CABLE TRAMS IN MELBOURNE – A MAJOR NINETEENTH CENTURY ENGINEERING ACHIEVEMENT

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ABSTRACT

Melbourne's boom period in the mid 1880s saw the inauguration of a cable tram system that by 1891 had grown to encompass seventeen routes with a combined length of 46 miles (73 km) of double track. In its extent, it was only surpassed by San Francisco's cable tram network. The 43.7 miles (70 km) of double track, constructed by the Melbourne Tramways Trust (representing twelve municipalities), and leased for operation by the Melbourne Tramway & Omnibus Company had the distinction of being the largest cable tram network in the world to be operated by a single company. It evolved from the determined vision of Francis Boardman Clapp and was implemented under the guidance of renowned cable tram engineer George Smith Duncan. The last cable tram service closed in 1940. This paper focuses particularly on the engineering aspects of the system and thus on its infrastructure.

1 OVERSEAS BACKGROUND

The use of a continuous loop of wire-rope driven by an engine and to which buckets or track mounted vehicles could be coupled and uncoupled in order to propel them had its origins in mining by way of aerial cableways and the underground haulage of skips running on rails within mine tunnels. Its first successful application to propel streetcars or 'trams' was in San Francisco where Andrew Smith Hallidie, who had interests in wire rope manufacture, set up a cable tram service on the steeply inclined Clay Street. It had its first run in August 1873 and was an immediate success. (Bucknall Smith, 1887; Hilton, 1982).

The essential elements of Hallidie's tramway comprised a cable tunnel between the tram rails in which the continuous loop of wire-rope cable ran on supporting sheaves. The cable was driven from an engine house by steam power. A steel lipped longitudinal slot at grade in the top of the cable tunnel allowed the narrow shank of a cable gripping device – 'the grip' – mounted in the haulage vehicle, termed 'the dummy', to clamp onto the cable from above and thus propel the dummy along its running rails. The grip could be activated and released via a hand-wheel forming a part of the assembly and was positioned in the middle of the dummy where it was operated by 'the gripman'. (Bucknall Smith, 1887; Hilton, 1982). The dummy hauled an enclosed car behind it known as the 'trailer'. The cable tram, comprising dummy and trailer, was well suited to providing a convenient form of street based public transport in the hilly topography of downtown San Francisco.

Four years later another company inaugurated a separate cable tram service in nearby Sutter Street that incorporated a number of improvements including to the design of the cable gripping mechanism. Yet other lines followed, and by 1890 San Francisco had twenty-three cable tram routes totalling some 53 miles (85 km) of track. They were operated by a variety of private companies, some of which later amalgamated. (Hilton, 1982).

Chicago was the next USA city after San Francisco to implement the technology with its first cable tram route starting operation in 1882. Other lines then followed such that this city hosted about 41 miles (66 km) of double-track cable tram routes at its peak. In contrast to San Francisco, Chicago's streets were essentially flat and the advantage of being able to accommodate steep gradients was not applicable. Nevertheless, the enterprise was successful until superseded by electric trams in the first decade of the twentieth century. (Hilton, 1982; Wikipedia - Cable Cars in Chicago).

Cable tram systems were established in a total of twenty-nine USA cities during the 1880s (Hilton, 1982). Kansas City with some six separate systems and operators had a combined track length of 41 miles (66 km) whilst New York, Denver and St Louis each had around 25 miles (40 km) of cable tram tracks (Dodd, 2002). Other USA cites had less extensive systems. Short cable tramlines were also built in London, Birmingham and Edinburgh between 1884 and 1889. (Bucknall Smith, 1887).

The first cable tramway to be constructed outside of the USA was the 0.7 mile long (1.1 km) line between the CBD and the suburb of Roslyn in the hilly city of Dunedin, New Zealand. It commenced operation in 1882, comprising a single track with passing loops and included two reversed curves (Bucknall Smith, 1887; Hilton, 1982). A double track line about 1.0 miles (1.6 km) in length to service the Dunedin suburb of Mornington was commissioned a year later following the early success of the Roslyn cable tramway. It in turn was later extended to serve the suburb of Maryhill. The Dunedin lines used dummy vehicles and cable grips similar to the San Francisco Sutter Street system (Bucknall Smith, 1887).

The Dunedin cable tramways were conceived by a young locally born engineer, George Smith Duncan, who in 1879 obtained a concession from the City for his consulting engineering firm of Reid and Duncan to construct the Roslyn cable tramway. Duncan apparently had not previously seen the San Francisco cable trams, but evidently obtained technical information about the Sutter Street installation in particular and used similar design features. (Keating, 1971; Hilton, 1982). The Roslyn tramway route included a double curve on a steep gradient for which Duncan devised the 'pull curve', a world first development - see later. (Hilton, 1982; McAra, 2007).

2 THE MELBOURNE TRAMWAY & OMNIBUS COMPANY

Francis Boardman Clapp, born in Massachusetts in 1833, emigrated to Melbourne in 1853 in company with many other gold seekers, but soon turned his attention to public transportation opportunities based on his experience with horse drawn vehicles in the USA. By 1857 Clapp was heading a small syndicate (1857-1860) running horse drawn coaches to Ballarat, Geelong and other regional centres. In 1860 Clapp was part of another syndicate that tried unsuccessfully to gain a concession from the Melbourne City Corporation to build and operate a horse drawn tramway – that is a carriage pulled by a horse or horses and running on rails laid in the street – from the city to Collingwood. The idea was favoured by the City at the time but failed for legal reasons. (Keating, 1970).

After a visit to Europe and back to the USA in 1867, Clapp in partnership with two other associates established a horse drawn omnibus (a horse drawn multi-passenger conveyance operating on city streets) service that commenced in March 1869, plying between the city and suburban Collingwood. In the following month the partnership became a limited company called the Melbourne Omnibus Company. Other inner city horse drawn omnibus routes followed, but Clapp retained his ambition to eventually run on rails and planned his omnibus routes with this firmly in mind (Govett & Twentyman, 1973). Reflecting this, the successful Melbourne Omnibus Company was re-constituted as the Melbourne Tramway & Omnibus Company. (MT&OC) in 1877.

In order to construct tramlines along public streets it was necessary to obtain legislative authority. In May 1882 the MT&OC succeeded in having a private members bill, sponsored by Duncan Gillies, member for Rodney, introduced to the Victorian Legislative Assembly. The Bill had in-principle support of the affected municipal councils, but was subjected to extensive and sometimes irrational and/or vested interest opposition. It was examined by a Select Committee and then, at the beginning of 1883, endured a change of government. Under the new government the Bill was reconsidered and eventually passed by both Houses with limited amendments in September of

1883. It received Royal assent the following month and thus became *The Melbourne Tramway & Omnibus Company's Act 1883.* (Keating, 1970). As Keating observes, it is somewhat surprising that whilst there were prior concerns about a single company having a monopoly to operate multiple tramway routes, no specific consideration appeared to have been given to the merits of a non-monopolistic setup allowing for multiple separate tramway companies, as applied in the USA.

Whilst the MT&OC Bill was nearing acceptance in 1883, George Duncan, soon after he had completed construction of the Mornington cable tramline in Dunedin, accepted an invitation from Francis Clapp to take up a position as engineer to the MT&OC in Melbourne. Clapp clearly had an ambition to introduce cable trams to Melbourne albeit that the proposed tram routes submitted in support of the parliamentary Bill envisaged horse drawn trams. Significantly, the MT&OC Act, although providing for horse trams, specifically permitted the choice of cable traction or other mechanical power, other than steam trams (tram cars hauled by small purpose-built steam locomotives as then in use in Sydney) 'where appropriate'.

In his evidence to the 1882 parliamentary Select Committee, Clapp presented comparative costings for horse drawn trams and cable trams indicating that the latter would be the more favourable option for expected higher patronage routes. He also revealed that he had previously obtained for the company the rights to use USA based cable tram technology and patents in Victoria. (Keating, 1970; Select Committee Report, 1882).

The twelve municipal councils in whose jurisdictions it was planned to construct tramways had the right under the MT&OC Act to form a Tramways Trust. This right was promptly exercised with the Trust members comprising representatives from each municipality. (MTT Chairman's Report 1883 – 1888).

With the Act in place, Clapp and Duncan together visited the USA and England to check on the latest tramway developments there. Not surprisingly, given Clapp's previous interest in cable trams and the newly recruited Duncan having successfully implemented two cable tram routes in Dunedin, they returned from their overseas trip with the confirmed conviction that 'it would be reasonable to use cable traction in Melbourne as widely as possible'.

Clapp and Duncan duly reached agreement with the newly formed Melbourne Tramways Trust (MTT) to use cable traction on all but six of the then planned tramway routes including two short extensions east of the Yarra River to Hawthorn and to Kew, where horse drawn trams were considered to be sufficient for the then anticipated patronage. For the other four projected lines to the north, south, west, and to Port Melbourne, the number of track curves (changes of direction – particularly on short radii) was perceived to make them impracticable for cable traction, a decision that was later overturned. (MTT Chairman's Report 1883-1888; Keating, 1970).

Under the 1883 MT&OC Act, the Tramway Trust was charged with construction and ownership of the tracks themselves along respective municipal streets and roads whilst the private company (MT&OC) was to be responsible for the rolling stock and related ancillary items and facilities as well as maintaining and operating the tramway system for the lease period of thirty years. For the cable routes, this translated to the Trust being also responsible for building and equipping the engine houses to power the traction cables, and for constructing the cable tunnels between the tram tracks to contain the moving cable. The Act enabled the Trust to borrow money to undertake the necessary works, with the loan interest plus a further annual percentage as a sinking fund (to ultimately discharge the loans) to be paid to the Trust from the Company's operating revenue. (MTT Chairman's Report 1883–1888; Bucknall Smith, 1887; Keating, 1970).

In that the primary engineering tasks of providing most of the fixed infrastructure was within the Tramway Trust's ambit, George Duncan was appointed as the Trust's engineer in 1884. He did however continue to serve the Company in a consulting capacity. Pending raising initial loan funds, the Trust arranged for the Company to build the first route from Richmond to Spencer St station. Three contractors constructed sections of the permanent way starting in late 1884 and the line was opened in November 1885. (MTT Chairman's Report 1883-1888). Figure 1 shows a photo collage produced by the Company at the time depicting the various elements of the system.

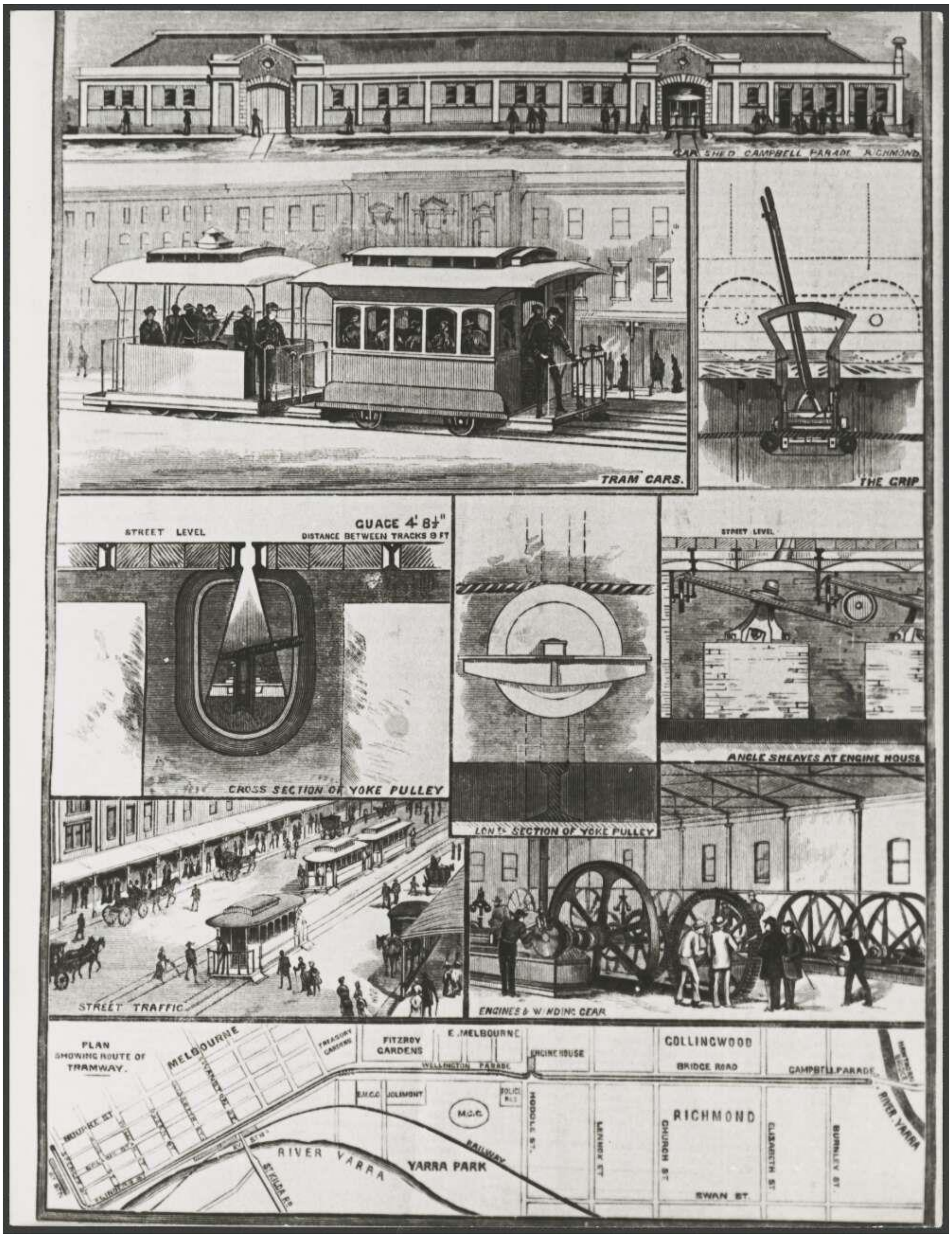

Figure 1: MT&OC photo collage for opening of Richmond route 1885

An initial loan of £500 000 (roughly $65M current value) was quickly raised in London by the Tramway Trust and contracts subsequently let for construction of other routes along with the supply of engine house plant and equipment. Within six years a total of sixteen cable tramway routes were operational, most of which radiated out from the CBD to suburbs within about a 3 miles (5 km) radius. Several tramways 'route extension' Acts were passed following the original Act to permit various route extensions.

Figure 2 shows the geographic disposition of the respective cable tram routes at the beginning of the twentieth century and the commencement dates are listed in Table 1. (See later re the independent Northcote line).

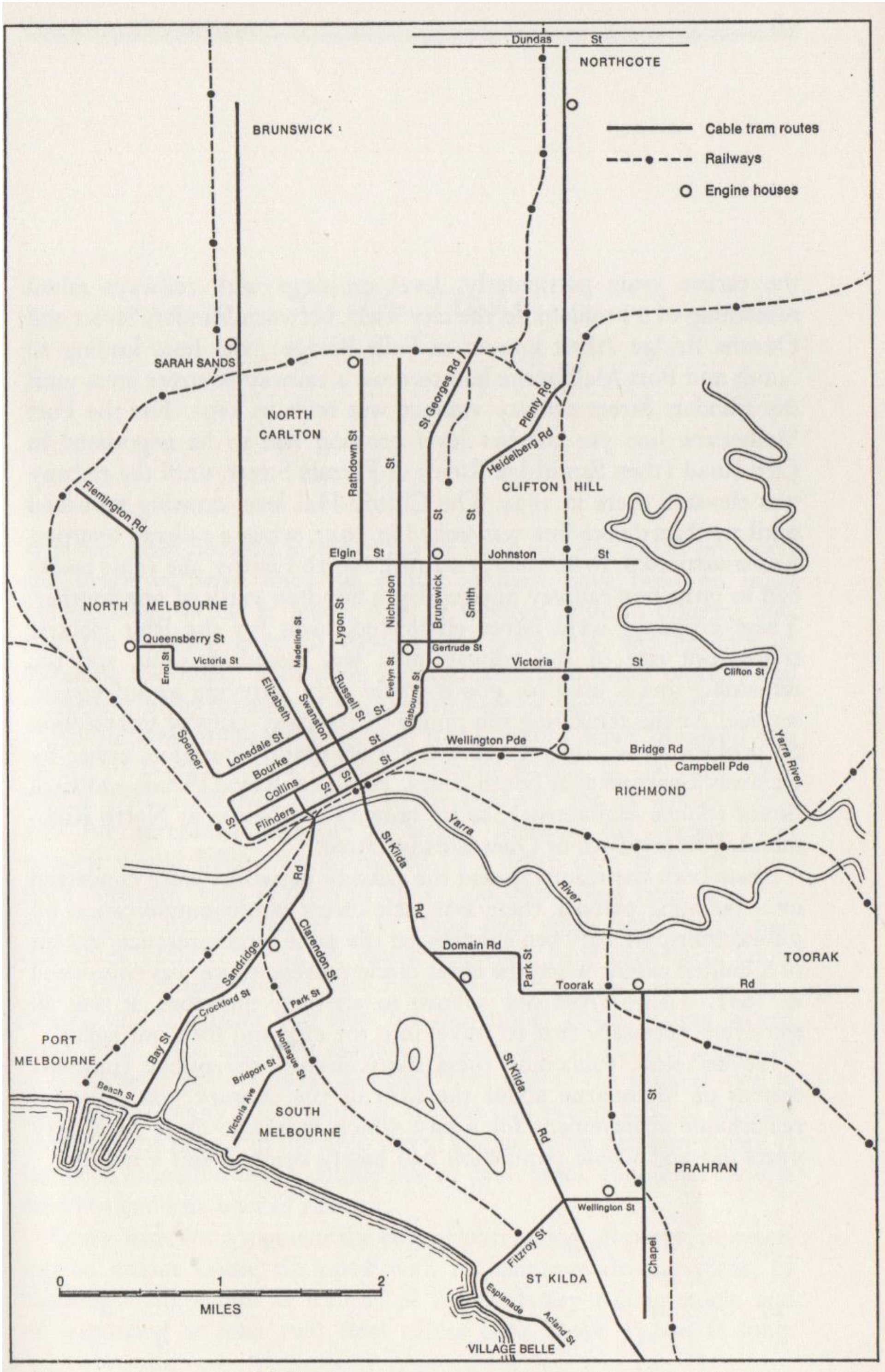

Figure 2: Cable Tram Routes 1900

Table 1 - Cable tram routes opening dates (MTT Chairman's Reports, 1888 and 1892)

Route	Opening Date
Richmond	11 Nov 1885
Collins St and Fitzroy	02 Oct 1886
Victoria Parade	22 Nov 1886
Collingwood and Clifton Hill	10 Aug 1887
Bourke St and Nicholson Street	26 Aug 1887
Brunswick	01 Oct 1887
Carlton	21 Dec 1887
St Kilda	11 Oct 1888
Prahran	26 Oct 1888
North Carlton	09 Feb 1889
Toorak	15 Feb 1889
North Melbourne	03 Mar 1890
West Melbourne	18 Apr 1890
South Melbourne	17 June 1890
Port Melbourne	17 June 1890
Windsor – St Kilda Esplanade	27 Oct 1891
Northcote [Independent line]	18 Feb 1890

3 CONSTRUCTION OF THE MT&OC CABLE TRAMWAY LINES

The Melbourne cable tram permanent way consisted of twin tracks – 'up' and 'down' – with the running rails spaced at the standard gauge of 4' 8½" (1435). The rails, laid on 6" (150) thickness of concrete, were 57, 67 or 87 lb/yd (28, 33 or 43 kg/m) grooved steel type with the heavier rails used on expected high traffic sections. Located centrally beneath between each pair of rails was a concrete lined tunnel reinforced at 3' (915) intervals by steel yokes formed from 50 lb rail to which the continuous steel lips of the cable slot, termed the slot beams, were secured. Adjustable tie rods ran from the slot beams to the running rails. (Pollock, c1950; MacMeikan, c1960). Within the tunnels 9" (230) diameter pulleys at half chain (10 m) intervals were installed to support the running cables. The cable tunnels required excavation to a depth of 3' 9" (1140). This deep excavation often entailed rerouting and/or reconstruction of existing utility services including duplication of gas and water mains so that the individual service connections would not have to be routed under the cable tunnel. (Govett & Twentyman, 1973).

The surface level slot midway between the tracks was carefully set to 7/8 inch (22) width so as to be wide enough to freely admit the neck of the dummy car grip but at the same time not allow the narrow wheel of a light buggy to enter it. The roadway between the tracks and out to a total width of 17' (5200) was reconstructed with wooden blocks and finished with distilled tar. It has been estimated (Pollock, 1928) that there were some 20.5 million woodblocks used in total. Figure 3 shows a typical cross-section of the lines. By the time that all of the routes had been constructed the Tramway Trust had spent A£1.7M (roughly $220M in today's equivalent) or about £39 500 per route mile ($3.1M per route km). (Pollock, c1950).

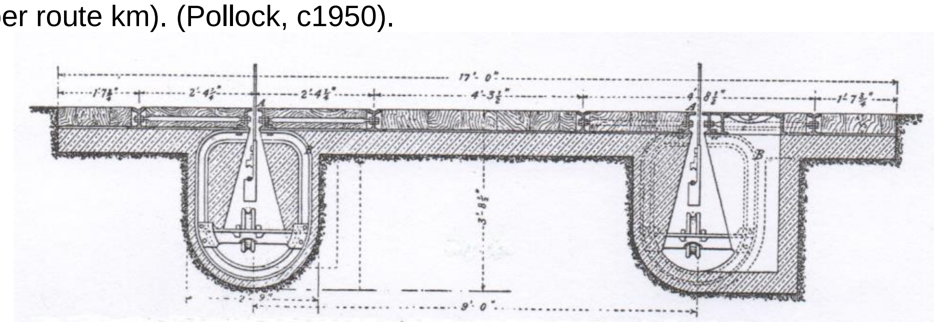

Figure 3: Typical Track cross-section. Shows line sheave access pit on right-hand side.

At the route termini, large diameter grooved sheaves, horizontally mounted in a below ground pit, reversed the direction of the cable. Preceding it, crossover points permitted the uncoupled dummy or 'grip' car to be separated from its trailer and having released the cable be transferred across to the return track and then moved forward so that the decoupled trailer could then be similarly moved across to the return track behind the dummy and the two cars then re-coupled. At terminus areas that were flat, the respective tram cars were manually pushed across by the grip man and conductor, but where there was some advantageous slope it was arranged to facilitate gravity-assisted transfers with separated crossovers for each car. With the cars recoupled, the cable for the return track could then be lifted into the jaws of the grip by the conductor using a trackside mechanism, ready to propel the tram set on its return journey.

In six places in the Melbourne CBD and at a further five locations in the nearby suburbs, cable tram routes crossed over each other, usually at right angles. At these sites, 'depression sheaves' forced the cables of one of the routes – 'the inferior route' - down beneath the intersecting cables. A tram approaching the crossover on the inferior route would have to release its grip on the cable at a point designated by marking strips on the roadway, and coast across the intersection before picking up the propulsion cable again on the opposite side. (Pollock, c1950). If a stop or loss of momentum occurred during the short transit, some passengers could have to alight and help push the vehicles across.

Changes of direction, or 'curves', and particularly tight radius ones dictated by available street width, posed special problems for cable tramways. According to Keating, 1970, the Melbourne cable tram routes involved some 63 curves for right and left-hand turns into different streets, etc. A table of curves in MacMeikan, c1960, lists 90 curves inclusive of the non MT&OC Northcote line. *(The large difference in the numbers might be due to differences in what was considered to be curve aside from obvious 90° bends).* Curve radii ranged from around 15 m to 120 m.

Faced with a double curve on steeply sloping ground on the Roslyn cable tramline in Dunedin, Duncan's solution was to install a series of closely spaced horizontal sheaves or drums (wide faced sheaves) to direct the cable around the curve. A regularly greased curved steel rubbing – or 'chaffing' - bar was mounted immediately above the sheaves to keep the moving grip from itself being bent sideways by the cable tension as it progressively lifted the cable out of the succeeding sheaves. Pull curves on this principle were subsequently adopted on the 1883 extensions to the San Francisco Sutter St lines and on later USA cable tramlines. (Hilton, 1982).

A drawback of pull curves as described above was the fact that the cable trams rounded the curve at the full speed of the cable with attendant risks in relation to other road traffic. The multiple sheaves and the bending of the cable by the grip itself also accelerated cable wear and the sheave assembly was costly to install and to maintain. An option to ease the problem of pull curves, and first used on the San Francisco 1883 Market St line (Hilton, 1982), was to use a separate auxiliary cable running around the multiple sheave arrangement with the main cable then traversing the corner via only one or two deflecting sheaves. In this case, approaching trams would drop the main cable and grip the auxiliary cable to be hauled around the bend(s), then drop it and re-grip the main cable on the other side. The auxiliary cable could be arranged with a lower tension, thus reducing the sideway force on the cable grip and avoiding the flexing and consequent wear on the expensive main cable. It could also run at a lower speed, making the direction change safer and more comfortable for the tram and its passengers.

At curves close to an engine house an auxiliary cable could be separately driven. Elsewhere, interconnected pulleys and gearing were used so that a main cable drove the auxiliary cable. The former arrangement was employed at the double curve from Gisborne St East Melbourne, across Victoria Parade and into Brunswick St Fitzroy, and also for the Nicholson St / Gertrude St corner, both being adjacent to the respective engine houses. The second method applied to auxiliary cables that were used for one block in Lonsdale St on the Carlton line for through running to Swanston St and to facilitate transfer from the Brighton Rd line onto the Windsor - St Kilda line at St Kilda Junction, although the latter was later removed. (MTT Chairman’s Report 1883-1888; Govett & Twentyman, 1973; Keating, 1970).

It appears that George Duncan used his multi-sheave ‘pull curve’ widely at changes of direction on the cable tramlines in Melbourne. A short article in the Street Railway Review, 1893, claims that this provision had initially been used on ‘all’ curves on the MT&OC operated cable tramlines. However, as mentioned above, experience in Melbourne, as elsewhere, showed that pull curves greatly accelerated the wear on cables, due to it having to run over multiple small sheaves around the curve and the bending of the cable as the grip held the cable out from the successive sheaves as the dummy traversed the curve.

By the early 1890s and in the interests of reducing wear on main cables at tight radius corners, George Duncan replaced some of his multi-sheave pull curves on the Melbourne network with single large diameter horizontal sheaves positioned at the apex of the direction change, thereby converting them into ‘let go’ curves. This was found to be workable on level curves or where the gradient (in one direction) would assist the process. On approaching the curve, the gripman had to release or ‘throw’ the cable and utilise the tram’s momentum, with or without the assistance of gravity, to traverse around the curve before picking up the cable again on the other side, similar to dropping and subsequently reacquiring the cable at an inferior crossover. The first so called ‘let go’ curve was employed on the San Francisco Presidio & Ferries Railroad’s 1880 cable tram (Hilton, 1982). This method was not acceptable for curves on steeply sloping ground as applied for the two curves on Duncan’s Roslyn cable tram route in Dunedin where Duncan is credited with the design and construction of the first ‘pull curve’. (Hilton, 1982).

The high cost and disruption of retrospectively removing the pull curve equipment and constructing a large wheel pit and substantial cover over it was found to be more than offset by significantly prolonging cable life. The above mentioned article in the Street Railway Review, 1893, claimed that on one section of line with ‘two right angle curves and one obtuse curve’ that had then recently been converted to ‘let go’ operation, the rope then in use had lasted 57 weeks compared with a previous average life of 16 weeks and a maximum of 28 weeks. Further conversions from pull curves to let go curves proceeded in subsequent years. (MTT Chairman’s Report 1892-1905; Pollock, 1928). (Experience with pull curves on the Melbourne cable tram network is elaborated in Pollock, c1950 and MacMeikan, c1960).

In the vertical plane, 2’ 6” (760) diameter heavy sheaves were used at significant crests in the cable route to take the added weight of the cable (Pollock, c1950). Conversely, depression sheaves were used to stop the cable rising up at low points (dips) in the cable route. For the dummy to pass over, the cable would have to be dropped from the grip on approach and regained on the other side. On the Bourke St lines, depression of the cables at the low point at Elizabeth St intersection was combined with depression of the same cables in order to pass under the Elizabeth St cables. Thus, an up tram headed for the Spencer St terminus would throw the cable just before the intersection, coast across and pick it up again immediately on the west side of Elizabeth St. Conversely, down trams in Bourke St would release the cable close to the bottom of the downhill run and coast across the intersection. (Govett & Twentyman, 1973).

Where individual cable tram routes diverged, point mechanisms had to simultaneously shift the point blades on the running rails and change the direction of the slot so that the empty grip could follow the same direction as the rails. The mechanical operation was complicated by the depth of the cable tunnel that precluded simple cross-linking of the rail point blades as for conventional railway and non-cable tramways. Typically, the conductor would alight to operate a retractable trackside point lever then signal the gripman to briefly grasp the cable to gain momentum before throwing it in order to pass through the junction points. (Pollock, c1950; Govett & Twentyman, 1973).

Figure 4 from McCarthy, 1983, shows diagrammatically the various cable sections, cross-overs and auxiliary cables on the cable tram routes.

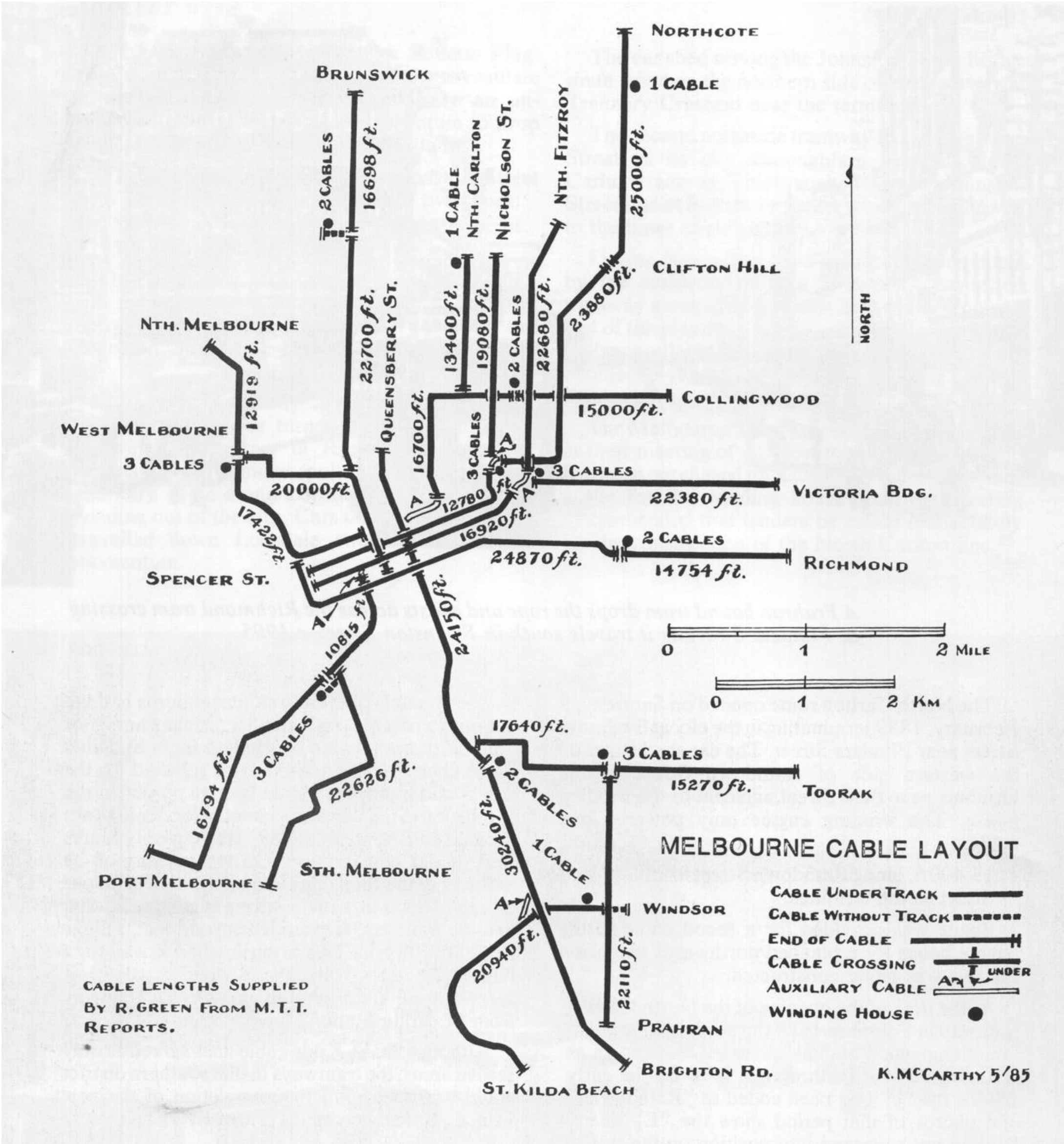

Figure 4: Schematic route diagram showing cable sections.
[Reproduced with permission from Australian Tramway Museum's *Trolley Wire,* No 221, Dec 1985]

4 ENGINE HOUSES

Engine houses – or winding houses - to drive the continuous cable loops were typically located near the mid-point of the route with separate cables then running out and back to the respective 'up' and 'down' terminals. In places were geography permitted, one engine house accommodated the driving equipment for the cables of two tramway routes. Figure 5 shows the interior of a typical cable tram engine house c1890. The main running cables are directed into and out of the engine house by large horizontal or inclined sheaves in an extensive pit beneath the roadway and a connecting tunnel into the building. Inside each engine house the cables ran around the timber lined grooved periphery of large diameter driving sheaves and then around a similar diameter sheave set on a rail mounted carriage that was dead-weight loaded so as to maintain a constant tension on the cable.

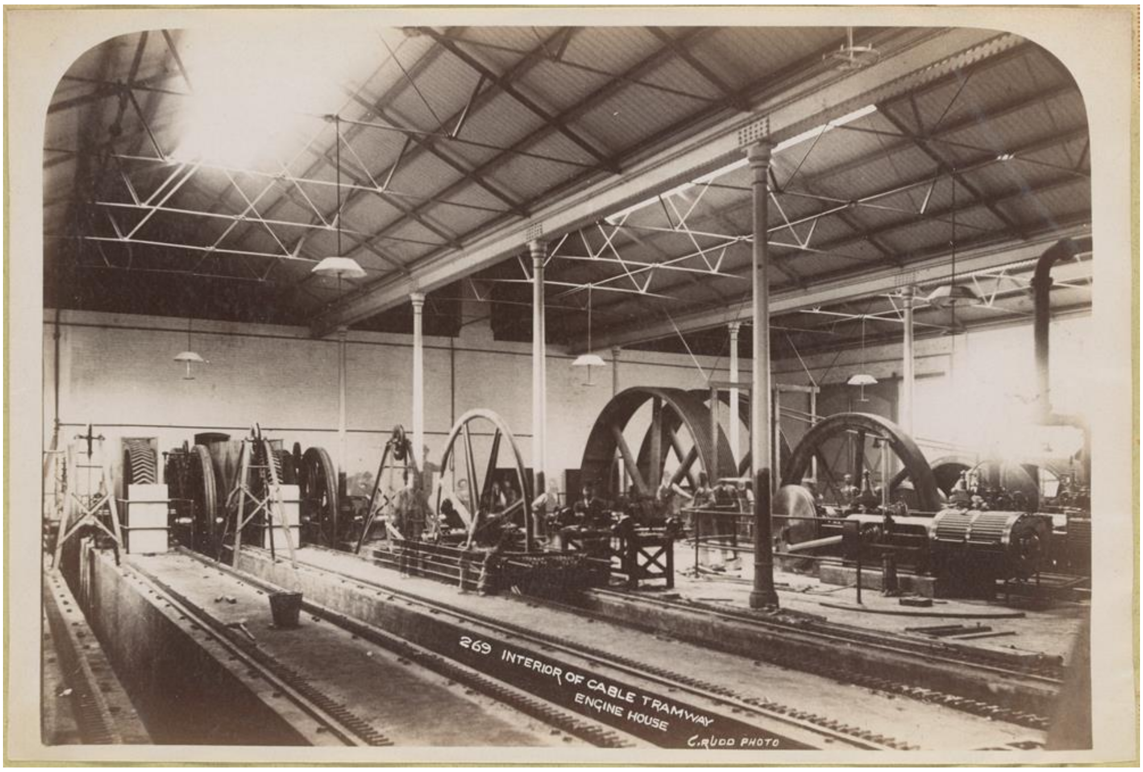

Figure 5: Interior of a typical engine house, showing engines, manila rope drives, cable driving wheels, cable raceways and tensioning gear c1895. Photo SLV H39357/56

The cable driving sheaves were in turn driven by horizontal, non-condensing steam engines via a speed reduction provision. At the first engine house this was achieved by helical gears but later the multiple-pass rope drive using grooved driving pulleys was preferred for its lower noise level and reduced maintenance requirements, and was ultimately used in all engine houses serving the MT&OC operated lines. This comprised a multi-grooved drive pulley on the common engine shaft linked to a larger diameter grooved pulley on the cable drive shaft via 16 – 18 manila rope passes. (MacMeikan, c1960).

The pair of 24" x 48" horizontal steam engines installed in the first engine house in Richmond and designed to act as duty and standby to each other were made by Jessop & Sons of Leicester, England, and rated at 370 hp (275 kW). This power was considered to be liberal relative to the anticipated working load (The Argus, 9 Aug 1885; MTT Chairman's Report 1883-1888). Later, two pairs of horizontal steam engines manufactured by Shanks & Co., Scotland, with 24'' dia. cylinders and 48" stroke (610 x 1220) and rated at 800 hp (600 kW) per pair at 60 rpm were installed at the Fitzroy, Nicholson St and Toorak (Toorak/Prahran) engine houses. Locally manufactured Austral Otis (formerly Hughes Pye & Rigby), 20" dia x 40" stroke (508 x 1016), engines rated at 560 hp (420 kW) at 72 – 80 rpm were employed at other engine houses (Pollock, 1928). Reportedly the Austral Otis engines, fitted with Myer expansion valves, 'caused much less trouble and expense than the imported engines' (Pollock, 1928). (Austral Otis later supplied similar engines for the MCC Electricity Supply Department's initial 1894 Spencer Street power station (Pierce, 2010)). The cable tram steam engines exhausted to atmosphere via duplicated direct contact feed water heaters.

The boilers to supply steam to the engines, also duplicated, were locally made multi-tubular marine type with a working gauge pressure of 100 psi (670 kPa) excepting for the Richmond and Fitzroy engine houses that had Babcock & Wilcox pattern water tube boilers. The boilers were manually fired with coal or gasworks coke and all of the original boilers reportedly lasted until closure of the respective engine houses. (Pollock, 1928). Figure 6 shows the interior of the boiler room at the Toorak engine house c1916.

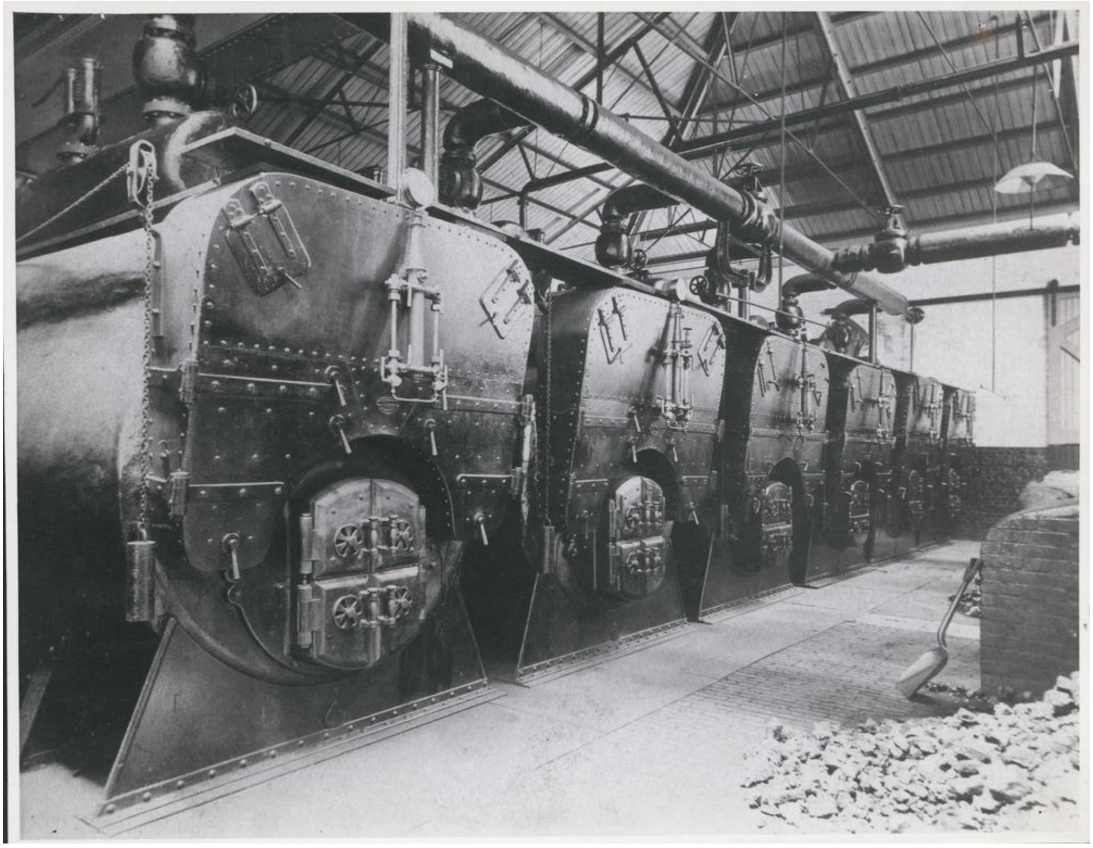

Figure 6: Interior of boiler room at Toorak engine house 1916. Photo SLV 36280/1

Governors on the steam engines were employed to maintain a nearly constant running speed of the cable in the face of constantly changing load as multiple trams released and gripped onto the cable as they progressed along the route picking up and setting down passengers and/or negotiating crossovers and curves demanding dropping and then regaining of the cable. The cable running speed, and thus that of the trams when gripping on to it, was initially about 8 mph (13 km/h). It was later generally increased to 12.5 or 13.5 mph (20 or 22 km/h), to reduce travel times and increase the service frequency. This was typically achieved by substituting larger diameter driving wheels of up to 14' (4.3 m) in diameter. (Pollock, c1950).

Initially, two 12' (3.7 m) diameter cable driving wheels were used with the cable running in an 'S' curve around them in accordance with normal USA practice – referred to as 'the American system' by Bucknall Smith, 1887. The first wheel was mounted on the main drive shaft and the second gear driven from the latter so as to counter rotate. This resulted in noise emission from the open gear wheels, which, like the speed reduction gearing at Richmond engine house, reportedly annoyed residential neighbours. The problem was first mitigated by using replaceable 'horn beam' gear teeth, but later, and presumably as a result of experimentation by the MT&OC, it was found that a single driving wheel was sufficient with the second wheel running as an idler to increase the angle of wrap of the cable on the driving wheel and then reverse the direction of rope travel in order for it to run at high level to the separate tensioning wheel. The single driving wheel had replaceable cast-steel segments securing machined hardwood pieces that transferred motion to the cable as it passed around the periphery. This arrangement was adopted at all engine houses. (Pollock, 1928; MacMeiken, c1960).

According to Pollock, the average power demand per tram was approximately 9.5 hp (7 kW) including ropes and driving machinery although it varied considerably depending on the number of curves and gradients on the particular cable section (Pollock 1928). The St Kilda engine house was the heaviest loaded with an average of 411 hp (307 kW) in 1918 and a maximum recorded of 683 hp (510 kW) with 75 trams on the line. The engine houses where adequate for the traffic for which they were designed and coped well until around 1918. (From 1900 to 1918 the number of passengers moved across Princes Bridge on the St Kilda route increased from 7 to 23 million, a factor of 3.3). The continuing growth in patronage necessitated heavier cables on some popular lines, and forced running speed reductions at peak times. This was overcome by adding forced draft to some boilers to increase steaming capacity or by adding supplementary drives to augment the the steam engines. (MacMeiken, c1960).

Based on comparative contemporary illustrations the dead weight cable tensioning arrangement used in the Melbourne engine houses was similar in principle to the arrangement first used on the 1883 San Francisco Market St line. (Bucknall Smith, 1887). The large diameter tensioning sheave was mounted on a wheeled carriage that ran on rails fixed on a larger carriage or trolley that itself ran along rails secured on each side of the long cable raceway trench. Chains affixed to the back of the tension wheel carriage ran over pulleys at the inner end of the lower carriage to a weight bucket of several tons suspended in the raceway. Movement to and fro of the tension wheel carriage enabled the maintenance of a constant tension as the cable length changed in response to load and temperature changes. The lower carriage was prevented from moving forward by pawls engaging in racks on each side of the raceway rails.

When a new cable was installed, the lower carriage would be positioned close to the driving wheel end of the cable raceway. As the cable stretched with use, this could be compensated by first lashing the upper and lower tension wheel carriages together and then using a block and tackle to pull the lower carriage further out along the raceway tracks. This was facilitated by running the end of the tackle rope around a capstan drum on end of the tension wheel shaft after first slowing the cable drive. (Pollock, c1950).

A prominent brick chimney stack to which the boiler flues connected marked the location of each of the engine houses that were themselves large single-story brick buildings. The facades of some engine houses in prominent locations, like the Nicholson St building, were given ornamental treatment. The operating staff immaculately maintained the engine houses and their machinery. In all there were eleven separate engine houses serving the MT&OC operated cable tram system. Each one powered from one to three main cables.

5 THE CABLE

The cable or ‘rope’ – arguably the ‘heart’ of the system – was initially a 3.5” (90) circumference wire rope comprised of six strands each of seven wires wrapped around a hempen core with an 11” (280) lay. Later, as traffic increased, heavier cables ranging up to 4.5” (115) circumference and 15 wires per strand were used on some route sections. The ropes were always imported and arrived to order for the particular route section and coiled as a single length in ship hulls. (Pollock, 1928). The earliest ropes came from English wire rope makers. Roebling, USA, supplied some later ones. Most cables used the Lang lay, where the lay of the strands was in the same direction as the lay of the wires making up the strand. This was preferred because when the rope was bent around a sheave the wires tended to slacken and more of the surface area of the cable was exposed to wear (Pollock, 1928).

The longest single cable used in Melbourne was about 30,000’ (9.2 km) for the suburban section of the St Kilda route (St Kilda Rd engine house to Brighton Rd / Milton St terminus) (Pollock, c1950; McCarthy, 1985). Based on comparable contemporary cable costs (Bucknall Smith, 1887), the cost of an average cable length for the Melbourne network at that time would have been in the order of A£1,300 ($170,000 current equivalent) plus freight charges.

The Company maintained very detailed ‘rope histories’ (Pollock, c1950), however these do not appear to have survived. Keating asserts that on average the Melbourne cables lasted around six months (Keating, 1970). This was appreciably less than typical experience in San Francisco, which Keating postulated was probably due to the many curves in the Melbourne network. The chairman of one of the Chicago cable tramway systems claimed that their cables normally ran for at least a year ‘without any flaw’ (Bucknall Smith 1887). Evidently there was great variability in cable life, part of which may have been attributed to the as manufactured wire rope quality. Some cables remained in service for one or more years. One English Bullivant’s rope, used on the relatively straight North Fitzroy route reportedly lasted for four years and seven weeks, and covered a distance of upwards of 286,100 miles (458 000 km). In later years the MT&OC was able to extend cable life by first using a new cable on a busy inner city route section, and when it became worn, relocating it to a lesser traffic section (Pollock, 1928).

When cables were drawn into the underground tunnels for the first time, teams of horses were used. For subsequent replacements, the old cable could generally be used, driven from the engine house, to pull the new cable in. Once installed the ends of the cable were carefully spliced so as to form a continuous loop from the engine house to the terminal point and back. Rope splices were from 60’ to 80’ (18 to 25 m) long and when completed the splice was almost undetectable with its diameter matching that of the cable itself. It typically took a team of seven men about two hours to make a splice although it is claimed that one emergency splice was completed in a record time of 23 minutes. (Pollock, 1928).

Protecting the cables from damage during operation and early detection of any damage was critical given the high cost of new cable. They were regularly lubricated with rope oil as they passed through the engine houses and constantly inspected by experienced rope men. Mechanical devices were also set up in the engine houses to automatically sound a bell if broken wires were detected protruding from the cable. Protruding broken wires could foul the grips and were cut off and tucked in by a rope man at the engine house. A damaged section of cable could be repaired by cutting it out and then splicing in a replacement length of sound cable. In the case of severe damage, tram services on the route would be suspended whilst the repair was undertaken. In less severe cases, the repair work could be delayed until after the normal cessation of service.

6 THE GRIP

Figure 7 shows the general arrangement of the cable-gripping device – ‘the grip’ – as developed by the MT&OC for use on its Melbourne network. The grip was secured longitudinally to the floor in the middle of the dummy with its lower section held within the cable tunnel via the narrow cheek plates that passed through the longitudinal slot between the tram rails. Small sheaves on the base of the grip enabled the cable to run freely through the grip jaws when it had been lifted into them until the gripman operated the upper lever to close the soft metal clamping jaws onto the cable and thus cause the dummy and its coupled trailer to move forward at the speed of the moving cable. A notched quadrant rack and pawl associated with the operating lever enabled the upper jaw to move downwards to grip the cable and to be so maintained, and also allow for increasing the clamping force to arrest any slippage by further movement of the operating lever.

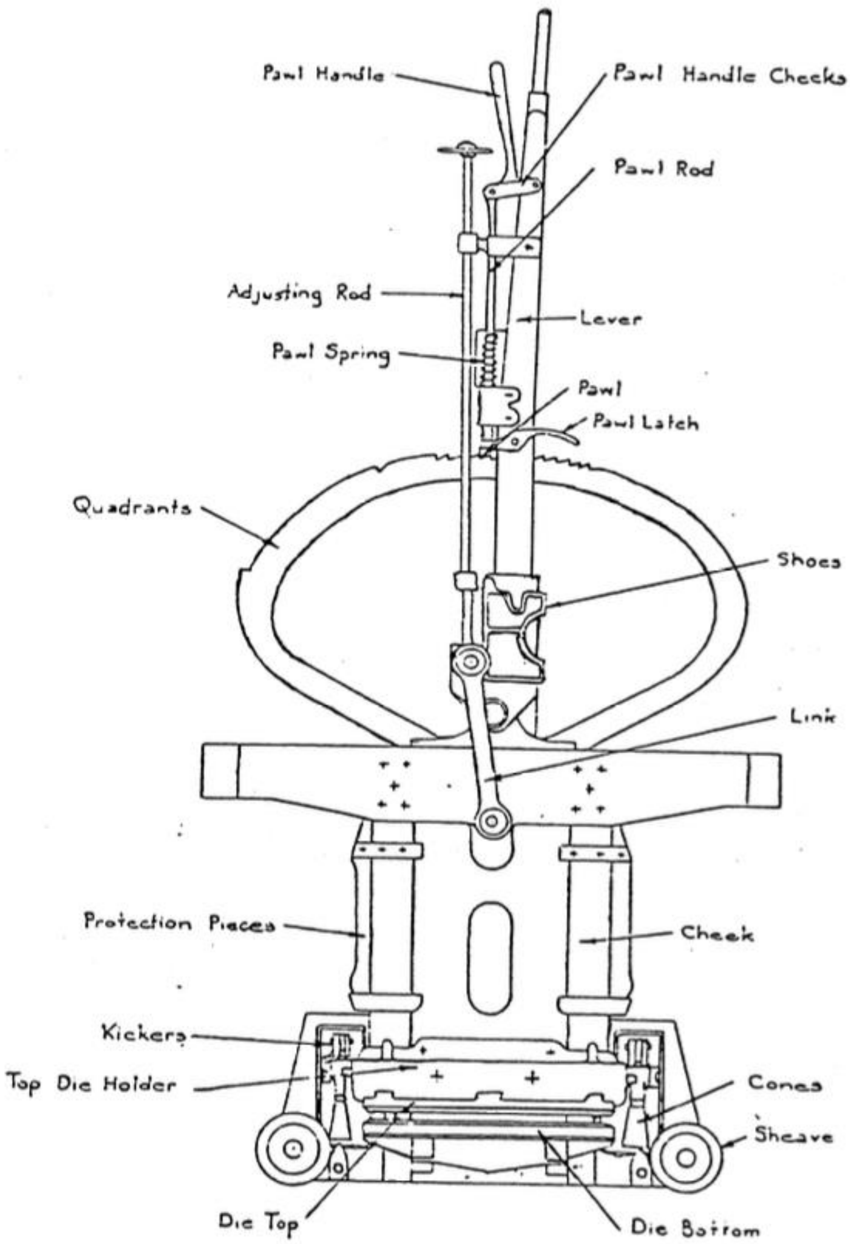

Figure 7: Diagram of grip. Grip jaws (dies) at bottom

When the grip was clamped onto the continuously moving cable, the cable was progressively lifted off the tunnel sheaves and then returned onto them after the dummy had passed. Due to the slightly 'L' shape of the lower part of the grip, the position of the cable in the tunnel was offset by 1.5" (38) from the centerline of the slot. This had a spinoff advantage that debris falling through the slot from the roadway tended not to directly contact the moving cable. However, with the clamping jaws on one side only, the grip had to always face the same side of the cable tunnels. This limited the options for 'through running' between routes. (Keating, 1970).

The first grips for the Richmond line were modelled on those used on the San Francisco Sutter Street line (Bucknall Smith, 1887). An article in the Melbourne 'Age' newspaper asserts that the initial grips were made locally under contract by Johnson & Co, Tyne Foundry (The Age, 1885). Subsequent grips were made by the MT&OC at its extensive North Fitzroy workshops and appear to be an improved amalgamation of those used on the Sutter St and the California St lines in San Francisco, with a fixed lower jaw and moveable upper jaw. Further improvements included a better operating mechanism for 'kicker cones' that pushed the cable out of the open jaws when the operating lever was moved in the reverse direction. A provision for the gripman to be able to adjust the grip jaws to accommodate cable wear or suit different cable sizes via a small hand-wheel and shaft secured along the operating level arm also appears to have been a local enhancement. Once the refinements had been proven, the grip remained essentially the same for the life of the system. (MacMeikan, c1960).

As mentioned previously, dropping the cable altogether was necessary at crossovers, when traversing some curves and also when swapping from one cable to another near an engine house, etc. In most of these situations various pulleys on the other side of the transition automatically directed the moving cable back into the open jaws of the grip. If the cable was 'lost' it could be retrieved and re-inserted into the open jaws of the grip by dangling a simple hook through the slot in the underground conduit.

The lower parts of the grip were deliberately made somewhat brittle so that if the gripman failed to drop the cable when he should and the grip then struck a safety 'check bar' in the cable tunnel, the bottom of the grip would likely break. This would cause it to release the cable and drop to the floor of the tunnel, something that was preferable to otherwise potentially serious damage to the costly cable. (Pollock, 1928).

Pairs of hinged trapdoors were provided at intervals along the routes and outside engine houses and car depots to permit the grip assembly being lifted out of the cable tunnel if necessary, using a simple manual block and tackle suspended from a support in the roof of the dummy, directly above the grip. In this way a defective grip device could be removed and a replacement inserted and re-secured to the dummy floor, or with the grip raised, the dummy then manually pushed or pulled by horse into the car shed on lines that did not include a central slot.

7 THE TRAMS THEMSELVES

For the opening of the Richmond route in 1885, the tram sets comprising the grip car or 'dummy' and trailer were imported from the USA, and like the locally made cable grips, were modelled on the San Francisco Sutter Street tramway. Subsequent tram sets and grips were made by the company at its workshops in Nicholson Street, Fitzroy. They retained the same form and features of the imported sets. The vehicles were all built to a high standard of quality and finish by skilled artisans employed by the MT&OC.

The 16' (4.8m) long dummy that contained the grip was roofed but open sided with passenger bench seats arranged around the middle section where the gripman stood to operate the grip. The trailer car was an enclosed saloon with open end platforms. The Company's 'standard' trailer or saloon car was 22' (6.7 m) long mounted on four wheels. A shorter trailer was later used on some lighter traffic routes and 30' (9.2 m) long cars mounted on two four-wheel bogies was developed by the company for use on the heavily patronised and relatively straight Brunswick route from about 1900. All of the trailer saloon cars were identical in their layout, with access to the enclosed saloon via sliding doors from a platform at each end. At night, the dummies and trailer cars were dimly lit by oil lamps until around 1920 when electric lights powered by storage batteries were substituted. (MacMeikan, c1960; Keating, 1970). Figure 8 shows a typical dummy and trailer set.

Figure 8: Dummy and trailer turning into Victoria Parade from Gisborne St, East Melbourne c1890. Photo SLV H393657/52

Wheel brakes (brake shoes applied to the running wheels) were incorporated in both dummies and trailer cars, with those in the dummy operated by a lever adjacent to the grip lever. A third lever could apply timber-lined slipper brakes onto the rails themselves. If required, the conductor could operate the trailer brakes via a gooseneck handle on the platform at each end of the trailer. George Duncan also developed an additional emergency slot-brake based on jamming a wedge between the lips of the slot. It was not considered warranted on the relatively flat Melbourne cable tramway routes, however it was reportedly retrofitted on the steeply inclined San Francisco routes and on Duncan's Dunedin cable tramways. (Keating, 1970; Govett & Twentyman, 1973).

The trams were constructed largely of wood and at about 2.8 t for the dummy and 2.5 t for the standard trailer were relatively light vehicles. This facilitated their being able to be manually moved on level track. Also, their lightweight combined with the absence of any driving wheels – all wheels merely rolled along the tracks – prolonged the life of the running rails with some original rails still in service when the cable lines finally closed. (Pollock, c1950; MacMeikan, c1960).

The MT&OC tram sets were normally dedicated to a particular route and as such were painted in a distinctive colour to represent that route. At night, lenses of the same colour were illuminated by oil and later electric lamps. Each route had a car shed or depot, were the trams were stored when not in service. These were typically close to the outer ends of the respective routes. In most cases cars were manually moved about the car sheds, or were pulled by a horse – or later a tractor at some sheds – to and from the running tracks.

By the time the cable tram network was completed in 1891, the company had a fleet of about 430 car sets. (Street Railway Review, 1891). As passenger traffic increased in later years, more car sets were built by the company, and by the Tramway Board and then the Melbourne & Metropolitan Tramways Board that superseded it in 1916 and 1919 respectively. By 1923 – the peak year - the system had 592 dummies and 539 standard size trailers plus 58 longer bogie cars in service (Keating, 1970).

8 THE INDEPENDENT NORTHCOTE LINE

The independent Northcote line in Table 1 was built under contract for the Clifton Hill to Northcote and Preston Tramway Company that was instigated by local German-born retailer, George Clauscen. (Lemon, 1983). George Duncan was engaged as engineer. The line opened in February 1890, running from the terminus of the MT&OC Clifton Hill line, north along High Street in Northcote to Dundas St in Preston (Jones, 2004; Cranston, 1988: Keating, 1970). The double track line had a route distance of 2.25 miles (3.6 km) with an engine house at Martin St, and according to Keating, the MT&OC agreed to allow the Northcote Company to use the patents that they held for cable traction for a modest monetary consideration.

To reduce capital cost, it appears that Duncan used ‘oscillating’ line pulleys (for which he took out U S Patent No. 462379 in 1891) and a grip with a bottom moveable jaw and operated such that the cable, when released, normally continued to run through the open jaws of the grip and not dropped or ‘thrown’ as for the MT&OC operated lines. If the grip then approached a line pulley due to the dummy moving forward under its prior momentum or gravitation, the bottom of the grip depressed the line pulley in its cradle mount as it passed over. This arrangement enabled a much shallower, and thus less costly cable tunnel compared with those on the MT&OC lines. (The Argus,1891). The expedient did however preclude ready inter-connection to the MT&OC network. The separate company purchased its initial trailer cars from the MT&OC whilst the Melbourne firm Wright and Edwards made its dummies. (Mercury and Weekly Courier,1890).

The Argus, 1891, article refereed to above envisaged Duncan’s oscillating line pulley to be applied on another then proposed independent company cable tram line from Clifton Hill to St Kilda via Hoddle Street with even shallower cable tunnels than used for the Northcote line. This proposed cable tram route by the then Melbourne and Suburban Tramway Company never proceeded. The article’s claim that it would also likely gain application in the USA also appears unfounded as by then, the time for new cable tramway ventures had passed with the ascendancy of the electric tram.

9 OPERATION AND DEMISE

The MT&OC operated its cable tram network profitably through to the end of its lease in 1916, including surviving lean times during the 1890s economic depression. In 1916, the network was taken over by an interim Tramway Board who purchased rolling stock and tram depots from the Company. Three years later the Tramway Board was absorbed into the government owned Melbourne & Metropolitan Tramways Board (M&MTB). See below.

The independent Northcote cable tram enterprise suffered from the collapse of the land boom and the onset of the economic depression in the early 1890s and the line was closed in mid 1893. It ran again under a private lease arrangement from 1894 until the lack of maintenance forced another closure in 1897. The Northcote Council acquired the assets in 1900 and carried out necessary refurbishments. Then, after a number of leases to successive private operators from 1901, the Council itself ran the line from 1916 until it was taken over by the MM&TB in 1920 (Keating, 1970). Under the M&MTB ownership the Northcote cable tramway infrastructure was changed in 1925, replacing Duncan’s ‘oscillating line pulleys with smaller diameter fixed pulleys to thereby lower the cable to permit operation with the grips as used on all other cable lines. The Northcote line was then linked to the Clifton Hill line, enabling through running from the Bourke St terminus to Dundas St Preston. (Jones, 2004).

In the latter part of the second decade of the twentieth century, the engines at a number of the cable tram engine houses were reaching capacity during peak traffic periods. As mentioned earlier, this was addressed in some cases by installing supplementary electric motors or diesel engines. The pair of steam engines on the North Carlton line were replaced by an electric motor in 1919 and the engines moved to the Richmond engine house (Govett & Twentyman, 1973).

Whilst Melbourne was installing its extensive cable tram network in the late 1880s, Frank Sprague in the USA successfully inaugurated his electric streetcars in the city of Richmond, Virginia, in 1888. They operated by having a roof mounted trolley pole contacting a wire suspended over the tracks with the electric current return to a central generating station – later a substation – via the tramcar wheels and the steel track rails. The vehicle was driven by series-connected DC motors geared to the truck wheel axles, with the speed regulated by the driver using a drum controller. The commercial success led to this type of street based urban public transport quickly spreading around the world (Pierce, 2015).

A key advantage of electric trams over cable trams was their much lower capital cost by avoiding the cable tunnels that were expensive to build and very disruptive to regular use of the streets and roadways during their construction. Cable tram lines started to be replaced by electric trams in USA cities from the beginning of the twentieth century, a process that was hastened in San Francisco by the devastating 1906 earthquake. This was clearly influential in the Melbourne Tramways Trust and the Melbourne Tramways & Omnibus Company firmly rejecting turn of the century proposals to extend the cable tram network in Melbourne.

In 1906 The North Melbourne Electric Tramways and Lighting Company opened an electric tram service from the cable tram terminus at Flemington Bridge to Essendon and adjacent suburbs. In the same year the Victorian Railways, albeit reluctantly under political pressure, opened an electric tram service from the St Kilda railway station to Middle Brighton, which was later extended to Brighton Beach. In the following year the Prahran & Malvern Tramways Trust was set up under a new Act of the Victorian Parliament. Its first electric trams ran in its namesake suburbs in 1910 and the routes were subsequently extended. Next was the Hawthorn Tramways Trust that in 1916 succeeded in breaching the MT&OC's monopoly on tram routes running to/from the CBD by its route from Hawthorn via Swan Street to Princes Bridge near Flinders Street railway station. Three other municipal tramway trusts using electric trams followed to serve other then outer suburbs of Melbourne.

A Royal Commission set up by the Victorian Government in 1910 to enquire into railway and tramway public transport in Melbourne recommended that the suburban railways be electrified; that all metropolitan tramways be vested in a single Municipal Tramways Trust and that cable tramways be progressively converted to electric traction based on its lower capital cost for extensions, greater speed of operation and simplicity. The intervention of World War 1 slowed the electrification of the suburban railways and deferred conversion of any cable tram routes until 1924. By this time the MT&OC's lease had expired and the operation of the cable trams was taken over by a temporary Tramway Board in 1916, and then absorbed into the government owned Melbourne & Metropolitan Tramways Board in November 1919. The M&MTB subsequently took over all of the separate suburban municipal tramways trusts and purchased The North Melbourne Electric Tramways and Lighting Company's system. (Keating, 1970).

In 1924 several track sections in the city were closed by the M&MTB for conversion to electric traction. As an interim measure in order to reduce service disruption when the northern end of Swanston St was being converted for electric trams, a 230 m length of double track cable tram line was constructed in Lonsdale St to create a link between the Swanston St and Elizabeth St cable tram lines and thus permit through running on those north-south routes. This was a complex and challenging project in it own right with curves and points at both ends and the requirement to minimize tram and road traffic disruptions during normal hours. The finished form of the work was similar to the existing system with the notable exception that the concrete walls of the cable tunnels were reinforced with mesh between the yokes. It also appears that future electric tram operation was allowed for, although this never happened. (O'Meara, 1924). As Keating opines, it was likely the last stretch of new urban cable tramway to be built anywhere in the world. (Keating, 1970).

The conversion to all electric trams took place over a period of fifteen years, during which street disruption again occurred when the concrete cable tunnels were broken up and removed and tracks re-laid. The process was slowed down by the 1930s economic depression with work being suspended for several years in the early 1930s. Motorbuses were used on an interim basis during the changeovers and in a few places on some routes it was decided to use buses permanently. Bourke Street saw last cable tram departing from the Spencer St terminus to Clifton Hill and Northcote/Preston on Saturday evening, 26 October 1940, bringing to an end 55 years of continuous cable tramway operations in Melbourne.

Cable trams were contemplated in several other Australian cities in the latter part of the nineteenth century but the only city other than Melbourne to build such lines was Sydney. The two Sydney cable tram routes were constructed to provide services where the grades precluded using steam trams. A 2.4 km route from Milson's Point ferry wharf to St Leonards Park was inaugurated by the NSW government owned tramways in mid-1886. It was extended a further 0.8 km to Crows Nest in 1893. The second cable tram route was opened in 1894, running from King St wharf along a 4.4 km steeply curved and graded route to Edgecliff. Both of these isolated lines were relatively short lived and were converted to electric tram routes like the rest of the Sydney tram network early in the twentieth century. (Kings et al, 1960).

10 REMAINING CABLE TRAM HERITAGE

Not much remains of Melbourne's once world-renowned cable tram network. Most notably, the No. 1 car set was preserved and is in the custody of Museum Victoria. This museum is also believed to hold the only surviving complete grip (W Doubleday per coms). Several other cable tram sets have survived with one set held at the Melbourne Tramway Museum, Hawthorn. A number of the original engine house buildings and a car shed also still survive, albeit converted to other uses. Most of these are listed on the Victorian Heritage Register. The first engine house for the Richmond line was demolished in 1991 for road intersection improvements. A bronze plaque now marks the site. Sadly all of the winding machinery was removed from all of the engine houses and it appears was mainly broken up for scrap metal.

In general, as cable tram routes closed, the upper parts of the concrete cable tunnels between the tram rails were broken up and removed along with their surface slot. The process again caused severe disruption to affected streets although it was reportedly well managed and expeditiously performed by the M&MTB (Keating, 1970). A short section of steel edged slot remained at the Spencer St. end of Bourke St. until the late 1980s when the Bourke St tram lines were linked into lines in Spencer St. A section of intact cable tram tracks and tunnels was rediscovered in Abbotsford St North Melbourne in 2007 during roadwork. It was documented by Heritage Victoria and added to the heritage registration for the adjacent former North Melbourne engine house. The road surface was reformed over the remnant tracks thereby preserving them, albeit without visibility.

Many lengths of cable tram cable found reuse for roadside barriers and fences around sporting grounds and the like. The author believes that it was used in this way in places along Victoria's iconic Great Ocean Road. The M&MTB itself recycled some cables for roadway boarder fences in its former Wattle Park reserve in Burwood and sections of this remain in place today. Another interesting early recycling of tramway cable was for the still extant privately built 1890 heritage listed Wollaston suspension bridge across the Merri River at Warrnambool.

The former Venetian Gothic style MT&OC head office, purpose built by the Company in 1891 at 673 Bourke St, that in turn from 1920 became the headquarters of the M&MTB, was acquired by the Donkey Wheel charitable trust in 2008. It has been progressively restored and is tenanted by community organisations. The building is listed on the Victorian Heritage Register and recognised by the National Trust.

An excellent and valuable visual record of the cable tram system based on extensive monochrome and some colour movie camera footage taken by Neville Govett and others has been assembled into a 55 minute professionally narrated DVD: *'Commuting by Cable',* by the Australian Railway Enthusiasts (ARE). As well as showing the cable trams in operation on various routes, the footage includes inside an engine house and operation of the grip mechanism. It also depicts the important social aspects of the system as a popular public transport utility.

11 CONCLUDING COMMENTS

Melbourne's cable tram network serving the CBD and adjacent inner suburbs via seventeen distinct routes with a total of 73 km of double track was built and successively commissioned in the space of seven years from 1884 to 1891. It was second only in total extent of routes to San Francisco, the 'birth place' of cable tram technology, and the sixteen routes (70 km of double track) operated by the Melbourne Tramway & Omnibus Company was the largest cable tram network in the world run by a single entity.

In the chapter on 'Engineering Works' in the 1888 book: *Victoria and its Metropolis: Past & Present*, W C Kernot, the first professor of engineering at Melbourne University, asserted that "the cable tram system is a very satisfactory one, convenient, free from smell, smoke or other nuisance and neat in appearance". He did however observe that its high initial cost was a drawback, making it unsuitable for light passenger traffic routes, and its vulnerability to a single incident bringing the entire route to a stop. (Kernot, 1888 in Sutherland).

Although the Melbourne cable tramways were based on principles and experience developed in the USA, its engineer George Duncan, successfully adapted the technology to Melbourne's conditions and implemented a range of significant improvements. The latter included improvements to the all important grip design and operation, and to car braking arrangements. As the inventor of the 'pull curve' Duncan initially used it extensively on the Melbourne network but in the light of operating experience later replaced many such installations with single large sheaves with the curve then negotiated using the tram's momentum and/or gravitational assistance – so called 'let go' curves – that materially extended cable life. Being a single operator of a large system, the MT&OC and its engineering department was able to experiment and continuously improve the efficient operation of the network. Also, being fairly late in its implementation, the Melbourne cable tramway system was able to benefit from the by then accumulated experience in the USA. It was built to a very high standard and was world renowned.

The physical construction of the cable tramway routes in Melbourne was also a major engineering and logistics task in the days when labour was by man and horse with few machines, and concrete had to be mixed on site. The numerous relocations of existing piped services, including rebuilding of some brick sewers, added to the challenge of completing the ambitious undertaking in just seven years.

Operating for over fifty years, the cable tram network had wide ranging social benefits in providing a generally reliable and frequent, if not fast, public transport service to convey large numbers of people to and from work and leisure activities when initially the main alternatives for many people were riding a bicycle or walking. It also facilitated the expansion of the suburban areas serviced by its various routes and became to be a much-valued public service. In 1918 the cable tramways were carrying 113 million passengers annually, rising to 150 million in the peak year of 1923, (Jones, 2006: Keating, 1970).

Cable trams had a limited 'window of opportunity' from when Hallidie opened his 1873 Clay Street service in San Francisco until the last decade of the nineteenth century when the superiority of the electric tramway in terms of a much lower setup cost, flexibility and speed for all but the steepest routes, was confirmed. It seems likely that had Clapp not started to build other than horse drawn tramways until the 1890s, he too would have opted to use electric trams instead of cable trams. But also like the public hydraulic power system in Melbourne (Pierce, 2009), the conservatively built cable tram system lasted well into the twentieth century, a testament to its sound engineering principles and to those who designed and operated it.

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