Quantitative Analysis of Rapid Transit Alignment Alternatives

MICHAEL SCHABAS

Mr. Schabus is Chief of Rapid Transit Planning for the city and county of Honolulu. He holds a Masters of City and Regional Planning from Harvard University's John F. Kennedy School of Government, and a Bachelor of Architecture from the University of Toronto. He previously participated in design of the Vancouver, Canada “Skytrain” rapid transit system.

HONOLULU has long considered building a rapid transit system. Squeezed in a narrow corridor between the mountains and the sea, with only a few main roads, the city suffers extreme traffic congestion. In a city with only 800,000 inhabitants, the morning peak extends almost 3 hours and many commuters spend more than 2 hours per day on the road. An extensive freeway system has reached its limits and cannot be significantly expanded (Figures 1 and 2).

The same geography should make it possible to build a rapid transit system providing service unequalled in the world. The unusually dense suburban residential areas, typically built along narrow valleys and ridges at 12 units per acre, already support good bus service, with almost 80 million riders per year. Most employment and activity centers are in the same narrow corridor, nearly half of all jobs and most other trip destinations are within a short walk of the system. A coordinated bus and rapid transit system could offer commuters substantial time and cost savings.

Honolulu began planning a conventional heavy rail rapid transit system in the 1960s. After extensive study and debate, the project was cancelled in 1981 when both the Mayor and Governor opposed it. The city is now considering a new advanced rapid transit system. Using one of the newly proven mini-metro or people-mover technologies offers benefits of smaller and more frequent trains providing better service. The compact stations and slender elevated guideways can be threaded through the existing urban fabric and integrated with new development.

Honolulu is also attempting to maximize the involvement of private developers in order to reduce public costs and risks, and to create the most efficient system. Besides encouraging joint develop-
Figure 1. Honolulu’s location on Oahu’s south shore

Figure 2. Honolulu’s crowded Lunalilo Freeway
ment of stations as part of initial system construction, system supply consortia are being invited to submit proposals for turnkey supply, or even franchise implementation and operation. This new approach to the project is gaining widespread support from both the city and state, and from the public.

The use of newer technology opens a wide range of new alignment alternatives, including short branch lines that penetrate into the centers of Honolulu International Airport, the University of Hawaii, and the Waikiki tourist area (Figure 3). This article describes the process used to optimize the system design, by minimizing costs and impacts, while maximizing the potential for efficient bus transfers, walk-in ridership, and joint development. Besides environmental laws and community concerns requiring that all reasonable alternatives be considered, this bottom-line approach to system costs and revenues should generate the best possible return on investment, increasing the potential for private funding and implementation.

Somewhat surprisingly, this was the first time a formal, quantitative process was developed for this purpose. Normally rapid transit designers rely on their judgement and political decision makers to choose between comparable route and station alternatives, making subjective and perhaps inefficient trade-offs between concerns of

---

**Figure 3. Conceptual route schematic**
different technical disciplines. It can be said that the ideal alignment for the civil engineer is straight and level, preferably in open country at the edge of town. The equipment designer prefers that there be no stations to delay operations, and perhaps no passengers either. The city planner prefers that the system have many stations, usually near the most valuable real estate, while the politician wants a route that appears to serve as many communities as possible, but adversely impacts none.

As an example, if planning or political concerns suggest consideration of an additional station, typically a construction cost estimate is prepared and used as the basis for decisionmaking. If politicians are convinced to provide funding, the station is typically added (or in the reverse case, deleted).

In fact, actual construction may make up less than half the real cost of a station. Additional dwell time will increase the vehicle fleet required to carry a given capacity. This in turn will require more maintenance and storage capacity, and will increase lifetime operating costs. On the other hand, increased ridership due to the convenience of an additional station may generate substantial revenues. There may also be savings to bus operating costs if feeder routes can be shortened.

The process described in this article attempts to add some rigor to the system design methodology, rather than rely simply on who talks loudest in staff meetings or at public hearings. While environmental and other community concerns might in some circumstances require selection of something less than the most cost-effective alignment, at least the trade-offs would be explicit and quantified.

**METHODOLOGY**

Honolulu’s first-stage rapid transit corridor was identified according to existing bus ridership. Daily passenger volumes along the corridor climb from 20,000 at Pearl City to 100,000 through downtown.

The first-stage corridor was divided into seven evaluation segments, generally with a nodal point between each segment where all alternatives converge (Figure 4). The convergence of alternatives at nodal points is a convenient aspect of Honolulu’s unique linear geography, as it allowed independent consideration of alignment alternatives between each segment. Selection of an alternative in one
segment usually does not dictate the range of choices in an adjacent segment.

The net total cost of each alternative for each segment was estimated, using a set of yardsticks. These yardsticks were developed to efficiently estimate the different costs and benefits of different alignment alternatives, without requiring detailed design of each alternative or running elaborate computer models. The yardsticks estimated differences in rapid transit system costs, feeder bus costs, ridership generation, and joint development for each alignment alternative.

RAPID TRANSIT SYSTEM COSTS

Generally, planners and politicians understand the benefits and costs of a rapid transit system as depending on its length, the number of stations, and the peak-system capacity. They generally recognize that right-of-way requirements, which dictate an elevated, at-grade, or underground alignment, also have a significant impact. However, this is typically the limit of their understanding.
Bottom-Up Cost Estimating Procedure

The black box perception of rapid transit costs is at least partly the result of a bottom-up cost estimating procedure. Equipment (vehicles, rails, control systems) and construction (concrete, steel, right-of-way and utilities) cost estimates are normally built up piece-by-piece, based on relatively detailed system designs. Operating cost estimates are developed similarly in a bottom-up process. Life-cycle costing, if done at all, is estimated on a haphazard basis, with very little meaningful feedback to the system designers.

This process is appropriate once a project is defined and ready to be built, but it provides inadequate information for designing the optimum system. Furthermore, the bottom-up method is notoriously inaccurate during the early stages of a project, when requirements are not yet clearly defined.

The bottom-up method requires detailed identification of all required inputs, and estimation of numerous input costs, such as labor cost per hour, concrete cost per cubic yard, electricity cost per kilowatt-hour, and so on. Bottom-up cost estimates invariably leave many things out, intentionally or by accident, so a contingency is usually added, depending on the competency and honesty of the engineering organization and their political masters. Of course politicians may look at the inconsistent record of capital project budgets and add a contingency of up to 100 percent. The result can be either a bad project being built because of low estimates, or a good project being delayed or not built.

Top-Down Cost Estimating Procedure

The yardstick approach works from the top-down. The cost of a system is estimated much as one would budget for a wedding reception. Instead of a cost per guest, there is a cost per station and per linear foot of guideway, based on total capital and operating costs of recently completed similar projects. Different yardsticks can be developed for different system capacities and guideway types, just as one might budget differently for male, female, and child guests based on varied rates of eating and drinking. Yardstick costs must also be adjusted for local conditions and productivities. Costs estimated per unit of output are far more useful for the decision maker than input costs, whether deciding on a guest list or a rapid transit route.
RAPID TRANSIT ALIGNMENT ALTERNATIVES  409

In Honolulu, where the planned system is virtually all elevated, three sets of guideway and station yardsticks sufficed. High volume guideway and station yardsticks were used in the central portion of the main line, where two tracks are required and stations and trains must provide an ultimate capacity of about 15,000 passengers per hour, per direction. Medium volume guideway and stations were used for outer line segments, where capacity of about 8,000 passengers per hour will be required. Low volume yardsticks were developed for the short branch lines that will serve Waikiki, the university, and the airport. These relatively short, low-volume branch lines can be built primarily using single guideways, with some passing tracks.

Ideally, cost yardsticks are calibrated using statistical methods, such as multiple regression, but the limited data makes this impossible. Besides differences in local materials, labor, technology, and power costs, only a few completely new rapid transit systems are built each year. With the effects of inflation and fluctuating currency conversion rates, a sufficiently large data set could not be developed. Instead, budgets of recently completed similar projects were analyzed and allocated to each yardstick, with consideration of the effects of local costs, inflation, and currency conversion rates.

For example, construction costs for guideways and stations were adjusted for local rates. Vehicles, however, are supplied by a competitive international industry and were not adjusted. Vehicle costs were assigned to stations and guideways proportional to the time required by each. Operating labor and power costs were adjusted by local rates, but not spare parts prices. All operating costs were capitalized and assigned to stations and guideway yardsticks, on the same basis as vehicles.

Cost yardsticks were in turn validated by multiplying them by appropriate factors for each of the recently completed projects: the Miami Downtown People Mover, the Vancouver Skytrain, the Detroit People Mover, and the Chicago Airport People Mover. They estimated actual system costs within 30 percent.

The estimated variances corresponded fairly well with known differences in project management methods and history, with the Detroit budget approximately 30 percent above the yardstick estimates, and the Chicago and Vancouver projects slightly below estimate. While all three projects were constructed under single supplier turnkey contracts, the Chicago and Vancouver customers
were willing to make and stick with design decisions while the Detroit project required frequent changes and ultimately was transferred from state to city jurisdiction.

FEEDER BUS COSTS

Location of rapid transit stations can substantially affect the ability to provide an efficient feeder bus service. Bus cost models exist that use a yardstick approach, with costs per bus hour, peak buses, and bus miles. It was decided that for evaluating alignment alternatives, peak bus requirement alone was a sufficiently accurate yardstick, combining both operating and capital recovery costs.

A hypothetical bus service plan was developed, based on reasonable assumptions of bus routes, ridership, and service standards for the year 2005, for one possible rapid transit alignment. The variation in round-trip time required for buses to feed each alternative station location was estimated, and the impact of peak bus fleet requirements calculated. The long-term differences in feeder bus costs were estimated and capitalized in current dollars.

STATION RIDERSHIP

Although Honolulu plans to coordinate feeder buses with rapid transit, the need to transfer at one and especially at both ends of a trip can significantly deter potential users. If transit stations can be located within convenient walking distance of jobs, shopping, recreation areas and homes, many trips will not require a transfer, and most trips will only require one transfer. This makes the system more attractive to potential customers. A method was developed to estimate the potential additional ridership at each alternative station location, and to estimate the direct effects on system revenues.

Rapid transit system ridership is typically estimated using complex, regional transportation models. Although recently some of these models have been adapted for microcomputers, they remain relatively unwieldy and insensitive for estimating ridership differences for alternative station locations. Instead, a yardstick approach was developed to estimate the differences in ridership that could be expected for different station locations, based on existing and future land uses within the immediate walking distance of a station.

Actual pedestrian routes around each station alternative were mapped and measured, identifying the areas within 
\[ \frac{1}{6}, \frac{1}{4}, \text{ and } \frac{1}{2} \text{ mile}. \]  
This method is a substantial improvement over the standard method of
travel zones, where pedestrians may in theory be within walking distance of a destination, provided they can cross a stream or eight-lane freeway. The number of residents, jobs, shopping areas, and other destinations within each area was estimated from a variety of data sources, including land use maps, development plans, and census data. Anticipated development to the year 2005 was included in the analysis.

Standard trip generation and mode split rates from Honolulu's regional transportation model were used to estimate the riders within each radius that already use transit and would use it even if a bus feeder trip is required. This base ridership was not considered in the evaluation of alignment alternatives, although it will be considered in sizing station entrances.

Additional riders, who would likely use transit because a station is within walking distance, were estimated as a multiple of the base ridership. Although there is no empirical estimation of such multiplication factors, a wealth of related research was used to identify reasonable bounds so the assumed values are not entirely arbitrary.

For example, even with the extremely good service that Honolulu's rapid transit system will offer, one would not expect transit's overall mode share to increase above 50 percent even within \( \frac{1}{4} \) mile of a station. Similarly, one would expect walk-in ridership from shopping areas to drop off beyond \( \frac{3}{4} \) mile, while travelers to work or recreational centers facing severe parking problems might be prepared to walk up to \( \frac{1}{2} \) mile.

The value of an incremental rider to the system was assumed to be $1.00, based on the net revenue from a reasonable average fare. Of course, the actual fare structure has not been determined, and will probably vary depending on the type of traveler and trip. A more complex bottom-line approach might give a higher value to attracting tourist riders, who will probably pay a cash fare, compared with commuters who compete for scarce rush-hour seats and may use discount passes.

Either approach underestimates the value of a new rider from a public perspective, as it does not consider indirect benefits such as reducing traffic congestion and air pollution. The Urban Mass Transportation Administration has suggested that a public expenditure of several dollars may be justified to attract a single new transit rider, and in fact many city bus systems currently operate with a marginal cost of more than $3.00 per passenger. However, since
Honolulu is attempting to make the project attractive to the private investor, indirect benefits were not considered in this analysis.

Finally, the additional ridership per day in the year 2005 was multiplied by $2,100 to yield current value. This assumed 300 equivalent weekdays per year and a 15 percent discount rate provide for some consideration of risk.

JOINT DEVELOPMENT

Just as Honolulu’s constrained geography is the cause of extreme traffic problems, it also results in very high land values and severe development constraints. There is, quite literally, no such thing as low-cost fringe land. Even industrial areas cannot economically provide adequate employee parking. Shopping centers typically provide much less than the recommended number of parking spaces, even with two-, three-, and four-level parking decks. So-called free parking is closely supervised for poaching by adjacent occupants.

In such an environment, availability of rapid transit may add substantially to the value of nearby properties. For example, it currently costs between $15,000 and $30,000 to provide one additional structured parking space in Honolulu, and a new apartment or office building typically requires several hundred spaces. Buildings within walking distance of rapid transit could very likely reduce their parking provisions by 30 percent or more. With an estimated 50,000 parking spaces planned for construction in the next 20 years in central Honolulu, savings from this alone could be in the order of $500 million.

The effects of rapid transit on parking requirements will most likely extend to areas with good feeder bus service, but they will be most important within walking distance of stations. Although no single mechanism has yet been selected, Honolulu is considering a wide range of techniques to share in these benefits. At minimum, the city will benefit from increased tax revenues where rapid transit allows more efficient development. Ideally, developers close to stations will be induced to contribute to system costs proportional to the benefits they receive. In any case, it is certainly preferable to locate stations adjacent to property that is suitable and likely to be developed at high densities, rather than in the center of a freeway interchange, or surrounded by industrial or military land that is unlikely to be redeveloped. Naturally, this requires some way of quantifying the
value of joint development potential, so trade-offs can be made with other system costs and objectives.

The potential savings in parking costs appear to be a reasonable basis for estimating joint development benefits. The probable development in the vicinity of each station alternative was identified and estimated, as well as the effect rapid transit might have on parking requirements. The reduction of parking requirements within ¼ mile of each station site was valued at $5,000 per space, considering that much development would not occur for many years, and might not occur at all.

APPLICATION OF YARDSTICKS

Alignment and station alternatives were quantitatively evaluated, as described. In no case did the findings appear illogical, although several marginal stations and alignment changes ranked higher or lower than conventional wisdom would suggest. The results justified significant changes from the previous heavy rail plan.

The original heavy rail route through the densely built up downtown and Kaka‘ako areas, including the large Ala Moana shopping center, was more or less straight. Five stations were spaced on average about ¼ of a mile apart (Figure 5). It included a 1½-mile long underground section, to be constructed by cut-and-cover methods along streets often only 40 feet wide between historic buildings.

Quantitative analysis reveals that a longer alignment through downtown with twice as many stations is justified on walk-in ridership and joint development potential alone. The proposed route has a sideways S-shape, swinging north and then south of the original alignment. It maximizes coverage of current and future employment areas and multiplies the opportunities for new development around stations.

By taking advantage of wider streets lined with generally non-descript new buildings and parking structures, an entirely elevated alignment is possible, avoiding the costs and disruption of tunnelling and offering a better passenger environment. Although this route is longer and has many more stations, it should actually cost less and generate more riders and system revenues. From the potential investor’s point of view, whether government or private, it has a much higher bottom-line value.

East of downtown, the original plan followed a meandering route
in order to serve both the Waikiki tourist area by the ocean, and the university in a mountain valley. While both are large walk-in ridership generators, the single line served neither very well, with most hotels and many classrooms beyond reasonable walking distance of the stations.

Instead, a more direct main line alignment with two branch lines appears to be more cost-effective. The branch lines can effectively penetrate both areas with increased walk-in ridership potential. Because branch line stations do not add to main line travel times, these stations can be closely spaced, multiplying the opportunities for profitable joint development. Closely-spaced branch line stations can also be quite small and inexpensive, with a single elevator and stairs instead of escalators (Figure 6). Both Waikiki hotel developers and the university may be willing to contribute to costs of short extension to the branch lines, which will also reduce feeder bus costs.

Outside of downtown, quantitative analysis suggests following a shorter and more direct alignment, with fewer stations. For example, the original heavy rail scheme followed the H-1 freeway passing the airport and Pearl Harbor base (Figure 7).

Reportedly these were identified early in the planning as “must
serve" destinations, because of their perceived large employment and traffic concentrations. It would appear that the alignment and stations were never subjected to a rigorous quantitative alternatives analysis.

In fact, an alternative route that is more than one mile shorter with two fewer stations appears much more cost-effective. Feeder buses were required in any case to serve the dispersed naval base, and the savings from shortening the rapid transit line more than offset the costs of operating the slightly longer bus routes. While the original alignment ran mostly along a freeway through industrial and military lands, the shorter alternative serves a dense apartment area, with many potential walk-in riders. The stations may be combined with joint development of expanding community shopping centers.

Although the original scheme was designed to serve the airport, due to cost and curvature requirements it only provided one station behind the parking garage, as much as a 10-minute walk to some check-in counters. Instead, a single-track branch line can connect the
airport to the main line. Besides substituting one mile of low-cost branch line for expensive main line, the branch line can penetrate the airport terminal better, with separate stations actually on the roof of each major terminal. Branch lines at each end of the first-phase system may also reduce costs by avoiding the terminal station syndrome. Instead of building a single, expensive interim terminal station, requiring off-street bus loading areas and possibly road and freeway ramp modifications, feeder routes can be terminated at two or three stations, where moderate volumes allow low-cost loading on existing streets.

CONCLUSION

The quantitative alignment and station evaluation methodology offers system designers a simple and reasonable way to make trade-offs between different objectives. This should make it possible to evaluate a wider range of alternatives, better optimize a system's cost effectiveness, and thus make a project more attractive to public and private investors. The methodology also provides a valuable tool for justifying decisions that might otherwise be determined less efficiently in the political arena.