in much more variable speeds depending on the ship and crew, what it was carrying, and where it was going. The tow paths along the banks of the channels not only provided sure footing for towing the vessels but also had the added advantage of serving as roads for land based transportation such as those found on the northern network.

Among the many items transported by boat were: grains (especially barley), wood, stone, bricks, metals, reeds and reed products, asphalt, textiles, fish, cattle, sheep, jugs of liquids like beer and wine, flour, bread and straw. Water provided a key transport medium where very large and bulky shipments could be transported much more easily and efficiently than by land. Barley was of particular importance and some of the recorded shipments are extremely large, necessitating the use of multiple boats. For example, *CM* 26 145 records a single transaction of 1,808 gur of grain (542.4 cubic meters). If we make the reasonable assumption that this was a boat shipment, the transaction would require more than 30 boats with 60 gur capacity. In *MVN* 11 11 an enormous load of 3,020 gur (960 cubic meters) of barley is being shipped by boats from Girsu to Nippur. Such a large shipment would have required more than 53 boats with 60 gur capacity. Other texts, such as the Girsu text *CM* 26 100, record the actual boats used in shipments. In this text, no less than 25 60-gur boats, 6 50-gur boats, 8 40-gur boats and 9 30-gur boats are recorded to have been used to ship grain to Nippur. The total capacity of these boats would have been 2,390 gur (717 cubic meters).

Interconnections with Mobile Communities

In both the north and south, local and long-distance exchange mechanisms provide links between the systems of the sedentary and mobile pastoralists. Although it is possible to infer webs of communications between sedentary and mobile communities, it is difficult to show how they actually articulated. Nevertheless, it is likely that exchange networks enabled these different patterns of movement to be intertwined. Exchange provided a mechanism by which shortfalls in production at the household level could be alleviated. Such exchange systems occurred between households of the same kinship group, between households that were not related, between different sedentary or mobile communities, and between sedentary and mobile communities (see Chapters 8 and 12). At the very largest scale, long-distance exchange networks based upon differential availability of products would have operated to satisfy the needs of, among others, the developing economies of the growing urban areas. What specific role mobile communities played in long-distance exchange of materials such as obsidian, metals, textiles and so on is often unclear.

Whereas some mobile pastoralists carried minerals or secondary products with them for exchange, other groups, like the Bedouin population of eighteenth and nineteenth century AD Arabia, must have been in a position to inhibit or thwart long-distance trade by exacting taxes or plunder. As a result of such complications, it is best to assume that long-distance exchanges and movements at any given time were practiced along a series of routes or networks rather than just one. These different routes could be used either simultaneously or alternatively, depending upon circumstances. Although it is difficult to capture the full complexity of such networks, in order to produce a plausible model for ancient society it is essential to incorporate social and transport networks into the simulations.

Modeling Movement and Interaction in ENKIMDU

The movement of social agents from one locale to another in the course of the simulations is an integral aspect of most modeled subsistence-based activities, as well as of many other modeled societal behavior patterns. Movement is accomplished by the agent planning and then traversing a route through a surface transportation network that may include both overland and waterborne pathways between network nodes. Early simulations addressed single settlements in northern Mesopotamia, where waterborne transport could be neglected and where only short travel distances between a nucleated settlement and its agricultural fields (typically less than 3 km) were involved. Under these conditions, agent movement was originally handled quite simplistically, as a simple delay in the agent's being able to begin a new activity at a new locale. Travel times (delays) were estimated by assuming straight-line transit between origin and destination, at a nominal, rather torpid overland speed of 2.4 km/hr (1.5 mph) that was intended to account for meanders in the route and incidents and breaks along the way. As ENKIMDU simulation scenarios have become more complex and spatially expansive, a much more rigorous approach was developed. This approach was pioneered in a variant of the ENKIMDU simulation system in studies of modern Thai village agroeconomics, using an actual village road network and land cover mosaic that incorporated the small rice plots of the local villagers (Christiansen & Altaweel 2006). It has since been further expanded for use in regional-scale ancient Mesopotamian simulations. The expanded movement method proceeds as follows:

1. An agent identifies a need to move a WorkPackage (a collection of agents, vehicles, devices, fauna, and cargo capable of movement as a group) to a different location. The agent may also identify constraints on the proposed relocation that are specific to the type of task to be attempted, such as a need to avoid waterborne routes when no vessels are available to the agents' party.

2. The agent consults his RouteAtlas of known routes between pairs of locations, to see whether any of them are appropriate to the current need. (This is done purely to avoid redundant, computationally

expensive route determinations). If there is an appropriate route to the destination in the RouteAtlas, it is selected.

3. If the agent's RouteAtlas does not contain an acceptable route to the destination, he finds a new optimal route through the surface transport network using an implementation of the A-Star multivariate least-cost routing algorithm (Dechter & Pearl 1985). Link costs vary according to the inherent qualities of the link, such as roadway material and condition, potentially modulated by additional contextual information on WorkPackage constituents and task-specific constraints provided by the initiating agent. In addition, the WorkPackage itself can be queried to determine its nominal maximum rate of travel based on the slowest traveler in the group, taking into account such factors as mode of travel (pedestrian, mounted, etc.), tractive power (for draft teams), and passenger and cargo loading.

4. Routes are expressed as an annotated sequence of transport links connecting a list of transport nodes that begins at the origin of movement and ends at the destination. When called upon to start the journey, the agent's designated WorkPackage begins to traverse the selected route, and continues until the destination is reached or a simulation event that interrupts or preempts the journey is received.

The quality of links in the network may vary over time as a function of current and prior traffic, weather, and possibly due to deliberate modifications (e.g. repair or destruction) by other social agents. Thus depending on the situations being simulated, there may be a need for agents to re-compute routes each time they are needed rather than accepting a previously established route from the RouteAtlas. Further, in some cases it may be appropriate to re-plan in order to accommodate new information, by re-computing remaining portions of a route even after movement is underway. As discussed above, this is because the route taken may vary depending upon the local conditions of authority in the settlements along that route. This feature has not been implemented in ENKIMDU, but it was anticipated that it would be added for upcoming studies needing fine-scale pedestrian movement patterns to determine sequences of 'linguistic cliques' for the simulation of language evolution (Riggle & Christiansen 2007).[2]

The surface transport networks over which agents move are generated by the MASS Landscape Partition Engine (LPE), a program that supports ENKIMDU simulations. The LPE operates on geospatial data presented in the form of closed polygons, polylines (continuous lines made up of multiple straight line segments), and points, along with a formal specification of the coordinate system to which the geospatial data elements are referenced. In the geospatial datasets used in the MASS Project thus far, closed polygons have delineated urban sites, and polylines have represented natural and artificial surface drainage channels and regional roadways. When no other contextual data are at hand, the LPE can use these data alone to construct a complex multi-scale transportation network that incorporates several diverse elements:

a. A generally sparse network of explicitly predefined regional, inter-settlement roadways;

b. Dense networks of pathways within each settlement's built-up area(s), linking individual dwellings and other structures along urban lanes and interior courtyards;

c. Extensive networks made up of all crop field boundaries for the mosaic of crop fields surrounding each settlement, interpenetrated by regional roadways; and

d. A radial network of connector pathways linking each settlement's internal route network with the surrounding network, through an optional suburban belt comprised of variable land use plots between the settled area and the field system.

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[2] SHULGI, software developed within the Repast Simphony (Repast S) environment to simulate fine-scale pedestrian movement patterns at both urban and regional scales of transportation networks, is another outgrowth in this vein from the collaboration brought about by MASS (Branting *et al.* 2007).

The spatial layouts of polygons representing settlement plots and crop fields are synthesized by the LPE using a flexible, recursive implementation of the Voronoi spatial decomposition algorithm (Voronoi 1907).

The various networks described above are maintained as separate entities within the simulations, but they can operate as a single network as needed. The separate identities of settlement-specific networks are maintained within the simulation mainly in the interests of computational efficiency, to facilitate route-finding operations on reduced network sizes whenever possible. For simple operations, such as those related to a household's repeated daily forays to and from a local field that they are tilling, the A-Star algorithm can find an optimal route within the settlement's agricultural catchment far faster than if it had to search the entire regional network for a route.

In addition to the network of links along field boundaries, special types of transport link provided by ENKIMDU's spatial data libraries allow for pathways *through* each field, for situations where more complete freedom of movement is warranted. For example, a household work crew should be free to walk anywhere in its fields, and depending on the social scenario in play, such freedoms might be extended to kin households as well. This is accomplished via a TransportNexus software object for each field, carrying the same geometry as the field.[3]

By way of example, Figure 10.3 in Chapter 10 shows a large swath of northern Mesopotamia (the North Jazira region), which includes agricultural catchments for all 46 settlements in the region and a complete LPE multi-scale surface transport network linking the settlements. The 2.0 km hexagonal mesh superimposed on the network partitions the interstices between settlement agricultural catchments into potential grazing areas for herds and flocks for local villagers and nomadic groups. For purposes of movement, each grazing area is represented as a TransportNexus link, allowing unrestricted movement within its boundaries.

For southern Mesopotamian simulation scenarios in which waterborne transport is a significant factor, the transportation network is more complex. This is discussed in Chapter 14 as part of a different modeling framework. The interconnected, nominally navigable surface channels (above the size that represents minor ditches serving individual fields) constitute a surface waterborne transport network. The smaller channels are treated as field boundaries only. Both banks of all navigable channels are assumed to have overland transport links along their lengths, and are assumed to have been connected across minor channels by bridges, fords, or hydraulic structures such as weirs and dams. 'Dry' crossings of major watercourses would of course require substantial bridges or a ferry service. These can be explicitly specified in the scenario's geospatial data. The problem of synthesizing such features in the absence of prescribed bridge or ferry sites has not yet been addressed. Any location that is associated with both a waterborne and an overland transport node is currently assumed to be an 'intermodal' node, at which travelers may in principle switch from waterborne to overland mode or vice versa. Although not commonly discussed, examples where water transport and overland routes are linked (perhaps for cattle droving through marshes) have recently been recorded by Pournelle (2003) and Stone (2013: 160-161).

CONCLUSION

As has been demonstrated, social networks vary widely in scale from immediate friends and family to people who never, or very rarely, met. How interaction takes place within these social networks across varied spatial scales is the key element driving movement across the physical networks. There are fundamental differences in the physical networks and how they were utilized, specifically between the land based transportation system in

[3] A TransportNexus is essentially a two-dimensional construct that performs in ENKIMDU transport networks in the topological role of a transport *link*, able to connect to both 'normal' zero-dimensional TransportJunction nodes and one-dimensional TransportBoundary nodes.

the north and the primarily water based system in the south. In addition, this chapter has detailed how ENKIMDU has incorporated all of these variables in order to simulate the movement of social agents, an absolutely critical factor in all the MASS simulations. Although not all of the above processes are actively incorporated into the examples discussed in Chapters 11 to 14, the preceding discussion demonstrates how networks of movement can be incorporated into modeling scenarios.

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