Demand-Responsive Transit: An Overview of Integrated Systems

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It is time to consolidate our knowledge about demand-responsive transportation and to consider what can be learned from the successes in Ann Arbor, Michigan, and Rochester, New York; from the stalled program in Orange County, California; and from the demise of the ambitious experiment in Santa Clara County. Demand-responsive transportation (DRT) is an expanding segment of public transit in the United States. It offers the best prospect for attracting new riders and is ideally suited for the multinucleated, suburban metropolis, which is America's urban future. Consolidation of our knowledge about the successes and failures of integrated DRT systems is therefore appropriate, and I have chosen to do so in the format of a propositional inventory.

Space does not permit the presentation of all propositions. I will, therefore, restrict myself to those pertaining to definitions, cost, automation, and attitudes of transit managers, unions, and taxicab companies.

PROSPECTS FOR DRT

Proposition: DRT will obtain an increasing share of the transportation market as public officials respond to the transit demands of multinucleated metropolitan areas.

Dispersed activity centers characterize metropolitan areas. In the past, streetcars enabled families to reside outside the central city in medium density suburbs. Automobiles extended this process: Interstitial areas and the suburban fringe were urbanized at even lower densities (Figure 1, 1940 and 1970). Suburban locations were chosen for shopping and professional centers as well as for industrial and educational parks, which accelerated deconcentration.

Despite the billions of dollars spent on urban renewal, freeways, and rapid transit, the decline of the central city neither has been nor will be arrested. The ring of high density residence in the inner suburbs is decreasing and not moving outward as anticipated (6). A plateau of medium density—between 6,000 and 10,000 persons per mile^2—is developing.

More than half the urban commuter trips originate and terminate in these medium density suburbs and, as Ward (18) indicated, transit must find a way to capture a share of these trips from automobiles if it is to expand ridership. At the lower density, DRT can compete effectively with fixed-route transit (FRT); at the upper density, it can complement FRT.

DRT provides an attractive, practical, and economical alternative to the automobile. It will not displace the automobile, but it can reduce the need for multiple cars. Why

then is DRT not more prevalent in the transit industry? Simpson and Wilson (16) suggest that the costs are too high when operated by transit employees. Murphy, Paisley, and Siersema (12) believe it is too slow unless linked to a superior arterial FRT. Roos (14) suggests that it is too soon to evaluate, for we have not yet perfected the algorithms that will allow DRT to handle peak demand. And to these I would add the attitude of both the transit and the taxi industry.

COST OF DRT AND FRT

Proposition: Transit authorities cannot sustain DRT if they must pay drivers and controllers salaries equivalent to those paid FRT operators.

Salaries on the larger transit properties are about $10 per hour with benefits. Labor accounts for the major portion of costs, which vary with ridership (variable costs) and are between $16 and $20 per hour of FRT operation and higher on the more expensive properties.

Suburban bus lines carry about 18 persons per hour when transfer passengers are included, giving a variable cost ranging between $0.88 and $1.11 per passenger.

The variable cost for DRT is 20 percent higher because of added control room costs and lower passenger productivity. Normally, passenger productivity starts at 4 per hour and, with superior management, attains 10 per hour. The medium variable cost of $21.60 per hour and a productivity of 7 give a variable cost of $3.09 per passenger for DRT. In Rochester, where labor costs are lower than normal, the variable cost is $2.63 per passenger; in Santa Clara County, it was $4.39. Despite the higher fares charged and the superior service offered by DRT, few transit authorities can sustain this additional loss.

The use of transit employees is not essential. Unionized taxi drivers and part-time employees willingly work for $3 to $4 per hour. In Orange County, the 2 DRT modules are operated under contract by private companies who employ nonunion, frequently part-time, personnel (20). Passengers are transferred to the FRT service operated by the Orange County Transit District with union drivers without passenger inconvenience. Because of the lower salaries and the higher fares on DRT, the cost to the transit district is competitive. The net cost is $1.34 per passenger for DRT.

The price for a DRT trip should be at least twice the price charged for an FRT trip. Demands for service far exceed the supply of vehicles in DRT. Ridership is depressed by delays rather than fares.

Fares that were too low was one reason for the failure of DRT in Santa Clara County. Only $0.25 was charged, and discounts were given for special groups. Potential demands for service were estimated at 20 per 1,000 people per day, and that exceeded the capacity of the 75 vehicles available for off-peak DRT service (2). Response times would have been 96 minutes with a level of service 18 times as long as an equivalent automobile trip. With a fare of $0.50, 210 DRT buses would have been required to provide satisfactory off-peak service.

An increase in fares could have depressed demand and reduced customer dissatisfaction. Had the fare been increased to $0.50, satisfactory off-peak service could have been offered with 150 buses (11). At $1, 100 buses might have been sufficient, but even this was in excess of the available equipment.

The balance between available vehicles and potential demand for service deserves careful evaluation early in the planning process. Professional assistance is recommended. DRT is an extremely attractive service. It has more than doubled the anticipated use of transit in Ann Arbor (1). A crisis in expectations can easily be created that may embarrass elected officials. Even paid advertising should be delayed for 4 to 6 weeks after service is inaugurated. Press reports alone will create more demand than can initially be accommodated (15).

INCREMENTAL DEVELOPMENT

Proposition: Expansion in zonal increments rather than all at once has proved beneficial for DRT as it has for other transit developments (13).

There are so many difficulties that delay or deter service that a critical path approach to planning is required (16). Estimates of demand can be calculated by using the models developed by Zobrack (20) and then related to the number of vehicles needed to provide the desired level of service by using the model developed by Wilson and Lerman (19). But beyond this step, difficulty can be experienced in obtaining vehicles of sufficient size and reliability and in training personnel and allowing them sufficient time to become acquainted with streets and traffic in the service area.

A summary report (2) on the Santa Clara County DRT system, which is known as Arterial Personal Transit (APT), illustrates the need for incremental development.

> APT is the most innovative of the newer transit systems, because it combined the speed of the arterial fixed route service with the convenience of door-to-door service.
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> The attractiveness of APT has created a crisis in expectations. The demand for services on APT has far exceeded the capability of the District to supply service. Even when the learning phase for reservationists, controllers and coach operators is completed; and even if all the radio communications problems were solved, the District does not have sufficient vehicles available to operate APT as described in the Rider's Guide. A significant increase in the number of buses is required.
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> Personalized transit is an admirable goal. A sequence of expansion phases could be stated as objectives and achieved incrementally over several years. However, if the people of Santa Clara County desire this superior transit service, then it is clear that they must also be willing to expand the bus fleet to meet the desire for this service.
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> APT was initiated with only 212 vehicles. In order to satisfy anticipated demand with five to ten minute wait times, the system was designed to require 680 buses. The system, thus, went into operation with less capacity than required to meet other goals of the Transit District, that is, "reliability," and "reasonable speed and trip time."
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> Thus, in terms of the District's goals, the attempts to "serve all people"—a transit opportunity for 97 percent of the population—with only 212 vehicles seriously impairs the goal of "quality service." Equally important, ubiquitous geographic coverage does not equal availability. In actual fact, APT service, because of strong demand is available to a very small percentage of the population in its "many-to-many" mode—approximately 2,500 people per day—and many-to-many is effectively not available at all during peak commuter hours.

The most ambitious DRT system failed because sufficient time was not allowed to work out the problems in one zone before the APT was offered to the entire county. The elected officials were so embarrassed by the disparity between the promise of the transit professionals and actual system performance that they had no alternative other than to abandon DRT and revert to FRT. Opposition by the taxi companies was not the principal cause. Integrated DRT was abandoned because the elected officials realized that the district could not afford to supply sufficient service to meet the anticipated demand.

Equipment

Unanticipated delays in the delivery of vehicles and communications equipment are customary. Even when installed, the unreliability of this equipment reduces DRT productivity. For these reasons, a critical path method of incremental development is recommended.

No satisfactory DRT vehicle has been developed. Most small buses are built on modified truck or recreational vehicle chassis, and their components, especially brakes, transmissions, cooling systems, and valves, cannot sustain the rigor of stop-and-go driving in transit. As many as one-third of the vehicles can be out of service. Spare parts are difficult to obtain, and these delays are seldom anticipated by transit

operators because the heavy-duty, transit bus is normally reliable.

The cost of maintenance is also underestimated. In both Orange County and Rochester, the maintenance cost for small vehicles is estimated at 11 cents per mile. A new heavy-duty transit bus costs 4.23 cents per mile to maintain, and this increases to 7.54 cents after 4 years and to 14 to 16 cents after 10 years.

The size of the DRT vehicle is frequently debated. Taxi operators claim that cabs are adequate because their average productivity ranges between 4 and 8 passengers per hour. However, higher productivity cannot be achieved unless subscription, buspool service is offered for workers and schoolchildren. For these services, the 15 to 20 seater bus—large enough for peak-hour demand, yet small enough to negotiate residental streets—has proved the most popular. Since it may take a year to obtain the desired bus, service can begin incrementally with cabs and vans and shift to buses when ridership increases.

Communications equipment is another source of frustration. Digital transmission is required for integrated DRT systems. Rochester had this equipment when it began to expand to an integrated system in 1975. Santa Clara County did not; a decision to begin with voice communications proved impractical. Any problem, such as a disabled vehicle or a driver who is unable to find an address, disrupted communication between other operators and the control center.

DRT is built around the concept of communication control. Channels must first be acquired from the Federal Communications Commission, and then field checks should be made to determine adequacy of capacity and clarity. This is seldom done in advance, and confusion is a feature of all new systems—another reason why starting one module and expanding service incrementally is advised.

Ann Arbor provides the best example of staged development dependent on reliability, capability, and finances (1). With only 100,000 people, the problems of system expansion are manageable. The Rochester-Genesee Regional Transportation Authority serving 1 million people and the Orange County Transit District serving 1.7 million face a more complex institutional environment. To manage an incremental program serving only parts of those regions is difficult. Rochester is perfecting its control technology in the town of Greece before expanding to Irondequoit and Henrietta. Orange County has a comprehensive plan and 2 modules are manually operating, but it is not implementing the plan rapidly enough to satisfy the demand for service by some other cities within the county. The incremental approach, which gives priority to a few areas, is difficult to justify in large, diverse communities.

Estimating Demand

The demand for DRT is restricted not by the desire to use the service but by the inability of operators to supply an acceptable level of service.

The studies by Wilson and Zobrack have demonstrated that relatively simple models can be used to predict demand. In suburban areas, with a mix of commercial, industrial, educational, and professional activities, a potential demand of 20 to 26 requests per day per 1,000 residents can be anticipated.

However, this level of demand has never been experienced because of the inability of DRT systems to provide a satisfactory level of service during peak hours. In Orange County, the maximum demand achieved has been 10 requests per 1,000 residents.

DRT is attractive to consumers and could increase the proportional share of transit ridership. But too often, this share is stated as a system goal that is impractical to achieve. Automated scheduling and information processing can increase efficiency. In fact, fully integrated DRT cannot be achieved without automation.

INTEGRATED DRT

Proposition: Integrated DRT systems link flexible-route and fixed-route transit to

provide metropolitan transit service. It is a mix of systems acting cooperatively, and not necessarily under single ownership, to provide transit that adapts to demand.

Integrated DRT differs from the small DRT units—usually fewer than 10 vehicles—that provide service for many towns (17). Integrated DRT systems are larger (Ann Arbor has 40 vehicles and Orange County has plans for 180) and are to be coordinated with FRT by computers to provide portal-to-portal transit for an entire metropolitan area. It is transit controlled by a communication system that hypothesizes an operation that, for the present, is only known in theory.

Ideally a set of DRT areas containing between 40,000 and 70,000 people can be served without automated controls by fewer than 20 buses (4). These smallest units should be nested in larger zones where 60 to 80 vehicles are controlled automatically (Figure 2). Movement among zones is provided by a grid network of FRT, express buses, and commuter rail stations (Figure 3). When the total system attracts sufficient ridership, high-speed rapid transit lines can be implemented on rail or freeway rights-of-way (Figure 4).

Santa Clara County developed an ambitious program (10) in which 75 DRT and 137 FRT vehicles in its Arterial Personal Transit System were to provide superior FRT during peak hours with some DRT and extensive DRT during off-peak hours. In the consultant's early reports, subscription bus service was to be used during peak hours and DRT was to be restricted to transit dependents during off-peak hours. Unfortunately, DRT was not restricted. Through advertising, a demand for many-to-many service was created that far exceeded the supply of equipment. Now, because the favorable response to integrated DRT created additional demand for the arterial routes, DRT has been abandoned so that all equipment can be used for FRT.

Ann Arbor has been more successful in switching vehicles between DRT and FRT. The city is smaller—100,000 compared to 1.1 million in Santa Clara County—and the transit authority has moved cautiously. Permanent DRT, called TELTRAN, operates in portions of the city. Elsewhere it operates only in the evening and weekends as a replacement for FRT.

The Rochester-Genesee Regional Transportation Authority is developing and testing the integration of DRT and FRT in the town of Greece. Sixteen buses provide many-to-many service, integration with FRT, and subscription services to school and work for 67,400 persons. Considerable emphasis is being placed on development of the computerized control system with UMTA's financial support. When the automated control system performs adequately, DRT will be expanded and route rationalization will continue. Underused routes will be discontinued, more express buses will operate at peak hours, and DRT will replace FRT during nonpeak hours.

AUTOMATION

Proposition: Computer systems are needed for the control and management of an integrated DRT system, but they result in complexities that are difficult to forecast in advance.

Approximately 20 percent of the hourly cost for DRT is for communication and control. This stimulates the search for automation. Five levels or generations of automation can be identified:

1. Nonautomated systems that are suited for special groups and in which 1 or 2 vehicles collect passengers on a prescheduled tour.
2. Systems that use 2-way voice communication and manual control. Once drivers and controllers are familiar with the community, as many as 20 vehicles can be controlled in these systems. Tests in Batavia, New York, indicate that digital communications produces savings when more than 12 vehicles are operated because drivers do not have to stop and record the next sequence of stops. Murphy, Paisley, and Siersema (12) say that computers should be introduced when there are more than

5 to 6 vehicles. In a private conversation, A. U. Simpson disagreed and suggested manual control when there are 10 or 20 vehicles, depending on the kind of operation. The many successful, noncomputerized systems in California and Michigan substantiate Simpson's claim.

3. Systems in which control is aided by the computer. Calls are entered into the system by reservations and allocated to zones and listed in priority by an algorithm. This is a computer-assisted system, which provides organized information for the controller who makes decisions and transmits assignments to the driver.

Ann Arbor uses computer-assisted dispatching to advantage. The FRT schedule "drives" the system, and tours are transmitted to each DRT driver and sequenced so that the vehicle returns to designated transfer points to meet the arterial schedule. Changes to the tour occur and are transmitted, but considerable discretion as to route and sequence is left to the driver. Information is accumulated for planning and management decisions.

4. Centralized systems in which the computer assigns each request for service to a vehicle to minimize some objective function and transmits this information to the vehicle. These computer-based systems use algorithms developed at MIT and programs developed by the Mitre Corporation for Haddonfield, New Jersey. The computer system receives the street addresses, translates them into coordinates, and uses an assignment algorithm to select the best vehicle for the trip. The automatic system can schedule vehicle arrivals more accurately than human dispatchers although the routes chosen do not always minimize travel time.

5. Computer-controlled systems that coordinate transfers between DRT and FRT and between adjoining DRT zones. These systems still challenge researchers. When accomplished, they will provide the potential for integrated transit with communications and control accounting for about 10 percent of variable cost. Automatic reminder calls could be initiated by the computer system to warn the passenger 2 minutes before the programmed bus arrival. This would increase efficiency by as much as 10 percent and would more than compensate for the cost of automation. It would also enhance customer appeal, for, according to an MIT survey, uncertainty over arrival is the most frequently criticized aspect of DRT. Regular DRT customers using push-button phones could even bypass the reservationist and "talk" directly to the computer.

Rochester has made the greatest progress in automation. Digital communication was initiated in the second-generation test site. Testing of a fourth-generation level of control, which goes a step beyond Haddonfield by attempting to integrate with stops along 5 FRT routes, is now under way.

Automation of the Santa Clara DRT system is difficult to appraise. The initial system did not incorporate address locations. Reservationists assigned requests by zone after a time-consuming search of address files. The computer system sorted and scheduled trips by zone, and the controller-dispatcher relayed the sequence and addresses to the driver by voice. When a customer needed to travel from one control zone to another, the reservationist made a manual search of the destination and the FRT schedule. Approximately 3.5 minutes were required to complete an interzone request, and this delay created a backlog of calls. A management algorithm advised dispatchers of delays beyond the 20 minutes, but overloading of the voice channels made it difficult to transfer vehicles between zones to reduce delays.

Use of minicomputers with limited memory, as opposed to a large time-shared system, also created a problem. Once a trip was scheduled it was transferred from memory. Therefore, reservationists could not easily review the customer's request before responding to complaints or advising customers of delays. The adverse public reaction was understandable.

There is much that is not known about automating the control of DRT. Unwillingness to recognize this immaturity caused the demise of the ambitious Santa Clara project. The same mistakes should not be repeated elsewhere, for it is important that experimentation continue. Management of transit organizations through information control is one of the few innovations possible in transit (3). Automation would enable transit managers to provide a range of services to meet the changing demand throughout the

week and provide a convenient alternative to the automobile in the suburbs. However, attitudes toward DRT by transit managers, union officials, and taxi operators must change if DRT is to expand.

TRANSIT ATTITUDES TO DRT

Proposition: Institutional attitudes rather than technical problems restrain the expansion of DRT in metropolitan areas.

The integrated DRT systems in Ann Arbor and Rochester and in Orange and Santa Clara counties have developed from distinct personal situations; the chief executives have come from outside the transit fraternity. Elsewhere in the United States, DRT has originated in communities that have little or no public transit. To some extent this reflects the recency of DRT, but there are contributing institutional factors.

Attitude of Transit Managers

Top management does not have the time to invest in experimental programs that take a year or more to plan, a year to implement, and another year to stabilize operations. Transit is a labor-intensive public service that tends to be managed more by crisis resolution than by the attainment of predetermined goals. When money is available for expansion, traditional rather than innovative programs are sought.

The sociology of transit associations is also an obstacle. Prestige among transit operators is ascribed in terms of the number of large buses operated and passengers carried. Small buses do not convey prestige, and it is conventionally assumed that more people can be transported for less on large buses.

Transit managers will not likely recommend that DRT be provided by nontransit operators. The concern is not competition for passengers but the potential competition for public funds. The long-range public interest in reducing congestion and the fact that all forms of transit will benefit by increased service are obscured by the short-range objective to protect sources of public funds from new claimants.

Attitude of Union Officials

Where DRT is operated by unionized transit employees, union officials have, over time, accepted changes in work rules that are more suitable to DRT. However, problems remain. Retraining costs and learning inefficiencies occur when drivers can "bid on or off" DRT, even when bidding occurs only once a year. Regular work breaks also disrupt service. Productivity is lost when vehicles are withdrawn from service, and the public is annoyed if passengers must remain on board while the driver takes his or her scheduled rest.

When the control room staff are covered by the same union as the drivers, they cannot report individual omissions to exempt supervisory employees. This discourages learning and adversely affects service.

Problems between labor and management have only been offset by the superior attitude of those drivers who have bid for DRT. These drivers enjoy the interpersonal relations established when they can greet passengers individually. And, as public opinion surveys (5) have indicated, attitude of the driver is the second most important attribute, after arrival on schedule, of transit service.

The opportunity to meet and confer and to bargain collectively is important in large organizations. Unionization is an obstacle only when the work rules of FRT are transferred to DRT. The work rules of unionized taxi drivers would provide a better basis for negotiating working conditions appropriate to DRT.

Transit unions have also opposed capital grants for DRT when they were not to be the operators. This is a short-sighted policy because union employees will benefit if

transit ridership can be expanded. However, much of the federal largess in transit has been created by the effective union lobby, so the employee protectionism of section 13c of the National Mass Transportation Assistance Act of 1974 is the political price that transit has accepted.

ATTITUDE OF THE TAXI INDUSTRY

Proposition: Taxi companies should be more actively involved as operators if integrated DRT is to expand.

Taxi companies have a great deal more flexibility than conventional transit. Their work rules, vehicles, and communication systems are also complementary. In several communities in which taxi companies operate special-purpose, DRT systems for public agencies and in Davenport, Madison, and Richmond, where regulations encourage shared cabs, operators have demonstrated their ability to provide well-patronized demand-responsive service without public assistance (8).

When DRT became the vogue after 1970, taxi companies did not have the finances to accept the challenge. The transit industry, largely a public enterprise, could seek federal assistance for capital purchases and soon thereafter began to receive operating support from state and local governments. Availability of funds gave the initiative to public transit. But now the taxi industry is better organized. Means have been developed to provide public funding for private transit ventures, and this should encourage taxi companies to operate DRT under public sponsorship. A city, county, or special district could apply for the capital and operating funds and contract with private companies for operations.

Unfortunately, the relations between the innovators in DRT and taxi companies have been negative. In Ann Arbor the taxi company was first offered the opportunity to operate, but refused. Subsequently, the company unsuccessfully attempted to prohibit service by injunction (9). In both Santa Clara and Orange counties the injunctions were allowed. The courts ruled that the provisions in the enabling legislation applicable to both transit districts, and intended to protect private bus lines from unfair competition, also applied to taxis.

In Orange County, the largest taxi company had applied to be a DRT operator and had been selected to manage the second module that commenced in June 1975. Late in contract discussions the taxi company withdrew and then sought the injunction. The court ruled that within 120 days the transit district must either discontinue service or commence negotiations to purchase the taxi companies. This purchase could be less than complete so as to compensate them for diverting passengers. This would allow the district to expand DRT and the taxi companies to provide normal service.

Progress in Orange County is stalled while negotiations continue. However, I am optimistic as to the outcome. The transit district does not wish to eliminate taxi service or to operate taxis itself. And the taxi companies recognize the financial incentive as operators of DRT. If a satisfactory compromise cannot be reached, then the legal protection for the taxi companies will have to be removed. DRT is too popular in Orange County for the elected representative to allow it to be stalled indefinitely.

Successful DRT requires the flexible operation of private management, the financing that public agencies can provide, and supervision that can occur by controlling information flow. This is the theoretical premise that underlies the Orange County plan (3). Each module is to be managed independently so as to provide a personal relation between manager and employee. All communications will be entered at remote terminals, but processed at a central computing facility. In addition to scheduling, the computer system will provide a management information system that will enable the transit district to monitor the level of service provided by each franchised management firm.

There are problems inherent in this approach. Not all taxi companies are capable of managing employees. This minority has already demonstrated how they can use the courts to obstruct the decisions of the majority. There is also the potential conflict between subsidized shared riding and normal taxi operations. Strict conflict-of-interest

guidelines are embodied in the California Code. Private taxi operators are jealously independent. They resist conflict-of-interest provisions and dislike the postaudits that are essential in government contracts.

Problems are also anticipated from the unions. If federal funds are used, local unions could invoke the constraints of section 13c of the Urban Mass Transportation Act, which was intended to prevent assistance to public transit agencies that might reduce employment in conventional transit service. In practice this legislation is used to promote expansion of union control and as a lever in contract negotiations. It could be argued that the unionized employees will benefit from improved service, but I doubt whether this will persuade the U.S. Department of Labor. Unless the transit unions see the likelihood of representing the DRT employees, any substantial grant will be stalled, for there is no appeal beyond the Secretary of Labor. Local officials can either support inefficient transit systems in suburban areas or go without federal funds for DRT.

The tyranny of section 13c is the major obstacle to innovations in transit service. If a more progressive approach is not adopted by labor and management, urban passenger transport will face the same labor-cost problems as interurban rail passenger service. The only indication of a more liberal approach is in Ann Arbor, where part-time employees were accepted for DRT.

CONCLUSION

There are real institutional obstacles to the expansion of DRT service. Given time and money, the equipment and automation problems can be solved. The attitudinal problems are more resistant to change. The aspirations of transit managers and their unwillingness to share public funds with new agencies will persist, although these competing programs are more efficient. Nor are there significant indicators of changing attitudes from the transit unions. The more flexible work rules of taxi unions are complementary, but can this difference be sustained when federal grants are sought?

The revived interest of the taxi industry, demonstrated by papers presented at the Fifth Annual International Conference on Demand-Responsive Transportation Systems in November 1975, is the brightest aspect at the present. Taxis could attract more business and offer variable services if there was cooperation between urban policy-makers and taxi managers (7).

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