Vertical Transportation Configuration – Design Approach and Traffic Analysis Theory

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As cities grow vertically, vertical transportation systems (elevators, escalators and moving walks) become the corner stone to support this vertical development and the life line for the buildings that constitute this development. Yet this criticality is not reflected in the approach to design, selection and integration of the total vertical transportation system. This paper is presented in four parts and explores the prevailing approach for establishing the vertical transportation configuration, introduction to traffic analysis, theory of traffic analysis and adoption of appropriate approach.

Keywords: Elevators; Escalators; Moving walks; Vertical transportation; Traffic analysis

PREVAILING APPROACH

The approach to most aspects of building design has evolved into a highly technical and specialized science, significantly departing from the days of thumb rules and yardsticks. This statement, however, should not be applied to the prevalent approach for selection of the vertical transportation configuration. The prevailing approach to establish the vertical transportation configuration is predominantly dependent upon two criteria, past experience, supplier's standards, and two considerations, namely, economic considerations and architectural considerations.

Past Experience

Past experience and references provide a sound basis for taking most of the decisions, regarding vertical transportation requirements. However the reference to the experience has to be in totality. But in reality this totality is impossible as no two buildings scenario can exactly be same which can be changed based upon occupation pattern, socio–economic time frame, the population character, etc. This can be illustrated by two examples.

In the Stock Exchange, Mumbai, people who have visited the impressive P J Jeejabhoy building through the 80s and the 90s would remember the serpentine queues to get to the lift. However as the change occurs from ring based trading to web based trading, the number of visitors to the building has been droped dramatically.

Similarly, the advent of call centres also probably demonstrates the extreme change to building population thumb rules.

While the stock exchange scenario is the rare one, present day inter floor and 24x7 commercial operations not only affect elevator traffic analysis thumb rules, but also blow away the 240 stops per hour (in some cases even less than 180 stops per hour) design and life span criteria for the elevator components.

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The socio – economic impact can also be seen in the residential segment with major changes in the traditional traffic patterns. In earlier days, most households managed with one full time domestic help. But now the new trend is task oriented 'multiple' helping hands with multiple trips in the apartments throughout the day. A study of a two–bedroom apartment indicated that four domestic helps usually can make six visits in addition to the delivery boys (covering newspapers, magazines, milk and bread, the car cleaner and the driver). Additionally the apartment also had frequent courier and pizza deliveries. Even the movement of the residents have increased with multiple activities through– out the day and not just limited to the morning and the evening rush hours. The children for instance, are engaged in tuition visits and multiple extra curricular activities in addition to their school schedules.

Supplier's Standards

With increasing competition, most businesses have been pushed to standardization to achieve cost reductions. The Elevators and Escalators (E andE) companies too have not been different. Yet the problem arises as these standard specifications have been derived from either historical assumptions or international assumptions. Both are out of place in the Indian context. While the E and E market in India is growing in comparison to world markets like China the Indian market is small (so far the technology, quality and service demands are concerned) and developing a product specifically for India is not a priority for most of the industry majors.

It also needs to be kept in mind that naturally each supplier would be compelled to propose recommendations (at times even backed with traffic analysis calculations) suiting their product offering, rather than what is appropriate for the building.

Economic Considerations

It can be understood that developers would have financial priorities during deciding for the vertical transportation configuration. An extreme example would be the acceptability of manual door elevators. Walking stick or wheel chair dependent users, while normally independent and mobile are constrained when faced with a manual door elevator. The other downside of this is that many building owners and occupants are stuck with manual door elevators even if they want to change as they would be restricted by smaller hoist way sizes that were considered at the initial stage for manual door elevators. Interestingly when the world and India are moving towards handicapped and elderly friendly environments, the Indian E and E industry has not done enough to push for change in this basic requirement. It is also self explanatory that legislation has not been too helpful either.

Economic considerations also force borderline design assumptions leaving no leeway for any change in the building characteristics. There are numerous instances of building owners, desperately searching for solutions to add additional hoist ways and elevators or increase capacities and speeds. Most of these have ended as exercises in futility.

Economic considerations also results application of single escalators when there should be actually double escalators to be provided for both directions of travel.

Architectural Considerations

Unless the elevators and escalators have been incorporated as show pieces of the building, their location tends to find low priority in the planning stages of a building. The norm is to fit in the solution into the building after accommodating all the other architectural priorities, with little attention in traffic analysis and simulation, the optimum circulation patterns within the building and the required locational priority. Even when there has been prior effort to accommodate it as a show piece, the solution ends up with very inefficient handling capacity by virtue of location, shape, etc.

The result is an under elevatored building through wrong specifications or straight forward inadequacy, wrong locations or lobbies etc. In various combinations and proportions, the resultant solution can be very expensive and at the same time very inadequate. Notwithstanding the cautionary footnotes, the wide availability of standardized product brochures and drawings encourage this trend.

In fact there are numerous instances where the solution has been finalized and sold just on the basis of standardized product brochure and without reference to project details. Some very prominent landmarks stand testimony to this fact.

No doubt the criteria and considerations mentioned above have their merits as a 'quick' thumb rule for estimating the vertical transportation solution. But they cannot be a substitute for a full fledged vertical transportation analysis including traffic analysis to arrive at the appropriate solution. After all, they are just pointers meant to compare recommendations and not an end in itself.

INTRODUCTION TO TRAFFIC ANALYSIS

Establishing Traffic Patterns

The first step in arriving at a vertical transportation configuration is to make a detailed projection of the population and the traffic pattern of the building. An estimate has to be made of the building population-occupants and visitors, their distribution by floors and their time and rate of arrival, departure and movement within the building.

The traffic pattern of a building depends upon the building characteristics, such as, building dimensions, building requirement, building type,public facilities and location, tenancy profile, operation time and location.

It is also important to remember that the population profile of a building keeps changing over a period of time. The design should be able to accommodate marginal changes in the passenger demand, specially in speculative buildings.

Determination of the Peak Passenger Demand

In every building, there is a critical peak period which determines elevatoring requirements. The design should provide sufficient service to meet this peak period in terms of quantity of service or the handling capacity and quality of service or the passenger waiting time

There are various approaches to determine the critical peak period. As per the industrial norm, size of a lift system is specified by the number of passengers requesting service during the heaviest five min of the up peak traffic condition (traffic predominantly upward from the lobby). Under typical conditions, such a configuration will produce acceptable average waiting time without having excess capacity during the slack hours.

The down peak traffic is usually larger than the up peak traffic. But during down peak a lift car fills at 3–4 floors and expresses (provided a load sensor has been provided and works) to the lobby. This reduces the time taken by the car to complete a round trip and increases its handling capacity. Down peak traffic is therefore not usually taken into account in the design of the lift system. There are, however some special situations, such as theatres and movie-halls, where a down–peak analysis would produce a more acceptable system than the up–peak analysis.

In single tenancy buildings with higher floor population, such as, call centres, two–way and inter–floor traffic can have a significant impact on efficiency of the lift system. A high traffic area, such as a restaurant, with an intermediate floor would completely alter the traffic pattern of the building. Additional traffic studies may be required to provide for such conditions.

THEORY OF TRAFFIC ANALYSIS

In this part the mathematics have been introduced by which a match can be esablished between the passenger demand and the operational performance of the vertical transportation system.

The Traffic Analysis Components[1–2]

The peak handling capacity (HC) of a lift system is the total number of passengers that it can transport during peak traffic conditions with a specified average car loading. The specified average car loading referred to as capacity factor (P), which is assumed to be 80% of the rated car capacity (CC), which would be out of place for premium buildings, hotels or residential buildings. The handling capacity is normally calculated for a five min peak period and is referred to as five min handling capacity [HC 5 min].

The passenger average waiting time (AWT) is the average period of time, in seconds, that a passenger spends waiting for a lift, measured from the instant the passenger registers a waiting call until the instant the passenger can enter the lift. To quantify these two determinants of operational performance, two parameters are needed to define, namely, round trip time (RTT) and peak interval (INT).

Round Trip Time (RTT)

It is the time in seconds for a single car trip around a building, from the time the car doors open at the main terminal, until the car doors reopen, when the car has returned to the main terminal after its trip around the building.

Peak Interval (INT)

It is the average time between lift car arrivals at the main terminal floor with cars loaded to 80% of the rated car capacity (CC) during peak traffic conditions. Thus, INT = RTT/L, where L is the number of lifts in the group and HC = 300/RTT × 0.8 × CC × L, where HC (5 min) is the 5 min peak handling capacity.

The other components of traffic analysis would include average travel time to destination (ATD), average transit time (ATT), which are not considered normally.

The Mathematics

As already mentioned, there is a critical period and a peak traffic pattern which determines the system's operational performance. For the purpose of illustrating the mathematics, the critical traffic is assumed to be up–peak as in normal practice.

Evaluation of Round Trip Time (RTT)

If P is average number of passengers carried (capacity factor); S, the average number of stops; H,the average highest floor (average reversal floor) and t_v, single floor transit time, *ie*, inter–floor distance/rated speed, then by definition,

RTT = P × (passenger loading time+passenger unloading time)+(S +1) × (door opening time + door closing time + single floor flight time) + (H–S) × t_v(time to travel remaining floors +(H–1) × t_v(time to express to main terminal)

For simplification of the above formula, two time variables have been introduced, namely, stoping time (t_s) and passenger transfer time (t_p); now,

stopping time (t_s) = door opening time + door closing time + single floor flight time – single floor transit time(t_v), and

passenger transfer time (t_p) = (passenger loading time + passenger unloading time)/2

So,round trip time (RTT)

$$RTT = 2Ht_v + (S+1)t_s + 2Pt_p$$

Assumptions to reach the above equation:

- There is a pure up–peak traffic profile.
- All floors have equal population.
- Rated speed is achieved through a single floor flight.
- Inter–floor distances are same between all floors.

Evaluation of H and S[2]

If passenger arrival is represented by a rectangular distribution function (assuming constant arrival process for passengers), then S (Basset Jones in 1923) and H (Schroeder in 1955) are calculated hereunder.

$$S = N\left[1 - \left[1 - \frac{1}{N}\right]^P\right]$$

$$H = N - \sum_{i=1}^{N-1}\left[\frac{i}{N}\right]^P$$

If passenger arrival is represented by a Poisson probability distribution function (Tregenza in 1972), then S and H are calculated as follows

$$S = N\left[1 - e^{\frac{-\lambda}{N}T}\right]$$

$$H = N - \sum_{i=1}^{N}\left[e^{\frac{-\lambda}{N}T}\right]^i$$

where, P is capacity factor; N, the number of floors above terminal floor; λ ,the arrival rate, T , the time interval and e is 2.718 (exponential function).

H and S can be calculated based on the projected population arrival rate to determine the RTT. Once RTT is known, one can evaluate the INT and the HC. Multiple iterations by varying the vertical transportation configuration required to be done to achieve a balance between an appropriate HC and INT that is close to the required.

It is also to be noted that the mathematics discussed above considers the up–peak as the critical peak. In reality, the actual critical peak pattern would vary depending upon the building, yet is normally not considered due to the complexities involved as well as the reluctance to get into the detailing.

Average Waiting Time

Keeping in mind that average waiting time (AWT) and interval (INT) are not identical, Barney and Santos have established that a theoretical relationship could exist between interval (INT) and passenger (AWT) depending upon the percentage of actual car loaded to the rated car capacity (CC).

During up–peak traffic conditions, this approximates as,

$$\text{AWT} = [0.4 + (1.8P/\text{CC} - 0.77)^2]\ \text{INT}$$

Yet, Barney admits that passenger waiting times cannot be easily measured. Other experts use thumb rule assumptions ranging from 50% of INT to 80% of INT to establish AWT.

Realistically, AWT can be established only using computer simulation. And this could be the reason why most standards (including IS 14665) refer to the acceptable norms of interval and not to the average waiting time. Yet, what matters to a passenger is the time he has to wait and not the time between two elevators.

It is obvious that the mathematics involved in traffic analysis and the required understanding is complicated. Acquiring the required understanding of the subject is beyond the sales budget priorities of most E and E sales engineers.

Moreover due to involved complexity, most traffic analysis approaches do not go beyond the simple up–peak analysis, ignoring inter floor traffic patterns or even extremes of a shift change as would be applicable for a call center.

THE APPROPRIATE APPROACH

Vertical Transportation Analysis

The reluctance to undertake the required detail of vertical transportation analysis is due to its complex science and mathematics. In fact most E and E companies do not even include traffic analysis as part of their induction or training program for their engineers. In this regard, some books are served as ready references[1–2].

All major E and E companies and some other consultancy firms have proprietary software for transportation analysis. However as rightfully said by one of India's prominent developers and supported by a very senior manager from one of India's largest construction companies, each elevator company ends up with varying recommendations. Understandably their arguments have to be favouring their product offering.

The results obtained from traffic analysis software, even when from independent sources, cannot be expected to interpret the analysis or arrive at the final appropriate solution. Further to establish the primary data for the analysis itself is a specialized job that requires extensive experience and understanding.

Limitations of Vertical Transportation Analysis

Even if the vertical transportation requirements were established on the basis of detailed and unbiased traffic analysis calculations, the absence of further collaboration to establish the circulation patterns and optimum locations, configurations, access routes, lobby sizes and layouts, improper zoning etc diminish the efficacy of the vertical transportation solution. Actually, optimization cannot be achieved without integration of the vertical transportation requirements and logic with the horizontal transportation patterns within the building.

For escalators also,these factors have the potential to provide a serious impact on the business beyond the consequences of poor traffic handling.

The Appropriate Solution

Vertical transportation analysis and design has to be recognized as a vital science critical to any building. The vertical transportation solution and the planning for this solution has to be established at the drawing board stage itself and not as an after thought. All supporting players to a project need to appreciate that rarely will there be a second chance to remedy deficiencies.

The appropriate vertical transportation solution will be a derivation from the requirement as per scientific vertical traffic analysis and simulations covering all aspects, which can influence the traffic handling and a balanced past experience, supplier’s standards, economic considerations and architectural priorities.

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