

San Francisco Cable Car – Original Design and Current Operation

By

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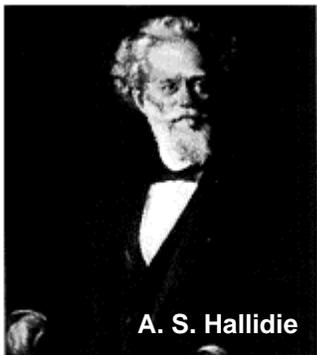
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The Birth of the Cable Car

San Francisco in the late 1860s was a rapidly growing metropolitan area with a very cosmopolitan atmosphere. Since the 1848 discovery of gold in the western foothills of the Sierra Nevada mountain range, people from all over the world had flocked to the city. The money pouring in from the gold fields, combined with a general economic upturn throughout the northern and western United States following the Civil War, had produced in San Francisco a growing economic center of considerable wealth and population.

With the increase in population came inevitable crowding and transportation problems. New homes were built further up the steep hills and transporting people and material up these inclines proved no easy task. Early attempts included horse cars (rail guided carts drawn by one or more horses) and steam powered trolleys, neither of which had the power or traction required to safely and consistently climb the hills of the city.

In 1869, a team of five horses struggled to pull a loaded car up Jackson Street. Subjected to vigorous lashing of the whip by the driver, the horses finally lost their footing and were dragged down the hill to their deaths by the car loaded with frightened passengers. One of the onlookers that day was Andrew Smith Hallidie, owner of a wire rope manufacturing business in San Francisco and inventor of several suspension bridges and cable powered mining trams in the western US.

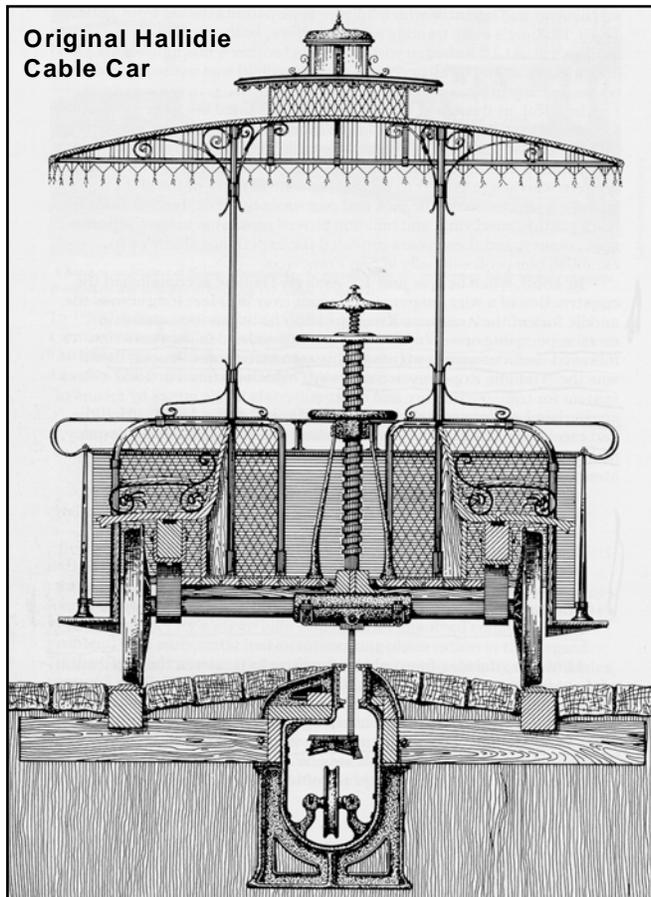


In this Scottish immigrant, San Francisco found the man who could solve the transportation problems of this unique city. Son of Andrew Smith, the Scottish inventor who had helped to pioneer wire rope technology in England in the mid 1800s, Hallidie combined the technical knowledge, manufacturing capacity, engineering experience and determination to turn his idea into reality.

The first cable car line along Clay Street, derisively referred to as "Hallidie's Folly" by skeptical San Francisco residents, made its maiden trip on August 2nd, 1873 and was opened to the public one month later. The success of the system, both technically and financially, silenced the critics and soon competing cable rail lines were being installed throughout the city. The peak came in 1890 when a total of almost 110 miles (177 km) of cable railway were in operation. Of those, four lines, a total of 9 miles (14.5 km) are still in operation today. Regrettably, Hallidie's original Clay Street Line is not one of the four, having been shut down in 1941 in favor of electric street cars.



Mechanical Workings of the Cable Car System



Original Hallidie
Cable Car

The basic principle of Cable Car operation is actually quite simple. A central power source (power house) drives a steel wire rope (haul rope) at a constant speed. The cars grip the rope when they need to move and release the rope when they need to stop or coast. The challenge is making this work safely, reliably and at a reasonable expense, all with mid-1800s technology.

The first attempt at a Cable Car system was actually made in New York by Charles T Harvey in 1868. His West Side and Yonkers Patent Railway failed financially after two years so it was left to Hallidie and his engineer, William Eppelsheimer, to create the first financially successful public transport Cable Car system.

The original San Francisco Cable Car lines were privately built and maintained. Each owner tried new designs for tracks, cars, grips and configurations of machinery. Several years of operation gradually weeded out the inefficient and costly solutions resulting in the consolidation of all the Cable Cars into a small number of successful designs.

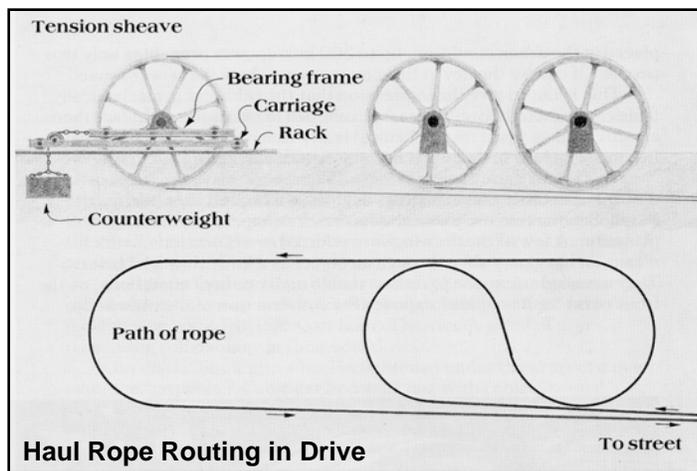
The proliferation of the cable car systems in those early days created more engineering challenges. Those that will be explained here are still present and may be observed as one rides the cars today:

- Driving and Routing the Haul Rope
- Gripping and Releasing the Haul Rope
- Negotiating Curves
- Negotiating Crossings
- Turntables and Switchbacks

The system is not high tech by our standards today, but the introduction of wire rope powered public transport here in San Francisco almost 130 years ago laid the groundwork from which many of the technical innovations in ropeway transportation arose.

Driving and Routing of the Haul Rope

Standing beside the Cable Car tracks, one can hear the steady hum of the haul rope moving beneath the surface. The haul rope speed is maintained at a constant 9.5 miles per hour (15.3 km/hr). The original Cable Car lines ran at only 6 to 8 miles per hour which, although not as fast as the present system, was still a great improvement over the 4 or 5 miles per hour to be expected from the horse drawn cars. While each original line was driven independently, the haul ropes of the four lines still in operation today are all driven from the same location, the power house. Here, the four ropes converge and are routed through the drive system such that all move at the same speed all the time.

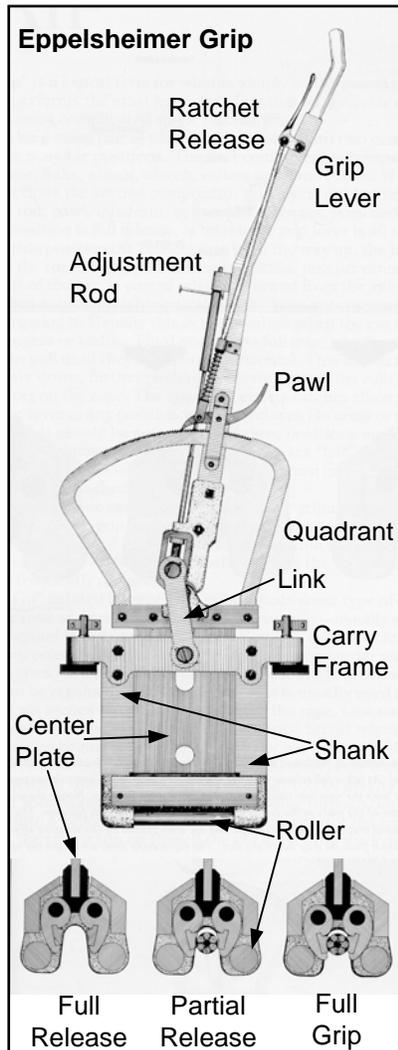


The steam engines that powered the original Cable Cars have since been replaced by electric motors. The traction system consists of two drive bullwheels and one tension bullwheel for each cable. Each haul rope is a spliced loop which passes around each drive bullwheel before passing over to and around the tension bullwheel, after which it exits back out to the street. The tension system is necessary to take up slack in the haul rope which may result

from temperature elongation, permanent stretch in the cable over time, or stretch due to load changes during operation. Maintaining correct tension ensures good traction is achieved between the drive bullwheels and the haul rope.

Drive power in the present system is provided by two electric motors which together drive all four existing lines. The power house contains all drive machinery and also has space for parking, maintenance and repair of the cars, which is why it is called the "barn" since, before the cable cars, the horses were stabled together at the end of the day in much the same way.

Grips



The most important element of the system which made the use of the Cable Car practical was the grip. Originally, the Hallidie cars had a grip which gradually closed on the haul rope as a wheel was turned in the car. This technique worked adequately but was later changed to a lever system which allowed the rope to be secured more quickly. This lever configuration is shown in the figure at the left and is known as the Eppelsheimer Grip, developed by William Eppelsheimer, who worked for Hallidie, in 1880. Also shown are the three positions of grip jaws – full release, partial release, full grip.

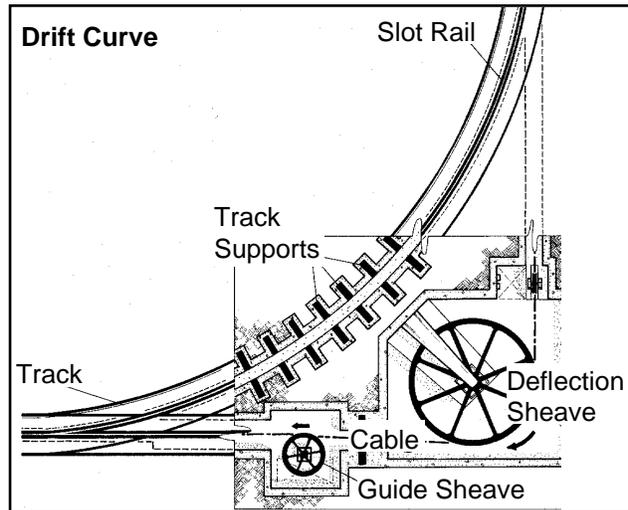
When starting a car from a dead stop, the operator, or “gripman” will pull the lever back once to the partial release position. In this condition, the continuously running cable is sliding against the jaws, without actually moving the car. The gripman can then pull back on the lever, to the full grip position, which accelerates the car up to rope speed. He controls the speed of the transition such that the cable car acceleration is more gradual than an instantaneous jump from stationary to full speed, which would be too abrupt for passenger comfort and could damage the equipment.

Mechanically, the lever achieves grip force by driving down the center plate, forcing the jaws between the roller bars. This squeezes the jaws together, compressing the rope, and the pawl holds the lever in position like a ratchet, allowing the gripman to relax his arms. Each transition point of grip position is felt by the gripman, without concrete references, since wear of the grip jaws is constantly changing the position of the lever relative to the three jaw positions. When necessary, the gripman can use the adjustment rod to take up the “slack” caused by this wear and return the lever to a normal operating position. Once the jaws have worn out completely, they are replaced (about four days).

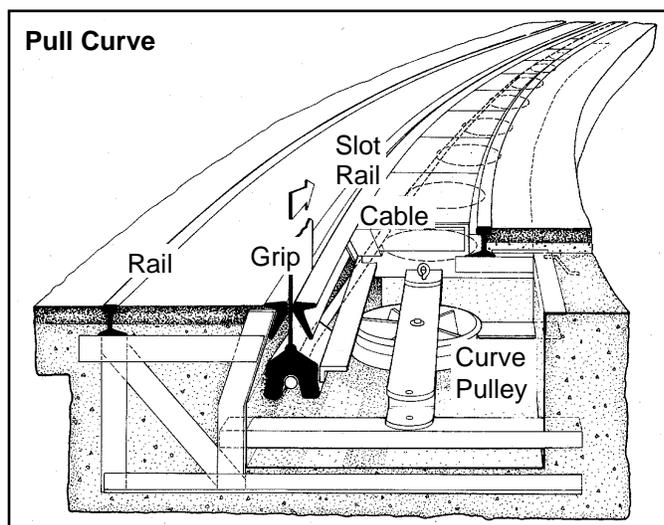
Negotiating Curves

There are two types of curves used in the Cable Car system: drift curves and pull curves. In general, drift curves were used whenever possible, pull curves used only when the grade of the line would not allow a drift curve to be used.

A drift curve uses a simple routing of the cable around a deflection sheave to redirect the cable between two straight sections of track which are connected by a curve. The cable does not follow the contour of the curve, however. This requires the gripman to release the grip just prior to entering the curve and reattach the grip once the car is back on the straightaway. Drift curves are generally simpler and require less maintenance but are only possible if the geography of the line will allow. If the grade does not permit the car to drift all the way to the next straight section, a pull curve must be used instead.



Proper negotiation of a drift curve is dependant on the gripman since the detaching and reattaching of the car to the cable is a manual operation. His training and the warning signs along the route remind him exactly where this maneuver is to be performed.

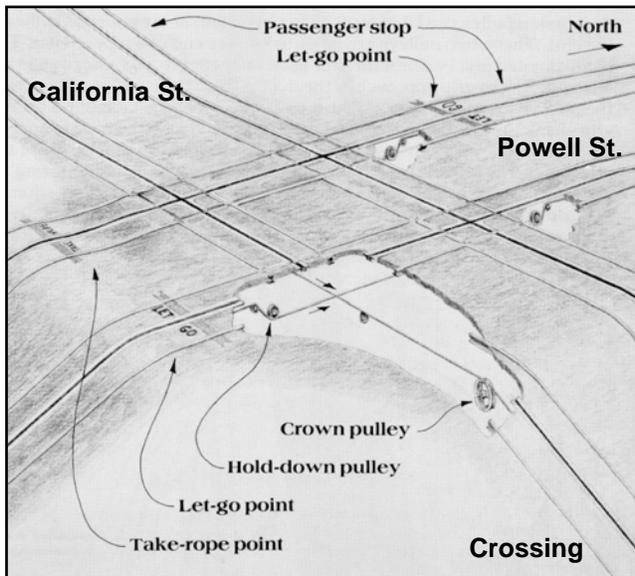


In a pull curve, the haul rope follows the contour of the curve exactly and the car remains attached to the grip at all times throughout the passage of the curve. This requires a series of curve pulleys, aligned along the path of the curve, which maintain the proper position of the haul rope below the center slot. As the grip passes each pulley, it pulls the haul rope slightly off of the pulley surface. Once the grip has passed, the haul rope returns to its normal position. Pull curves provide the simplest operation but at a higher cost in both construction and maintenance when compared to a drift curve. They also introduce more friction into the system, requiring more horsepower from the drive.

It is interesting to note that the pull curve was not an original invention of the San Francisco Cable Cars but was actually first developed in Dunedin, New Zealand.

Crossings

The proliferation of Cable Car lines in the early days of development inevitably led to new lines being built along streets which crossed existing Cable Car lines. The need then arose to establish an arrangement of the tracks and cable which allowed each system to operate independently without interfering with the other.



An existing example of this can be seen where the Powell St. tracks are crossed by the tracks on California St., the older of the two systems. Since the California line was there first, the operation of this system was unaffected. The cars remain attached to the haul rope as they pass the intersection. This is possible since the haul rope remains at the proper elevation below the center slot just as if there was no intersection at all.

The cars on Powell St., however, must release ahead of the intersection and coast across to avoid hanging up on the California St. haul rope. The Powell St.

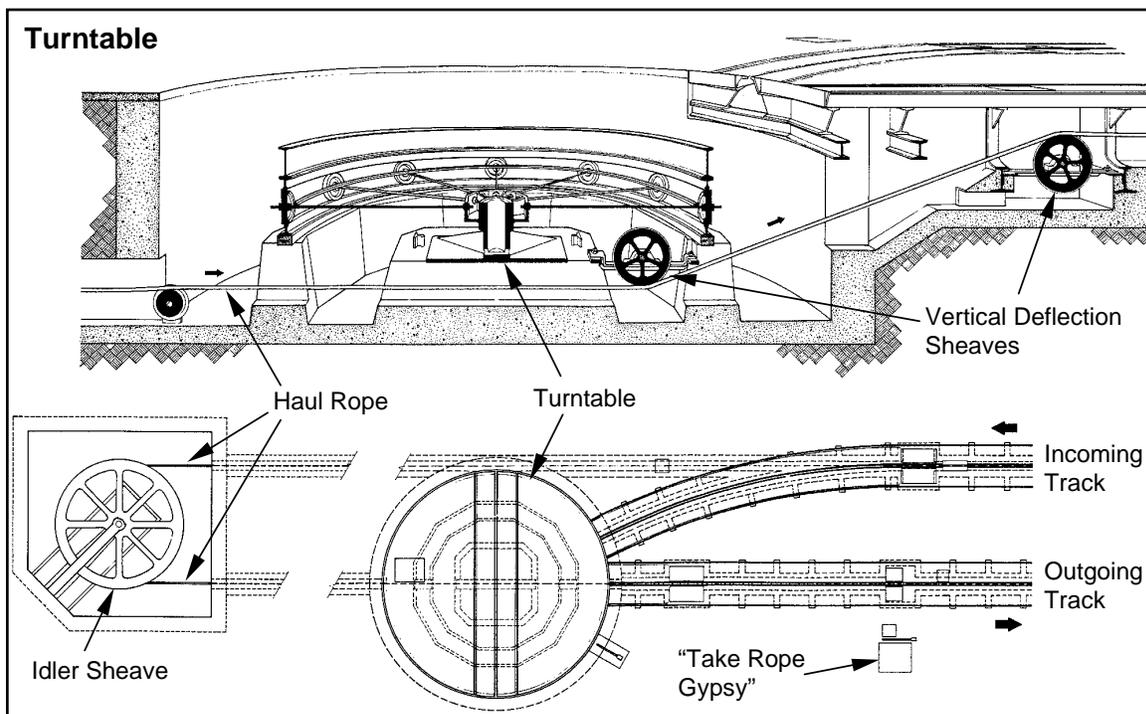
haul rope is then deflected downward to pass under the California St. haul rope, and is deflected upward again at the far side so that the cars can reattach.

The gripman is once again called upon to manually perform this maneuver - nothing is automatic on these systems. As with drift curves explained earlier, he is reminded of the need to detach by his training and by lines painted on the street indicating the correct points to release and reattach.

Switchbacks and Turntables

Each Cable Car line consists of two parallel tracks, one for each direction of travel. At the end of the line, the manner in which the car transfers to the opposite track depends on the type of car. The California Street line uses double ended cars which means the car itself can go in either direction. It is not necessary, therefore, for these cars to be turned around at the end of the line, they simply need to switch tracks. This allows this line to use a simple switch to transfer. The gripman changes to the opposite end of the car which now becomes the front. This is a simpler operation but requires a more complicated car since many mechanical features must be duplicated.

The other lines running today use single ended cars which means that each car has a distinct front and back and the front must always be pointed in the direction of travel. In this case, a turntable is used to switch tracks and reverse direction of the cars.



At the entrance to each turntable, the gripman must release the haul rope completely, allowing the car to coast by gravity or inertia onto the turntable where it is stopped. The turntable is rotated by manually pushing the car around until the tracks of the turntable line up with the tracks of the return line. The car can then be pushed onto the return line track where the haul rope is in position below the track and can be raised up, using a device called a "take rope gypsy" to allow the grip to attach.

For each type of turn-around, the haul rope is simply deflected around a large idler sheave, the diameter of which is equal to the gauge of the two parallel tracks. In the case of the turntable, the rope must also be deflected downward, beneath the table itself, to allow free spinning of the mechanism.

Technological Challenges of the Early Cable Cars

By the early 1890s, Cable Cars could be found in many cities in the US and even in Europe, Australia and New Zealand. The total length of operating Cable Car lines in the US alone was over 500 miles. Among the problems faced by 19th century engineers trying to develop and maintain these systems, the most pressing involved the haul rope itself. Wire rope technology was still a developing industry and the heavy workload of the Cable Cars produced a boom in development and production of wire ropes.

The constant gripping, releasing, sliding, of the haul rope through the grip jaws, combined with the often tortured routing of the haul rope over numerous deflection sheaves, made haul rope life very short. Hallidie himself had established a wire rope manufacturing company in San Francisco in the late 1850s, under the name A. S. Hallidie & Co., and had even developed his own 6x19 wire rope construction to deal with the rapid wear experienced on his mining trams.

Demand for wire rope for Cable Cars was beyond Hallidie's ability to satisfy. As more and more lines were built, the increasing need for good quality wire rope in large quantities brought more and more manufacturers into the market. The great wire rope producing capacity of the US and the rest of the industrial world was thereby jump-started by the introduction of Cable Cars to the streets of our cities.

Technical developments soon followed. In 1885, Thomas Seale was working as the construction engineer for Leland Stanford, who had built his own Cable Car line on California St. (a portion of which is still in operation today). Seale observed the short life of Cable Car haul ropes and developed his own construction, now known as the 6x19 Seale, which put the biggest wires at the outside of the strand, giving more durability under the extremely abrasive environment of Cable Car operation. Later, James Stone in 1889 improved on Seale's design with a construction now known as 6x25 Filler Wire. This rope had the abrasion resistance of Seale's but was more flexible under the repeated bending around sheaves and pulleys so typical for Cable Car ropes. These two cable constructions are now the most commonly used in the ropeway industry. Improvements are constantly being made even today, but the basic technology still in use was developed by engineers just trying to keep the Cable Cars running.

Eventually, the many competitors in the wire rope market were consolidated and the manufacturing base we are more familiar with today emerged. Even Hallidie's company was included. His business was eventually bought by James Stone's Washburn & Moen, which was later incorporated into the conglomerate now known as United States Steel. The availability and quality of wire rope we take for granted today was a direct result of the demand created by the Cable Cars over 100 years ago.

The high cost of operation eventually led to the replacement of the Cable Cars around the world by diesel or electric powered trams and buses. Only in San Francisco did they survive, mainly due to the early buses' inability to climb the steep hills and the nostalgic attachment of the local population to this unique system of transportation.

Technical Challenges of the Modern Cable Car System

The San Francisco Cable Car lines in operation today still run in much the same way they did in the early years. In fact, almost all of the cars in operation today, although periodically refurbished, were built in the late 1800s and early 1900s.

The greatest continuing challenge remains the life of the haul ropes. Even with the advances in wire rope technology over the last 130 years, the Cable Car system's appetite for rope continues to be voracious. Typical haul rope life today is between 90 and 180 days. The four cables of the present system add up to 56,500 ft (17,221 m). This translates into an annual wire rope turnover of 115,000 to 230,000 ft (35,000 to 70,000 m). It is obvious that any improvement in haul rope life could significantly reduce the maintenance costs.

Physical wear on the haul rope by the harsh application of the car grips is compounded by the heat built up during the sliding phase of grip closing. The friction developed will raise the surface temperature of the haul rope to the point where austenite is formed. Immediate cooling thereafter results in a thin layer of untempered martensite – a very hard, brittle layer which is easily scraped off by subsequent grip application or other abrasive contact. This process, combined with the physical compaction of the core by repeated grip applications, gradually reduces the diameter of the haul rope until it is no longer usable. Add to this the occasional equipment failure or gripman error and one can see that these haul ropes really do take a beating.

Haul rope lubrication is also an ongoing challenge. Lubrication of the rope is necessary to prevent premature failure of the wires under the repeated reverse bending which results from the constant deflection of the rope over sheaves and pulleys. However, too much lubrication will compromise the traction of the rope within the drive and the grip of the car jaws on the haul rope. In addition, the process of the haul rope sliding through the gradually closing grip jaws rapidly depletes the lubricant in that area, both by physically pushing it away and by burning it off through the tremendous heat developed by the friction.

Grip Jaw wear is another high maintenance item. The steel jaw inserts which actually contact the rope are subjected to the same high friction, high temperature and tremendous physical stress described above for the haul rope. Normal operation takes its toll but to that is inevitably added greater wear due to the frequent need of the gripman to partially release the grip to avoid traffic or pedestrians. This constant grinding of the jaws results in a jaw life of only about four days.

These issues, added to the usual tasks of car upkeep, track repair, and drive machinery maintenance clearly demonstrate the tremendous dedication required to keep this historic system in operation. The basis of the wire rope transportation industry as we know it was laid here in San Francisco and it is still a pleasure to be able to enjoy the ride of these unique machines in much the same way as people did almost 130 years ago.

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Internet Resources

1. The Cable Car Home Page by Joe Thompson at <http://www.geocities.com/CapeCanaveral/Launchpad/3518/cablecar.html>
2. Museum of the City of San Francisco at <http://www.sfmuseum.org/>
3. The San Francisco Cable Car Website at <http://www.sfcablecar.com/>
4. San Francisco Transit: Cable Cars at <http://www.nycsubway.org/sf/cable.htm>

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