A Comparison of Some New Light Rail and Automated-Guideway Systems

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The past decade has seen dramatic developments in urban rail transit, particularly in the field of light rail transit (LRT). At the same time, several proprietary automated systems have been developed and deployed, often claiming superior levels of service and cost-effectiveness. Data are now becoming available that make it possible to check, for the first time, how well the new automated-guideway transit (AGT) systems are meeting their promoters' claims, and to compare such systems with the new conventional LRT systems. Methodologies are presented to collect and screen performance data from different systems in a uniform manner, and examples are developed to show how these data can be used to compare modes using actual operating information to the maximum extent. When new AGT systems are compared with new LRT systems, or when AGT and LRT are compared on identical alignments, it appears that the cost of additional maintenance and supervising staff and additional "non-staff" budget may exceed the savings that AGT systems achieve by eliminating operators. Although the new AGT systems represent a further advance in the development of urban transit technological capabilities, and reflect great credit on those who have built and financed them, they may also contain the seeds of future problems. Having a significantly higher construction cost per mile than LRT, urban areas with AGT will tend to have smaller rail networks than equivalent areas selecting LRT. Being proprietary systems in limited use, they may experience future procurement problems, particularly if the promoter goes out of business. Being a contemporary, high-technology product, there is also a high risk of obsolescence in future years.

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THE PAST DECADE HAS seen dramatic developments in urban transit, particularly in the field of light rail transit (LRT). Several proprietary automated-guideway transit (AGT) systems have been developed and deployed, often claiming superior service and reduced operating costs, mainly through the elimination of the need for train operators.

Until recently, the manufacturers were the primary source of information on the new AGT systems. Data are now becoming available from other sources, making it possible to check, for the first time, how well the AGT systems are meeting their promoters' claims in actual transit service, and to compare the results with those of some new LRT systems.

This paper offers a compilation and interpretation of data from some of the new LRT and AGT systems, and a methodology to measure how well the claims of the proponents are being realized. For the purposes of this paper, only transit systems that are in revenue service are considered, and minor special purpose lines, such as downtown or airport people movers, are not included.

Characteristics of LRT usually include the following:

- Manual operation, with one operator per train;
- Large, articulated cars, typically 80 to 90 ft long, able to run in trains of up to four cars;
- Operation on a variety of rights-of-way, from city streets to fully grade-separated tracks; and
- Use of a long-established "generic" technology, with many supply sources available for every component.

Characteristics of AGT usually include the following:

- Automatic operation, not requiring an operator for each train;
- Medium-sized cars, typically about 40 ft long, and often operated as married pairs, and in trains of up to two pairs (four cars);
- Requirement for full grade separation, often with elaborate anti-intrusion devices at stations and on the right-of-way; and
- A number of competing proprietary technologies, mutually incompatible, and in some cases, aggressively marketed.

Examples of AGT systems include these seven:

System	Country
Skybus	United States
VAL	France
SkyTrain	Canada
Docklands	England
TAU	Belgium
Portliner	Japan
M-Bahn	West Germany

INFORMATION SOURCES AND INTERPRETATION

Information on the operation of various LRT and AGT systems was derived from a variety of sources. These included reference material, promotional material, industry publications, budgets, correspondence, and field visits. Whenever possible, data were cross-checked between sources, and major inconsistencies explored. Sources are referenced as they are used throughout the body of this paper.

As information was collected and cross-checked, the need for careful screening became more apparent. Reporting methodology differed between systems, and information was sometimes published in a format intended to show the operation concerned in the best light. Such partial or incomplete data can be said to suffer from the "iceberg effect"—only part of it is visible.

This "iceberg effect" is commonly caused by at least one of several factors. On new systems, the suppliers are sometimes required to provide maintenance or spare parts for a period of time. Such costs may not be reported as operating costs. The published budget or staffing on a system may not be complete. In Portland, for instance, fare inspection and security personnel are budgeted in the finance department, and therefore do not appear in the rail department budget. In addition, many systems contract out for some maintenance functions. Consequently fewer operating staff are needed by the agency. For instance on the Docklands system, station maintenance is performed by outside contractors, and some of the vehicle maintenance is carried by the supplier. Contract personnel may not be considered as an operating cost. And finally, direct operating cost may or may not include all maintenance, clearly a pivotal issue when such indicators as farebox recovery ratio are being compared between systems.

Another problem is the need to screen special events from transit statistics. For instance, during Expo '86, SkyTrain carried almost twice as many passengers as it did in 1987, many of them on a short shuttle. This Expo '86 ridership is still sometimes quoted as system ridership, despite its irrelevance to the corridor or regular daily operation. Similar ridership surges are experienced on most other transit systems, for instance in Calgary during the Winter Olympics or in Portland during annual Rose Festival week, and have been screened out of this analysis.

On some systems operating surpluses have been claimed without explanation of what was included as operating cost. Such claims cannot always be substantiated when system budget is considered.

To minimize such problems, this paper draws mainly from basic unprocessed data, and on budgets, where available.

SOME STATISTICS

Some 20 new LRT systems have opened during the past decade, as well as several AGT systems. Eight of these systems were selected for more detailed study, three AGT systems and five of the more numerous LRT systems.

The LRT systems were selected to present a range from the low-cost "no frills" systems adopted for some of the low-density North American cities to the high-capacity, grade-separated Manila system.

The Nantes system was the first new LRT in France, and, together with the new LRT in Grenoble, offers an interesting contrast to the Lille VAL. It exhibits the low-cost, simple design approach to LRT carried out with great elegance. The policy background, design, construction, and first year of operation of this system are described in detail in *Le Tramway Nantais* (*1*). In the first year of operation, this system recovered its direct operating cost plus amortization and tax charges. Operating improvements and line extensions are planned.

The San Diego LRT was the first of the new low-cost LRT systems in the United States and has been cited as a prototype by several more recent systems. The San Diego system offers an excellent example of how rail transit can be built in corridors requiring only medium capacity for the least cost. Several new lines are being planned and constructed.

The Portland LRT drew heavily on the San Diego system for its design and operating philosophy. It includes a wide spectrum of right-of-way design, from full grade separation to a short section in mixed traffic, with some elegant downtown street improvements. An expanded LRT system forms the core of the region's long-term transportation plan, which will be implemented over the next 20 years as funding becomes available.

The Calgary LRT system was included because it has the highest ridership of any of the new LRT or AGT systems in North America. A somewhat "heavier" application of LRT than those in Portland or San Diego, it has operated very successfully in the demanding climate of Alberta. Two major extensions have been built since the first line opened in 1981.

The Manila LRT is an example of a fully grade-separated LRT operating in a corridor requiring high capacity. LRT was selected for this system to make possible low-cost at-grade extensions and branches wherever right-of-way permitted. In 1986, Manila LRT recovered 98 percent of its direct operations cost, as well as interest and depreciation, from fares (2).

A similar high-capacity LRT opened in Hong Kong (Tuen Mun) in August 1988. However this system is entirely at grade.

Three AGT systems were selected, representing major applications of three different AGT technologies in urban transit service.

The Docklands Light Railway in London is actually an AGT system. It uses large, LRT-type vehicles on standard gauge track, but with automated operation. Each car is staffed by a "train captain" who checks fares, monitors operation, and can operate the train when necessary. Efficiency is constrained by operation of single-car trains only. Two-car trains will eventually be operated when the stations have been expanded and more cars purchased. Staffing levels cover only the operating agency staff. Much of the vehicle maintenance is done by the supplier, and station maintenance is also contracted out. Full operating costs are not available.

The VAL AGT in Lille, France, is the first, and most successfully marketed, of the AGT systems in transit service. Operating in a heavy corridor through central Lille, it uses relatively small cars on a rubber tire/concrete guideway system. The full operating cost of this system has not been published and staffing levels reported by independent sources differ. Recently CFDT, the French Transit Union, published a comparison between VAL and the Nantes LRT containing current information on the performance of both systems. This information is generally consistent with material from other sources, where available, and has been used as a resource in this paper (*3*). The VAL system is being expanded in Lille, and new systems are under construction in Strasbourg, Toulouse, and at Chicago's O'Hare Airport. The Lille VAL recovers its full operating cost from the farebox.

SkyTrain, in Vancouver, British Columbia, is North America's first major AGT in transit revenue service, and its construction and performance have been extensively documented. Using relatively small vehicles on standard gauge track, it was conspicuously successful at moving large crowds at Expo '86 only a few months after start of revenue service. Under normal ridership since Expo, the system appears to require a rather large operating staff, but continues to perform satisfactorily (*4*). An extension is under construction. Other SkyTrain-type systems are operating in Detroit and Toronto (Scarborough).

Table 1 presents the information collected from the above eight systems, listing primary sources.

TABLE 1 COMPARATIVE STATISTICS

	LRT Systems					AGT Systems		
	Nantes	San Diego	Portland	Calgary	Manila	Docklands	VAL	SkyTrain
Line length (km)	10.6	32.8	24.3	27.7	15.0	12.1	13.5	21.4
Cost (incl. cars) ($ millions)	115.0	150.2	212.0	358.9	157.0	139.0	328.0	615.0
Cost/km ($ millions)	10.8	4.6	8.7	13.0	11.0	11.5	24.3	28.7
Year opened	1985	1981–1986	1986	1981–1987	1985	1987	1983	1986
No. of stations	22	22	28	30	18	15	18	15
No. of cars	20	30	26	83	64	11	76	114
Car size, w × l, m	2.3×28.5	2.65×24.3	2.65×26.8	2.65×24.3		2.65×28	2.06×12.7	2.4×12.7
Max cars/train	1	4	2	3	2	1	4	4
Capacity, seats	58	64	76	64		84	34	40
Standees 4/m^2	112	86	90	86		130	43	35
Total	170	150	166	150		214	77	75
Annual car-km (millions)	0.9	3.3	2.4	5.1			5.9	20.0
Annual board. pass. (millions)	12.0	8.4	7.0	24.3	100±	6.8	27.0	18.0
Annual pass.-km (millions)		105.2						
Max trains scheduled	15	10	11	23	27	9	18	21
Operating staff—total	51	54	48	81		55	103	132
Administration	4	2	4	6[a]		incl.	29	6
Control/supervisors	5	11	11	6		12	28	28
Train operators	42	41	33	69		–	–	–
Other	–	–	–	6		43	46	98
Maintenance staff—total	27	51	55	90		35	87	144
Administration	4	incl.	6	8		3	11	incl.
Vehicles	10	incl.	22	30		32	31	75
Way, power, signals, storage	7	incl.	27	52		incl.	45	69
Fare inspection/security	4	contract	12	30		incl.	incl.	incl.
Other	2	20	–	–		20		42
Total rail staff	78	125	115	207		110[b]	190[c]	318
Rail staff budget ($ millions)	2.1	4.2	4.7	5.7			–	13.2
Materials/service budget ($ millions)	1.5	3.8	1.8	2.0			–	5.9
Total rail budget ($ millions)	3.6	8.0	6.5	7.7			21.9	19.1

NOTE: Data are generally current year, except where stated otherwise.

[a]Calgary does not segregate bus/rail administration. This number is estimated from the other LRT operations.

[b]Docklands staffing is budgeted to increase from 110 to 140 in 1988.

[c]According to *Railway Gazette International* and CFDT (the French transit union) the VAL system also requires 47 "vigiles" for right-of-way security.

SOURCES: Nantes data from Semitan and CFDT. San Diego data from MTDB. Portland data from Tri-Met 1987–1988 budget. Calgary data from Calgary Transit. Manila data from *Modern Tramway*. Docklands data from Docklands Light Railway. VAL data from Matra Transport, CFDT, and Semitan. SkyTrain data from I. Graham and S. Hall, SkyTrain Operating Experience—January 3, 1986 to April 30, 1987, presented at APTA Rapid Transit Conference, 1987.

COMPARISON BETWEEN MODES

The comparison between modes based on real operating statistics is fraught with the potential for confusion, and it is here that the identification of relevant comparative measures is most important. Once relevant comparative measures have been established, then data based on real operating statistics are far more valid than the theoretical projections that must usually suffice in transit planning projects.

A common cause of confusion is the oft-made claim that ridership on a given line is a mode-related attribute rather than a corridor characteristic. Proponents will imply that the SkyTrain or VAL ridership is a consequence of mode choice (*5*). Thus it is interesting to note that the VAL line, serving Lille, a city of 1.06 million, carried 28 million passengers in 1985, while the Lyon Metro, serving a city of 1.1 million with about the same length of line, carried some 62 million (*6*). The Manila LRT, also about the same length, now carries some 100 million passengers a year (*2*).

Nor is the ability to attract off-peak ridership necessarily a modal characteristic, at least when comparing tracked modes. In Portland, the LRT has attracted a midday ridership not experienced on the bus system, and the daily ridership is usually heaviest on Saturdays.

Other factors influencing ridership in a given corridor, such as speed, headway, access time, security, comfort, and system integration, are not necessarily related to mode, except for perhaps headway. One advantage of automatic operation is that the cost to run two one-car trains is much the same as one two-car train (unless on-board attendants are required). It is thus possible to offer reduced headways when to do so with LRT would be considered uneconomical. It should also be noted that several AGT systems operate with a train attendant, thereby losing this potential benefit.

The impact of headway on ridership has been extensively documented elsewhere. Total travel time for a trip plays a significant part in choice of travel mode. Total travel time includes access time, wait time (half the headway), in-vehicle time, and time to exit the system and travel to a destination. Typically, LRT will have reduced access time compared with AGT, but longer wait time, particularly in the off-peak hours. METRO, the Portland metropolitan planning organization, projects a 2 percent change in ridership on the LRT for every 10 percent change in headway. As headway gets smaller, the impact on ridership diminishes.

It should also be noted that in major corridors such as those in which AGT systems are operated, LRT headways would need to be relatively close (4 min or so). At this frequency further headway reduction would produce little additional ridership, the rail transit potential of the corridor having been fully developed. Thus, for purposes of comparison between tracked modes, potential ridership is primarily a corridor characteristic.

Length of line, or more properly, average trip length, is often ignored when comparing productivity between systems. Yet a passenger traveling 10 mi clearly "consumes" more transit in terms of vehicle miles and associated operating and maintenance costs than one who travels half the distance or uses a shuttle. Consideration of passenger totals alone is meaningless when comparing lines of significantly different length.

Another area of potential confusion is in the presentation of capacity. There can't be much confusion about the number of seats in a car, but the number of standee spaces is a function of standee density. Design capacity is usually presented with 4 standees/m^2, but sometimes other units are used without acknowledgment. If this is done, comparative capacity calculations are meaningless (*5*).

It is also important to compare systems representing the most recent and effective applications of the mode on the assumption that those interested in such comparisons are attempting to reach a valid conclusion for their own situation and certainly intend to make effective application of the mode selected. A recently published comparison between VAL and the Lille LRT (*5*) omitted to mention that the Lille LRT was a remnant of an 80-year-old narrow-gauge streetcar system, operated with 28-year-old second-hand cars.

COST OF SERVICE COMPARISON

There is considerable interest in France in the comparative merits of LRT and AGT systems. Several new systems of each type are planned. This topic was the subject of a recent study by the French Transit Union (*3*).

Besides the ancient Lille LRT, with which VAL is often compared by its promoters, there are also in France two new LRT systems, in Nantes and Grenoble. The Nantes system, opened in 1985, operates largely on street right-of-way with few grade separations or preempts, using only single-car trains. Improvements are currently in progress in Nantes to expand the use of preempts at traffic signals and to introduce two-car trains. Current statistics do not reflect these future improvements. Not surprisingly, the Nantes LRT recovers 117 percent of its operating cost from fare revenue (see Table 2).

It should also be noted that VAL's estimated total rail budget cost is very high in proportion to the reported operating staff, which would distort the comparative productivity of the two systems had staffing been used as the sole measure of cost effectiveness. Nor does this comparison screen out the corridor effect. Lille is twice the size of Nantes and would therefore be expected to contain stronger transit corridors.

Although some earlier work (*1, 7*) had alluded to this situation, the numbers are so clearly at odds with conventional opinion in the transit industry that independent corroboration was sought. The French government

TABLE 2 COMPARISON BETWEEN LILLE VAL AND NANTES LRT

	VAL (AGT)	Nantes (LRT)
Capital cost ($ millions)	328	115
Operating employees	190	78
Length (km)	13.5	10.6
Ridership (millions/year)	27	12
Annual passenger-km (millions)[a]	182	64
Projected budget ($ millions)[b]	21.9	3.6
Capital cost/km ($ millions)	24.3	10.8
Passenger-km/employee (millions)	0.96	0.82
Operating cost per passenger-km (¢)	12.0	5.6

NOTE: Derived from Table 1.
[a]Both systems run suburb to suburb, across the city center, and are likely therefore to have similar trip length characteristics. Because average trip length data are not yet available, this analysis treats each line equally, and assumes average trip length is half the line length.
[b]$1 = 5.71 francs.

TABLE 3 1980 TO 1986 TRANSIT SYSTEM TRENDS IN LILLE AND NANTES (*8*)

	Lille[a]			Nantes[b]		
	1980	1986	Percent	1980	1986	Percent
Total system operating cost (FF million)[c]	188	471	151	116	239	106
Subsidy (FF million)[c]	97	210	116	62	112	81
No. of buses operated	365	402	10	334	365	9
Total system ridership (millions)	51	75	47	44	65	48
Ridership/capita	48	72	50	103	140	36

[a]Opened in 1983.
[b]Opened in 1985.
[c]$1 = FF 5.71.

publishes statistics for the transit industry annually and comparison was made, using these data (*8*), of key indicators for the Lille and Nantes transit systems. These are summarized in Table 3, for the years 1980 and 1986, which bracket the opening of the VAL line and LRT line, respectively.

From Table 3 it can be seen that during the period in which both cities opened rail lines, both experienced similar gains in ridership, but the system operating cost and subsidy grew at a much faster rate in the Lille system. This would support the conclusions from Table 2. All of which begs the question: If Lille had used LRT on the alignment of the VAL system, how cost-effective might it have been?

DIRECT COMPARISON TECHNIQUE

The literature of AGT is sprinkled with assertions that automated operation eliminates operators and therefore reduces operating costs (*9*) and, if a line is largely grade separated, then it "might as well" be automated. The direct comparison technique models AGT and LRT on the identical line, and with identical ridership to test these assertions, using data from actual operating conditions.

The strength of such an analysis technique, when applied to existing systems, is that it uses the maximum of hard data. Each element of the comparison, from system to system, is tied to known conversion factors. Thus the number of cars required to carry a given ridership is known, and hence the number of train operators or car maintenance personnel can be estimated with a high degree of certainty. The direct comparison technique can also screen out the "corridor effect" that hinders the comparison of AGT and LRT on different corridors with different ridership potential.

Two systems for which much information is available, and that are similar in size, are the Vancouver SkyTrain and the Portland LRT. About a third of the Portland system actually operates on a grade-separated right-of-way similar to SkyTrain's at similar speeds. On several occasions, the Portland ridership has reached or exceeded the average daily ridership of SkyTrain. Portland has a centrally located business district. Vancouver is a larger city with its business district on the waterfront and all the suburbs to one side. For this and other primarily nonmodal reasons, the Portland LRT corridor produces less than half the SkyTrain corridor ridership.

Several assumptions are required to simulate LRT operation on the SkyTrain line:

- Peak-hour capacity must be maintained;
- LRT and AGT operate on the same minimum headway of 5 min during the base period;
- Both AGT and LRT operate on the fully grade-separated SkyTrain alignment.

Table 4 develops the Table 1 data to simulate how a grade-separated LRT might perform on the SkyTrain alignment.

While it is possible to debate the minutiae of such calculations, the general conclusion is very clear and makes obvious sense. If you take a line like the Portland LRT, remove all the grade crossings so that it goes faster, and more than double its ridership, it is highly likely to become more productive. In fact, the numbers suggest that, in this corridor at least, LRT would have been

TABLE 4 COMPARISON BETWEEN SKYTRAIN AND LRT OPERATING ON SKYTRAIN CORRIDOR

Line	Existing AGT SkyTrain	Existing LRT in Portland	Conversion Factor	Simulated LRT on SkyTrain
Length (km)	21.4	24.3		21.4
Stations	15	28		15
P.H. trains	20 × 4 cars	11 × 2 cars		14 × 3 cars[a]
P.H. headway	3 min	7 min		5 min
P.H. capacity	5,700	2,656		5,976
Base trains	13 × 4 cars	8 × 2 cars		14 × 2 cars[a]
Base headway	5 min	15 min		5 min
Cars required	100± AGT	26 (LRV)		48 (LRV)
Boarding passengers (millions/year)	18	7		18
Passengers/km (millions/year)	193	85		193
Staff				
Operations				
Administration	6	4		6
Control/supervisors	28	11	P.H. trains	15
Operators	–	33	P.H. trains	43
Field operations	98	–		18[b]
Maintenance				
Administration/finance	42	6.5	cars	12
Vehicles	75	21.5	cars	40
Power	incl.	3.5	length	3
Signals	incl.	2	signaled length	4
Trackway	69	9.5	length × trains	11
Stations	incl.	5.5	pass. × stations	8
Lifts/fare machines	incl.	6.5	passengers	17
Fare inspection	incl.	9	passengers	23
Security	?	3	passengers × 2	15
Contingency[c]	N/A	N/A		22 (10%)
Total staff	318	115		237
1987 budget in $ millions	19.1	6.5		13.4
Passenger-km/employee	0.60	0.74		0.81
Cost/passenger-km	10.0¢	7.6¢		6.9¢

NOTE: Assumes average trip length is half the line length.
[a]LRT includes extra train to allow operator layover time.
[b]Assumes six key stations have an attendant part-time.
[c]Contingency provides additional staff to cover extra off-peak service, and supervision, maintenance, etc., thereof.

a lot more productive than an AGT operation when compared under identical conditions. It is also interesting to note the similarity between this comparison and that between the two French systems in Table 2.

Other measures and comparisons can be developed from the Table 1 data for capital or operating costs measured against various performance indicators. For instance, "break-even" fare, the average fare at which the total rail budget would be met from fares, is shown in Table 5.

TABLE 5 BREAK-EVEN FARES

System	Nantes	San Diego	Portland	Calgary	VAL	SkyTrain
Annual boarding passengers (millions)	12.0	8.4	7.0	24.3	27.0	18.0
Total rail budget ($ millions)	3.6	8.0	6.5	7.7	21.9	19.1
Break-even fare ($)	0.30	0.95	0.93	0.32	0.81	1.06

AN INTERPRETATION

The installation of a simple LRT system in a transit corridor can lead to major gains in productivity compared with bus operations. This is achieved basically because the gain from the six- to eightfold increase in operator productivity is much greater than the added maintenance-of-way and equipment costs, particularly if the LRT system is of simple "no frills" design.

Compared with the productivity gain from the bus/LRT substitution, the potential for further productivity increase by eliminating the operator entirely is much less. In fact there will be no productivity gain if the added costs of supervising the line, trains, and stations, and maintaining the more numerous (small) cars, signals, and safety devices, etc., exceed the cost of the operators displaced on the alternate LRT system. This seems to have occurred on the AGT systems built so far.

Although the technical problems that have attended the first AGTs will probably be solved with time, the factors that hold down productivity are not of a predominantly technical nature. Simple everyday events, such as tripping the car door emergency switch, an almost daily occurrence on the Portland LRT, become a significant operating problem in the absence of on-board personnel. Even a minor delay on a close headway system can quickly become a major problem. Policing the line, supervising grade-separated stations, and maintaining the extra control and safety devices needed for automatic operation are a permanent requirement.

The oft-quoted AGT advantages, such as the ability to add service at short notice or the added ridership attainable with very close headways, may not be worth as much as the higher operating costs required to achieve them. Moreover, these same attributes can probably be attained on an LRT system at less cost (see Table 4).

CONCLUSIONS

Unlike LRT technology, in which no party holds a proprietary interest, AGT systems have been enthusiastically marketed by their developers with glowing claims of efficiency and even profitability. The AGT systems now operating are indeed triumphs of transit technology and reflect great credit on those who brought them into service. However, it appears that requiring fully grade-separated right-of-way and stations, and with higher car and systems costs, total AGT construction cost is invariably higher than that for LRT. As a result, the potential for future extensions is weaker, and a city selecting AGT will tend to have a smaller rapid transit network than a city with LRT. Nor do existing AGT systems operate any more efficiently than conventional, simple LRT systems, particularly if compared on the same quality of alignment.

In addition, being the product of contemporary technology, AGT systems carry with them the probability of obsolescence as technology changes, and the future problem of matching different generations of technology. And finally, being proprietary systems, the AGT owners' future procurement options are more limited, particularly if the manufacturer ceases production.

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