CVS: COMPUTER-CONTROLLED VEHICLE SYSTEM

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CVS, which stands for computer-controlled vehicle system, is a pure personal rapid transit system. That is, in contrast to most other new urban transportation systems, it does not group passengers together into common vehicles. An individual and his traveling companions can utilize a vehicle just as they presently use a taxi or a personal automobile. As a necessary consequence, CVS aims at a network traffic system rather than a linear one.

The first step to CVS development began in 1968. From March to September 1970, the World Exposition was held in Osaka and many new applications of technology were exhibited. One of them was the "traffic game," demonstrated in the Automobile Industries Pavilion, in which several dozen electric vehicles were operated individually under computer control and ran on a checkerboard-like guideway network with intersections every five meters. Though primarily designed as an exhibition facility, it was aimed at the technical development of a future transportation system. In this game, a specially designed minicar for two persons ran on the guideway and communicated with the computer by radio, through an underground communication channel. Grade-crossing technology was also developed, as it was essential to the highly integrated network.

About 1968, when the planning of this system started, new urban transportation systems were not a topic of interest in Japan; therefore, the concept of this system was treated as a fantasy, except by a few persons. But by 1970, when the World Exposition was held in Osaka, the people in Japan had begun to pay attention to the various problems of urban transportation. Research into its practical applications began with the support of the Ministry of International Trade and Industry. The basic concept called CVS was formulated in July of that year. In the autumn of 1970, the work on the basic design of the system began. Miniature models of vehicles and a guideway were constructed, and a total system with 1,000 vehicles was simulated using a large-scale computer. The fundamental technical specifications were thus completed.

Based on this research, a reduced-scale experiment was prepared from April to October 1971. Miniature cars reduced to one-twentieth scale were operated under computer control, on a scale model of the Ginza area of Tokyo. The results of this experiment were made public at the 18th Tokyo Motor Show from October 28 to November 21, 1971. The result of this experimental project in the Tokyo Motor Show is the Higashimurayama Project. This project, which has been proceeding since November 1971, is aimed at a more realistic level of development.

The experimental facilities of CVS are located at the site of the Laboratory of Industrial Technology, Ministry of International Trade and Industry, in Higashimurayama City, about 30 kilometers to the west of Tokyo, as shown in Figure 1. The experimental facilities include 4.8 kilometers of guideway, two kilometers of which are constructed along the test course for automobiles and called "superway" for high-speed running. On the northern side, there are two traffic lanes running parallel to each other, where high-speed lane changing experiments are conducted. A diamond-shaped section in the center of the guideway is called "path." It contains a sample of the grid in the low-speed network. One side of the grid is 100 meters long, the minimum length technologically possible between stations. A portion inside the grid has a straight and circular guideway with a radius of five meters, and is used as a maintenance area. This portion is shown in Figure 2. Two stations called "stops" are provided. One is located beside the "path" on which vehicles arrive from a side lane. The other is located on the northern side of the "superway," adjacent to the main traffic lane. Each "stop" has two berths, one for passengers and one for freight containers, equipped with an automatic loading and unloading device. CVS is designed so that at-grade crossing is possible. For this experiment, two grade crossings are set on the "path" network.

The CVS control center is located beside the guideway for vehicle maintenance. This building has a vehicle maintenance workshop on the first floor, an office on the second floor, and a computer room on the third floor where three computers are in use. A TOSBAC-40 controls the path and a HIDIC-350 controls the superway. Both have a memory capacity of 64 kilobytes. A FACOM 230-35, a supervisory computer, controls the whole system and has a memory capacity of 128 kilobytes.

The Higashimurayama Project was begun in 1971 and its basic design was completed by the middle of 1972. In the autumn of the same year, the guideway for the maintenance area and the first experimental vehicle were completed. Soon after, basic driving tests were conducted under

Figure 1. Aerial View of CVS Test Track at Higashimurayama City

Figure 2. Maintenance and Short Radius Guideway Area
at Higashimurayama City Test Track

manual control. In the spring of 1973, the basic experiments with the computer control began. The full length of guideway was constructed in the autumn of 1973, and the second stage of the experiments has begun since then. This stage involves computer control of several vehicles, operation for passenger services at the stations, control of automatic loading and unloading of freight containers, lane changing experiments, and overtaking of vehicles at high speed. Since the spring of 1975, the entire system has been governed and controlled by the supervisory computer, and about sixty vehicles are operated all around the 4.8-kilometer guideway under complete computer control. This facility is one of the largest urban transportation system research facilities in the world.

CVS is an entirely new system designed for pure personal transportation. To the passenger, it seems like an automatically controlled taxi that runs on an exclusive guideway network. To use this system, the passenger need only buy a ticket specifying his destination and ride in the dispatched vehicle. Hereafter, the selection of the route and the operation of the vehicle will be handled automatically by the computer system. In this way, the passenger will arrive at his destination without having to share the ride and without changing vehicles at intermediate stops.

Since the system is designed for personal transportation, the body of the vehicle, the stop, and the guideway are small in size and light in weight. A standard vehicle is 3 meters long, 1.6 meters wide, 1.85 meters high, and weighs about one ton. One of these vehicles is shown in Figure 3. One lane of the guideway requires a space above it less than 2 meters high by 2 meters wide. For this reason, it is very easy to provide guideways and stops in a building without adding any reinforcement. The standard elevated guideway is 0.8 meter in depth with supports every 30 meters. The diameter of a supporting pier is approximately 0.8 meter. As the stops are located very close to each other, the space required for each stop is very small.

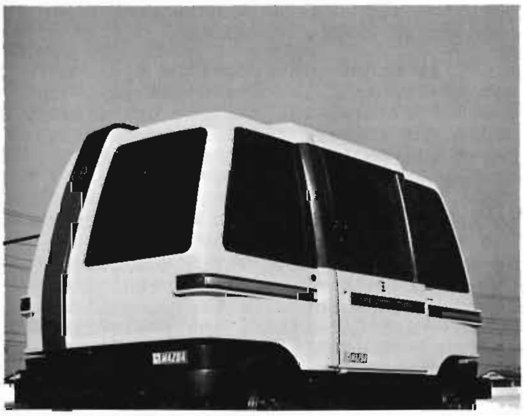

Figure 3. Typical CVS Vehicle

In addition to a passenger transportation system, CVS provides a means of freight transportation. Conventional means of transportation which require changes at terminals cannot efficiently handle freight traffic, because freight cannot move a centimeter by itself. For this reason, subways and buses cannot carry freight. According to the 1973 Japanese government white paper on transportation, 93.6% of freight is moved by automotive vehicles, 5.2% by ships, and 1.2% by railways. This conclusively shows that freight traffic depends almost exclusively on road transportation. Therefore, we cannot overemphasize the importance of freight transportation in the urban transportation systems. To solve urban transportation problems, it is an urgent requirement to introduce a new freight transportation system and to replace the present automotive one.

Because taxis are utilized personally and not shared by many people at the same time, they offer good service when compared with other means of public transportation. However, taxis are very expensive and are becoming more so, because they require an intensive application of labor. Consequently, it does not appear that they will be able to compete successfully with private vehicles in the future, since it is becoming more and more difficult to obtain the labor required. For this reason, taxis cannot play a key role in the future urban transportation systems.

On the whole, demand for road traffic is still high and many urgent problems such as traffic congestion, accidents, air-pollution, noise, vibration, and freight transportations, are due to the deteriorating road traffic conditions.

The system targets of CVS reflect the above-mentioned urban circumstances and can be achieved with the natural and necessary introduction of computer control. The concept of a pure personal transportation system makes the transfer to another vehicle unnecessary and saves travel time. Because of these capabilities, CVS can fully respond to the demands for a network transportation in the urban area. If CVS offers around-the-clock unmanned service, pure personal transportation will be essential to protect the passengers from late night crimes. Under the present railway and bus systems, full-time service is difficult, considering that not many people use these systems during the night. Other merits of the pure personal transportation system lie in the small size, light weight and low cost of the vehicles, guideways, and stops. Its overall compactness makes it possible to build a dense network of guideways in the urban area or to build stops within the buildings. Freight transportation will also be possible provided that no transfer of shipment is required. CVS provides special features such as low cost and high-quality service both for those who have automobiles and those who do not. In small or medium-size cities where there is neither a sufficient demand for, nor the ability to finance the high cost of, a subway system, CVS will become the primary passenger and freight mover of the future.

There are two basic types of CVS vehicles: one for passenger transportation called a "personal car," and the other for freight transportation called a "wagon." Both have several variations to meet special requirements. The standard personal car is a four seater; two of the seats are collapsible to provide space for a baby carriage and hand luggage. Standard models can be modified to special models such as wheel-chair cars, bed cars, patrol cars, and ambulances. It is also possible to connect several vehicles together with joints covered by bellows to cope with commuting rush-hour demands or other special occasions. In this case, each "train" does not offer personal transportation but rather shared transportation carrying 20 to 30 passengers and running along the fixed route as a bus would. The interior of the "personal car" is more spacious than that of a large-size automobile. The vehicle is air-conditioned and has a spot-light, a radio receiver, and a telephone for information services. The "wagon" on the other hand, is designed to carry a standardized CVS container. Various types of CVS containers have been designed such as garbage containers, mixed loading containers, and other containers for special uses. All these containers are the same size to fit the wagon. The maximum payload of the container is limited to 300 kilograms.

The switching system is mechanically controlled on the vehicle, not on the guideway. Switching is accomplished by the use of the front arm attached to the front wheel steering mechanism, which is very similar to that of a conventional automobile. The other end of the front arm is inserted into the guide groove located at the center of the guideway. This end of the front arm has two small wheels which run along the horizontal guide rail located within the guide groove. At a switching point, if the front arm moves to the right, the vehicle's steering mechanism turns the vehicle to the right. For a turn to the left, the operation is exactly the same except that the front arm moves to the left.

As previously explained, there are no moving parts on the guideway. Thus, the vehicle is not subjected to any side force and is as comfortable as a conventional automobile. The CVS switching system was designed to enable the vehicles to be operated at short headways. It also makes grade crossing and lane changing possible. Moreover, the front arm has an antenna for wireless communication. There is another arm at the rear of the vehicle which is also inserted into the guide groove of the guideway. This prevents the rear wheels from derailing, collects electric power from the power rail and supports an emergency brake that operates by clamping a brake lining to a steel rib fixed to the guideway. This brake system will produce a high rate of deceleration approximately equal to 2.0 g.

The vehicle is driven by an electric motor and can climb a 6% slope at a speed of 60 km/hr under zero wind conditions. The maximum possible speed is 80 km/hr.

The vehicle has three kinds of brakes: an electric brake used for braking from high speeds, a common friction brake used at low speeds, and an emergency brake. The emergency brake is necessary in order to maintain safety and to ensure a high traffic capacity, but it is seldom used. When traffic density or requested capacity is low and there is no need for a fail-safe function to protect against unusual emergencies, it can be removed.

High-back seats will be installed to protect passengers when the emergency brake is applied, and passengers will sit facing the rear of the vehicle with their backs forward. The maximum deceleration using the regular brake and the maximum acceleration during normal driving conditions are both 0.2 g, while the maximum lateral acceleration is 0.1 g.

CVS guideways consist of a low-speed network called a "path" and a high-speed network called "superway." On the path network which covers an area with a minimum grid of 100 meters, vehicles run at the speed of 40 km/hr. The off-line stations called "stops" are placed along path networks and wherever possible, they can be installed inside buildings. Paths can cross one another on the same level, and thus provide a high-density network. The driving speed on the superway is 60 km/hr. The superway network is connected with the path network via the "module gates" which are located on the links to the superway. Since there are no stops on the superway, no direct access can be made from a stop to the superway network. Where the superways cross each other and where the superway crosses the path, the crossings are by grade separation. Since CVS allows for lane changing, the superways have more than one lane in each direction.

As CVS is a network operation system, even if one link becomes unusable owing to some failure, the routing of vehicles around the inoperative link is possible. Therefore, no breakdown of the entire network can occur.

A guideway is composed of the road surface upon which the rubber tires run, the guide groove into which the guide arms of the vehicle are inserted, the ground antenna for wireless communication and position detection, the power line supplying the vehicle with electric power, and the steel rib for emergency braking.

The guideway can be constructed as an elevated line, opencut line,or underground line. The maximum gradient is 10%, the minimum turning radius is 5 meters, and the space required for one lane of guideway is an area less than 2 meters high by 2 meters wide: the guideway can therefore be installed in a limited space. It can also contain urban utilities such as electric power cables, telephone cables, cable television lines, and local cooling and heating pipelines; thus, it functions as the utility corridor of a city.

Since the stops can be located so densely, each stop is generally small. However, in places where many passengers are expected, such as railway stations and department stores, a stop may provide several independent berths. If the stop is placed adjacent to the building and connected with its elevator corridor, better door-to-door service can be provided than by automobile. The entrance of a stop is equipped with an automatic door which opens and closes in synchronization with the door of the vehicle. A stop is equipped with an information board, automatic ticket vending machines, ticket reader, ascent and descent mechanisms for the blind and other physically handicapped persons. The gap between the platform and the vehicle is automatically closed by a flexible board so that a wheel-chair or a baby carriage can easily board and leave the vehicle.

Where a stop is built on the pedestrian sidewalk, an elevator connecting the stop directly with the ground is operated in synchronization with the departure and arrival of a CVS vehicle. Similarly, the underground stop has only an elevator without having an underground platform; construction costs and the possibility of crime are thus reduced.

As for freight transportation, automatic loading and unloading devices for CVS containers are available. At large freight terminals such as factories, market places, and department stores, individual automatic loading and unloading devices are installed. Area freight service centers are planned for retail shops and ordinary houses. These centers are also equipped with the automatic loading and unloading devices and have custody and distribution functions. Door-to-door collection and delivery services are provided by a small electric car.

The control system of CVS is composed of three stages: the microscopic control of vehicle operations, the macroscopic control of the entire traffic flow, and the system management control including fare collections and operation recordings. These operations are performed by the multi-level computer hierarchy system in which different computers are assigned to control specific levels of operation.

Each path link and its stop are under the microscopic control of a mini computer called a "quantum computer." Each vehicle on a path communicates frequently (at intervals of less than 0.5 second) with the quantum computer by polling, and is controlled to follow an imaginary moving signal on the guideway. In the CVS system, this is called the "moving target system." One rescue computer per several quantum computers is assigned as a back-up function for unexpected failures of the quantum computers. The upper level computer, called the "module computer," tells each quantum computer under its control which moving target the vehicle should follow and in which direction it should proceed at a junction point. The module computer is a medium-scale computer which is provided for each unit grid of the superway and is in charge of the so-called macroscopic control. For each superway link, one "superway computer" is provided to control the vehicles on the superway. At the highest level, a large-scale computer system called the city computer exists. It is in charge of overall management such as vehicle maintenance, operation recordings, fare calculation, and the analysis of traffic demand patterns.

Position detection of vehicles is made by twisted wire antennas installed in the guideway with a distance resolution of 0.2 to 2.0 meters, depending on the speed of the vehicle. At the same time, these twisted wire antennas communicate with the vehicle at the rate of 1,200 bits per second by an inductive wireless communication system. Vehicles passing recognition terminals are also installed at important points such as junctions and crossings. They send fundamental information directly into the computer system to improve the reliability of system operations.

Although CVS is an automatic transportation system, the user has to put in a minimum of necessary orders to the system. First, the user inserts a credit card or a coin into a ticket vending machine located at each stop, and indicates the code number of his destination stop by pushing a keyboard. The code number of a stop can be easily determined by an information board or a guidebook at the stop. Once the code number of the destination stop is keyed in, the computer system begins the dispatch of a vacant vehicle, simultaneously with the issuance of the ticket. Usually, a vacant vehicle is waiting for the passenger in the berth. The ticket is a magnetic card with the ticket number and the code number of the destination stop written on it. The computer stores this information regarding the ticket number. The blind, or physically handicapped have their infirmities recorded on their credit cards, so that a remote guide service can operate through a closed circuit television and a speaker system, and arrangements for a special vehicle are made by the control center.

The passenger who has already bought a ticket, then inserts the ticket into the ticket reader beside the door of the vehicle entrance. The entrance door opens in synchronization with the vehicle door, and the passenger boards. At this moment the computer assigns the destination stop to the vehicle referring to the information previously stored.

The passenger who has boarded the vehicle only has to depress the start button when he is ready to start. A change in the destination stop after the passenger has boarded is not possible under the present specifications. If he wants to change his station of destination, the passenger should leave the vehicle at the nearest stop by depressing the cancel button and buy another ticket at that stop. In case of an emergency, such as fire on the vehicle, the passenger can depress the emergency button to stop and leave the vehicle. In case of a sudden illness in the vehicle, the passenger can contact the control center by telephone and the vehicle is routed directly to a hospital. When the vehicle gets near its destination stop, a chime sounds to give notice so that the passenger can prepare to leave the vehicle.

Although CVS has a very small capacity per vehicle, it achieves a large lane capacity by shortening the time headway between vehicles. The minimum headway time of the present system is 1.0 second; hence, the basic lane capacity becomes 3,600 vehicles per hour. In real operation, the practical capacity for a path is estimated to be about one third of this figure, because of mergings, branching, and grade crossing.

Since a short time headway has been adopted, a closer examination of the emergency braking system is warranted. The deceleration necessary to prevent a vehicle from colliding into a stalled vehicle is determined by the vehicle headway and speed. Taking 2.0 g as a reasonable deceleration for a passenger sitting in a rear-facing, high-back seat, the minimum vehicle time headway becomes 0.7 second with a speed of a little less than 40 km/hr, and the lane capacity is about 5,000 vehicles per hour. In the present specifications, the emergency deceleration is 2.0 g and a minimum vehicle headway of 1.0 second has been established, shifting toward the safe side in consideration of the dummy running time and the deviation in deceleration.

CVS has a higher lane capacity than roads and a lower one than railways; however, CVS occupies a much smaller space per lane than either a road or railway, so that it equals a railway in transportation capacity per unit of cross-section space. If CVS vehicles are connected and operated together, lane capacity can be increased even more. If freight is transported during the night, to make the best use of the characteristics of automatic operation, the day time transportation capacity will be increased. If mass transportation systems are compared to a single thick rope, CVS can be compared to a net of fine threads unravelled from this thick rope.

The compactness and the lightness of the vehicles and the guideway contribute to the savings of urban spaces and of the materials required for their construction. The energy consumption of a CVS vehicle is only about one half to one third that of an equivalent automobile operated in the city. This is true even when 40% efficiency of the power plant is taken into account, because once a CVS vehicle has begun a trip, it does not stop until it reaches its destination. Furthermore, another important advantage is the flexibility possible in the selection of the primary energy source, since CVS is driven by electricity and does not necessarily require petroleum fuel. CVS created almost no problems such as air pollution, noise, or vibration because vehicles are electrically powered, supported by pneumatic rubber tires, and easily maintained. The effects of the elevated guideway on urban landscape, sunshine, and privacy are a matter deserving much consideration in the planning of the guideway network.

A number of CVS application studies to existing urban areas have already been made. Thus an application study for the central district of Tokyo, an area of about 30 square kilometers, was made in 1972. A CVS guideway network to cover this area was planned as a grid of guideways every 200 to 400 meters. The network has a total length of 230 kilometers with 480 stops which were designed at an average interval of about 230 meters. In the year 1985, the total person trips in this area is estimated at about 2.1 million per weekday, according to the Tokyo metropolitan person trip survey. By using the modal split formulations, about 30% or 700,000 person trips were calculated to shift to the CVS system. As a result of the computer simulation, it was determined that 8,300 vehicles are needed to transport these passengers.

If one third of the initial construction costs are financed with equity at normal acceptable interest and two thirds with money borrowed at 7.7% interest, this CVS system could be operated by the revenue from the passengers' fares alone at a price per trip of 200 yen (about 67 cents).

An application study to Maebashi and Takasaki, twin cities with a population of 600,000, about 100 kilometers to the north of Tokyo, has been under way since 1973. According to the preliminary report, about 250 kilometers of network and 500 stops are necessary to cover the urban area of both cities. For the year 1985, passenger demand for CVS is estimated at about 700,000 person trips. The initial total construction costs are estimated to be about 120 billion yen ($400,000,000) in 1973 price. If we assume the same conditions as in the Tokyo study, this system can be operated with a charge of 110 yen (37 cents) for intra-city traffic, and 220 yen (73 cents) for inter-city traffic.

The basic specifications of CVS are summarized in Table 1.

Table 1. Basic Specifications of CVS

Subsystem	Description	Specification
Driving Performance	System Operation	
	Maximum traffic lane capacity	3,600 vehicles/hour 14,400 persons/hour
	Minimum vehicle headway	1.0 second
	Ordinary driving speed (on the path)	40 km/hr
	(on the superway)	60 km/hr
	Maximum driving speed	80 km/hr
	Ordinary acceleration and deceleration	0.2 g
	Maximum emergency deceleration	2.0 g
	Stop	
	System	Off-line system
	Minimum stop interval	100 meters
	Guideway	
	Maximum gradient	10%
	Maximum cant	10%
	Minimum turning radius	5 meters
	Standard supporting interval	20 to 30 meters
	Standard girder height	700 mm
Vehicles	Dimensions	
	Length	3.0 m
	Width	1.6 m
	Height	1.85 m
	Empty Weight	1 ton
	Seating Capacity	4 persons/vehicle
	Power Supply	200 volt AC
	Guidance System	Central groove system
	Vehicle Body Support	Pneumatic rubber tires
Control	Vehicle Headway Control	Computer control by moving-target system
	Collision Avoidance System	Moving-block system
Communication	Vehicle Control	Inductive wireless system (1,200 bits per second)
	Passenger Service	Telephone

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