Strategic analysis of public transport coverage

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Abstract

Public transport service provision is viewed as an important component of the overall transportation planning and management process. Research examining public transportation performance and how it may be enhanced is much needed. This paper addresses strategic aspects of service access. Public transport in Brisbane, Australia is evaluated using a commercial geographical information system integrated with various spatial analytical techniques including a location covering model. The developed strategic analysis approach is effective for justifying local modifications to the public transport system with respect to system inefficiencies and also allows this to be done with significant user (or public) input. Such strategic approaches are likely to result in higher regional utilization of public transportation. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Population growth exerts considerable pressure on infrastructure and natural resources in urban regions. One of the most obvious in daily life is the transportation system, both in terms of how it impacts the environment and the congestion typically experienced in most cities. How additional transportation demand will be served in growing urban regions is considered to be an important issue for achieving sustainability. Indeed, the relationship between the transportation system, urban form, trip demand, and energy use is paramount in addressing the challenges presented by urban growth. This may be attributed to the considerable economic inefficiency and environmental degradation associated with excessive private vehicle travel based on current technology [1,2]. For these reasons, public transportation is recognized as a key component in the management and planning of urban regions [3]. Public transport represents a means by which
people can efficiently move throughout a region with the least amount of impact on the environment. However, automobile travel offers individuals more freedom and flexibility in movement. Most urban regions in Australia and the United States, in particular, must contend with inherent automobile dependence and a reluctance of individuals to make a switch to public transportation.

The challenge for urban planners and decision makers is to identify effective strategies for dealing with resistance to travel by public transport. One important factor is ensuring that the regional public transport system is a viable travel alternative [4]. In particular, the system must get people from where they are to where they need to go in a reasonable amount of time. Most urban regions with existing public transportation typically do a relatively good job at ensuring that stops and routes are established to sensibly serve origins and destinations. Those systems with low utilization rates, however, tend to have more difficulty competing with automobile travel times [2].

From the previous discussion, access provision and system efficiency are both important elements of public transport service. Thus, strategic modeling and analysis approaches are needed for evaluating public transport access and efficiency within the context of regional policies. This will better facilitate debate and discussion regarding the effectiveness of current services as well as establish a framework for developing system changes that ultimately provide better service.

In this paper, public transport access and efficiency is examined in Brisbane, Australia, the major urban center of the southeast Queensland region. Southeast Queensland is comprised of Brisbane, the Sunshine Coast, and the Gold Coast and contains approximately 2.1 million people. Population growth in the region from 1991 to 1996 was approximately 300,000 people, a continuing trend over the past two decades. Brisbane has less than half of the regional population, containing 806,292 people. Regional public transport policies and goals are well defined for Brisbane in the Integrated Regional Transport Plan [3], so this makes the associated analysis effort an essential component of the overall planning process. Public transport in the Brisbane region consists of bus, rail and ferry services, with bus being the dominant mode.

This paper evaluates public transportation service in Brisbane using geographical information systems (GIS) based spatial analysis techniques. The next section reviews relationships between transportation and sustainability. Public transport access is then examined in Section 3. A spatial model for identifying inefficiencies in public transport access coverage is presented and applied in Section 4. The implications of this analysis for public transportation in Brisbane are then discussed. Finally, conclusions and future directions are provided.

2. Transportation and sustainability

Urban regions, whether changing or growing, or both, are increasingly aware of the need to create better environmental, social and economic conditions over the short and long terms. Addressing these conditions is the basis for moving cities and regions towards a more sustainable existence. The relationship between transportation and sustainability is rather obvious and has been explored by a number of researchers [1,5,2,6]. Per capita energy use has a major influence on sustainability. Comparative studies on energy use in urban centers [2] have found linkages between population density and energy consumption. For example, low density cities found in
North America and Australia have been shown to be considerably less efficient than compact European cities [2].

The implications for transportation are obvious given its use of, and reliance on, non-renewable resources as well as the generation of negative externalities in the form of increased congestion and air and noise pollution. In addition, transportation systems contribute to the social qualities and attributes of a region. The ability to maintain one’s network of family and friends is vital to perceptions of quality of life since transportation provides the means for this interaction. The economic prosperity of a region is tied directly to the transportation services provided, with one of the primary activities being the distribution of goods and service. In all, there is an inter-connectivity and dependency upon the various elements of sustainability and transportation.

In southeast Queensland, where population growth has been substantial, addressing issues of sustainability has been recognized as being essential [7]. In fact, transportation, and public transport in particular, receives considerable attention and is seen as a key element in addressing sustainability concerns in the region [3]. A major priority is to increase public transport utilization rates, which are currently less than 7% of total trips taken. It is recognized that major changes are in order if public transport is to be a more effective travel mode option. However, little has been done to evaluate policy goals and system performance, particularly, with respect to access and efficiency of the public transport services in Brisbane.

Since World War II, public transport systems of Western cities have been declining as access to private vehicles has increased along with the development of highways and interstates [2]. During this period, public transport systems have largely proven to be unprofitable, resulting in reduced service levels. Subsidies have traditionally been provided by government agencies in order to ensure some level of mobility for the transport disadvantaged, such as the poor and elderly, as well as provide a commuter alternative in more congested regions [8].

As in many cities, the Brisbane tram system was dismantled in the late 1960s and replaced with a flexible bus system. These decisions now appear to have been myopic as tram and light rail services are being re-introduced throughout the world. With the benefit of hindsight, maintaining separate tram corridors could have been a good basis for strengthening public transport usage in Brisbane, and in other regions. At the least, cost outlays that would now need to be absorbed could have been avoided if this infrastructure still existed. However, the English experience has found that despite increased innovation, fare reductions, and higher service levels brought about by competition, few additional customers have been attracted to public transport [9]. Given that the more recent major public transit projects in the United States, as an example, have not necessarily altered travel behavior [1], strategies that require substantial investment could be quite risky. Nevertheless, many successful public transport projects in recent times may be identified [2]. Increasing public transport utilization in Brisbane, however, is not a simple or straightforward endeavor.

One method for addressing the substitutability of mode selection is to make the price of private vehicle travel more expensive and thereby increase public transport use. Economists have long stated that the way to reduce congestion is to charge motorists the marginal social cost of their actions [10]. This would ensure that each motorist pay for the externalities caused by vehicle use at particular times of the day, such as heavy congestion and pollution periods. Road user charges are a reality in Singapore and electronic road pricing has been or is being tested in cities like Hong Kong and Los Angeles [11]. The Bureau of Transport and Communications Economics has
examined road pricing in Australian capital cities and found that high costs for road use would in fact reduce private vehicle dependence [12]. However, the political realities appear to be that road pricing is too risky, regardless of its feasibility, as it is not being pursued. This leaves reductions in private vehicle travel to measures such as car pooling, telecommuting, or the increased use of public transport. Achievement through public transport services would require, at the least:

- more effective price structures;
- enhanced travel comfort;
- better suitability and convenience of service—quality;
- reductions in travel time—efficiency; and
- increased service access.

Each of these issues is important and worthy of further study. This paper will be limited to the last two items through the examination of access and efficiency issues related to public transport service provision.

3. Access to public transportation

A critical factor in public transport use is the access time or distance that someone is forced to overcome to get to a service stop. This is in contrast to the operation and connectivity of the public transport system. There is origin- and destination based access. The former may be considered the distance from one’s residence to their nearest public transport service stop, whereas the latter represents the distance from one’s desired trip target to its nearest public transport service stop. Access to public transport is an important service performance measure and is expressly recognized in most regional transportation plans [4]. In fact, regional transport planning guidelines for Brisbane specify an origin based access goal of 400 m to a public transport service stop for 90% of the total population [3]. This strategic policy is directed at increasing public transport utilization, so assessment of this performance measure is important for informing the planning and management process. Approaches for evaluating public transport access are detailed in Murray et al. [4].

The lowest spatial resolution of information associated with where people reside is the collection district level of the Australian Bureau of Statistics census hierarchy. This divides 806,292 people of the Brisbane statistical sub-division into 1538 spatial areas. The most recent population information for analysis is from the 1996 census. Spatial information in the form of public transport stops and routes was provided by the Passenger Transport Division of Queensland Transport for southeast Queensland. There are 10,909 public transport service stops located throughout the region, the majority of which are bus stops (98%). Given this, the focus of the analysis is limited to only bus service provision. The Brisbane sub-region contains roughly 7600 bus stops within its statistical sub-division boundary.

1Although cadastral information exists at an even finer spatial resolution, cadastral information does not report census oriented statistics like population or socio-economic characteristics. Given this, it is not suitable for the analysis carried out in this research.
Measuring regional access to public transport has been discussed in detail in Murray et al. [4] and may be determined by evaluating the proximity of an area to its closest public transport stop in relation to a distance or travel time standard. For Brisbane, the suitable access standard is stipulated as 400 m from an area to a stop. Thus, we may compute the minimum distance from a collection district to its nearest bus stop. If this distance is within the standard, then the area is considered to have suitable access to public transportation. In the current analysis, we utilize the collection district centroid as a representative location for an area and measure distance to transport stops using the Euclidean metric. The evaluation of access coverage is structured in ArcView version 3.2 [13] using Avenue scripts for real-time user interactive exploratory spatial data analysis. The user is prompted to identify the spatial layer being covered (collection districts), the attribute of interest (total population), the spatial layer providing coverage (bus stops), and an access standard. Processing and display of results takes less than a minute on a Pentium III/600 personal computer for this region.

In Brisbane, 86% of the total population is provided suitable access to public transport using the 400 m standard. The areas served within the 400 m standard are highlighted in Fig. 1. The city center is well served by public transport, so Fig. 1 reflects an outward access coverage pattern.

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It is worth noting that alternative approaches exist for evaluating access proximity (see [4]). The access results presented for the region under study here are consistent with alternative techniques such as buffering and areal interpolation of layers.
from the city. An important consideration before interpreting these findings is assessing the sensitivity of total population covered in relation to the access standard utilized. Such an evaluation may be done by varying the suitable access standard. This is summarized for Brisbane in Fig. 2, which shows access standard distances plotted against total population covered. In the figure, distance standards ranging from 200 to 600 m in 50 m increments are depicted. Total population covered ranges from 53.04% for 200 m to 93.26% for 600 m.

Given that there are no major jumps in the percentage of total population covered around the 400 m standard, it may be concluded that there exists reasonable stability in access coverage. Thus, some general conclusions may be drawn from the use of the 400 m standard. Brisbane essentially achieves the policy goal of suitable access coverage being provided to 90% of the regional population. Although this strategic planning goal is supposed to contribute to an increased use of public transportation, the overall percentage of trips taken using public transport has steadily decreased in the past decade. Obviously, increasing the use of public transport will require more than addressing access issues in the planning and management of urban growth. In fact, the efficiency of public transport is recognized as essential in that it must be more competitive with automobile travel times [2]. The important point here is that strategic regional planning tends only to focus on public transport access, which is found to be relatively good in the Brisbane region. However, the utilization of public transport is very low. Given this, it is important that alternative strategic approaches be developed and utilized in the analysis of public transportation service provision, if current trends of decreasing public transport utilization are to be altered.

4. Strategic analysis of stop placements

It is clear that access is only one element contributing to individuals electing to travel by public transport. Another consideration is travel time competitiveness. For this reason, public transport
must strive to achieve origin–destination travel times that are relatively competitive with automobile travel. Bus-based transit systems must, therefore, be concerned with developing appropriate routes that can be served efficiently. Clearly, fewer stops along a particular route increase the potential for bus travel speeds to be competitive with private vehicle speeds. However, stop placement should not be reduced to the extent that it decreases access to public transportation. In addition to stop minimization, public transport travel speeds may be further enhanced through strategies such as dedicated transit lanes and integration with higher speed light rail systems.

A critical issue, then, is what constitutes stop redundancy or inefficiency. Given the use and interpretation of the access standard, an approach for assessing system efficiency would be whether or not individual stops provide additional access coverage. As noted previously, the access standard in Brisbane is 400 m, so if a stop fails to provide coverage that would not otherwise exist, it is not enhancing regional access to public transport and its usefulness could be questioned. For example, Fig. 3 shows three pairs of bus stops along a route in Paddington (a suburb of Brisbane). On either side of the road (Given Terrace), the stops are within 150 m of each other. In this case, the middle pair of stops is not providing access to public transport, with respect to the 400 m access standard, that does not otherwise exist. That is, the outer stops essentially cover the same area served by the middle pair of stops; these stops may thus be considered redundant. This establishes a basis for identifying system inefficiencies in regional public transport service. The implication is that performance improvements are possible given that fewer stops served by appropriately structured routes reduce/minimize travel times from origins to destinations.

Murray et al. discussed the likely existence of redundancy in service access coverage in Brisbane [4]. Such superfluous stop placement may do little or nothing to increase access to public transport. Moreover, it likely increases system workload as there are more stops that must be included in routes. This, in turn, increases travel time and decreases service quality. Eliminating as much redundant transport stop access coverage as possible requires no institutional investment and theoretically has no associated costs. There are numerous levels for rationalizing how the analysis of service coverage redundancy is important. Perhaps the most significant is its use as a
strategic efficiency measure, much like the use of regional access coverage. In more operational terms, identifying access coverage inefficiencies represents an approach for assessing the existing configuration of public transport stops. Given that stop configurations typically evolve over time, it is quite valuable to engage in a system-wide or route level evaluation of service provision. Since bus services are characteristically flexible, such evaluation practices are an implicit feature of bus transit.

Altering public services is typically a politically delicate issue. This has certainly been an issue in public transportation service provision in Brisbane. Thus, it is important that impartial and defendable approaches be utilized when evaluating and modifying such services as it will be necessary to justify any and all changes to service provision. A strategically oriented approach addressing service coverage in terms of inefficient placement of stops is thus at the heart of making public transport a more competitive and appealing travel option.

4.1. Modeling approach

A strategic approach for measuring the degree of redundancy and inefficiency associated with the placement of public transport service stops may be structured using the location set covering problem (LSCP) proposed in Toregas et al. [14]. The LSCP was originally utilized for locating a minimum number of emergency service facilities [14] and has also been suggested for identifying a minimum number of express bus stop locations [15]. The use of the LSCP for assessing redundancy in service stop coverage for an existing public transportation system does not appear to be a previous application area.

Formulation of the LSCP for measuring system inefficiencies utilizes the following notation:

- \( i \) = index of service areas (entire set \( I \));
- \( j \) = index of current transport stops (entire set \( J \));
- \( d_{ij} \) = shortest distance or travel time between area \( i \) and stop \( j \);
- \( S \) = access distance or travel time standard;
- \( N_i = \{j | d_{ij} \leq S\} \);
- \( x_j = \begin{cases} 1, & \text{if transport stop } j \text{ is to remain in the service system} \\ 0, & \text{otherwise.} \end{cases} \)

Location Set Covering Problem (LSCP)

\[
\text{Minimize} \quad Z = \sum_j x_j, \quad (1)
\]

Subject to

\[
\sum_{j \in N_i} x_j \geq 1 \quad \forall i, \quad (2)
\]

\[
x_j = (0, 1) \quad \forall j. \quad (3)
\]

The objective (1) of the LSCP is to minimize the number of transport stops needed to provide complete access coverage to the service region. Constraint (2) specifies that each area is to be served by at least one transport stop. This ensures that all areas currently provided suitable access
coverage by the existing configuration of stops continue to be suitably served by the reduced number of stops. Constraint (3) imposes integer restrictions on the decision variables. The model structures a decision making process to determine which stops, in the existing configuration of stops, should be kept.

The LSCP is a spatial variant of the set covering (or minimum cover) problem defined in Edmonds [16] and Roth [17]. The difference between the two models, aside from the spatial context and application, is in the form of the objective function. The set covering problem includes a weighting on the decision variables in the objective function

\[ \sum_j a_j x_j, \]

where \( a_j \) is a non-negative integer. Thus, the weight for each site is equal to one in the LSCP. The LSCP and its more generic set covering extension are generally difficult to solve optimally for medium and large problem instances. Research associated with the development of exact and heuristic solution techniques for solving these problems is quite active. Although many advances have been achieved in terms of capabilities for solving set covering problems using commercial optimization software, heuristics continue to be developed and applied [18,19]. Lagrangian relaxation heuristics have proven to be effective for solving relatively large problem instances [18–20].

As noted earlier, the evaluation of stop placement efficiency was structured in ArcView version 3.2 coupled with a Fortran DLL (dynamic linked library) for real time user interactive exploratory spatial data analysis. Processing, solving and display of results generally took less than 1 min for the regional analysis of Brisbane. Solutions for the LSCP were obtained in the structured spatial analysis environment using a Fortran DLL written by the author, which solves the LSCP using a Lagrangian relaxation heuristic following the basic approach of Haddadi [19].

5. Coverage efficiency of public transportation in Brisbane

As noted previously, approximately 86% of the 806,292 people in Brisbane currently have suitable access to public transportation based upon the 400 m standard \((S = 400)\). The developed exploratory spatial data analysis tool enables potential redundancy or inefficiency in service stop placement to be identified. The planning problem involves 1538 service areas (collection districts) and 7589 bus stops. Using the ArcView analysis module integrating the LSCP, we found that only 588 bus stops are necessary for the continued provision of suitable access for 86% of the total population. That is, all areas currently characterized as having suitable access to public transport can actually be served by a substantially reduced number of the current stops. Given that there are 7589 stops in the Brisbane region, this represents a 92% reduction of existing stops. Thus, less than 1 in 10 stops are actually required to provide the current level of public transport access in

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3 A limit of 200 iterations was imposed in the Lagrangian heuristic given the large problem instances. Solution quality ranged from 0.28% to 5.58% of optimality, which is quite acceptable in such an analysis.

4 This particular problem has 7589 columns (variables) and 1538 rows (constraints). An attempt to solve the problem optimally using Cplex version 6.53 [21] was unsuccessful after 17 h of computational effort (1.5 million iterations and 550,000 branches).
the region. Fig. 4 depicts an inner city area of Brisbane, the suburb of St. Lucia, to highlight stop placement inefficiency in the region. Fig. 4 thus illustrates that there may in fact be considerable room for enhancing system performance if some stops are eliminated. Strategic questions may, therefore, be raised regarding the appropriateness of the current configuration of public transport stops throughout Brisbane.

Before going further, we shall interpret the above results in more detail in order to reflect upon their significance. There are 7589 bus stops, typically representing stop pairs on either side of a road. This situation is depicted in Figs. 3 and 4. Given this, we would essentially need to double the minimum number of stops identified using the LSCP to account for pairing of bus stops (which ensures service in opposite directions on a street segment). The strategic measure of inefficiency thus indicates that 1176 stops (doubling 588) would actually be the minimum number of stops necessary for complete coverage of those areas currently suitably served due to operational considerations. This still represents an inefficiency measure in the current configuration of stops of 84.5%. That is, at an operational level, only 1 in 5 stops are actually necessary to maintain current access provision. The comparison presented in Fig. 4 suggests that the significant reduction in necessary stops is in fact a result of the inefficient spatial distribution of public transport stops throughout the Brisbane region at this time.

The relationship between the minimum number of stops identified and various access standards may also be explored. This is similar to what was done for access coverage in Fig. 2. Thus, a range of access standards may be evaluated. The result is a tradeoff curve showing solutions in relation
to the access distance and the minimum number of stops needed. This has been done for Brisbane in Fig. 5 for access distances ranging from 300 to 500 m in 50 m increments. For example, if a suitable access distance is thought to be 500 m for this region, then only 469 stops would be necessary, whereas a suitable access distance of 300 m would require 715 stops in order to maintain current coverage. Although the Fig. 5 results are rather intuitive, they help to illustrate the subtle implications of varying regional public transport access standards in terms of a strategic perspective of stop placement inefficiency.

6. Discussion

The evaluation of tradeoffs associated with access coverage and stop placement efficiency can provide insight to policy evaluation and monitoring. The tradeoff of access coverage by distance standard shown in Fig. 2 gives some evidence that current strategic planning focused only on the provision of suitable access will do little, if anything, to increase utilization of public transport in Brisbane. After all, less than 7% of all trips in the region are taken using public transportation and this proportion is decreasing. There are significant implications in the evaluation of access for the current regional policy goals and standards established for Brisbane, since suitable access is essentially provided to 90% of the regional population. Current access coverage suggests that performance enhancements to the public transport system are necessary if utilization rates are to increase. In strategic terms, the LSCP provides a measure of coverage redundancies that may be directly interpreted as stop placement inefficiency. Based upon the stipulated access standard of 400 m, it was found that 84.5% of the bus system is technically not providing unique access coverage in the Brisbane region. This means that there is potential for increasing average bus
speeds (and decreasing origin–destination travel times) in order to make public transport more competitive with private vehicle travel.

Strategic techniques for assessing stop placement and access coverage tradeoffs are a starting point for the analysis of a regional public transit system. The process must be able to accommodate localized user interaction. Accounting for this in various ways would ensure the usefulness of strategic modeling tools, which provide direction for regional improvements. A number of extensions are worth mentioning. First, allowing for sub-regional or individual area access standards could be warranted. As an example, in the Brisbane city center it might be appropriate to consider a suitable access distance of 100 m, while suburbs on the periphery might be set at 450 or 500 m.

Second, the ability to adjust or modify solutions identified using the LSCP is critical. For example, due to terrain conditions, we may want to ensure that certain stops are included in an operational plan. The same may be true for route transfer stops. Thus, we could utilize the LSCP to ensure that these stops remain in the final system configuration and minimize the remaining stops needed to provide complete coverage. All this may be readily accomplished in the developed application environment. Third, incorporating differing levels of importance between stops in the objective function of the LSCP, as structured in Eq. (4), could be important. Stops serving as transfer locations, as an example, could have lower $a_j$ values than other stops. Finally, the developed approach using the LSCP could be utilized in a more restrictive way in order to focus on individual routes, suburbs or transport corridors.

The design of a transit system is certainly more complex and complicated than what could be structured in any optimization problem or analysis package. The developed strategic modeling approach presented in this paper provides a process for identifying system inefficiencies based upon established access measures. This information may then be used as a basis for debate or to justify changes to the current public transport system. In the course of such discussion, numerous alternative plans may be generated and evaluated. The developed exploratory tool also allows planners to demonstrate how local changes have regional benefits as well as positive effects on system performance. That is, fewer stops along a particular bus route, as an example, will undoubtedly mean shorter travel time along that route (assuming that each stop must be visited). These are in fact all too important issues considering the difficulty typically experienced in modifying the “flexible” bus-based public transit system in Brisbane. Once a stop is established, it is often extremely difficult to change or alter its location. Developing community support for system changes is essential in public service provision as individuals and local areas are often resistant to change or to a perceived loss of services.

An interesting implication of this research for bus services in Brisbane is that freeing up even one bus through the removal of inefficiencies could establish a basis for providing additional services to areas that do not currently have adequate public transportation service. Fig. 1 shows the areas without suitable coverage; some or all of these areas could thus potentially be served if efficiencies were to be achieved. Further, Murray and Davis [8] identified numerous areas in the Brisbane region that may be characterized as transport disadvantaged, which means that they need transportation services (given their relative socioeconomic makeup) but do not currently have suitable access to public transport. Additional such services could be dedicated to serve these high priority areas. An extension of the LSCP would conceivably be required to assist in this process.
7. Conclusions

Urban growth and change present challenges for regional development, particularly with respect to issues of sustainability. Public transportation will no doubt continue to play a major role in serving urban regions. In order to increase public transport use, service access and system efficiency are critical. An analysis of Brisbane, Australia was presented and illustrated the potential for improving public transport service efficiency while maintaining current levels of access coverage for the region.

The location set covering problem is an important strategic modeling approach for assessing public transport system inefficiencies. Integration with ArcView makes this an effective exploratory spatial data analysis tool. The public transport system in Brisbane was shown to have user access coverage that essentially meets regional policy goals; yet, utilization is particularly low. This suggests that changes to its public transport must improve system performance. Strategic assessment measures are needed for evaluating the extent to which current services may be enhanced. Use of our approach demonstrated that substantial redundancies exist in the current configuration of service stops. In fact, 84.5% of the bus stops in the region were found to provide no additional access coverage using the 400 m distance standard. The likely implication of this is that significant improvements in system performance are possible if some inefficiencies and redundancies are eliminated along routes. If a strategic planning objective is to reduce private vehicle dependence and increase the reliance on public transportation, then changes and modifications are imperative. The developed analysis measure is suggested to be an important component of the overall evaluation and provision of public transportation services.

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