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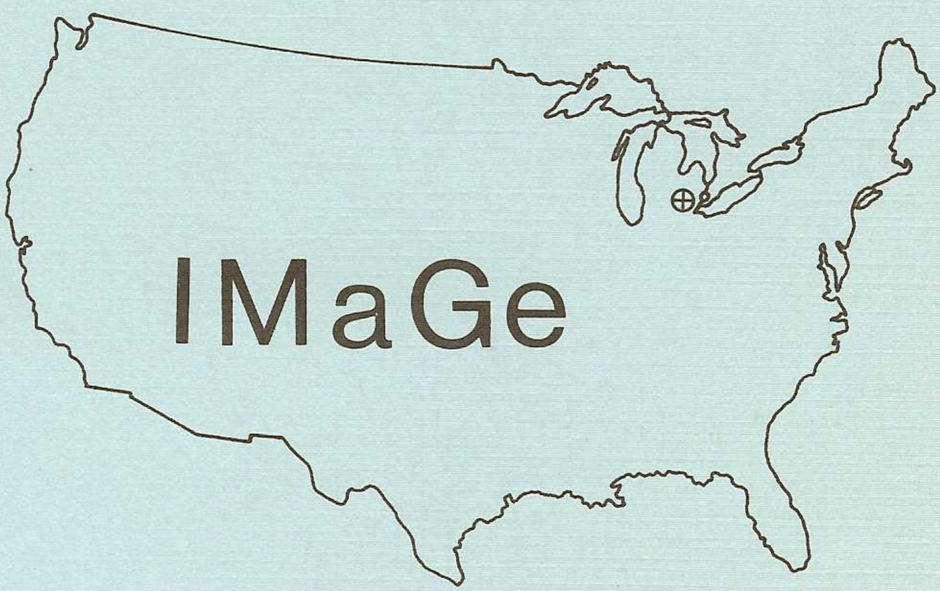
DOWN THE MAIL TUBES: THE PRESSURED POSTAL ERA, 1853-1984

by: Sandra Lach Arlinghaus, Ph.D.

Monograph #2



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SANDRA LACH ARLINGHAUS, Ph.D.

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Material in the "Appendix," as well as some of that in the body of the text, is derived from S. Arlinghaus, "On Geographical Network Location Theory," unpublished Ph.D. dissertation, directed by Waldo R. Tobler and John D. Nystuen, Department of Geography, The University of Michigan, 1977. Lectures concerning this topic, using similar titles, have been given by the author at The University of California, Berkeley, Department of Geography, 1979, and at The University of Michigan, 1983, as part of a symposium entitled, "Geography: The Heart of the Matter."

James M. Smith, president of Michigan Document Services, Inc., oversaw the typing of this manuscript. To him, to June Smith, and to the typists at Michigan Document, the author is indebted for their patience and care. Of course, omissions or errors in fact or interpretation that remain, despite the efforts of many individuals, are clearly those of the author, alone.

SANDRA ARLINGHAUS,

DOWN THE MAIL TUBES: THE PRESSURED POSTAL ERA, 1853-1984,

INSTITUTE OF MATHEMATICAL GEOGRAPHY
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PRE-PUBLICATION REVIEW BY SYLVIA L. THRUPP, MARCH, 1986.

ALICE FREEMAN PALMER PROFESSOR OF HISTORY EMERITUS,
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This lively and lucid account of experimentation with underground mailing systems in large cities should appeal to the growing number of readers who nowadays enjoy puzzling over the life histories of new forms of technology. Writing on these, at least in the English language, has tended to concentrate heavily on shifts in the sources of energy and their influence on industry and on long-distance transport and communication. Books and articles on the history and sociology of modern urbanism abound, but seldom touch on the theme treated in the Arlinghaus monograph.

The treatment is distinctive in five ways. 1) It is based throughout on information available in official reports involving postal authorities and brightened, not by journalistic simplification but pictorially, by maps showing the shape and extent of the tubal networks developed in the main cities discussed. 2) The discussion throughout is comparative, showing how far London, Paris, Berlin and New York dealt by similar or diverse means with the congestion of postal services that became common to all of them. 3) The financial problem of constructing underground networks and maintaining the efficiency of the air pressure systems adopted are adequately described. 4) The reasons for the return to surface distribution of mail, and the timing, in different countries, of the abandonment of the more rapid tubal transmission, are compared. 5) The most original part of the whole discussion, modestly relegated to an appendix, is the use made of all the historical evidence deployed in showing the limits of variance in the spatial design of the tubal networks. History is thus linked to geographical theory and both, to urban ecology.

Such brief comment does far less than justice to the intelligence and the stimulating quality of the author's writing, or to the breadth of her reading. The detail of her accounts of the interest of American private enterprise, in New York and other large cities on this continent, in pushing for construction of large tubes in systems to be leased to the government, brings out contrast between American and European views of how the new technology should be managed. This and many other sections of the monograph will set readers on new tracks of thought.

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DOWN THE MAIL TUBES: THE PRESSURED POSTAL ERA, 1853-1984

When Earth's last picture is painted and the tubes
are twisted and dried,
When the oldest colors have faded, and the youngest
critic has died,
We shall rest, and, faith, we shall need it--lie down
for an aeon or two,
Till the Master of All Good Workmen shall put us to
work anew.

Rudyard Kipling

Introduction

The closing of the Parisian "Pneumatique" on March 30, 1984, signalled the demise of a 117-year-old system of communication and of the pneumatic postal era. It also brought an end to a favorite device of novelists and film producers. Never again would Inspector Maigret stir the fears of a suspect by sending him a cryptic pneumatic message. Nor would Walt Disney wind his typical American film-family through the labyrinth of Parisian sewers, sending an occasional shiver through his audience with the mysterious swooshing sound of pneumatic carriers streaking through overhead tubes in the sewers.

In Europe and the United States, as cities became more congested after the mid-nineteenth century, surface postal circulation across central business districts became disconcertingly slow and inefficient, as did that of trolley and other urban mass transit.[1] In London Latimar Clark built the first pneumatic network designed for the exchange of postal messages in 1853, thus putting the mail down the tubes ten years prior to the operation of the world's first subway in 1863.[2] In France the telegraph engineer Charles Bontemps conducted experiments beginning in 1865 which led the government two years later to begin construction of a pneumatic network in Paris. In 1910 M. Gissot, supervisor of the telegraphic service of Paris, summarized the advantages accruing from the system as ". . . greater speed in handling a large number of messages, reduction in transmission errors, unencumbered circulation during rush hours, and reduction in number of manipulative personnel."[3] Meanwhile, in 1889, John Wanamaker, Philadelphia businessman and Postmaster-General under Benjamin Harrison, counted among his many duties the "study [of] the [communication] systems of other countries," to secure "transit for mail on faster schedules; provide quicker collections and distributions in cities and towns by pneumatic tubes," and in a broader setting, to "push forward American mails as the forerunner of the extension of American commerce."[4] Thus postal officials on both sides of the Atlantic proposed supplementing urban surface mail routes with a network of pneumatic mail tubes installed underground or separated in other ways from established surface systems.[5] This solution to distributing mail more efficiently through congested urban areas was but part of the larger effort of engineers and municipal authorities to create the "engineered" city via installation of extensive underground networks, including gas and water mains, sewers, steam pipes, subway tunnels, and telegraph lines.[6] Pneumatic postal networks appeared below London, Paris, and Berlin by the late 1860's, in other western European cities by century's end, in Philadelphia by 1893, and in Boston, New York, Chicago, and St. Louis by 1905.[7]

The French government explained the recent closing of the system in Paris by referring to the lack of continuing governmental financial commitment to rejuvenating the "Pneumatique" and to increased competition from telephone and telecopier technology which cut pneumatic transmissions. Statistics of the French Postal Ministry support its government's decision to discontinue this service: in 1960 the Parisian pneumatic network transmitted four million messages annually, in 1973 two million seven hundred thousand, and by 1982 only six hundred forty-eight thousand.[8] On the other hand, according to Jacques Lepage, director general of the pneumatic transport company of Lamson-Saunier-Duval, ". . . if the equipment is old, the idea is terribly modern. You can move things extraordinarily quickly through the system here. But when the state telecommunications people try to think in modern terms it's usually the obvious and the electronic."[9] As with the French system, earlier American and Western European commercial pneumatic postal networks had ardent supporters and critics. All were built in a period of intense urban systems development designed to convey a rapidly increasing volume of materials and ideas across limited space, and all are now defunct--thanks largely to changing budget priorities, the aging of physical equipment, and the advent of more competitive forms of technology.[10]

But in their heyday what were these systems like? What were the strengths and weaknesses of this promising new technology? Were there distinct European and American national styles of pneumatic postal technology? Finally, how did these styles diffuse within continental boundaries and how did they transfer, or fail to transfer, from one continent to another? This essay examines the historical diffusion, transfer of technology, and broad spatial aspects of network design as a model for the future. Its limits and the opportunities it suggests include lessons for the applications of innovative technology to the urban and postal scenes of the 1980s and 1990s.

Pneumatic Postal Networks in Western Europe

Experimental Networks: 1853-1871

In 1853 Latimar Clark designed the first pneumatic tube for postal transmission; it was one and one-half inches in diameter and 220 yards long and linked the head office of the Electric and International Telegraph Company of London to its branch office in the stock exchange.[11] A partial vacuum drew carriers loaded with telegrams through the tubing, and transmission using rarefied air (air that is less dense, or 'thinner', than atmospheric air) took place in one direction only. This particular system remained in operation until at least 1872.[12] Extension of Clark's ideas (within national boundaries) led to a successful test of a tube thirty inches in diameter for carrying small packages and mailbags on local trains running between the Euston station of the London and Northwestern Railway and a district post office one-third mile away.[13] Further development of this experiment by T. W. Rammell in 1861 produced the "Duke of Argyle," a pneumatic postal system composed of tubes three to four and one-half feet in diameter and of total length about two and three-quarters miles. Small trains of carriers, propelled by alternate use of rarefied and compressed air, carried mail bags and parcels between adjacent locations.[14] According to statements made by Kenneth E. Stuart to the U.S. Pneumatic-Tube Postal Commission (Chairman, Simon Guggenheim, Senator from Colorado) in 1912, the "Duke of Argyle" failed to provide effective two-way linkage since "compressed air is not suitable for operation of tubes of that size."[15] A final experiment in this series with wide-diameter tubes, performed by Rammell in 1864, demonstrated the possibility of conveying human beings through tubular systems.[16] This last effort sparked pneumatic railway, rather than pneumatic postal, construction. For, as Alfred Ely Beach, editor of Scientific American, owner of the Beach Pneumatic Transit Company and developer of the Pneumatic Tunnel railway under Broadway in New York, observed, Rammel's "large tunnel for passenger cars" carried "thousands of passengers" resulting in "the incorporation of the Waterton and Whitehall Railway, which is to extend from Charing Cross under the Thames to the Southwestern Railway."[17] Instead, pneumatic postal systems of diameter barely wide enough (two or three inches) to accommodate official government documents linked various British governmental offices in London over a distance of less than two miles.[18] The success of these more limited, specialized, and cheaper networks resulted in governmental purchase and in the subsequent extension of this idea to create other local installations in Liverpool, Manchester, Birmingham, Glasgow, Newcastle, and Dublin.[19]

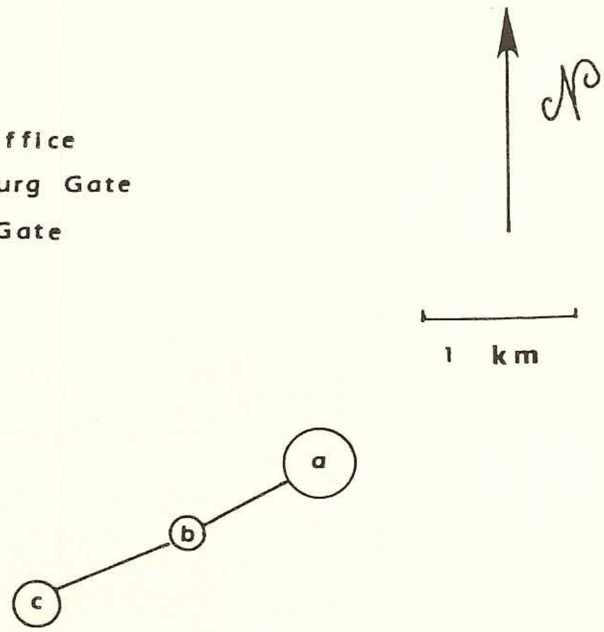
Meanwhile, in France, experiments by Bontemps in 1865 led to an underground pneumatic postal network in Paris two years later.[20] Also, according to reporters in Scientific American, "In 1865, Siemens and Halske of Berlin laid down...a system of pneumatic tubes for the transmission of telegraph messages." These "wrought iron tubes, two and one-half inches in diameter, were in duplicate, one...for transmitting and the other for receiving," and "They ran from the telegraph station to the Exchange, a distance of 5,670 feet."[21] Like London, both Paris and Berlin used small-diameter tubing to send messages in carriers through underground networks; unlike London, both carried primarily commercial rather than official governmental documents. By 1870 both London and Berlin used continuous air current flowing through two-way tubing. Paris employed non-continuous air flow, sent along one-way tubes, that required the dispatch of carrier trains at regular (one-quarter hour) intervals.[22] The networks shown in Maps 1 and 2 indicate the spatial organization of these earliest systems and represent the extent of their development to 1870.[23]

Wanamaker noted progress in Berlin, between the Seven Weeks' War (1866) and the Franco-Prussian War (1870): "The stirring events of 1866 had for a while placed the extension of the pneumatic network in the background, but soon it became all the more urgent." To facilitate communications, "The connection by pneumatic tubes between the central office and the Potsdam Gate, with an intermediate office at the Brandenburg Gate...was most urgently needed." Thus, the new line 2.3 kilometers in length extended "from the central office along Oberwald Street and Unter den Linden to the office room of the intermediate station at the Brandenburg Gate, and thence along the Königgreitzer street to the terminal station at Potsdam Gate." Additional extensions of the Berlin network did not occur until postal reorganization after 1870.[24] At the same time in France, war-related bottlenecks in traditional surface routing in and around Paris led to the use of gas-filled balloons to air-lift pigeons carrying mail in and out of Paris.[25] No further extension of the earlier pneumatic system took place.

a: Central office

b: Brandenburg Gate

c: Potsdam Gate

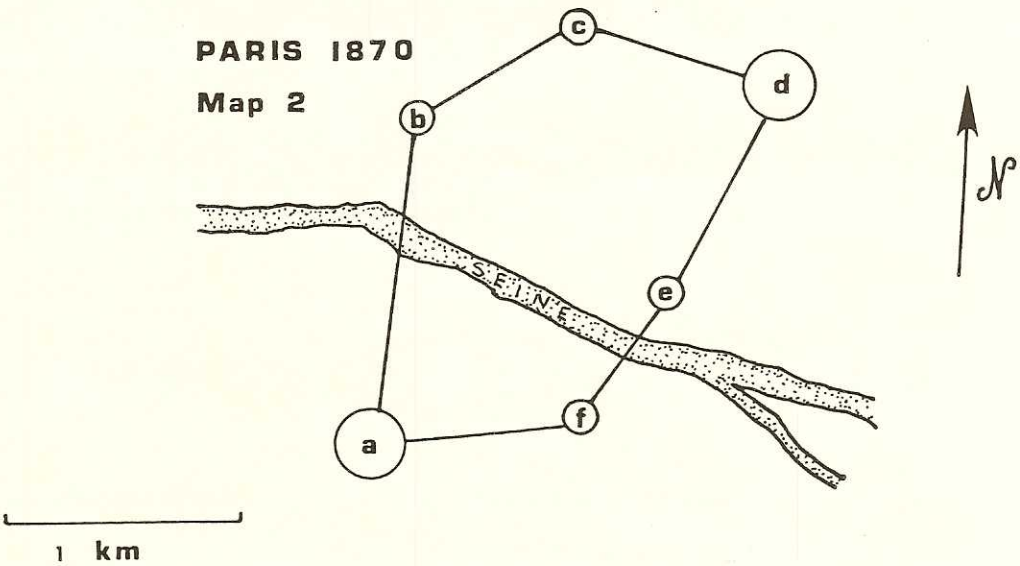


BERLIN 1870

Map 1

PARIS 1870

Map 2



a: 103 Rue de Grenelles

b: Boissy d'Anglas

c: Grand Hôtel

d: Bourse

e: Louvre

f: Saint Pères

Network Expansion: 1871-1918

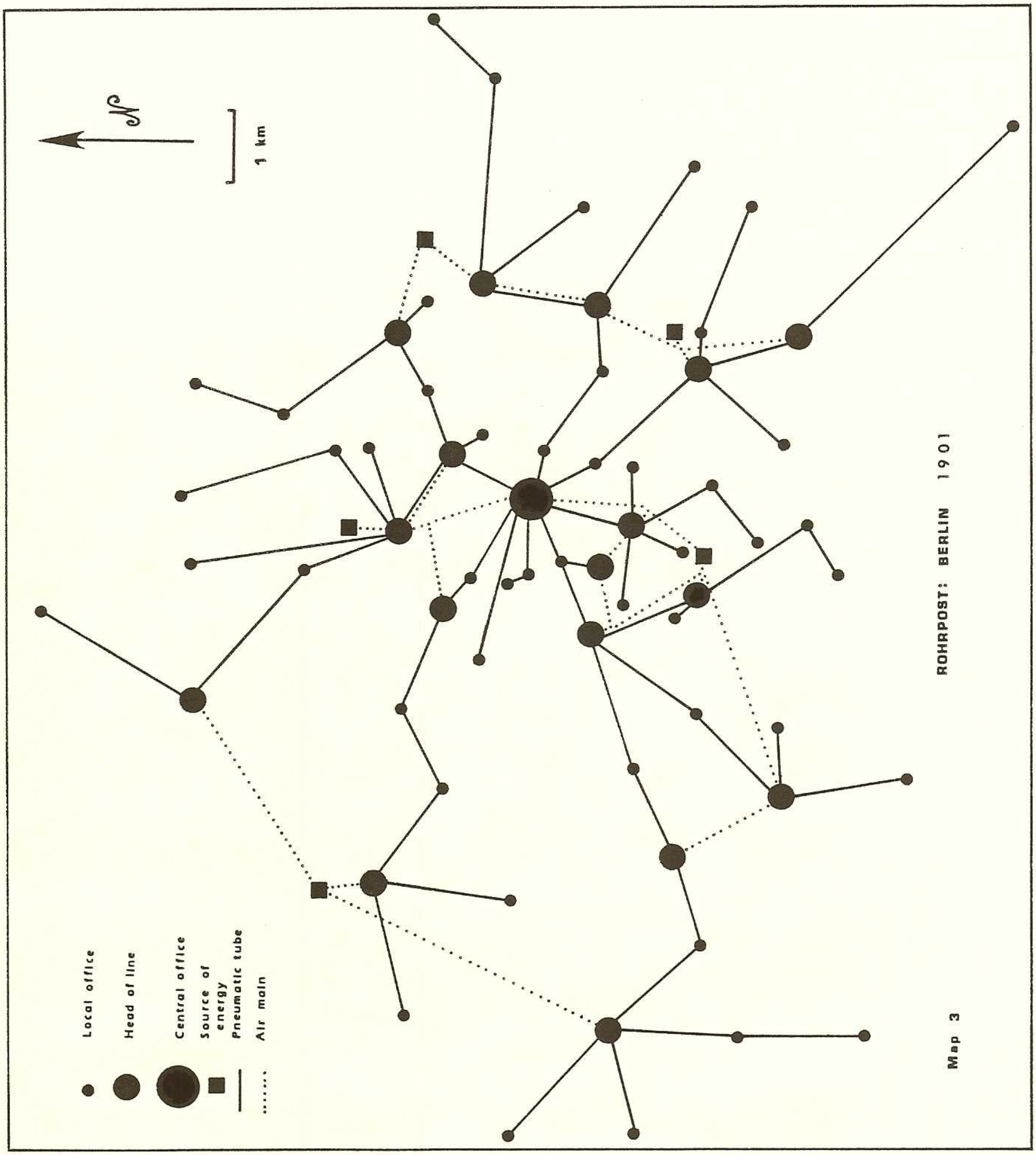
In 1870 London replaced Clark's continuous air flow system, which required a complete circuit from origin to destination, with Siemens's continuous current scheme, which did not. Also, expansion of the Berlin network to alleviate wartime congestion followed Siemens's formulas from the experimental period, but "various causes, partly of purely local character, prevented the further extension throughout Berlin on the Siemens' system."[26] Thus the Berlin and London networks developed differently after 1871.

Extensions of the earlier small-tube British system continued throughout this period to include, by 1897, 34 miles of tubing linking 42 stations via a radial plan of two-way tubing in London and smaller amounts (up to five miles) in other British cities.[27] A contemporary observer, describing the mechanics of the London system in an 1895 issue of The Gentleman's Magazine, explained that "to send a message from the West End to the City--it is only necessary to transmit an electric signal, when vacuum is turned on, and the 'carrier' is sucked back which a minute before had been blown out. The tubes are, in fact, gigantic pea shooters."[28] Networks designed according to a radial pattern of connection generally provided an efficient means of sending a message across the entire system; they emphasized user-convenience and minimization of user-costs by linking many locations directly via two-way tubing. But they required extensive initial and continuing supervisory investment, for even local mail often passed through the main office to add even more to central congestion.

Following the Franco-Prussian War, Imperial Chancellor Otto von Bismarck organized a commission in 1875 to study the Rohrpost (tubular post). This committee combined earlier postal and telegraphic governmental offices so that political separation of governmental funding sources would not block further network development.[29] Its members suggested using a network design that would not focus congestion at the hub of this rapidly expanding capital of the newly-established German Empire. Thus, in December of 1876, the Rohrpost Commission opened fifteen new stations joined by one-way tubing along Northern and Southern polygons, mutually tangent at the Central Office. As Berlin's population explosion continued, the various extensions in service along these two polygons proved inadequate. Indeed, Wanamaker reported that by 1881 an average Rohrpost transmission took 40% longer than it had previously; so from 1882 on, the Rohrpost Commission employed a radial design, which led (by 1901) to the full spatial form of the Rohrpost, shown in Map 3.[30]

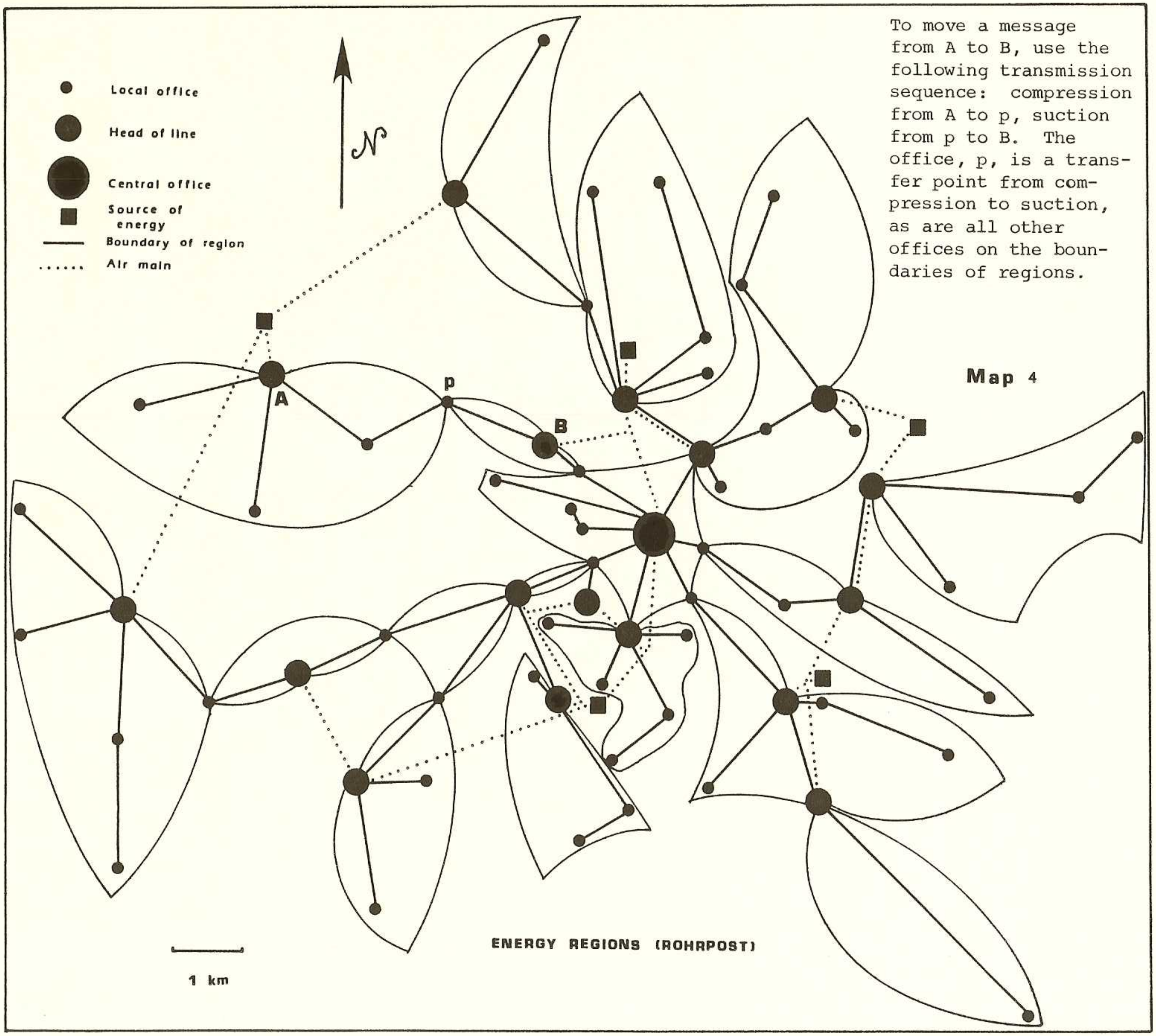
Within this network, trains of carriers, headed by bullet-shaped carriers and propelled by suction or compression, moved swiftly across the 73 miles of tubing.[31] Local postal operators dispatched carrier trains at intervals of fifteen to thirty minutes, depending on the length of tubing traversed, and these trains reached speeds of 45 mph over 0.6 miles or 35 mph over 1.8 miles with compression as the moving force. With suction as the propelling force, they attained speeds of 35 mph over 0.6 miles or 18 mph over 1.8 miles.[32] The warm compressed air condensed along the cool tube walls, and alternation of it with rarefied air kept the interior of the tubes dry. A typical sequence of moves, showing how to transmit carriers from head-of-line station A to head-of-line office B, appears in Map 4.

Even though the staggered use of compression and suction dried out the system, tubing placed at insufficient depth under streets and sidewalks froze in



ROHRPOST: BERLIN 1901

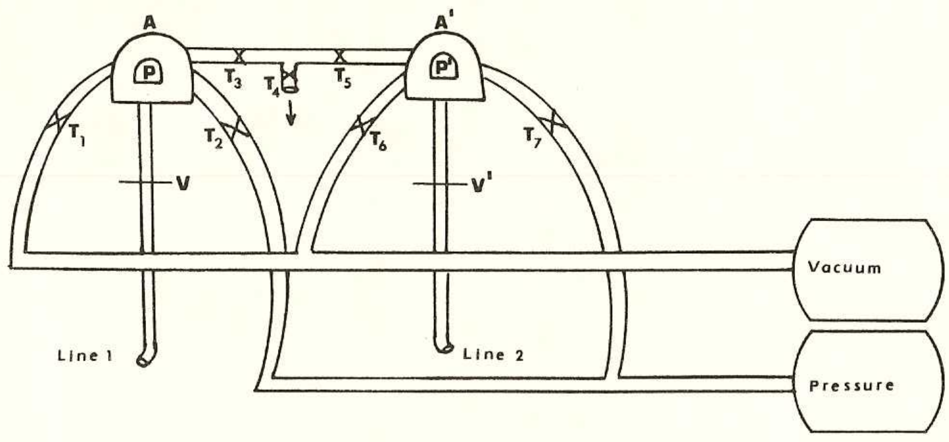
Map 3


To move a message from A to B, use the following transmission sequence: compression from A to p, suction from p to B. The office, p, is a transfer point from compression to suction, as are all other offices on the boundaries of regions.
Map 4
Local office
Head of line
Central office
Source of energy
Boundary of region
Air main
N
A
p
B
1 km
ENERGY REGIONS (ROHRPOST)

the winter. In Berlin "large quantities of liquid spirits of wine were introduced into the tubes for the purpose of detaching the ice from the walls of the tubes."[33] Of course, frozen tubes forced interruption in the service, as did other breakdowns resulting from damage to the tubing from street repair, from other underground urban systems (such as gas and water mains), and from changes in grade level.[34]

Heavy equipment associated with the Rohrpost included air mains of a diameter wider than the network tubing; they pumped the steam used as the energy source into selected heads-of-line from otherwise unincorporated sites.[35] Pneumatic transmission machinery designed by Felbinger for the original polygonal network, and modified by Wildemann in 1886 to simplify the manipulation of rarefied air, propelled messages to and from adjacent stations; by 1892, an observer noted in Engineering that "The Wildemann apparatus is exclusively employed in the pneumatic dispatch establishments of the Imperial German Post Office of Berlin."[36] Based on evidence of contemporary diagrams, it appeared that the Wildemann machinery was highly similar to the Hermann-Fortin apparatus in Figure 5, although its external housing was not.[37] The details of the method used to transmit carriers between adjacent stations appear in Figure 5.

The network designs exhibited in Maps 3 and 4 and the mechanical layout of Figure 5 were the results of increasing development throughout the period from 1871 to 1918. Competition from newly-introduced telephone technology in 1882 apparently did not interfere with the functioning of the Rohrpost: 644,000 messages passed through it in 1882, 934,000 in 1887, and an estimated 8,000,000 in 1901.[38] Moreover, Marshall Cushing observed in 1893 that the Rohrpost "notably increases the business of the telegraph and the telephone companies,



HERMANN-FORTIN APPARATUS

Figure 5

Mechanics of sending a carrier train from chamber A through general pneumatic Line 1:

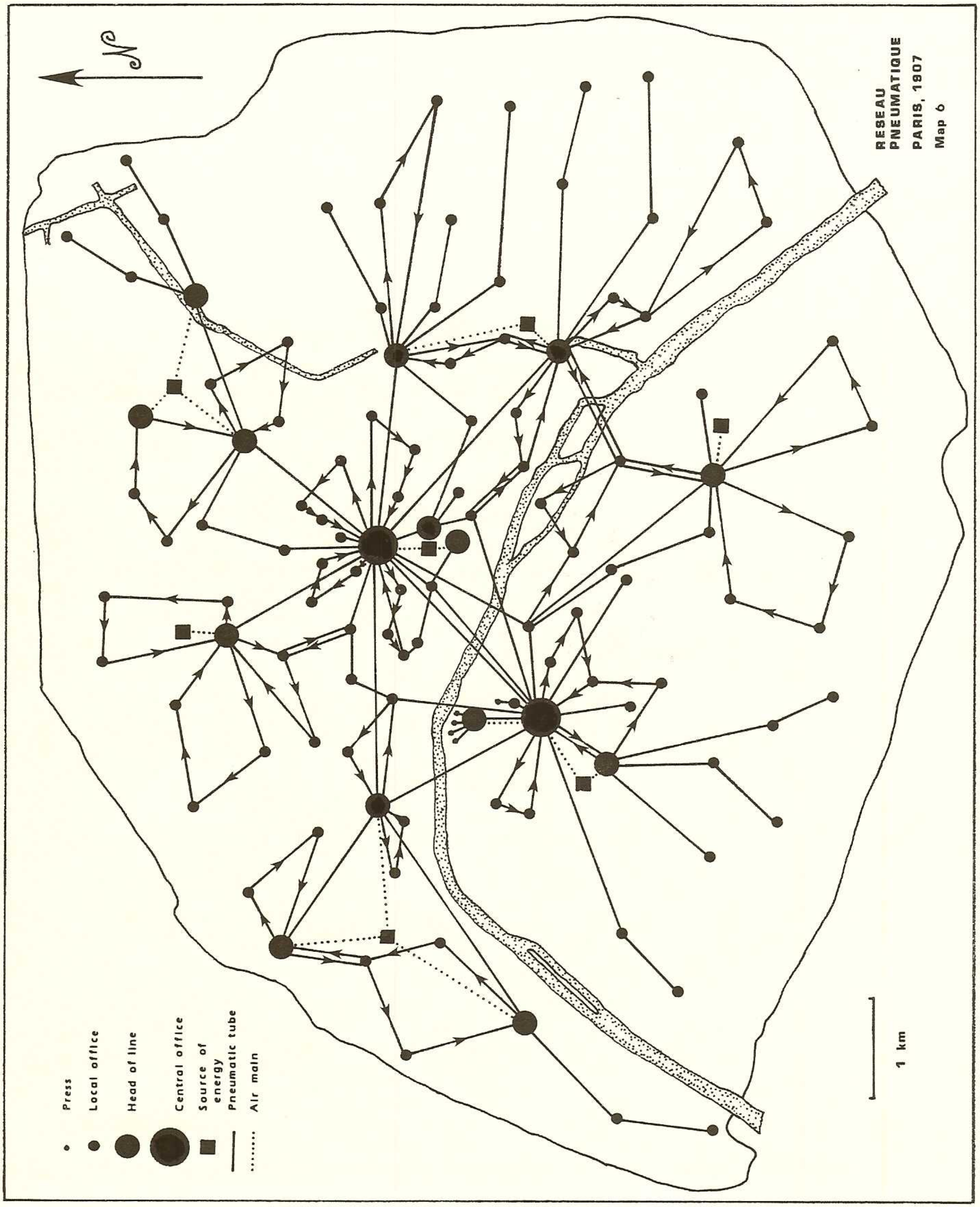
a) close taps T_1 and T_2; b) open taps T_3 and T_4, and close valve V, bringing the air pressure in A to the level of the atmosphere without letting the pressure from Line 1 escape; c) open the door P and insert the train to be transmitted into A; d) close T_3 and the door P; e) open T_2 allowing compressed air to enter the chamber; f) open valve V, and compressed air pushes the carrier train forward into Line 1. A corresponding set of moves will transmit a carrier from chamber A' into Line 2.

Mechanics of receiving a carrier train at A from Line 1:

a) close taps T_2 and T_3; b) open tap T_1; c) open valve V, and the carrier is drawn forward by suction into chamber A; d) close valve V; e) close tap T_1; f) open taps T_3 and T_4 bringing the pressure in chamber A to that of the atmosphere. Open door and remove train. A corresponding set of moves will permit reception from Line 2 into chamber A'.

and of course, the mail service."[39] Indeed, the Rohrpost remained a significant means of supplementary postal transmission. This period, from the Franco-Prussian War through World War I, saw the consolidation of governmental groups to form the Rohrpost Commission, which led to fiscal backing of about $1,000,000 from the German Empire and permitted the development of earlier experimental efforts into the comprehensive 1901 network exhibited in Map 3. This reflected the "Coordination of Technology and Politics" that Thomas P. Hughes observed in his analysis of the impact of electrification on urban industrialization in Germany generally, and in Berlin in particular, during this period.[40]

During this time span in Paris, the continued extension of the pre-War system along polygonal lines resulted in the inclusion, by 1876, of seventeen new pneumatic sub-stations.[41] The Bourse on the Right Bank and the General Office of the Postes, Téléphones, et Télégraphes (PTT) at 103 Rue de Grenelles on the Left Bank, the earlier focal points, remained central in this enlarged network. From 1889 the Parisian system ("Le Petit Bleu") developed rapidly until 1907, when 210 miles of tubing joined 120 stations, as shown in Map 6. Stratification of dispatchers into a hierarchy forced (a) linkage, via one-way tubing, of small offices along a single polygon centered on a higher level vertex, and (b) linkage, via two-way tubing, of higher level offices to one of the two major centers. (The Appendix describes this hierarchy in greater detail.) Thus local mail, written on special blue stationery (hence "Petit Bleu"), moved around individual polygons without focusing congestion on the busiest centers. Moving a message across the entire system, however, required shifting it from one polygon to another, thereby reducing both the security and speed of the mail.[42]


RESEAU PNEUMATIQUE
PARIS, 1907
Map 6
Press
Local office
Head of line
Central office
Source of energy
Pneumatic tube
Air main
1 km

The speed of transmission within the Paris system permitted the exchange of about 12,000 messages per hour between adjacent offices joined by two-way tubing. In fact, R. L. Maddox, Acting Superintendent Division of Foreign Mails in the United States Post Office, reported in 1913 that in Paris "In 1907, the number of articles of pneumatic correspondence was 9,069,285 and the proceeds therefrom amounted to 2,746,350 francs ($530,045)."[43] Compressed and rarefied air moved into head-of-line offices via air mains, as indicated in Map 6, and trains of carriers circulated around the polygons through tubing located in the sewers. Until 1903 the Paris network used the Hermann-Fortin pneumatic transmission apparatus to drive carrier trains through the tubes. This machinery worked well, but within the expanding Parisian system the floor space requirements and the equipment's weight made it impractical for all sales offices. Thus, by 1905 the government adopted an apparatus, proposed by Gissot, which retained all the flexibility of the Hermann-Fortin transmitter yet reduced the façade AA' from 47 inches to 14 inches and the weight on the floor from 3310 pounds to 400 pounds (Figure 5). The earliest Gissot equipment appeared in the Bourse, and as Gissot himself put it in 1909, "This installation has not failed since it was put into service in December 1905."[44] The reduction in weight came from putting in the basement the tubing that hooked into the general lines and from joining the various taps to a single tap that controlled remotely the workings of those in the basement. Thus the chambers that received the carrier trains were placed conveniently in sales offices where clerks dealt with the public, while the heavy machinery used to forward messages into the general pneumatic lines remained in a more remote location.

On government orders, the Gissot installations replaced the older Hermann-Fortin equipment throughout the entire system. One later modification by Gissot of his own apparatus involved the replacement of the façade AA' by a wheel with chambers interior to it for the reception and sending of carriers. Thus a train, drawn by suction into the upper chamber of the wheel, forced it to rotate downward under the force of gravity and to deposit the carrier in a tray surrounding this wheel. Reduction in the amount of human labor followed naturally. The government installed this sort of modified Gissot equipment in some head-of-line offices by 1910.[45]

Again, as in Berlin, governmental support permitted a specialized government group, the PTT in this case, to develop extensively the earlier experimental network. Total installation costs came to $1,022,900 and total annual operating costs of the 1907 network to $477,675. In contrast to Berlin's radial plan, however, the Paris network had a polygonal spatial design.

Smaller pneumatic installations also appeared in other western European cities. The first of these, begun in Vienna in 1873, linked eight of the nine wards to a central office in a polygonal plan. The resulting loss in user-convenience appeared inconsequential, since messages traversed the entire system in one hour.[46] This network, patterned after Paris' by a government-appointed engineer who studied the systems of Paris, Berlin, and London, joined 50 pneumatic stations along 37 miles of tubing and 6 miles of air mains by 1913. A combination of compression and suction propelled messages through tubes one-quarter of an inch in diameter, using an apparatus that appeared (from engineering drawings) similar to Gissot's modification of the Hermann-Fortin machinery.[47]

The technology spread across Europe. Indeed, Marseille and Lyon in France and Frankfurt am Main and Hamburg in Germany developed minor pneumatic postal networks, and by 1910 Italy had embraced the idea. The Italian government issued funding for such postal systems in Milan, Rome, and Naples: for Milan, 5.5 miles of tubing with one head-of-line and three local stations; for Rome, 7.5 miles of tubing, one primary office, and seven subordinate stations; and for Naples, 10.4 miles of tubing, one head-of-line, and six local stations.[48] By 1914 the government completed the networks proposed for Milan, Rome, and Naples according to the 1910 specifications and, in addition, constructed shorter systems in Turin and Genoa in 1910 and 1911.[49] These systems employed network tubing identical to those of Paris and Berlin; and, in keeping with the general trend toward electrification, used electricity, rather than steam, as the energy source. Electric motors pulled messages through the tubing, using suction only, along a circular route. This reduced the number of operations required to the opening of a single valve and to placing the carrier into the receiving chamber. Once again, as in the Gissot system, the Italians placed the heavy motor in the basement, and a clerk operated it remotely from a small, lightweight apparatus. Speeds attained by carrier trains ranged from 20 to 25 mph, permitting an interchange of about 9000 messages between adjacent stations in one peak hour. Gissot reported that these electrical pneumatic systems "had been built by the Berlin company of Lamson, Mix and Genest." As a result of these internal simplifications and the consequent ease of network use, he expected to see rapid diffusion of these systems to service banks, commercial establishments, "and in a word, in all establishments of any significance."[50] Gissot's observation, based on these smaller networks, that the choice of underlying energy source could have significant impact on the success of the entire system, emerged as an addition to the economic and spatial concerns present in the larger systems of Paris and Berlin.

Networks after World War I: 1918-1984

Following World War I, the pneumatic postal systems of Paris and Berlin changed little in underlying spatial design. Applications of contemporary advances in banking practices and in engineering techniques helped to promote the persistence of this style of commercial pneumatic network in Paris, until 1984, and in Berlin into the 1930s.

In France, the government introduced postal checking in 1918, and by 1930, pneumatic tubes installed within Parisian postal checking centers permitted the processing of checks in ten, rather than in thirty, minutes. These tubes linked the cashier who dealt with the public to any of several offices out of view, where those authorized to handle money cashed the check. The Société d'équipment de voie ferrés, the Société française de tubes pneumatiques, and the pneumatic transport firm of Saunier, Duval, and Frisquet commonly employed one of two technical pneumatic systems: the first executed switching from a point of remote control external to the tube, while the second used the carriers themselves to force switching between tubes. Both of these systems employed rarefied air only. The diffusion of this technology to other towns in France began around 1930. Indeed, according to E. Lapierre, sous-chef de bureau breveté des Postes et Télégraphes, and Raynier, rédacteur principal des Postes et Télégraphes, "Strasbourg and Dijon already have such equipment, . . . Bordeaux, Rennes, and Lyon will shortly, . . . and studies are underway for Toulouse and Lille."[51] The introduction of pneumatic technology in arenas other than, but related to, the postal network complemented the earlier postal technology. But the "Pneumatique," at its height in the 1930's, fell into disuse by the 1980's--the victim of changing fiscal priorities in the French postal ministry.[52]

Technological advances of the 1930's helped to stimulate pneumatic development generally and pneumatic postal networks specifically: the application to pneumatic transport of magnetism by Deutsche Telephonwerke und Kabel Industrie and by the Berlin company of Mix and Genest; of the photo-electric cell by M. Krieger; and of automatic switching via electrical circuitry similar to that used in telephone networks by the firm of Mix and Genest and by Zweitusch. The Deutsche Telephonwerke und Kabel Industrie tested its magnetic system in the Berlin pneumatic postal network, while Mix and Genest tried theirs in the Forest section of the Parisian network. Zweitusch and Mix and Genest also tested their automatic switching procedures in Berlin, and the general success of application of contemporary engineering techniques to pneumatic technology prompted G. Paulin, Ingénieur des Postes et Télégraphes to observe in 1933 that "the Berlin trial line is . . . satisfactory and the German government foresees extension of this system."[53] Although the German Government operated the Berlin system in the 1930's, the physical destruction in World War II of Unter den Linden and other streets that contained this network's heart appears to have terminated this postal service.[54]

During the period from 1853 to 1984 in Western Europe, national governmental financial commitment helped to develop these networks. Careful engineering analysis of their spatial ordering helped maintain and expand commercial pneumatic postal systems. Early leaders of technological innovation such as Clark and Rammell in England, Bontemps in France, and Siemens and Halske in Germany laid the experimental foundations for the future technological developments carried forward by Gissot in France and by Felbinger and Wildemann in Germany. Diffusion of this technology led to the installation of pneumatic postal networks across a wider French, Austrian, and Italian landscape. The impact of Gissot on the developing Italian systems, the use of a government-appointed Viennese engineer to study earlier French, German, and British networks, and the persistence of the names of Lamson, Saunier, and Duval in pneumatic transport companies, reflect a climate in which study of pneumatic networks extended beyond national boundaries. Thus a style of technology of 'Western European' character, rather than exclusively of 'French' or of 'German' character, developed and spread in the era from 1853 to 1984.

Pneumatic Postal Networks in the United States

Experimental Networks: 1889-1902

Prior to 1889, Beach's pneumatic railway (1870), Western Union's pneumatic message delivery across short distances in Chicago and New York (1869 and 1876, respectively), and Wanamaker's, Macy's, and Siegel Cooper's pneumatic transfer of cash from one store location to another, were the primary commercial applications of pneumatic technology in the United States.[55] As Postmaster-General of the United States from 1889-1892, John Wanamaker became the leading

American advocate of pneumatic technology for the postal system. He followed his initial statement of 1889, cited above, with a careful discussion, in 1891, of pneumatic postal systems in western Europe in which he recognized the need to " . . . show in detail how successful our European friends have been in the use of the pneumatic post, and how trivial by comparison any efforts made in this country have been." In calling for experimentation, he claimed in 1891 "that $100,000 would be enough money to try experiments" leading to tubular post "in New York, to meet the increasing needs of the metropolis; in Chicago, to illustrate the perfection of our postal development at the World's Fair, . . . in Washington, between the Capitol and the other public buildings; . . . in cities like Philadelphia, [and] St. Louis; . . . and ultimately in all the large cities, as a necessary step in the march of postal improvement." In 1891 the Postmaster-General's office received recommendations for the adoption of pneumatic postal technology from Philadelphia's Postmaster Field, following his trip to Berlin to investigate the Rohrpost, to link the heart of Philadelphia's business district on East Chestnut Street with the main post office; from St. Louis's Postmaster Harlow to run pneumatic postal tubing in the subway tunnel close to the general post office; from Postmasters Van Cott and Collins of New York City and Brooklyn, and finally, Wanamaker noted that "A proposition from Chicago, which is certainly worth examination, has lately come in." In addition, many specific proposals concerning the internal technological design of pneumatic postal networks appear in the literature before 1902.

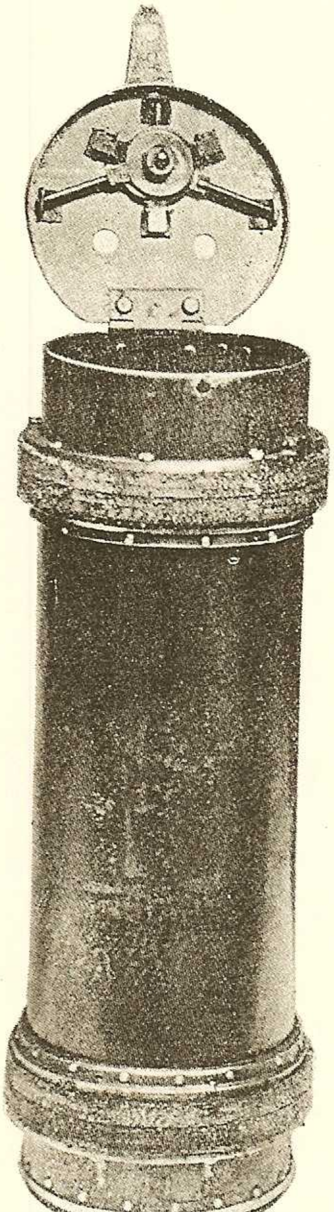
Wanamaker briefly presented a number of these different plans in his 1891 report. The United States Automatic Dispatch Company of Brooklyn suggested the use of light-weight tubing three-sixteenths of an inch thick "so that its weight is unappreciable on a structure like the Brooklyn Bridge or the elevated railroads." Additionally, it recommended mechanical sorting of carriers within the tubes employing a sequence of notches in carrier sides to correspond to different spacings of carrier wheels as they ran along rails of appropriate gauge. Electrical, rather than mechanical, switching of carriers formed the basis for the 1883 proposal of Philadelphia's Henry Clay to create a system in which continuity of switching paralleled continuity in air flow. An experimental line linking New York City to Newark, New Jersey, based on 1890 inventions of S. F. Leake that modified Clay's ideas, was under construction by 1891; according to Wanamaker, Leake expected carrier speed to reach about 240 miles per hour. Finally, Wanamaker noted the presence of an experimental magnetic system for propelling packages in carriers along tracks in tubes in Dorchester, Massachusetts. He reported claims of carrier speeds of 120 to 150 miles per hour.[56]

In addition, Wanamaker himself suggested in 1892 that "One of the [Chicago] World's Fair buildings, with tracks running into it connecting with all the railroads, would answer every purpose, after the exposition closes, for assembling and dispatching the mails." And, although "Jackson Park seems now rather out of town, . . . one of the buildings could be taken down and rebuilt," as a central postal receiving station joined to "all the substations by means of a belt line of pneumatic tubes." He saw this plan "To assort the mails on trains for these city districts and transmit them from the central station in tubes" as a way to "make an even greater Chicago and set the pattern for an ideal city postal service."[57] Another proposal reviewed by Scientific American in 1889 was the Johnson pneumatic tube system. It employed a tube 30 inches in diameter to move freight and mail in hollow spherical carriers. The spheres rolled along a track raised three-eights of an inch from the tube bottom. An experimental segment of 1000 feet of tubing built in Marion, New Jersey, used both rarefied and compressed air to propel carriers weighing 750 pounds at speeds of up to 300 miles per hour. Cushioning of air between closely spaced carriers prevented collisions.[58]

Although Wanamaker was unable to implement his World's Fair plan in Chicago, he reported on December 5, 1892 that

> I was able to secure an item of $10,000 in the last post office appropriation bill for experiments with pneumatic tubes. A call by advertisement in the newspapers of principal cities for propositions was issued and eight proposals submitted. One only of these proved practicable for immediate testing, that of the New Jersey Rapid Transit Company, and this company is already putting down tubes in Philadelphia between the Post Office and the East Chestnut Station, to be completed soon after December 1, 1892. This is at an expense of $25,000, as I am informed, to make this experiment successful, and the Department has by agreement the privilege of using the system for the period of one year without expense, and may then rent, purchase, or reject it without incurring any liability. As is well-known, the tubular post has been a marked success in Berlin and other foreign capitals, and, as is equally well-known, I have persistently advocated its use in such cities as New York and Chicago. I urge all this now more strongly than ever.[59]

Thus, in 1893, the first pneumatic postal system opened in Philadelphia. It consisted of tubes six to eight inches (the original segment was made of six inch tubing) in diameter in which cylindrical carriers 16 to 30 inches long slid on packing rings through the tubes, under pressure from a stream of compressed air, at speeds of 25 to 33 miles per hour. This carrier resembled closely the one used in today's drive-in banks (Figure 7). The energy source was either steam or electricity, whichever was convenient. Tubing was buried below the frost line, at depths of about four feet, to minimize freezing problems. This "experimental" network, engineered by B. C. Batcheller of the New Jersey Rapid

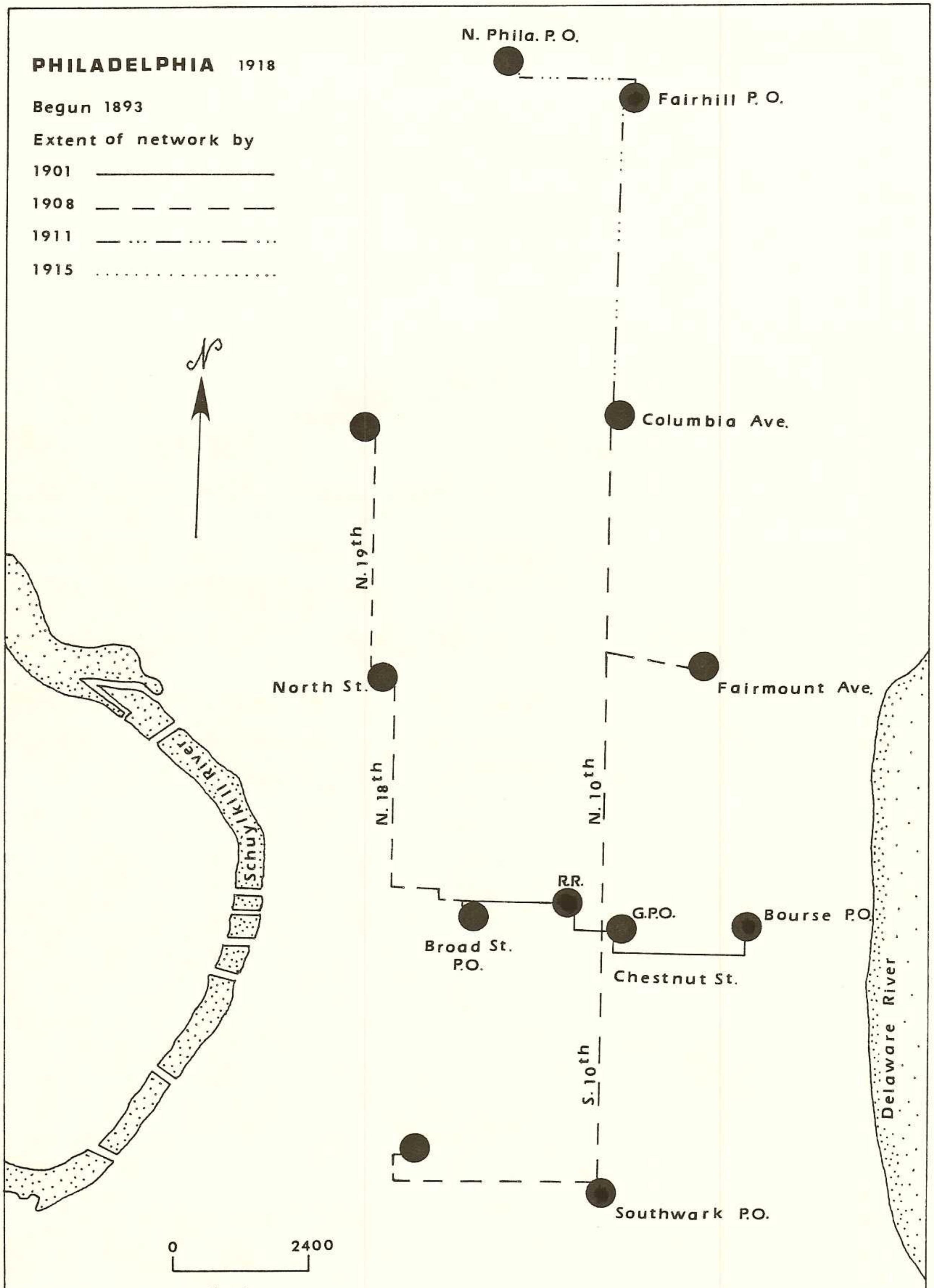


EIGHT-INCH CARRIER, BATCHELLER SYSTEM.

Figure 7

Transit Company, formed the foundation for the subsequent work of the Batcheller Pneumatic Tube Company of Philadelphia.[60]

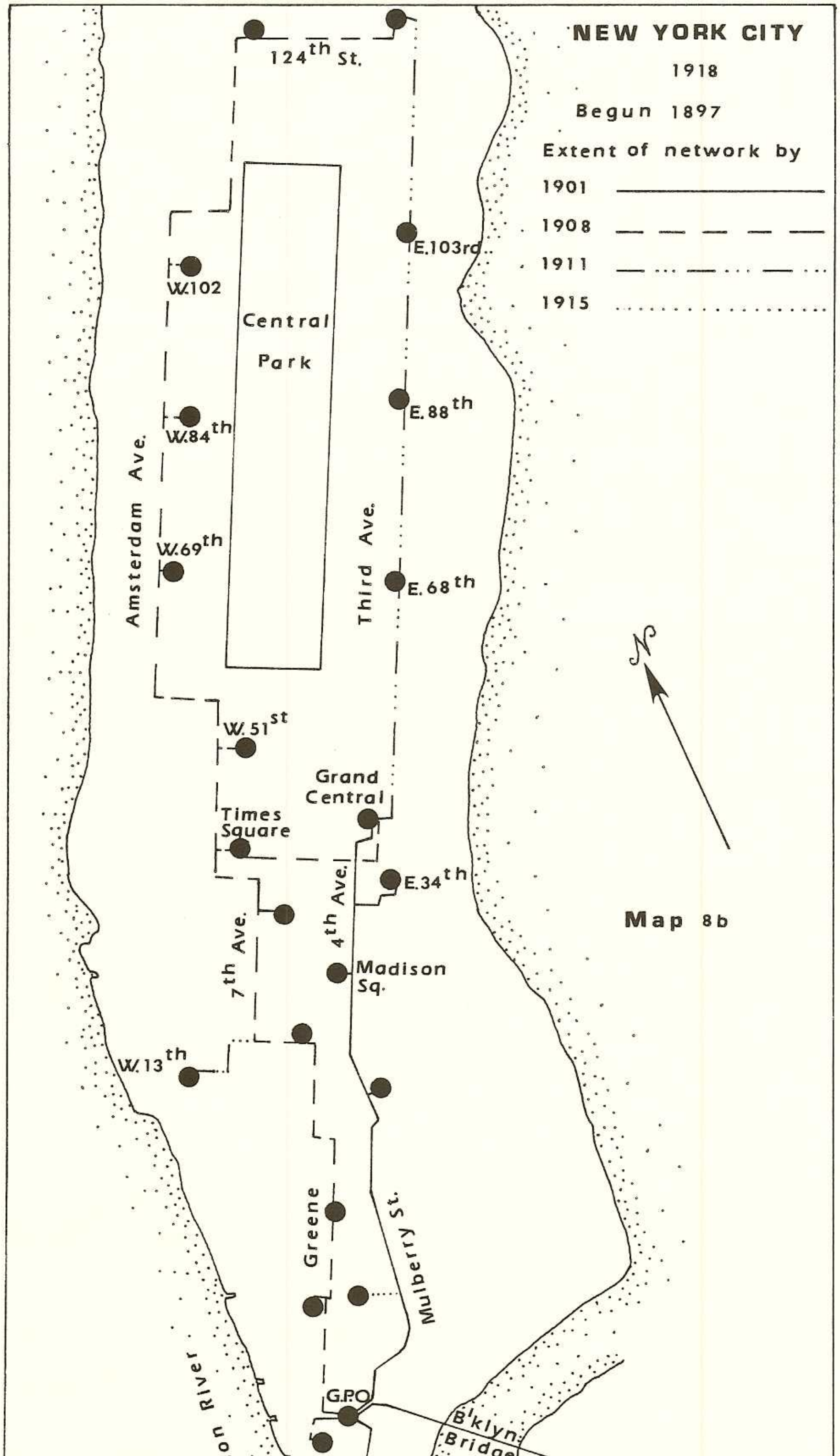
Continuing federal appropriations, from $3400 in 1894 to $500,000 in 1901, permitted extended experimentation in postal pneumatic transport; by 1901, pneumatic postal networks installed in Philadelphia, New York-Brooklyn, and Boston transmitted first class mail across a portion of the downtown area. The Philadelphia system, begun in 1893 and continued under Batcheller patents by the Pneumatic Transit Company, linked the General Post Office to the Bourse at 4th and Chestnut Streets as well as to the Reading and Pennsylvania railway terminal. The pattern of underground connectivity followed the pattern of the surface streets, and rental per year of the tube was $13,844 per mile.[61] Thomas L. Hicks, Philadelphia Postmaster, reported on October 31, 1900 that of a daily average of 546,292 letters dispatched, 469,721 went through the tubes while 76,571 went by wagon, and of a daily average of 370,807 letters received, 356,270 came through pneumatic tubes while 14,537 came by wagon (Map 8a). The New York-Brooklyn system, operated under Batcheller patents by the Tubular Dispatch Company, commenced service in 1897. It joined five postal stations in New York to the General Post Office by March 3, 1898, and linked this to the Brooklyn General Post Office via a tube across the Brooklyn Bridge, as of August 1, 1898. Again the underground spatial organization followed that of the streets, and tube rental was $17,326 per mile. Postmaster Van Cott of New York City and V. J. Bradley, Superintendent of Railway Mail Service, Second Division, estimated, on the basis of a test count in the first week of May in 1900, that daily volume handled by the experimental network was 1,050,100 first-class pieces of mail per day, of which 145,850 passed across the Brooklyn Bridge (Map

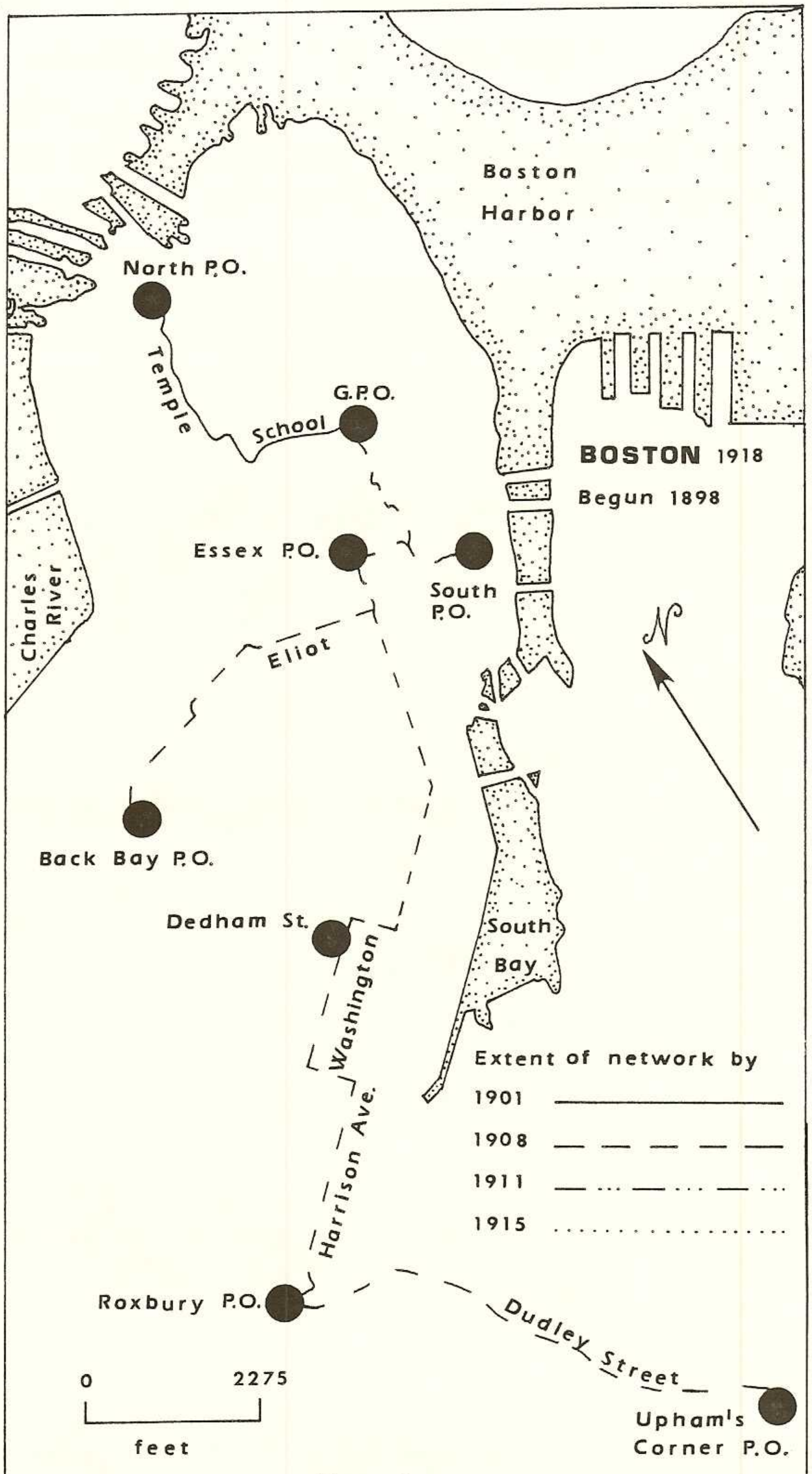

PHILADELPHIA 1918
Begun 1893
Extent of network by
1901
1908
1911
1915
N
N. Phila. P. O.
Fairhill P. O.
Columbia Ave.
N. 19th
North St.
Fairmount Ave.
N. 18th
N. 10th
Schuylkill River
R.R.
G.P.O.
Bourse P.O.
Broad St. P.O.
Chestnut St.
S. 10th
Delaware River
Southwark P.O.
0
2400
feet

Map 8a

8b). In Boston, a pneumatic tube connected the General Post Office to the North Union Station. The American Pneumatic Service Company laid this tube in 1898, under patents of Lamson and Bostedo, as well as under those of Batcheller, and rented it to the Post Office Department at a cost of $31,200 per mile. Using a count taken in the fall of 1900, Superintendent of Mails E. A. Reed estimated that cessation of tube service would result in an increase of 20 wagon trips per day from the General Post Office to Northern Union Station and an increase of 41 wagon trips per day in the opposite direction (Map 8c).

A congressional act appropriating Post Office funds, approved June 2, 1900, provided ten thousand dollars "For the investigation by the Postmaster-General of the cost of construction, operation, and utility of all systems of pneumatic tubes for the transmission of mail" in order "to enable Congress to determine whether the service should be owned, leased, extended, or discontinued by the Government." This order led to the publication of a document in 1901 describing many of the efforts in the experimental period. Second Assistant Postmaster-General W. S. Shallenberger, under Postmaster-General Charles Emory Smith, directed the investigation carried out by a national committee comprised of Theodore C. Search (Chairman), President of the Association of Manufacturers of the United States; Robert H. Thurston, Professor of Engineering in Cornell University; S. Cristy Mead of the Merchants' Association of New York; Alfred Brooks Fry, Chief Engineer and Superintendent of repairs of United States Public Buildings; William T. Manning, Frederick A. Halsey, and Lyman E. Cooley, all practicing engineers. Local committees comprised of various postal, business, and scientific personnel conducted detailed site investigations in the eleven cities selected for possible pneumatic postal


NEW YORK CITY
1918
Begun 1897
Extent of network by
1901
1908
1911
1915
124th St.
Central Park
W.102
W.84th
W.69th
Amsterdam Ave.
E.103rd
E.88th
E.68th
Third Ave.
W.51st
Grand Central
Times Square
E.34th
4th Ave.
7th Ave.
Madison Sq.
W.13th
Greene
Mulberry St.
G.P.O.
B'klyn Bridge
Wall
Hudson River
East River
0 2000 feet
Brooklyn G.P.O.
Atlantic Ave.
Map 8b


Boston
Harbor
North P.O.
Temple
School
G.P.O.
BOSTON 1918
Begun 1898
Essex P.O.
South
P.O.
Charles
River
Eliot
N
Back Bay P.O.
Dedham St.
Washington
South
Bay
Extent of network by
1901
1908
1911
1915
Harrison Ave.
Roxbury P.O.
Dudley Street
0
2275
feet
Upham's
Corner P.O.

Map 8c

development: New York, Brooklyn, Boston, Philadelphia, Washington, Cincinnati, Chicago, St. Louis, New Orleans, Denver, and San Francisco.

For those cities which did not already have pneumatic networks, the "Search" Committee developed a quantitative measure to determine which of the remaining eleven could support them. For a city to qualify, this committee recommended that the ratio of its aggregate proposed tube expenditure to its actual gross postal receipts be less than or equal to 0.031 (the ratio for Philadelphia was 0.031, for New York 0.028, and for Boston 0.025). The proposals submitted to this commission for Chicago and St. Louis met this condition; those for Washington, Cincinnati, New Orleans, Denver, and San Francisco did not.

In addition, this commission examined earlier proposals (other than Batcheller's) for experimental pneumatic postal technology. The United States Pneumatic Dispatch Company proposed a system of tubes over twenty inches in diameter to carry mail at speeds of 30 to 50 miles per hour within a cylindrical carrier three feet long and weighing 400 pounds. Four wheels on each carrier, one at the bottom front, top front, bottom back, and top back rolled along longitudinal grooves etched in the top and bottom of the tube. An experimental line of 200 feet built in Burlington, New Jersey, used steam as the energy source. The proposed Sampson Combined Curb and Conduit System housed wiring, pipes, and pneumatic postal tubes in a conduit buried below the curb. Carriers at least 24 inches in diameter and weighing between 500 and 1000 pounds would run along rails within these tubes. No record of an experimental segment appeared in this 1901 document. The American Pneumatic Service Company of Boston advocated use of tubing 10 inches in diameter containing cylindrical carriers varying in length from 18 to 30 inches. Carriers fitted with four or five wheels evenly spaced around each end, propelled by compressed air only, reached speeds of 25 to 30 miles per hour. Electrically powered air compressors fueled an experimental section of 4000 feet in Lowell, Massachusetts.[62]

As both Wanamaker and the Western European literature make clear, but as the "Search" report does not, two components were critical in the construction of a pneumatic postal network: internal technological design and external spatial organization. According to a report from Engineering, reproduced in a Scientific American Supplement of 1892, radial systems provided greater user convenience at greater expense than did polygonal systems. The author of that article stated (with reference to Berlin) that "Some years' service having shown the insufficiency of the polygonal system, its transformation to the radial system was determined and gradually accomplished," but did not comment on the continuing successful use of the Parisian polygonal network even though he did refer to the "Pneumatique."[63] Further evidence that American engineers treated network design more lightly than did their European counterparts appeared in the written report of the "Search" Committee of 1901-02. Van Cott and Bradley's report to this commission contained fourteen separate sections, enumerated below, none of which dealt with spatial design of the network. Even their section entitled "Proposed extension of the tube" included only tables of "distance and comparative speed" (by wagon, street car, elevated railroad, and tube), of "frequency of service," and of "receipts and mail handled at branches," but no discussion of the merits of a radial versus polygonal plan. The only indication of network arrangement in the 1901 document appeared in the map set showing positions of proposed networks in Chicago, St. Louis, Cincinnati, and San

Francisco, and of existing pneumatic networks, and of proposed extensions, in Philadelphia, New York, and Boston.

Regardless of internal design features such as tube diameter, carrier shape, size, and speed, or of external spatial plan, either radial or polygonal, a problem common to most of these early proposals was the dispatching and receiving of heavy carriers. All relied in some form or other on air cushioning to slow carriers in the line, and all employed various mechanical and manual means of inserting carriers into the tubing. The types of apparatus constructed were, because of the relatively large tube diameter and carrier size, necessarily more cumbersome than their European counterparts. Further, most American systems used only compressed air, whereas most European systems employed both compressed and rarefied air. The use of both modes generated greater carrier speed, but rarefied air was expensive to produce. While alternate use of these two air streams overcame problems resulting from condensation in the tubes, only the Europeans built networks that capitalized on this additional advantage to using rarefied air.[64]

Further evidence of divergence in American and European pneumatic engineering practice appeared in the use of wide, as opposed to narrow, diameter tubing. B. C. Batcheller, holder of more patents in pneumatic technology (37) than any other American, stated before a congressional committee in Chicago on September 17, 1900 that while tubing of considerable diameter (25 inches) was too expensive to warrant construction, tubing as large as 8 inches in diameter had successfully transmitted messages in Philadelphia. When asked by C. U. Gordon, Postmaster of Chicago "what would be the comparative cost of the 3-inch system (European) in Chicago and the 6 and 8-inch tubes?" Batcheller "was not prepared to answer that question," even though he had just previously apparently acknowledged the existence of small-diameter tubes in London and Paris (direct testimony omitted from the record) but not the existence of the earlier British large-tube systems.[65]

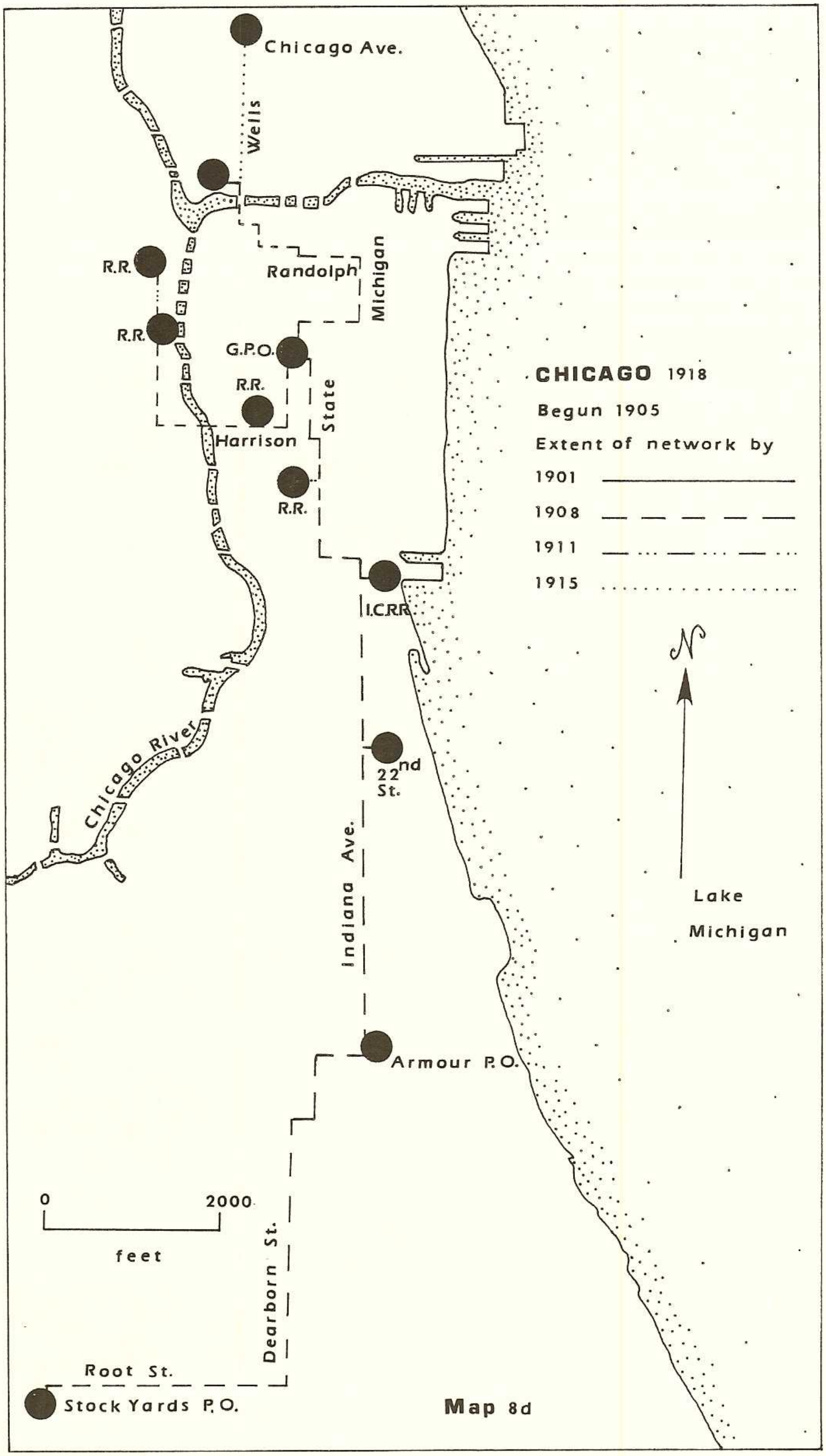
The experimental period from 1893 to 1902 was one of intense competition among engineering firms to produce technical equipment capable of transmitting heavy carriers of large capacity. Batcheller patents formed the basis for many of the systems actually constructed by 1902. The initiative taken by Batcheller in constructing an experimental segment and allowing the government to use it on a trial basis, free of charge for the year of 1893, fostered the adoption of his own ideas involving pneumatic postal networks, and reflected once again the Philadelphia reliance on private enterprise. The emerging American style consisted of systems formed from tubing 6 to 8 inches in diameter in which single carriers, pushed by compressed air only, passed through tubing laid under the streets. But in 1902 Congress suspended funding to the Post Office Department for pneumatic postal development, shutting down existing networks, until the completion of the study, by the "Search" Committee, of the Batcheller-based systems already in operation. This committee, in its report to Postmaster-General Smith, recommended further development of pneumatic postal networks, urged increased appropriations for private development of these networks, but discouraged government ownership until these systems proved themselves more fully as a significant means of postal transmission. An appropriation bill, signed April 21, 1902, provided that pneumatic mail service continue, that tube rental contracts be not longer than four years, and that rental charges not exceed $17,000 per mile.[66]

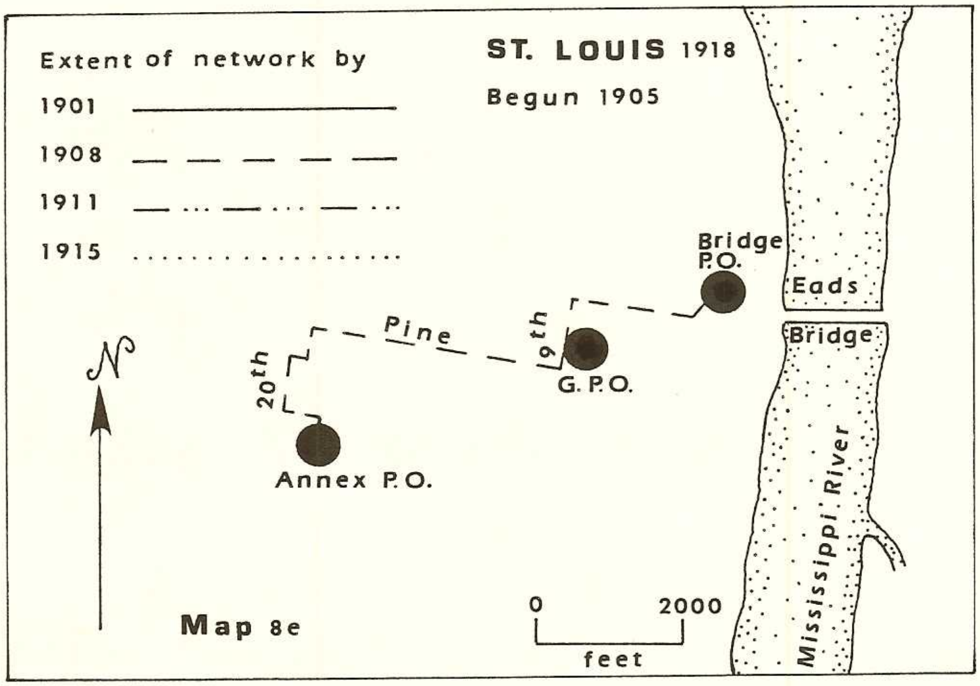
Network Expansion: 1902-1918

The push from Wanamaker and Batcheller to build pneumatic postal networks led to expanded systems in Philadelphia, New York, and Boston, and to new networks in Chicago and St. Louis. Government appropriations to the Post Office Department for pneumatic mail service increased steadily from $500,000 in 1901 to $1,388,759 by 1908.[67] Private companies contracted with the federal government to lease and operate these postal networks; the Pneumatic Transit Company, the operating company of the International Tube Company of Philadelphia, ran the Philadelphia system, while the American Pneumatic Service Company of Boston (which employed B. C. Batcheller as its Chief Engineer in New York) operated all the other pneumatic networks.[68] When the government reinstated pneumatic mail service at the end of 1902, it signed four-year leases with these companies. Following an investigation of the tube service by the Post Office Department in 1905, the Postmaster-General recommended that future rental contracts be for ten year periods. Thus, in 1906 the Post Office Department entered into rental agreements with the American Pneumatic Service Company and the Pneumatic Transit Company for continuing pressured postal service until June 30, 1916.[69] The yearly cost per mile of operating these systems in 1909, estimated by the operating companies, ranged from $13,375 in Philadelphia to $15,610 in New York; the cost for constructing a mile of tubing, estimated by the Pneumatic Tube Commission, was $64,647 in Philadelphia and $74,367 in the other cities. By 1909 the pneumatic operating companies had completed 42.5 of the contracted 64.5 miles of tubing, and by 1911 most of the systems were complete (see Map set 8).[70] Small extensions, tacked on shortly before the 1916 contract expiration date, rounded out the service in these five cities prior to the discontinuance of all pneumatic postal networks by the federal government on June 30, 1918.[71]

In Philadelphia, 10th Street served as a North-South axis for expansion of the experimental 1901 network (as in the 1908 and 1911 segments of Map 8a). The New York-Brooklyn system grew from an East Side network, joined to the Brooklyn General Post Office, to include West Side stops in 1908, and eventually, to run "all around the town" (Map 8b). By 1908, Boston's tubes linked all the stations of the full-blown network of 1918 (Map 8c). A new network, begun in Chicago in 1905, joined the General Post Office, then at Quincy and Dearborn, to the Stock Yards Post Office on the South, the Union Station on the West, and Kinzie Station on the North. Expansion of this 1908 network eventually included additional stops at the Dearborn Street Station, the Chicago and Northwestern Station, and Chicago Avenue (Map 8d). Tunnels under the river joined the La Salle Street Station to the Union Station under Harrison Street and linked the General Post Office to the Kinzie Station via the La Salle Street streetcar tunnel. When the War Department removed the latter in 1907, it ripped apart the pneumatic connection and disrupted service to the North Side for the following two years and seven months.[72] In St. Louis, a small network, begun in 1905, joined the General Post Office to two branch offices; the Post Office Department never built the connection proposed in the "Search" Committee's report, across the Eads Bridge to the East St. Louis Relay Depot (Map 8e).[73]

In 1909, the Pneumatic Tube Commission advised, in an investigation undertaken to determine the wisdom of federal investment in these pneumatic networks, that "it is not feasible and desirable at the present time for the Government to purchase, to install, or to operate the pneumatic tubes." This


Chicago Ave.
Wells
R.R.
Randolph
Michigan
R.R.
G.P.O.
R.R.
State
Harrison
R.R.
CHICAGO 1918
Begun 1905
Extent of network by
1901
1908
1911
1915
I.C.R.R.
N
22nd St.
Chicago River
Indiana Ave.
Lake Michigan
Armour P.O.
0
2000
feet
Dearborn St.
Root St.
Stock Yards P.O.
Map 8d


Extent of network by
1901
1908
1911
1915
ST. LOUIS 1918
Begun 1905
Bridge P.O.
Eads
Bridge
Pine
19th
G. P.O.
20th
Annex P.O.
Mississippi River
Map 8e
0
2000
feet

committee, composed of postmasters from Chicago, Brooklyn, Boston, and St. Louis, of Joseph Stewart, Second Assistant Postmaster-General, and of Railway Mail Service administrators, recommended instead to Postmaster-General George von Lengerke Meyer to continue rental contracts with various private companies until their expiration on June 30, 1916. The rationale was that "During [this] period there should be ample opportunity for the companies to perfect the systems and for the Post-Office Department to observe the effect upon the postal service. Further, . . . it is possible that other methods of transportation will be developed . . . so as to change entirely the outlook as it now appears." In addition, this hiatus presented the Commission with an opportunity to evaluate the success of attempts to standardize the pneumatic equipment used by the two operating companies.[74]

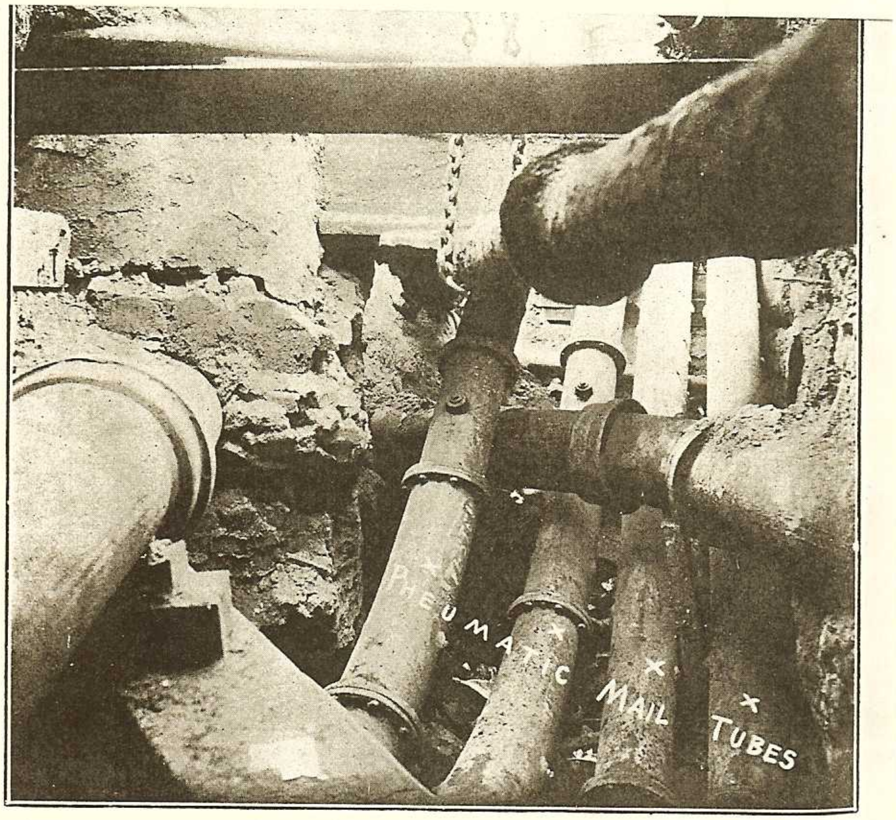
The 1909 Pneumatic Tube Commission viewed the wide-diameter American pneumatic systems as a means of conveying first class mail, across expanding urban centers, that was swifter than the horse and wagon and more reliable than the screen wagon in snowy, icy, and rainy weather.[75] It saw little to learn from the lessons of the three inch tubing in Europe; "The pneumatic-tube service abroad was established primarily in connection with the telegraph systems," and "There seems no country outside of the United States which uses tubes for the transmission of first-class mail generally."[76] Indeed, John E. Milholland, stockholder in the Pneumatic Transit Company of Philadelphia, echoed this view in 1912; "Most people suppose the system employed here to be an importation. This is a mistake. The only systems in use to-day on the other side are those of the small tubes . . . in London, Paris, Berlin, Vienna and a few other foreign cities." So did Merton L. Emerson, manager, American Pneumatic Service

Company, when he told Simon Guggengeim in 1912 that "there are small tubes abroad, but the large tubes are only used in this country."[77] However, Nelson O'Shaughnessy, Second Secretary of Embassy, Vienna, who observed the Rohrpost himself in 1908, sounded a discordant note when he stated that "the great caution of the German tradesman, who prefers to see an order . . . accompanied by a signature" leads him to use the Rohrpost in business deals and that "all stock-exchange business, or at least a great deal of it, is done by 'rohrpost'."[78]

Difficulties common to all five American networks included minor problems with the leather packing rings on the carrier ends. Condensation in the line caused these rings to decay and wear down rapidly (within two years); carriers with worn rings did not move at the same rate as those with new rings, and carrier collisions forced system shut down and street excavation.[79] In addition, when mail passed through an intervening station that required carrier transferral from one tube to another, extra personnel performed the task using extra carriers. Not only did this add to the total operating cost, but it jeopardized the security of the messages in the carrier as well.[80]

The major problem facing the 1909 group was reducing the high costs associated with constructing new pneumatic tubes. The most promising solution required placing the tubes in subway tunnels, or in pipe galleries. Precedent for reducing operating, rather than construction, costs through the sharing of facilities, already existed within these expanding networks; the 1901 committee reported that compressors placed in United States government buildings in Boston and New York provided steam to the pneumatic system paid for by the Treasury Department.[81] The 1909 commission concluded that "in the future . . .

construction of passenger subways and tunnels in cities, it may be feasible to lay pneumatic tubes more cheaply than heretofore, but the present outlook presents no . . . material economy in this direction." Attempts to locate tubes in subway tunnels in New York failed, since a Subcommittee headed by Joseph Stewart found that "the laying [of] tubes in the arches of the subways . . . would be subject to the consent of the Interborough Rapid Transit Company," and as a consequence that "the difficulty of laying tubes and of repairing them would be extremely great in view of the almost constant traffic through the tunnels . . ." Moreover, Henry B. Seaman, Chief Engineer of the Public Service Commission for the First District of the State of New York, noted in 1908 that "In these subways the clearances are small and difficulties in locating a line of tubes of the size used in the mail service would be multiplied many times by the signals used in operation of the railroads' existing lines for distribution of compressed air and electricity." Beyond that, pipe galleries appeared an attractive possibility, but in New York, according to the Stewart Subcommittee, "the only pipe gallery existing is a short one in connection with the Delancey Street Bridge," which did not "fit in with any . . . scheme of pneumatic-tube extension."[82] In a 1901 issue of Scientific American, an editor noted that "The galleries were abandoned . . . because of opposition from the heads of Sewer, Water and Gas Departments."[83] In Boston much of the pneumatic system pre-dated subway tunnels, and, indeed, subway construction caused disruption of this postal network.[84] In addition, the same article from Scientific American cited problems associated with reconstruction which involved suspending the pipes ". . . from falsework during the construction of the subway, and after a section is roofed, [filling the soil] in around the pipes [leaves] them in the



INTERSECTION OF SEVENTEENTH STREET AND SIXTH AVENUE, NEW YORK CITY, 1906.

Figure 9

unsatisfactory condition which necessitates pulling up the roadway whenever repairs or changes are to be made" (Figure 9).[85] Lacking the advantage of sharing another system's facilities, construction of these five pneumatic networks proceeded slowly toward the contracted completion in 1916.[86]

By 1912, most tubing was in place, and once again the Pneumatic-Tube Postal Commission conducted hearings before a joint Senate and House Committee to investigate the pneumatic postal service; Simon Guggenheim served as Chairman of this committee until March 1, 1913 when Hoke Smith, Senator from Georgia, succeeded him. Representatives Fred L. Blackmon of Alabama and Victor Murdock of Kansas, Joseph Stewart, Second Assistant Postmaster-General, and Senator William O. Bradley of Kentucky (from March 1, 1913) formed the rest of this committee. The issues facing them went beyond network extension and construction cost reduction; in 1912 the truck entered the postal scene, forcing additional evaluation of the merits of the tube service. Although mail did not move as quickly on trucks as it did through the tubes, the truck handled a larger volume and wider variety of mail than did the pneumatic system. It was more flexible than the tube for routing, and it followed easily along new public transport lines associated with the deconcentration of cities. Trucks, but not tubes, carried mailbags directly from the train station to the General Post Office without breaking of bulk; tubes, but not trucks, removed the mail stream from clogged surface arteries.

To overcome competition from the truck, J. M. Masten, Superintendent of Railway Mail Service at Pittsburgh, who investigated proposals for pneumatic mail service off and on between 1890 and 1908, supported, "Because of the inequality of the mail," a three-tiered dendritic plan using a 30-inch tube as an express line to transmit mail bags between the general post office and railway station, 8-inch tubing as feeder lines to link the general post office to postal stations in the business district, and cheaper 6-inch tubing to connect more remote stops. Masten estimated that a 30-inch tube joining Grand Central Station to the New York General Post Office would transmit mail bags at 30 miles per hour in under ten minutes; a screen wagon required up to forty minutes to perform the same task. Guggenheim pressed Masten for estimates for comparable service from the truck: "I think the greatest factor would be not so much the screen wagon as the motor power. Is there anything available in that line?" Masten reported a cost of one-half cent to move a pneumatic mail carrier one mile in New York, of 38.5 cents to send a horse and wagon carrying the same size load over the same distance, and 22.5 cents per mile in a test-run of trucks in upper Manhattan. Guggenheim, foreshadowing our present system, asked the question Masten treated as merely rhetorical, "Suppose the motor cars were owned and operated by the Government; would that not be cheaper [than by electric mail-car]?"

Economic advantage aside, the difficulty in using a 30-inch tube as a trunk line involved competition for the use of "the streets for other underground structures [including] the water, the gas, the telephone conduits, and the telegraph and underground street railroads." One test line of wide-diameter 18-inch tubing, operated on the Burton Vacuum System of rarefied air only, linked the House Office Building to the Capitol in Washington. Guggenheim, Blackmon, and Masten, under the guidance of Elliott Woods, Superintendent of the United States Capitol, examined its operation on December 17, 1912, and found from Woods that it had "never been put into practical operation, for the reason that we have no . . . employees to operate it," and that it served only as an exhibit. Samuel B. Donnelly, Public Printer in the Government Printing Office, reported to this committee on May 17, 1912, that he was "of the opinion that 80 per cent of our deliveries are of such a nature as to permit their forwarding by . . . a pneumatic or electric system at a considerable saving." Woods estimated that one carrier could haul 16 bound volumes of the Congressional Record. Senator Heyburn turned a proposal by the United States Pneumatic Company into a bill that included an appropriation of $250,000 to extend construction of the Washington system to "connect the Capitol, the Senate and House Office Buildings, the Congressional Library, the Union Railroad Station, the new post-office building and the Government Printing Office;" it passed the Senate unanimously prior to the construction of the exhibit test line.[87] Another experimental line built by the Universal Pneumatic Tube Company had tubing six feet in diameter and was part of an amusement park ride in Chicago by 1909; no serious proposal for using tubes like these to transmit mailbags appeared in the 1913 document.[88] Finally Batcheller reported that an experimental "tube large enough to carry several sacks . . . in Cambridge [Massachusetts]" was a success.

An alternative to the 30-inch, or other wide-diameter, tube was a trunk line of small railroad cars, capable of transporting mailbags, designed to run in tunnels under zones of heavy surface congestion. Milholland's view that "The pneumatic tube handles the mail in detail; the tunnels and the larger tubes will handle it in bulk" found support from K. E. Stuart, engineer for the Pneumatic Transit Company of Philadelphia, who argued more specifically, in referring to his company's trial line of tunnels in Chelmsford England, that "tunnels are only suggested for cases where there is a certain minimum quantity of mail and where it never has to break bulk."[89] Earlier limited experiments in Berlin, noted briefly in 1908 by R. L. Maddox, Acting Superintendent Division of Foreign Mails, consisted of a tunnel network on the site of the Siemens-Schuckert Werke; an observer reported in the "Daily Consular and Trade Reports," that he saw, in "A dispatch from Berlin to the London Times [that] this railway will be worked without a guard or driver, and the tunnel . . . is . . . 29 inches in height by 71 inches in width."[90] This trial line in Berlin overcame a problem present in a Chicago system of underground tunnels used for shipping freight in small trains; Stewart commented that in Chicago "they had to place a man in the car which made the service so expensive that they ultimately found the cost of operation so high that it could not be considered at all," and Milholland also noted that once "they had to put a man on the car . . . the fixed charges became terrific."

No significant expansion of either the experimental wide-tube or of the tunnel systems took place at this time. The government continued renting pneumatic postal networks from the American Pneumatic Service Company and its operating companies in New York, Boston, Chicago, and St. Louis, and from the Pneumatic Transit Company in Philadelphia, at a cost of about $17,000 per mile until the expiration of its contracts on June 30, 1916.[91] With the approaching end of the rental period Postmaster General Burleson appointed a committee on July 17, 1915, "to make careful investigation and report as to the needs and practicability of pneumatic-tube service," with its "report to be submitted not later than October 1, 1915."[92] Joe P. Johnston, general superintendent, Railway mail service and chairman of the Burleson committee, recommended discontinuance of the pneumatic networks and cited as reasons its "inflexibility . . . its limited capacity, and its consequent unadaptability to ordinary postal conditions, which neutralizes practically all the advantages of its high rate of speed." Milholland registered his "protest against all investigations with hearings in executive sessions for those opposed to the tubes who will not accept our challenge for discussion in open session." He accused this committee of "star-chamber inquiries [that] are discredit from the outset" and commented to Burleson that "I cannot believe that you really understood the situation of what is done in your name in this discreditable campaign to smash the tubes." Statements in this 1916 report ranged from untrue to uninformed, "In New York, with its many miles of subways, no attempt has been made to use the tubes for commercial purposes;" to nonsensical "transmission of mail by pneumatic tubes at such times [during crippling snowstorms] results in but little benefit to the public as neither the trains nor the letter carriers are able to perform service;" to inconsistent, "A study of the literature and correspondence received in reply to the inquiries of the committee shows that pneumatic tubes are used in foreign countries only for the transmission of telegrams and 'special tube letters' . . ." (no such attachment appeared in 193 pages of appendices).[93] Indeed, J. H. Bankhead, chairman of the joint commission to investigate the value of pneumatic-tube mail service, cited, in a separate section of a 1919 report, one and one half pages of "False and Misleading Statements and Their Contradiction and Testimony as to the Way in Which the 1915 Tests Were Conducted." The "Johnston" Report, submitted to Burleson two weeks after the October 1, 1916 deadline, forced the Postmaster-General to continue rental contracts until December 31, 1916; and, as Bankhead later noted, "Congress afterwards extended the contracts first to March 4, 1917, and later to July 1, 1918."

Bankhead reported, in 1918, Burleson's reasons for wishing to eliminate tube service as "1. The introduction of parcel post[;] 2. The use of automobile mail trucks[;] 3. Increase of letter mail to a point beyond the existing capacity of the tubes." Other arguments for discontinuance attacked the quality of mail service but failed to link it, as Charles T. Harrop noted, to the "inevitable deterioration in the railroad, telegraph, and telephone services, due to the draft and economic disturbances." This commission found that "The viewpoint of the public . . . is that letter mail pays for and warrants the highest grade of postal service;" and that "the government should not add to . . . traffic by abandoning existing means of underground transportation of mail." Furthermore, the committee itself recommended keeping the pneumatic postal service, for as the engineers they consulted from Stone and Webster stated, " 'No number of automobiles, even at a cost exceeding that of the best combined automobile and tube service, could obtain all the advantages of a combined service'." But Congress did not vote further funding for either the rental or purchase of the existing pneumatic networks; thus on June 30, 1918 all systems shut down.[94]

Networks after World War I: 1918-1953

In 1922 Congress reinstated pneumatic postal service in New York City, and by 1926 in Boston as well, but Chicago, Philadelphia, and St. Louis saw no post-war resurrection of their networks. Service in New York and Boston continued on a more-or-less regular basis, depending on the amount of the congressional appropriation, through the Great Depression and World War II, until 1947. The Brooklyn Bridge line closed in 1950, and the efficiency of the truck eventually forced the end of all pneumatic service in 1953.[95]

Throughout this period rental rates per mile fluctuated from $17,250 to $24,000; issues of major concern involved connecting the newly-established air mail service to the General Post Office via pneumatic tubing, examining the merits of a decentralized postal plan and its implications for pneumatic service, and investigating, once again, government ownership of the tubes. One bill, read to the Committee on the Post Office and Post Roads of the House of Representatives by Melvin J. Maas, Representative from Minnesota, on June 18, 1935, called for "the construction and use of . . . pneumatic tubes . . . for the transportation of mails between the general post office at St. Paul, Minnesota, and the general post office at Minneapolis, Minnesota; also between the general office at Saint Paul . . . and the Saint Paul Municipal Airport." Another presented to the same committee, introduced by Stephen A. Rudd, Representative from New York, sought authorization for pneumatic tubing to link "the general post office at Brooklyn . . . [with] the Floyd Bennett [Air] Field, Barron Island, Brooklyn . . . and the five postal stations lying parallel to Flatbush Avenue between these two points." The rationale in both cases involved finding efficient linkage from air field to downtown. Maas stated that "the installation of . . . this pneumatic service will . . . speed up the Air Mail Service." Rudd commented "Why should we in this congested area be compelled to transmit our air mail by truck after it arrives at the airport?"[96] In a letter dated November 22, 1933 to Silliman Evans, Fourth Assistant Postmaster General under Postmaster-General James A. Farley, a committee of New York postal personnel headed by John J. Kiely, Postmaster at New York, invited "attention to the change in the method of mail handling at the present time in comparison with the system in effect when the pneumatic tubes were in full operation in the various cities." This "change" referred to a shift from a centralized to a decentralized distribution plan in many cities and, according to this committee, since a decentralized plan "necessitates transportation facilities that will move a large volume of mail in a limited time . . . [it] eliminates the use of pneumatic tubes." The recommendations of the "Kiely" committee included the continuation of pneumatic service in New York and Boston only, as well as government purchase of these two systems.

John W. Mc Cormack, Representative from Massachusetts, introduced a bill, also on June 18, 1935, "To provide for the purchase of the pneumatic mail tube systems in New York and Boston." Farley reported, in a letter to James M. Mead, Chairman, Committee on Post Offices and Post Roads of the House of Representatives, June 7, 1935, that the maximum value of the physical plant now in place was $1,750,000, and he requested that "In the event legislation is enacted for the purchase of the pneumatic-tube systems in New York . . . and Boston . . . the bill should also authorize the Postmaster-General to make necessary additional expenditures . . . for extensions . . . [and] for the relocation and adjustment of present tube lines."[97] But according to a summary of United States pneumatic postal operations submitted by George D. Riley, staff director Post Office and Civil Service Committee, to the United States Senate Committee on Post Office and Civil Service on March 29, 1948, rental contracts for the early networks of Boston and New York continued until 1947. A ten-year contract carried the Boston system from 1937 to 1947, while a series of short term agreements, ranging in length from two months to five years, brought pneumatic service to New York until 1947.[98] Competition from trucks, in a post office emphasizing decentralized mail distribution, led to the phasing out of pneumatic service and, in 1953, to the termination of all service.

Between 1892 and 1953 federal financial commitment for short term tube rental, and extensive experimentation with the mechanics of the physical equipment by private companies competing for these contracts, characterized these wide-diameter, commercial, pneumatic postal systems designed to transmit first class mail, as well as fragile packages, under congested American streets. The early initiative taken by Wanamaker from an administrative standpoint, and by Batcheller from an engineering perspective, led a succession of postmaster-generals to fight for congressional appropriations to maintain and to extend the tubes, and for a sequence of engineering experiments in wide-diameter pneumatic tube technology. Diffusion of this technology based on Batcheller patents extended northward, along the Atlantic coast, and westward across the New York-Chicago axis to St. Louis. The impact of Batcheller in setting the tone for an American style of pneumatic postal technology different from the European resulted in the dominance of his wide tubes, despite the presence of the Lamson company's store installations (of narrow tubes) across this country. Batcheller's testimony of 1913, that he "was given an opportunity several years ago by the Government officials in Paris, Berlin, and London to inspect them [pneumatic postal networks]," suggests an American environment only mildly receptive to influences from abroad.[99] Thus a style of pneumatic postal system, distinctly American, began in Philadelphia in 1892 and diffused outward to four other cities where, by 1916, these networks attained full growth.

Transfer of Technology

A lack of federal fiscal commitment to developing entire pneumatic networks in the United States stood in sharp contrast to western European policy throughout the period from 1853 to 1984. Two different styles of technology consequently appeared on opposite sides of the Atlantic Ocean. In the early stages of design of the American networks and in later developments there was very little transfer from Europe to the United States. European engineers, politicians, and postal authorities used networks of small-diameter tubes that forced the use of specialized stationery, planned the spatial ordering of linkages within the entire network (polygonal or radial), considered significant the study of earlier networks outside their own national boundaries, and built systems that flourished under government ownership of the physical equipment. In the contrasting American style, engineers and government officials employed networks of large-diameter tubes to accommodate first class mail and packages, displayed a lack of concern for the spatial design of the entire system, exhibited an isolationist view toward pneumatic postal activities beyond national boundaries, and engaged in spirited technological competition to obtain short-term government rental contracts for pneumatic equipment. The adoption of Batcheller's wide-diameter system led many American engineers to conclude that the small-diameter European tubing could not provide a constructive example; this in turn led to concentration on internal technological design at the expense of a planned spatial order.

The European networks prior to 1918 progressed through time from a cumbersome system using pneumatic transmission apparatus based on steam to one using compact equipment based on electricity. Although these European systems were well-established means of postal transmission, the early American networks drew on little of this experience. Only John Wanamaker, and some of his representatives (such as Philadelphia's Postmaster Field, who visited Berlin), saw the benefits of examining the installations across the ocean; the transfer of technology that might have followed from Wanamaker's early studies did not occur in the developmental period of American networks.

Evidence from various American Congressional documents prior to 1918 displayed an increasing awareness, by American postal authorities and engineers, of the European networks. Batcheller did not make use of the European example in his early work, but by about 1910 had seen the systems of London, Paris, and Vienna. In 1912, Guggenheim insisted to his Senate colleagues that "There is one thing I should like the commission to ascertain, and that is information with regard to what is being done in Europe; whether the companies abroad have made any improvements, and if they have put the service in effect. How can we arrange for securing that information? . . . That ought really be brought up to date."[100]

Only the later concern for transmitting mailbags promoted a transatlantic interchange of ideas during developmental periods; the Pneumatic Transit Company of Philadelphia built an experimental line of tunnels in England in 1912, and at about the same time a team of British engineers visited United States pneumatic postal installations to see first-hand the relative merits of truck and tube.[101] Thus engineers and postal and government officials belatedly began an exchange of technological information between Europe and the United States only as automotive technology entered the urban American postal scene.

In the period after World War I, American pneumatic postal networks never regained the stature they enjoyed before the war, and eventually the dominance of the truck forced their demise in 1953. In contrast, the years prior to World War II in Europe saw experiments with pneumatic postal checking in France and with applications of telephone switching to pneumatic postal systems in Germany, which provided the stimulus necessary to carry the French network forward into the last half of the twentieth century as a significant means of supplementing the regular mail.

Generally, early experiments with pneumatic technology produced an initial surge of progress, whether they were privately funded (as in the United States) or nationally funded (as in Europe). Long-range governmental fiscal support enabled Europeans to expand and alter their pneumatic networks to keep pace with newer, competing, technology that emerged between the World Wars. Lack of that fiscal commitment in the United States impeded technological innovation, by forcing rival pneumatic companies to lobby for small amounts of funding at the expense of focusing on issues directly related to postal concerns. Translated into today's technological environment, in which competition among rival computer software companies is fierce, and in which competition between privately-owned computer hardware firms is sluggish, one wonders what direction America's technological progress will follow in the next few decades as compared to that of her enemies and allies. For, as Otto Friedrich noted (in a 1984 issue of Time magazine) in commenting on the parallel between pressured postal networks and computer-age communications--"the principle [of communication by computer] is the same as that of the 'Pneu'[matique]; a short written message that can be both quick and permanent."[102]

APPENDIX

DESCRIPTIVE ANALYSIS OF NETWORK DESIGN

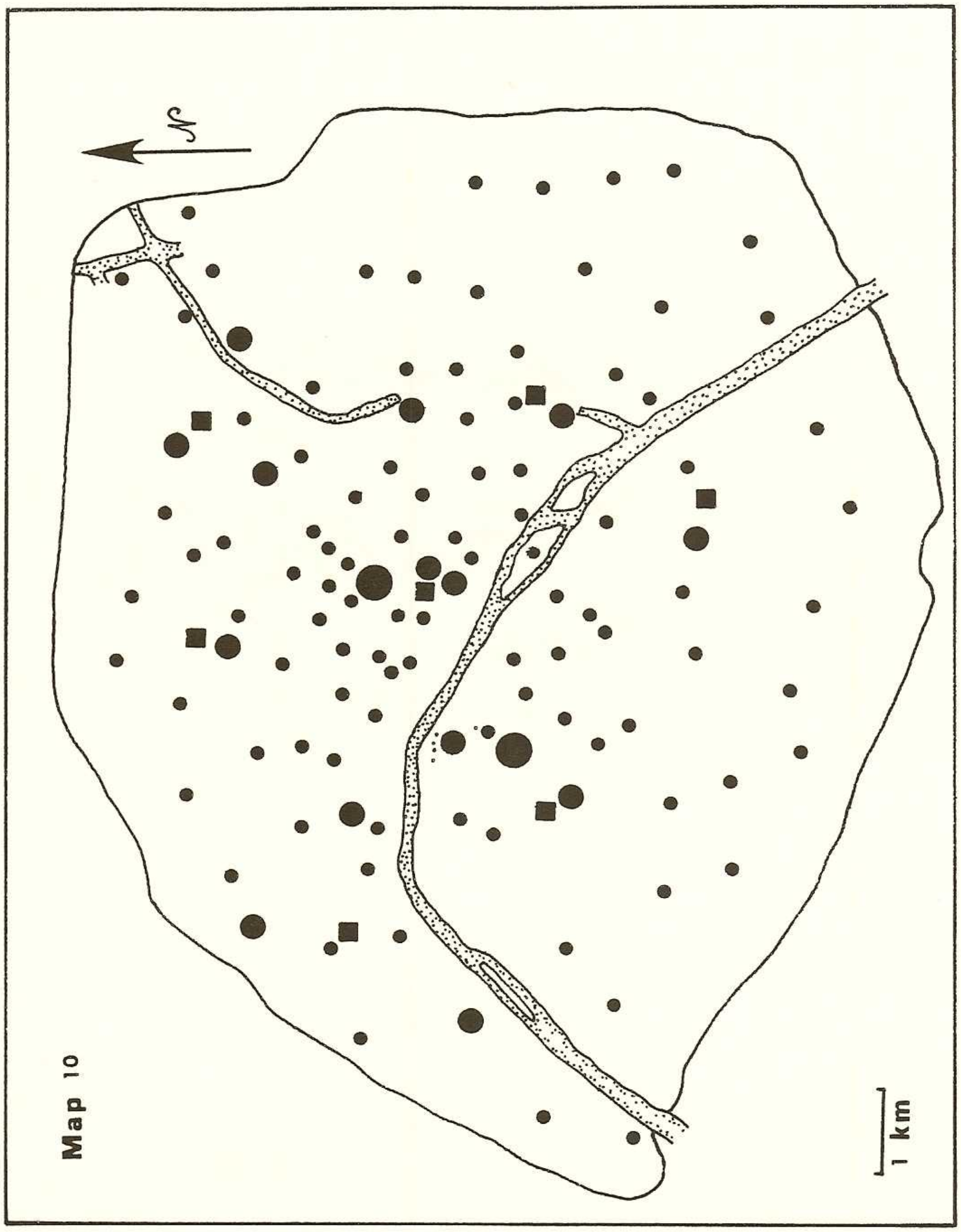
A network of any sort generally transforms patterns of diffuse circulation into lines of channeled activity criss-crossing the human landscape it is meant to serve. Careful design of the spatial position of a network is critical in determining not only how the network can be located to serve well the population that is to use it, but also how such location might force alteration in the use of space within that underlying landscape.

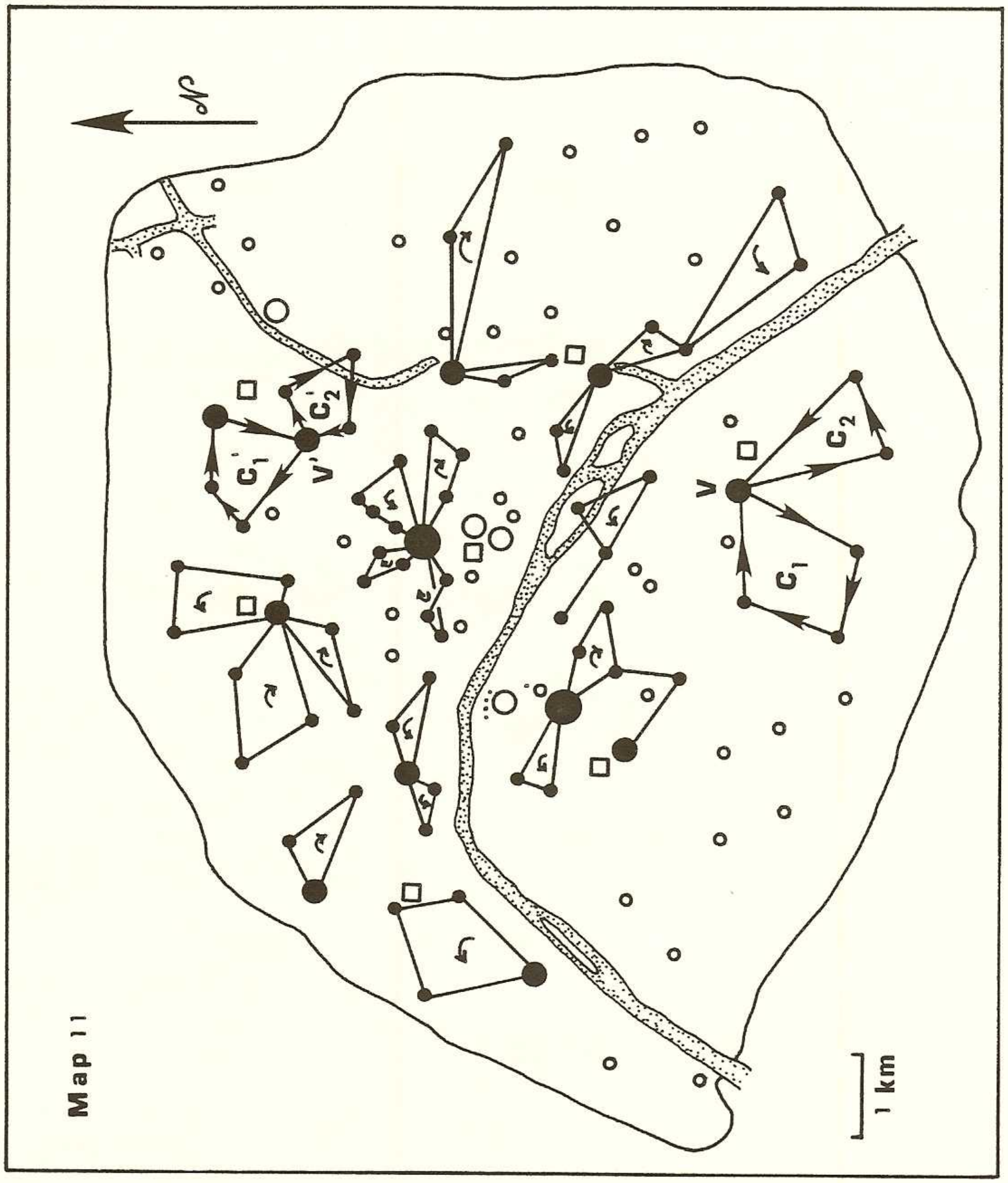
The design of networks in abstract space falls between two extremes: that of minimizing user costs and that of minimizing construction costs. Abstract solutions to these extremes, as well as to problems of spatial arrangement between these extremes, typically invoke the use of mathematics that is spatial in character, such as geometry, graph theory, or topology. The mathematical problem of minimizing user costs is easily solved abstractly by linking each point in the network to all others. In contrast, the problem of minimizing construction costs via minimizing total length of network (the Steiner network), is one whose solution is not unique. The topological problems associated with Steiner network construction linking six distinct locations are such that 105 minimal forms must be considered as candidates for the Steiner network.[103] Indeed, as the number of locations to be linked increases, the number of Steiner network candidates increases so rapidly as to render the problem NP-complete (as, for example, is the travelling salesman problem).[104] Clearly, then, other issues such as historical tradition, cultural setting, topographic and economic factors, which are of fundamental importance in the design of networks in actual geographic space, become of fundamental importance in managing problems associated with the design of networks in abstract geographic space. It is within this broad framework that a specialized nineteenth and early twentieth century style of network came to be examined for the insights it might provide in approaching these intractable problems associated with network design and in suggesting an arena from which such examination might project into the future.

The basic design of the United States networks, shown in Maps 8 (a-e), employs a graph-theoretic tree; in New York City two extra links provide two circuits within the graph--one surrounding Central Park and the other linking Grand Central Station and Times Square to Lower Manhattan (Map 8b). The Berlin network, which in its earliest form exhibited tree-like structure (Map 1), showed greater branching but retained its tree form as late as 1901 (Map 3). In contrast, the Parisian network, which began as a circuit (Map 2), continued as it developed to retain many circuits and redundant linkages (Map 6). Generally, redundant linkage forces a network to become more highly interconnected; and, this is desirable in case some sort of unforeseen break in transmission occurs, either in the tubing or at the stations. Thus the remainder of this section focuses on analyzing the network design of the Pneumatique.

Viewing the Paris network as a graph and separating it into directed and undirected subgraphs reveals restricted use of specialized (one-way) tubing servicing areas that are local relative to the entire system, and suggests use of network linkage with highest transmission capabilities to link centers that provide a relatively high degree of service to the entire system. Within this set of pneumatic linkages, the directed edges represent pneumatic tubes in which messages can be sent in only one direction, and the undirected edges represent pneumatic linkage that permits two-way interchange of messages (Map 6). Circles representing terminal and transmitting facilities have varying radii; the size of a circle apparently reflects directly the degree of importance of that facility to the entire system (Map 10). There are two highest order centers, one on the Right Bank and one on the Left Bank. Heads of line are scattered around the margin of the map, and local offices are frequently incident with neighborhood telegraph offices (Map 10). Press offices (the smallest circles) occur within the area containing the Chambre des Deputes. The actual connectivity patterns of sets of vertices in different levels of the network hierarchy will be examined below.

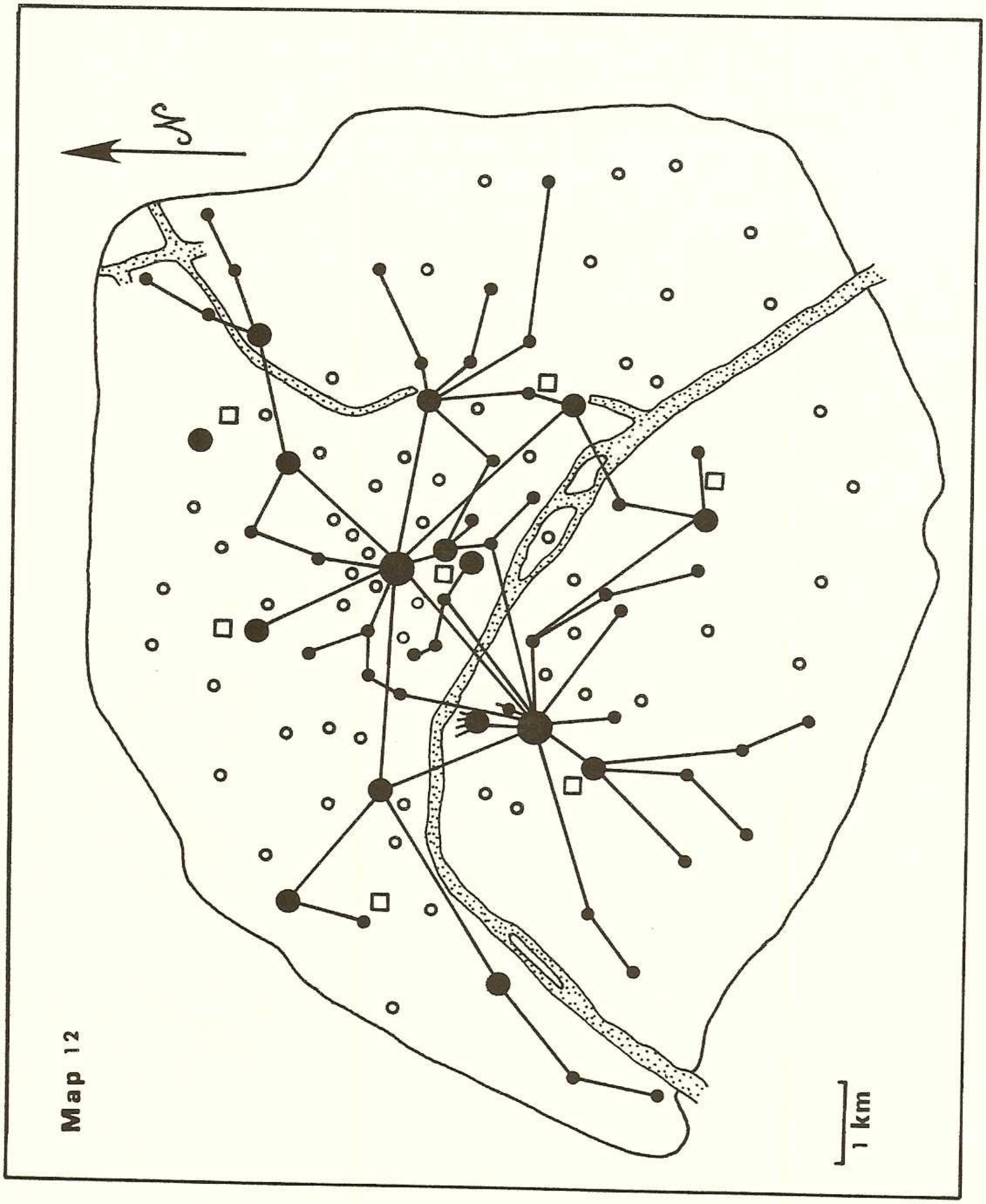
The subgraph composed of the network of one-way tubes is the set of most localized vertices, together with appropriate linkages (Map 11). It has eleven separate components, each servicing an area that is small, relative to the entire area serviced by the whole network (Map 11). Generally the circulation pattern within a component is cyclic, although one wonders in the two exceptional cases (on the left bank) how the carriers are returned to the origins leading into circuits. Circulation between components is not possible, within this subsystem, at this level. That is, one-way tubes have relatively limited use, and when they are used, are confined to servicing neighborhoods or other areas that are local relative to the entire system. The arrows within cycles in Map 11 indicate the orientation of flow within the particular cycle, and these

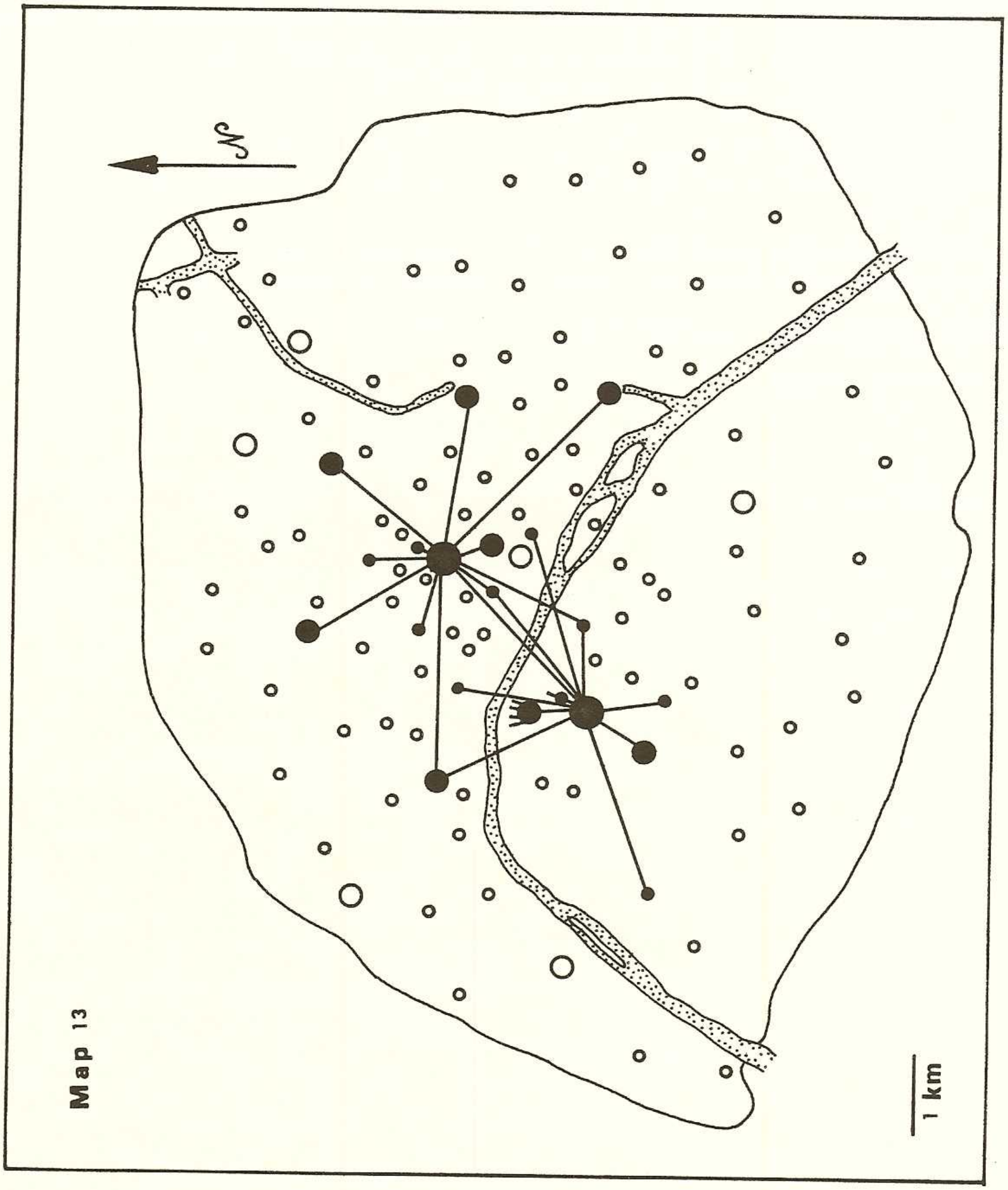

Map 10
N
1 km

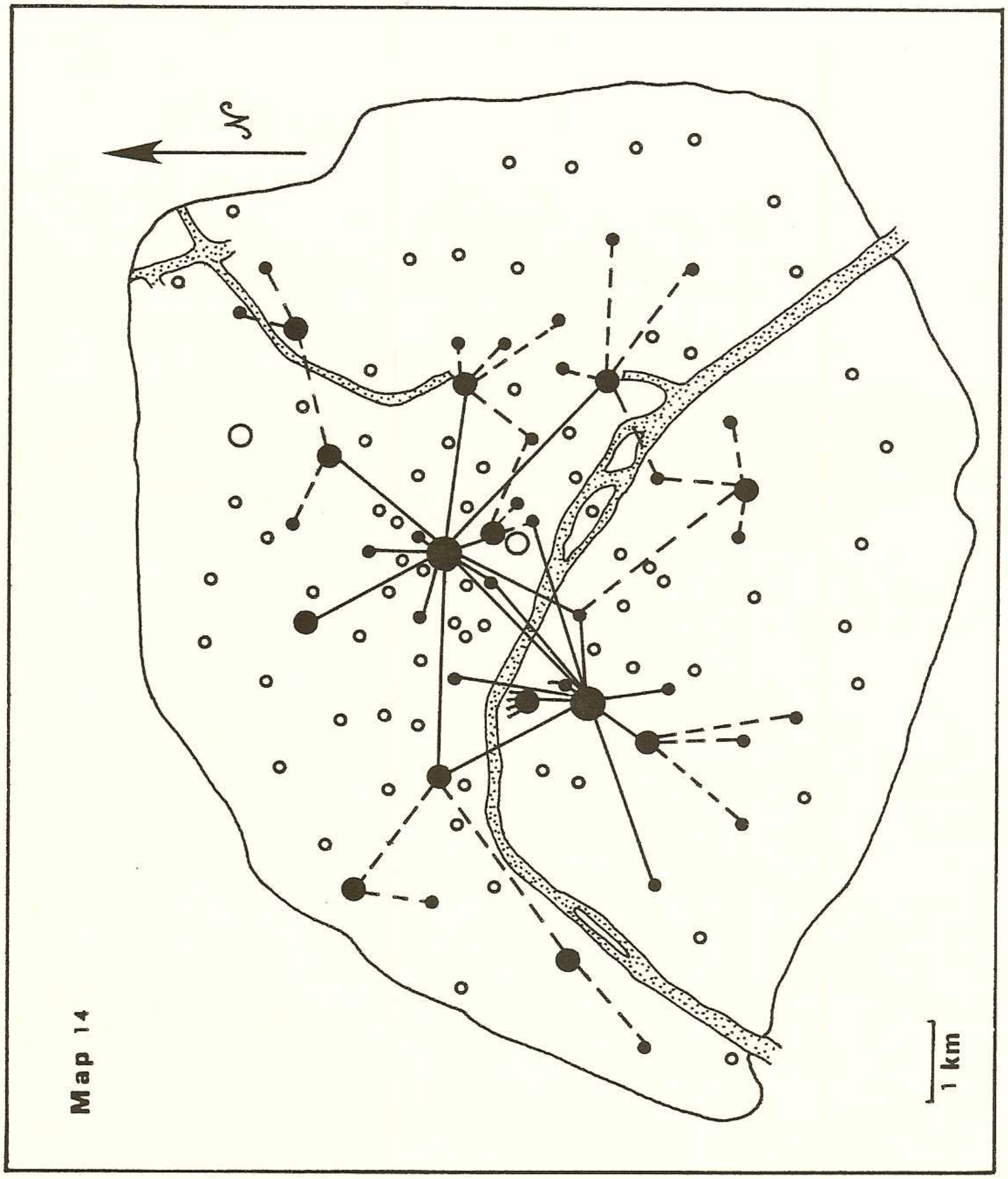

Map 11
1 km
N
V
V'
C_1
C_2
C_1'
C_2'

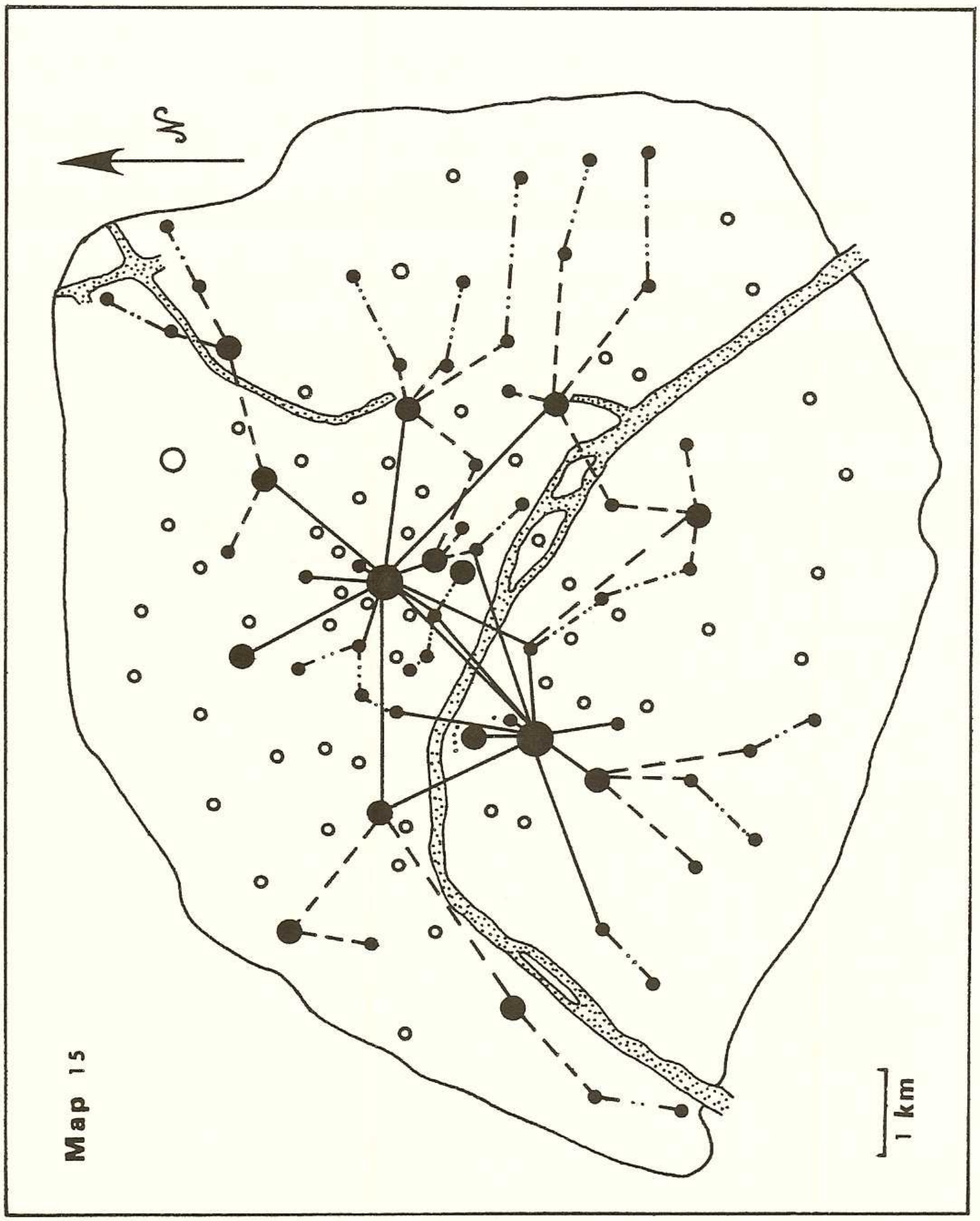
arrows label the flow as clockwise or counterclockwise. In many cases two cycles, such as C_1 and C_2, that share a common vertex, V, have opposite orientation (Map 11). In this case tubing through V that links C_1 to C_2 and tubing through V that links C_2 to C_1 must cross (if these tubes are in the same plane). Thus an attendant placed at this crossing point would have direct access, using one hand, to each cycle and to the union of these two cycles. However, it is possible that carrier collisions could occur at the crossing point. In other cases two cycles, such as C_1' and C_2', have the same orientation. Thus tubing linking C_1' to C_2' and C_2' to C_1' need not cross at V', and so physical functioning of the network could be made smoother; however, it would not be possible to have direct access to both cycles through the same opening (Map 11).

At the other end of the hierarchy, the subgraph composed of the network of two-way tubing consists of one component, and suggests that two-way linkages are preferable to one-way linkages for hooking up centers that provide a relatively high degree of service to the entire system (Map 12). Between these extremes, separation of the Paris graph into a set of subgraphs based on the vertex hierarchy exhibits radial patterns of connection (maximizing user connection), of facilities of higher order to selected facilities of lower order (Maps 13, 14, 15). These Maps should be viewed in succession: Map 13 shows direct two-way tubing to and from first order centers, Map 14 adds on direct two-way links (dashed lines) to and from second order centers, and Map 15 adds direct two-way links to and from third order centers (dashed and dotted lines). Map 15 is identical to Map 12 if energy sources and edges incident with energy sources are removed from Map 12. All other vertices that are not incorporated into the two-way subgraph in Map 15 are hooked into the system by one-way


Map 12
1 km
N


Map 13
N
1 km


Map 14
1 km
N



Map 15

tubing. The enlargement of network form displayed in the sequence of Maps 13, 14, 15 shows areal expansion of a basic network skeleton to include secondary and local centers into that skeleton in successive stages, and illustrates succession in inclusion of vertex, corresponding to stage of subnetwork integration into the network skeleton. If one considers that these subgraphs represent network enlargements in a space where barriers do not inhibit that enlargement, then these subgraphs represent a "natural" network expansion where first order centers are connected to second order centers (and second to third and so on). However, the final stage (Map 15) might be thought to reflect the influence of the political boundary on the system--radial connection of second level to third level centers is highly incomplete; only a few third level centers are hooked directly to any other center via two-way tubing. What is complete in this stage is network reach--a single two-way component now spans both banks of the entire city, from eastern to western and from northern to southern boundaries. In Maps 13 and 14 new radial structure is in evidence, but no new radial structure appears in Map 15--only linear extension (from third order centers to other third order centers) of previous radial structure, completing network reach within geographical constraints of the Paris boundary, is present. Separation of the Paris graph into subgraphs exhibits radial connection between levels of the vertex hierarchy and suggests that such a vertical linkage arrangement is appropriate within a network hierarchy that is structurally similar to this one.

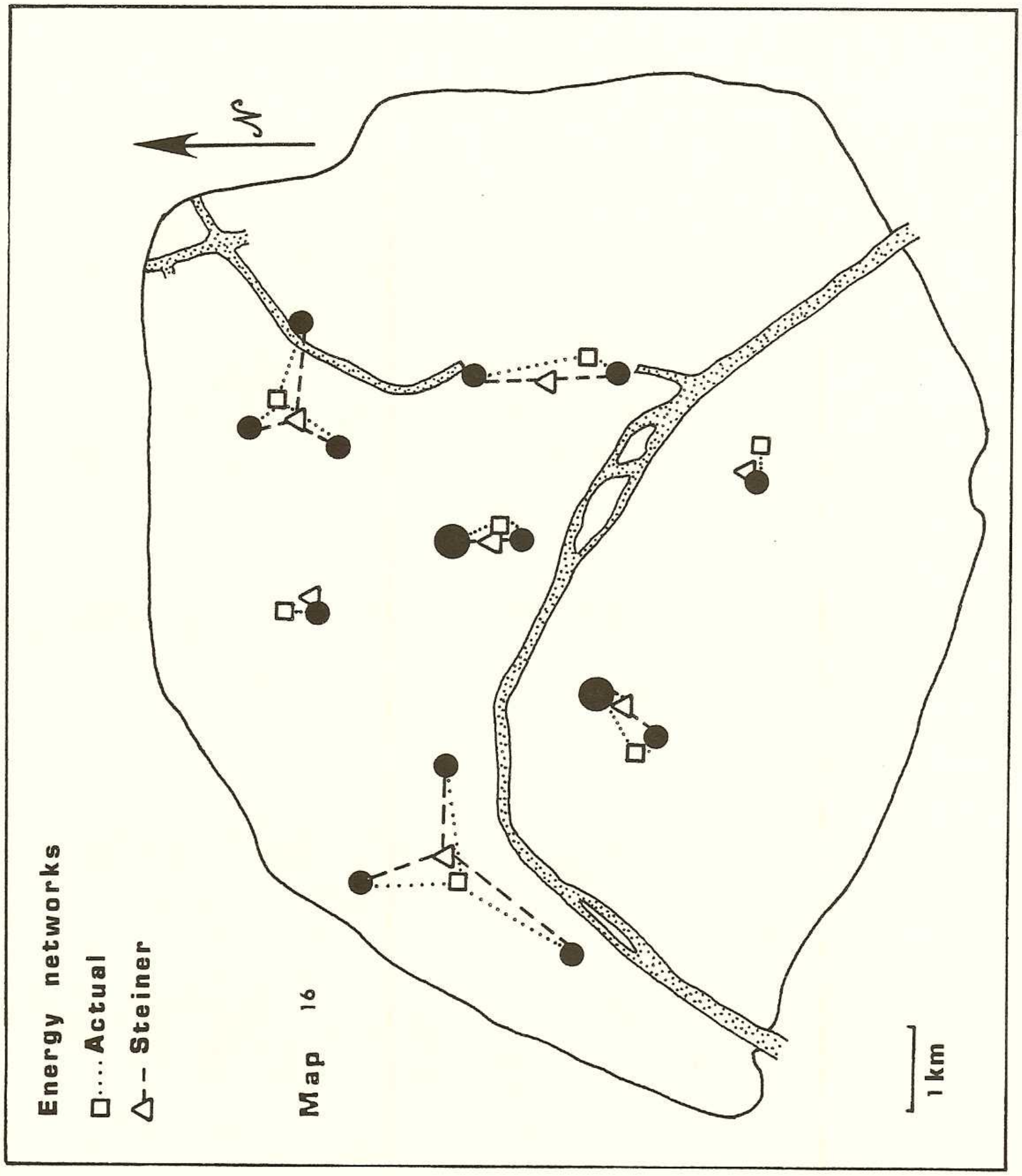
Restructuring of the vertex hierarchy on descriptive bases that assess relative dominance of centers within local constraints, such as site characteristics, suggests that minimization of total length of tubing within a level of the vertex hierarchy might be a successful lateral organizational plan.

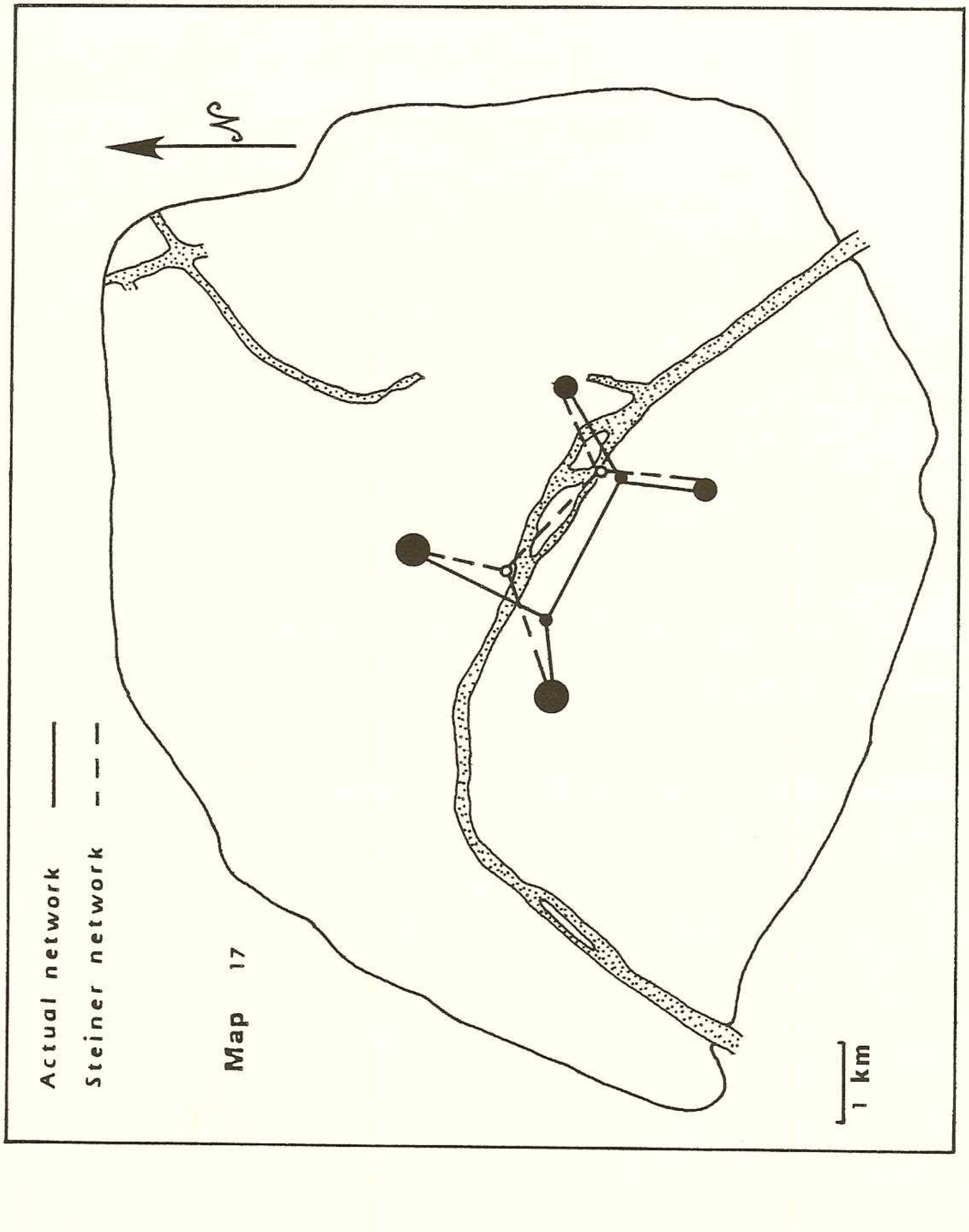
Evidence is drawn from the arrangement of energy sources and from the network form surrounding the Ile de la Cite (Maps 16 and 17).

The energy sources are spread across the city, and some of them appear to be incident with railway stations, possibly as sources of steam, which was used as the driving force of this system (Map 16). The spacing of the energy sources is apparently directly related to the maximal distance over which channelized air could be forced efficiently at that time. The energy sources can then be viewed as fixed points within the system. In order to assess how well this set of fixed points is integrated into the entire system, it might be useful to measure the shift of fixed points necessary in order to move this actual distribution of fixed points to an "ideal" distribution of fixed points. In keeping with minimizing total length, such "ideal" points are to be Steiner points of a polygon (located by the Steiner algorithm) when the graph is considered to be contained in two-dimensional Euclidean space.[105] Whether or not the usual metric of Euclidean two space is 'best' is beyond the scope of this discussion.

By visual inspection, Steiner and actual location for energy sources correspond to some extent, and actual pneumatic linkages among the points under consideration follow closely those induced by the Steiner energy source locations (Map 16). Quantitative measures for comparing ideal and actual form would have little meaning; standards for map accuracy are unknown.

Further constraints imposed on the system by prominent site characteristics are also vital to the effective functioning of the system. The most conspicuous site characteristic is the Seine River. The set of observations that follows is derived from the presence of the Seine and deals with the


Energy networks
□ .... Actual
△ - - Steiner
Map 16
1 km


N
Actual network
Steiner network
Map 17
1 km

effects of its presence on network structure. The existence of two primary centers on each bank might be seen as a response to the partitioning created by the Seine. This suggests viewing the network as composed of the following components: 1) the subgraph consisting of vertices on the Left Bank and edges joining those vertices. The pneumatic loop including the Ile de la Cité will be included in this component since there is no direct connection from the island station to the Right Bank; 2) the subgraph consisting of vertices on the Right Bank and edges joining these vertices.

Components (1) and (2) are joined into one component by the set of pneumatic connections that pass across the Seine; i.e., removal of all of these "bridge" connections separates the graph into two components. A vertex that is incident with an across-the-river connection might therefore be considered to have a position within its function level that is different from others of the same hierarchical level of the vertex hierarchy shown in Map 10. Map 17 displays a set of six vertices of this sort.

These observations suggest that multiple linkage of Left and Right Bank components across the river would be worthwhile if it alleviated overload and breakdown of the system. In order to place this tubing, assessment should be made as to relative importance of terminal within hierarchical classes formed on either formal or descriptive bases, and the differently placed tubing should be incident with the terminals that have been singled out on either basis.

An additional set of observations could lead one to group together the four larger centers of this sort, first on the basis of similarity of terminal function in tying together the Left and Right Banks, and second on the historical basis that the convex hull of these four centers is the smallest convex hull formed on a set of relatively large offices that contains Lutèce, the traditional heart of the city. Positions for the two smaller offices to be made dominant within this hull suggest that when tubing is to be installed which is relatively expensive, it be laid so as to minimize, within local constraints, total length used; that is, along lines of a Steiner network (Map 17).

The arrangement of the Paris pneumatic postal network suggests that between levels of a hierarchy of pneumatic terminals, radial arrangement of tubing linking high order terminals to low order terminals has been successful, and that within a level of a hierarchy, minimization of total length of two-way tubing appears effective. Such a hierarchy can be formed on a variety of bases, from the formal based in elementary graph theory to the descriptive based on historical tradition, site characteristics, and strategic military placement. Analysis of a system which already is present in the landscape on any, or all, of these bases is a relatively easy task. Far more difficult is the development of a new system in which the degree of emphasis placed on these varying modes of analysis is unknown.

If such descriptive historical evidence is to be useful in planning, it seems natural to ask for a characterization of human activity that might give rise to channels linking locations that could benefit from observing evidence such as this. Fundamentally, it appears that such activity should be based on interaction that is diffuse rather than concentrated. The human desire to communicate with others is diffuse; such desire leads to various channels for transmission and eventually to the formation of national and international networks.

Further, once such diffuse activity is organized as a network, it seems that the nature of the network should be such that efficiency in circulation responds more favorably to standardization of input than to standardization of routing; flexibility in routing is more significant than flexibility in type of input. One style of linkage within the network that permits such emphasis is to form (on some bases) a hierarchy of terminal facilities and then to minimize user connection between levels and minimize cost connection within levels.

Following this characterization is Barry Commoner's view of solar energy as a diffuse phenomenon that is relatively standardized in the form in which it interacts with the surface of the earth.[106] Solar networks of the future with structural characteristics similar to those cited above might evolve in conversion to solar energy that would rely on the development of highly localized delivery systems for the transmission of solar methane.[107] In any event, independent of any particular future application, the theoretical base of this characterization suggests that the topological approach, rather than solely the technological approach, would be significant in bringing about not only a solar "transition" but also a solar transformation, when solar energy is viewed as an affine transformation of geographic space, that "shall put us to work anew."

NOTES

[1]Charles W. Cheape, Moving the Masses, (Cambridge, Mass., 1980), p. 8.

[2]John Vinocur, "Paris Pneumatique is now a dead letter," The New York Times, Staurday, March 31, 1984, p. 19. Associated Press, "Technology kills pneumatic postal system," The Ann Arbor News, Thursday, March 29, 1984, pp. C1, C2. U.S. Postmaster General, Annual Report, U.S. Post Office Department, (Washington, 1891), pp. 150, 158. Cheape, p. 8.

[3]M. Gissot, "La Télégraphie Pneumatique," Annales des Postes, Télégraphes et Téléphones, 1 (Paris, 1910-1911, No. 3), p. 32.

[4]U.S. Postmaster General, Report, House of Representatives, Document 1, Part 4, 51st Congress, 1st session, (Washington, 1889), p. 9.

[5]U.S. Postmaster General, (1891), p. 72.

[6]Harold M. Mayer and Richard C. Wade, Chicago: Growth of a Metropolis, (Chicago, 1969), p. 217. "Some features of the New York Rapid Transit Tunnel," Scientific American, May 25, 1901, p. 327.

[7]U.S. Postmaster General, (1891), pp. 150-161, passim.

[8]"Pneumatique," N.Y. Times, Mar. 31, 1984, p. 19. "Technology kills," Ann Arbor News, Mar. 29, 1984, pp. C1, C2.

[9]"Pneumatique," N.Y. Times, p. 19.

[10]U.S. Senate, "Pneumatic Tube Mail Service," Hearing, Eightieth Congress, 2nd session, (Washington, March 29, 1948), pp. 14-18 passim. U.S. Congress, House of Representatives, Committee on Post-Office and Post Roads, (Washington, June 18, 1935), pp. 58-59.

[11]U.S. Postmaster-General, (1891), pp. 150, 158.

[12]Ibid., p. 158. U.S. Pneumatic-Tube Postal Commission, Hearings to Investigate the Pnuematic-Tube Postal System, Senate Document, (Washington, 1913), p. 374.

[13]U.S. Postmaster-General, (1891), p. 150.

[14]Ibid., pp. 151, 158, 159. "Pneumatic Mail Tube System, New York City," Scientific American, (Dec. 11, 1897). "The Pneumatic Tunnel Under Broadway, N.Y.," Scientific American, (March 5, 1870), p. 155.

[15]U.S. Pneumatic-Tube Postal Commission, (1913), p. 157.

16 "Broadway," Sci. Am., p. 155. U.S. Postmaster-General (1891), p. 151.

17 "Broadway," Sci. Am., p. 155. A later plan for a pneumatic railway appeared in L. K. Edwards, "High speed tube transportation," Scientific American, (August 1965), pp. 30-40.

18 W. Moon, "Pneumatic Tubes," Electrical Review reported in Scientific American Supplement No. 536, (April 10, 1886), p. 8562. U.S. Postmaster General, (1891), pp. 158, 159.

19 "Tube . . . New York," Sci. Am., p. 373.

20 Gissot, "Télégraphie Pneumatique," p. 32.

21 "Tube . . . New York," Sci. Am., p. 373.

22 U. S. Postmaster General, (1891), p. 151.

23 Ibid., pp. 152-153, 157. Beschreibung der Rohrpost, (Berlin, 1901), map, "Rohrpostnetz von Berlin." U. S. Postmaster General, Investigations as to Pneumatic-Tube Service for the Mails, House of Representatives, 60th Congress, 2nd session (Washington, 1909), map of Paris interleaf, pp. 140-141.

24 U.S. Postmaster General, (1891), pp. 152, 153.

25 John Pringle, M.D., Early British Balloon Posts, (privately printed in England, 1908), p. 66. Carl H. Scheele, The Story of the United States Mails, (Washington, 1970), p. 81.

26 U.S. Postmaster General, (1891), pp. 151, 152.

27 Ibid., pp. 155-160. Sci. Am. Supp. No 536, (1886), p. 8562.

28 The Gentleman's Magazine in Scientific American, (August 3, 1895), p. 75.

29 U.S. Postmaster General, (1891), p. 153.

30 Ibid., pp. 152-156. "Rohrpost," Map set.

31 Ibid., Blatt I. U. S. Postmaster General, (1909), p. 22.

32 "Rohrpost," p. 4.

33 U. S. Postmaster General, (1891), pp. 154, 152.

34 "New York . . . Tunnel," Sci. Am. (1901), pp. 327, 328.

35 "Rohrpost," p. 4, Map set.

[36]"Pneumatic dispatch improvements," Engineering, in Scientific American Supplement No. 843, (Feb. 27, 1892), p. 13465.

[37]"Pneumatic postal transmission," Engineering, in Scientific American Supplement No. 90, (Sept. 22, 1877), p. 1426 (etchings).

[38]U.S. Postmaster General, (1891), p. 70, data for 1882 and 1887. "Rohrpost," comment written in margin by unknown direct observer on the 1901 estimate.

[39]Marshall Cushing, The Story of Our Post Office: the Greatest Government Department in All its Phases, (Boston, 1893), p. 1016.

[40]Ibid., Thomas P. Hughes, Networks of Power: Electrification in Western Society, 1880-1930, (Baltimore, 1983), pp. 175, 184.

[41]U. S. Postmaster General, (1891), pp. 155,159.

[42]Gissot, "Télégraphie Pneumatique," p. 33. U. S. Postmaster General, (1909), p. 141, 29.

[43]U. S. Pneumatic-Tube Postal Commission, (1913), p. 142.

[44]Gissot, "Télégraphie Pneumatique," p. 43. U. S. Postmaster General, (1909), p. 142.

[45]Gissot, "Télégraphie Pneumatique," pp. 32-53 passim.

[46]U.S. Postmaster General, (1909), p. 142. U. S. Postmaster General, (1891), pp. 71, 160.

[47]Ibid. M. Couderc, "La télégraphie Pneumatique à Budapest," Annales des Postes, Télégraphes et Téléphones, 4 (1913-14, No. 1), pp. 117-120. "Pneumatic postal transmission," Scientific American Supplement No. 90, (1877), p. 14.

[48]"Organisation de la Poste Pneumatique en Italie," translated from Rivista delle Communicazioni, in Annales des Postes, Télégraphes et Téléphones, 1 (1910-11, No. 4), p. 133. U. S. Postmaster General, (1909), pp. 136, 143.

[49]"Organisation . . . en Italie," p. 133.

[50]M. Gissot, "Les tubes pneumatiques en Italie," Annales des Postes, Télégraphes et Téléphones, 4 (1913-14, No 4), pp. 513-523 passim; Hughes, p. 184.

[51]E. Lapierre and Raynier, "Utilisation de Tubes Pneumatiques a Sélections pour le Payement des Chèques à Vue dans les Bureaux Centraux de Chèques postaux," Annales des Postes, Télégraphes et Téléphones 22 (1933, No. 2), pp. 208, 207-217 passim.

52"Pneumatique," N.Y. Times, Mar. 31, 1984, p. 19.

53G. Paulin, "L'aiguillage automatique en boulisterie pneumatique," Annales des Postes, Télégraphes et Téléphones, 22 (1933, no. 7), pp. 609-618, 617.

54Ibid., and "Berlin," World Book Encyclopedia, 1960.

55"Broadway," Sci. Am., (1870), pp. 154-156. "Pneumatic Tubes in Chicago," Scientific American (March 10, 1894), p. 151. "Pneumatic Tubes," from Chicago Journal of Commerce, in Scientific American, (Dec. 4, 1869), p. 356. U. S. Pneumatic-Tube Postal Commission, (1913), p. 7.

56U. S. Postmaster General, (1891), pp. 71, 73, 160.

57U. S. Postmaster-General, Annual Report, (Washington, 1892), pp. 40-41.

58"The Johnson pneumatic tube," from N. W. Mechanic in Scientific American, (Oct. 19, 1889), p. 239.

59U. S. Postmaster-General, (1892), pp. 18-19.

60U. S. Postmaster-General, Report to Congress, (Washington, 1901), pp. 20-22. U. S. Postmaster General, (1909), p. 133.

61Ibid., p. 18. U. S. Pneumatic-Tube Postal Commission, (1913), map facing p. 114.

62U. S. Postmaster-General, (1901), pp. 102, 18, 57, 18, 50, 8, 4, 3, 35, 23-24, 25, 22-23.

63"Improvements," Sci. Am. Supp. No. 843, p. 13465.

64U. S. Postmaster-General, (1901), pp. 55-67, passim. The sections of this report describe "Existing pneumatic-tube service," "Adequacy of existing tube service," "Advantages of tube service in comparison with other service," "Reduction in wagon service," "Importance of branch post-offices now connected by tube," "Proposed extension of tube," "Volume of mail to be transmitted," "Possible economies," "Size of tube for present and prospective use," "Necessity of the proposed service," "Possible use of single tubes as feeders," "Special postage rates," "Space at the General Post-Office and at Branch Post-Office Stations," "Most economical and practicable system of installation and maintenance." pp. 59-61, fold-out map set, 20-25. U. S. Postmaster General, (1909), pp. 42-43.

65U. S. Pneumatic-Tube Postal Commission, (1913), pp. 31, 53, 38-39. U. S. Postmaster-General, (1901), p. 164.

[66]*Ibid.*, p. 40. Joint Committee to Investigate the Value of Pneumatic Tube Mail Service, *Pneumatic Tube Mail Service*, Senate, Document 191, 65th Congress, 2nd session, (Washington, 1919), p. 392. Sam Bass Warner, Jr., *The Private City*, (Philadelphia, 1968).

[67]U. S. Pneumatic-Tube Postal Commission, (1913), map and table facing p. 114.

[68]*Ibid.*, pp. 42-51. U. S. Postmaster General, (1909), p. 39.

[69]Joint Committee, (1919), pp. 392-393.

[70]U. S. Postmaster General, (1909), pp. 11-12.

[71]Joint Committee, (1919), pp. 3-5.

[72]U. S. Postmaster General, (1909), pp. 38, 50, 57. Committee of the Post-Office Department, *Report*, (Washington, 1916), p. 16.

[73]U. S. Postmaster-General, (1901), map facing p. 40.

[74]U. S. Postmaster General, (1909), pp. 13, 12-13, 62-63.

[75]*Ibid.*, pp. 8-12. U. S. Postmaster-General, (1901), pp. 22, 27. Some third class mail and fragile packages went through these systems; a live cat passed through as a test object for fragile packages according to U. S. Postmaster General, *Annual Report*, (Washington, 1897), p. 175.

[76]U. S. Postmaster General, (1909), p. 8.

[77]U. S. Pneumatic-Tube Postal Commission, (1913), pp. 203, 53.

[78]U. S. Postmaster General, (1909), pp. 136, 139.

[79]*Ibid.*, p. 42. U. S. Postmaster-General, (1901), pp. 41, 56, 79, 97.

[80]U. S. Postmaster General, (1909), p. 29.

[81]U. S. Postmaster-General, (1901), p. 34.

[82]U. S. Postmaster General, (1909), pp. 12, 57, 83, 57.

[83]" . . . New York . . . Tunnel," *Sci. Am.*, (1901), p. 327.

[84]U. S. Postmaster General, (1909), p. 50.

[85]" . . . New York . . . Tunnel," Sci. Am., (1901), p. 327. The photograph in Figure 9 illustrating this sort of problem appeared in U. S. Pneumatic-Tube Postal Commission, (1913), facing p. 377.

[86]Joint Committee, (1919), chart, p. 356.

[87]U. S. Pneumatic-Tube Postal Commission, (1913), pp. 2, 89, 58, 61-62, 73, 77, 73, 62, 108, 111, 112, 105-106.

[88]U. S. Postmaster General, (1909), p. 47.

[89]U. S. Pneumatic-Tube Postal Commission, (1913), pp. 30, 53, 156.

[90]U. S. Postmaster General, (1909), p. 140.

[91]U. S. Pneumatic-Tube Postal Commission, (1913), pp. 165, 163, 89.

[92]Joint Committee, (1919), pp. 393-394.

[93]Committee of the Post Office Department, (1916), pp. 11, 192, 8-12, 16-17.

[94]Joint Committee, (1919), pp. 399-401, 4, 415, 5, 3.

[95]Committee of the Post Office Department, (1916), p. 214. Scheele, U. S. Mails, pp. 70-72. Hearing, (1935), pp. 16, 18, 19, 21. Committee of Post-office and Post Roads, Hearing, House of Representatives, 76th Congress, 1st session, (Washington, 1939), pp. 8, 75, 77. Hearing, (1948), p. 3.

[96]Ibid. Hearing, (1939), pp. 27, 4, 5, 4, 6.

[97]Hearing, (1935), pp. 16, 17, 27, 7, 69.

[98]Hearing, (1948), pp. 3-4.

[99]U. S. Pneumatic-Tube Postal Commission, (1913), pp. 9, 31-32.

[100]Ibid., p. 71.

[101]Joint Committee, (1919), p. 59.

[102]Otto Friedrich, "Adieu to the Pneu," Time, (April 30, 1984), p. 82.

[103]E. N. Gilbert and H. O. Pollak, "Steiner minimal trees," SIAM, Journal of Applied Mathematics, 16, (1968), pp. 1-29.

[104]Eugene L. Lawler, Combinatorial Optimization: Networks and Matroids, (New York: 1976).

[105]E. J. Cockayne, "On the Steiner problem," Canadian Mathematical Bulletin, (1967), pp. 431-50.

[106]B. Commoner, "Reflections: the solar transition--I," and "II," The New Yorker, (April 23, 1979, and April 30, 1979), pp. 53-98, 46-93.

[107]Ibid., Part I, p. 54.

Sources for Maps and Figures

1) Map 1 and Map 2 were derived from written materials in Wanamaker, U.S. Postmaster General, 1891.

2) Map 3 is a composite of selected materials from maps appearing in Rohrpost, (1901), "Das Rohrpostnetz von Berlin," and "Rohrpostnetz von Berlin."

3) Map 4 uses Map 3 as a base map.

4) Figure 5 is from Gissot, "La Télégraphie Pneumatique," p. 34.

5) Map 6 is derived from a map, as a base map, in U.S. Postmaster General, Investigations, (1909), p. 141.

6) Figure 7 appears in, Postmaster-General, Report, 1901, photographs facing p. 40.

7) Map set 8 is formed from a composite of materials drawn from maps in 1901, 1909, 1913, and 1919 U. S. Government Publications on pneumatic tubes referred to in the "Notes."

8) Figure 9 appears in the U.S. Pneumatic-Tube Postal Commission, 1913, photograph facing p. 377.

9) Maps 10 through 17 are based on maps appearing in Arlinghaus, "On Geographical Network Location Theory."

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1. Sandra L. Arlinghaus and John D. Nystuen. *Mathematical Geography and Global Art: the Mathematics of David Barr's "Four Corners Project,"* 1986.

This monograph contains Nystuen's calculations, actually used by Barr to position his abstract tetrahedral sculpture within the earth. Placement of the sculpture vertices in Easter Island, South Africa, Greenland, and Indonesia was chronicled in film by The Archives of American Art for The Smithsonian Institution. In addition to the archival material, this monograph also contains Arlinghaus's solutions to broader theoretical questions--was Barr's choice of a tetrahedron unique within his initial constraints, and, within the set of Platonic solids?

2. Sandra L. Arlinghaus. *Down the Mail Tubes: the Pressured Postal Era, 1853-1984*, 1986.

The history of the pneumatic post, in Europe and in the United States, is examined for the lessons it might offer to the technological scenes of the late twentieth century. As Sylvia L. Thrupp, Alice Freeman Palmer Professor Emeritus of History, The University of Michigan, commented in her review of this work "Such brief comment does far less than justice to the intelligence and the stimulating quality of the author's writing, or to the breadth of her reading. The detail of her accounts of the interest of American private enterprise, in New York and other large cities on this continent, in pushing for construction of large tubes in systems to be leased to the government, brings out contrast between American and European views of how the new technology should be managed. This and many other sections of the monograph will set readers on new tracks of thought."

3. Sandra L. Arlinghaus. *Essays on Mathematical Geography*, 1986.

A collection of essays intended to show the range of power in applying pure mathematics to human systems. There are two types of essay: those which employ traditional mathematical proof, and those which do not. As mathematical proof may itself be regarded as art, the former style of essay might represent "traditional" art, and the latter, "surrealist" art. Essay titles are: "The well-tempered map projection," "Antipodal graphs," "Analogue clocks," "Steiner transformations," "Concavity and urban settlement patterns," "Measuring the vertical city," "Fad and permanence in human systems," "Topological exploration in geography," "A space for thought," and "Chaos in human systems–the Heine-Borel Theorem."

4. Robert F. Austin, *A Historical Gazetteer of Southeast Asia*, 1986.

Dr. Austin's Gazetteer draws geographic coordinates of Southeast Asian place-names together with references to these place-names as they have appeared in historical and literary documents. This book is of obvious use to historians and to historical geographers specializing in Southeast Asia. At a deeper level, it might serve as a valuable source in establishing place-name linkages which have remained previously unnoticed, in documents describing trade or other communications connections, because of variation in place-name nomenclature.

5. Sandra L. Arlinghaus, *Essays on Mathematical Geography–II*, 1987.

Written in the same format as IMaGe Monograph #3, that seeks to use "pure" mathematics in real-world settings, this volume contains the following material: "Frontispiece–the Atlantic Drainage Tree," "Getting a Handel on Water-Graphs," "Terror in Transit: A Graph Theoretic Approach to the Passive Defense of Urban Networks," "Terrae Antipodum," "Urban Inversion," "Fractals: Constructions, Speculations, and Concepts," "Solar Woks," "A Pneumatic Postal Plan: The Chambered Interchange and ZIPPR Code," "Endpiece."

6. Pierre Hanjoul, Hubert Beguin, and Jean-Claude Thill, *Theoretical Market Areas Under Euclidean Distance*, 1988. (English language text; Abstracts written in French and in English.)

Though already initiated by Rau in 1841, the economic theory of the shape of two-dimensional market areas has long remained concerned with a representation of transportation costs as linear in distance. In the general gravity model, to which the theory also applies, this corresponds to a decreasing exponential function of distance deterrence. Other transportation cost and distance deterrence functions also appear in the literature, however. They have not always been considered from the viewpoint of the shape of the market areas they generate, and their disparity asks the question whether other types of functions would not be worth being investigated. There is thus a need for a general theory of market areas: the present work aims at filling this gap, in the case of a duopoly competing inside the Euclidean plane endowed with Euclidean distance.

(Bien qu'ébauchée par Rau dès 1841, la théorie économique de la forme des aires de marché planaires s'est longtemps contentée de l'hypothèse de coûts de transport proportionnels à la distance. Dans le modèle gravitaire généralisé, auquel on peut étendre cette théorie, ceci correspond au choix d'une exponentielle décroissante comme fonction de dissuasion de la distance. D'autres fonctions de coût de transport ou de dissuasion de la distance apparaissent cependant dans la littérature. La forme des aires de marché qu'elles engendrent n'a pas toujours été étudiée ; par ailleurs, leur variété amène à se demander si d'autres fonctions encore ne mériteraient pas d'être examinées. Il paraît donc utile de disposer d'une théorie générale des aires de marché : ce à quoi s'attache ce travail en cas de duopole, dans le cadre du plan euclidien muni d'une distance euclidienne.)

7. Keith J. Tinkler, Editor, *Nystuen—Dacey Nodal Analysis*, 1988.

Professor Tinkler's volume displays the use of this graph theoretical tool in geography, from the original Nystuen—Dacey article, to a bibliography of uses, to original uses by Tinkler. Some reprinted material is included, but by far the larger part is of previously unpublished material. (Unless otherwise noted, all items listed below are previously unpublished.) Contents: " 'Foreward' " by Nystuen, 1988; "Preface" by Tinkler, 1988; "Statistics for Nystuen—Dacey Nodal Analysis," by Tinkler, 1979; Review of Nodal Analysis literature by Tinkler (pre–1979, reprinted with permission; post—1979, new as of 1988); FORTRAN program listing for Nodal Analysis by Tinkler; "A graph theory interpretation of nodal regions" by John D. Nystuen and Michael F. Dacey, reprinted with permission, 1961; Nystuen—Dacey data concerning telephone flows in Washington and Missouri, 1958, 1959 with comment by Nystuen, 1988; "The expected distribution of nodality in random (p, q) graphs and multigraphs," by Tinkler, 1976.

8. James W. Fonseca, *The Urban Rank-size Hierarchy: A Mathematical Interpretation*, 1989.

The urban rank–size hierarchy can be characterized as an equiangular spiral of the form $r = ae^{\theta \cot \alpha}$. An equiangular spiral can also be constructed from a Fibonacci sequence. The urban rank–size hierarchy is thus shown to mirror the properties derived from Fibonacci characteristics such as rank-additive properties. A new method of structuring the urban rank–size hierarchy is explored which essentially parallels that of the traditional rank–size hierarchy below rank 11. Above rank 11 this method may help explain the frequently noted concavity of the rank–size distribution at the upper levels. The research suggests that the simple rank–size rule with the exponent equal to 1 is not merely a special case, but rather a theoretically justified norm against which deviant cases may be measured. The spiral distribution model allows conceptualization of a new view of the urban rank–size hierarchy in which the three largest cities share functions in a Fibonacci hierarchy.

9. Sandra L. Arlinghaus, *An Atlas of Steiner Networks*, 1989.

A Steiner network is a tree of minimum total length joining a prescribed, finite, number of locations; often new locations are introduced into the prescribed set to determine the minimum tree. This Atlas explains the mathematical detail behind the Steiner construction for prescribed sets of n locations and displays the steps, visually, in a series of Figures. The proof of the Steiner construction is by mathematical induction, and enough steps in the early part of the induction are displayed completely that the reader who is well–trained in Euclidean geometry, and familiar with concepts from graph theory and elementary number theory, should be able to replicate the constructions for full as well as for degenerate Steiner trees.

10. Daniel A. Griffith, *Simulating $K = 3$ Christaller Central Place Structures: An Algorithm Using A Constant Elasticity of Substitution Consumption Function*, 1989.

An algorithm is presented that uses BASICA or GWBASIC on IBM compatible machines. This algorithm simulates Christaller $K = 3$ central place structures, for a four–level hierarchy. It is based upon earlier published work by the author. A description of the spatial theory, mathematics, and sample output runs appears in the monograph. A digital version is available from the author, free of charge, upon request; this request must be accompanied by a 5.5–inch formatted diskette. This algorithm has been developed for use in Social Science classroom laboratory situations, and is designed to (a) cultivate a deeper understanding of central place theory, (b) allow parameters of a central place system to be altered and then graphic and tabular results attributable to these changes viewed, without experiencing the tedium of massive calculations, and (c) help promote a better comprehension of the complex role distance plays in the space–economy. The algorithm also should facilitate intensive numerical research on central place structures; it is expected that even the sample simulation results will reveal interesting insights into abstract central place theory.

The background spatial theory concerns demand and competition in the space–economy; both linear and non–linear spatial demand functions are discussed. The mathematics is concerned with (a) integration of non–linear spatial demand cones on a continuous demand surface, using a constant elasticity of substitution consumption function, (b) solving for roots of polynomials, (c) numerical approximations to integration and root extraction, and (d) multinomial discriminant function classification of commodities into central place hierarchy levels. Sample output is presented for contrived data sets, constructed from artificial and empirical information, with the wide range of all possible central place structures being generated. These examples should facilitate implementation testing. Students are able to vary single or multiple parameters of the problem, permitting a study of how certain changes manifest themselves within the context of a theoretical central place structure. Hierarchical classification criteria may be changed, demand elasticities may or may not vary and can take on a wide range of non–negative values, the uniform transport cost may be set at any positive level, assorted fixed costs and variable costs may be introduced, again within a rich range of non–negative possibilities, and the number of commodities can be altered. Directions for algorithm execution are summarized. An ASCII version of the algorithm, written directly from GWBASIC, is included in an appendix; hence, it is free of typing errors.

11. Sandra L. Arlinghaus and John D. Nystuen, *Environmental Effects on Bus Durability*, 1990.

This monograph draws on the authors' previous publications on "Climatic" and "Terrain" effects on bus durability. Material on these two topics is selected, and reprinted, from three published papers that appeared in the *Transportation Research Record* and in the *Geographical Review*. New material concerning "congestion" effects is examined at the national level, to determine "dense," "intermediate," and "sparse" classes of congestion, and at the local level of congestion in Ann Arbor (as suggestive of how one might use local data). This material is drawn together in a single volume, along with a summary of the consequences of all three effects simultaneously, in order to suggest direction for more highly automated studies that should follow naturally with the release of the 1990 U. S. Census data.

12. Daniel A. Griffith, Editor. *Spatial Statistics: Past, Present, and Future*, 1990.

Proceedings of a Symposium of the same name held at Syracuse University in Summer, 1989. Content includes a Preface by Griffith and the following papers:

Brian Ripley, "Gibbsian interaction models";
J. Keith Ord, "Statistical methods for point pattern data";
Luc Anselin, "What is special about spatial data";
Robert P. Haining, "Models in human geography:
problems in specifying, estimating, and validating models for spatial data";
R. J. Martin, "The role of spatial statistics in geographic modelling";
Daniel Wartenberg, "Exploratory spatial analyses: outliers, leverage points, and influence functions";
J. H. P. Paelinck, "Some new estimators in spatial econometrics";
Daniel A. Griffith, "A numerical simplification for estimating parameters of spatial autoregressive models";
Kanti V. Mardia "Maximum likelihood estimation for spatial models";
Ashish Sen, "Distribution of spatial correlation statistics";

Sylvia Richardson, "Some remarks on the testing of association between spatial processes";
Graham J. G. Upton, "Information from regional data";
Patrick Doreian, "Network autocorrelation models: problems and prospects."

Each chapter is preceded by an "Editor's Preface" and followed by a Discussion and, in some cases, by an author's Rejoinder to the Discussion.

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