TRB Paper Manuscript #11-1301

Zen and the Art of Commuter Rail Operations:
Taiwan Railways Administration's Design, Operations, and Philosophy

Alex Lu*, Amanda N. Marsh
** Corresponding author*

Alex Lu
Operations Planning, New York City Transit,
2 Broadway, Cubicle A17.111, New York, N.Y. 10004-2208
Tel: (646) 252-5664
Email: *me@lexciestuff.net*

Amanda N. Marsh
Freelance Writer and Photographer,
P.O. Box 406, Islip, N.Y. 11751-0406
Tel: (631) 277-6514
Email: *amanda@amandamarsh.me*

Word Count: 246 (Abstract) + 6,010 (Text) + 5 × 250 (Figures) = 7,506 Words

---

ABSTRACT

This paper offers a review of ideas and practices making Taiwan Railways Administration (TRA) unique and distinctively different to North American commuter railroads, based on two weeks' field observation, published sources, authors' cultural knowledge, and discussions with locals. Unlike most transit systems, TRA accommodates different trip purposes and train types on shared railway infrastructure, covering areas with varying traffic densities, travel needs, and geographic features. As an importer of railway technology, to meet diverse requirements, and because of incremental and stop-gap measures devised in response to capital budget restrictions, TRA has needed to embrace, operate, and maintain a wide assortment of different standards and procedures. This willingness to accept outside designs and consider functionality/cost/simplicity trade-offs when addressing specific needs resulted in constantly varying daily routines for management, staff, and customers. In turn, it may have cultivated expectations of learning curves with new technologies and continuous training requirements, apparently resulting in higher skill levels and a more nimble workforce that contributes to overall higher reliability, tolerance of changes, and nuanced operations tailored to maximize railway effectiveness. These observations suggest further research needs for commuter rail authorities: Can infrastructure and schedules be designed with better cost-flexibility tradeoffs? Should train priorities be explicit in public schedules? What is an appropriate level of standardization? Is technology better thought of as workplace assistance and not functional replacement for employees? Embracing diversity in engineering and operating solutions could reduce investment costs yet improve effectiveness by requiring humans to think on their feet.

Notes: (1) English transliterations of station names reflect (where available) those in TRA's passenger rail timetables, which shows a mixture of Wade-Giles (historical and popular usage, particularly outside Taipei), Tongyong Pinyin (former standard), and Hanyu Pinyin (current official standard); (2) Throughout this paper, "Taiwan" refers to the Pacific island, and "Formosa" refers to the culture of Taiwan's inhabitants.

INTRODUCTION

Taiwan's railways are like the City of New York – both great melting pots of culture, philosophy, and technologies from all over the world. Quite unlike home-grown railways in Europe and North America – incrementally re-designed and improved upon since the Industrial Revolution – Taiwan's railways reflects accumulated results of changing procurement policies, whimsy of international diplomacy, and continuing worldwide search for best-value technology and practices. The Taiwan Railways Administration (TRA) operates and maintains Swedish and Japanese signal systems, a Franco-English electrification system, a Taiwanese-designed tunnel originally envisioned by Japanese and German planners through Taipei, American and South African locomotives, Indian and Taiwanese coaches, Japanese, English, Italian, and South Korean trainsets (*1*). Because of Taiwan (Formosa)'s history as a Spanish, Dutch, Japanese, and Chinese colony, and recipient of significant American and British assistance after the Second World War (WWII), Formosa's islanders have shown an exceptional tolerance and openness to different ideas, and demonstrated great flexibility and resilience under a smorgasbord of outside influences. This willingness to entertain alternatives is reflected in their railway system. A brief survey of TRA's designs and operating practices is offered, demonstrating how TRA has melded diverse technologies and utilized a mixture of manual operations and automation.

Profile of Taiwan's Railways

Railway services (Keelung-Hsinchu) began in 1891 under China's Qing dynasty (*2*). Completely rebuilt and substantially expanded under Formosa's Japanese colonial government (1895-1945), the network's Japanese influence and heritage persists (*3*). Similarities between TRA and the Japan Railways (JR) companies can be noted in signal aspects, signage, track layout, fare controls, station architecture, and operating procedures. As Japan's southern base during WWII, Taiwan's railways suffered significant damage by Allied air raids. Taiwan Railways Administration (TRA, 臺灣鐵路管理局) was founded in 1945 to reconstruct and operate railway infrastructure (*4*).

With ~13,500 employees (4,700 in transportation and 7,700 in maintenance titles), TRA is a government organization under Taiwan's Ministry of Transportation and Communication (MOTC) that directly operates 682 route miles of 3'6" (1,067mm) gauge railways (*5*). Three mainlines form a complete circle around the island (Figure 1(a)). TRA's West Coast Mainline (WCML) and East Coast Mainline (ECML) Badu-Hualien section features mostly double-track, electrification, modern colour light and cab signalling, overrun protection, and centralized traffic control (*6*) (CTC). Southern Link Mainline, ECML Hualien-Taitung (converted from 762mm gauge), and three "tourist" branches are non-electrified single-track with passing sidings.

Since the early 1980s, conventional railway capital improvements are nationally funded and managed by MOTC's Railway Reconstruction Bureau, then turned over to TRA for operations (*7*). Taiwan's challenging terrain meant all lines feature extensive tunneling and long bridges. Double-tracking frequently requires construction of parallel single-track railroads or bypass tunnels on new alignments. The US$14.5 billion standard gauge high-speed rail (HSR) line was built and operated by a separate public-private partnership under a 35-year concession (*8*), but TRA provides feeder services to HSR terminals. Although TRA operates all commuter rail, other quasi-private organizations operate subways in Taipei and Kaohsiung.

Local and intercity passenger services (5am – 1am, very few overnight trains) operate at 95.3% on-time performance. 2008 annual passenger ridership was 179 million (incurring 5.45 billion passenger-miles), generating US$434 million in revenue (*9*). Commuter trains carry 76% of riders (43% of passenger-miles). WCML carries >90% of ridership. TRA's loose-car and unit-train bulk freight services haul mainly aggregates (58% of tonnage), cement (26%), and coal (9%). In 2008, 9.5 million tons of freight (481 million ton-miles) generated US$28.6 million in revenue. Limited container services operate between Port of Hualien and suburban Taipei, but loading gauge restrictions preclude piggyback operations. During typhoon season, small trucks are carried on flatcars when highways are closed by flooding or mudslides (*10*).

In years past, an extensive shipper-owned light railway network (762mm gauge, never operated by TRA) handled freight services throughout Taiwan and once boasted 1,800 route miles. Largely abandoned today, it served important industries including sugar, logging, coal, salt, and minerals (*11*). Unlike JR East and Hong Kong's Mass Transit Railway, revenues from ancillary businesses accounts for only 17.8% of TRA's revenues (*12*). TRA's estimated farebox recovery ratio (including freight operations) is ~40%.

Staffing costs, pension benefits, capital debt, changing demographics, highway competition, and low-fare policies resulted in accumulated deficits nearing US$3.3 billion (*14*). Locally considered large and problematic, TRA's deficits pale in comparison to those incurred by European and U.S. transit agencies, and Japan National Railways (JNR) prior to its 1987 privatization. Like JNR and U.S. transit authorities (*15*), interest payments on long-term debt represents a significant burden for TRA. Planning for TRA's restructuring had been underway since 2000.

Observational Method of Comparative Research

This research was conducted through field observations and original language document review. The authors spent two weeks as TRA revenue passengers, routinely interacting with management and staff (without specific interviews), holding informal discussions, and visiting publicly-accessible locations (stations and wayside). Substantial time was devoted to observing TRA's infrastructure, equipment, and operations, giving particular attention to interactions between fellow employees and between passengers and staff.

The intent is to describe and identify interesting areas worthy of further exploration or potentially applicable to other commuter railroads, like comparative studies routinely conducted by transit peer organizations (*16*) under experience and technology exchange (*17*) programs. Observational studies emphasize qualitative questions of design and philosophy, rather than potentially misleading interagency quantitative comparisons (*15*) using self-reported and sometimes-questionable (*18*,*19*) statistics that essentially reduces to a 'pick-your-indicator' (*20*) ranking game. "Bottom-up" methods highlight features that make engineering and operating sense (*21*) and determine their relevance elsewhere, instead of identifying high performance areas then seeking explanations (*22*).

Each feature and practice discussed reveals subtle differences in assumptions and expectations between TRA and other railroads about what railroads do, and how railroads work. Interpretations of design decisions, procedures, and philosophy were based on observable phenomena and authors' background knowledge of Formosa, its culture, and its railway system. Using sources in Asian vernaculars is important:

> "[T]rue comprehension requires a knowledge of the country and its people as well as the language. Translations rarely, if ever, can fully do justice to the 'reality' as it was presented in its original form." (*23*)

Observational science necessarily involves inferences and assumptions, limiting its usefulness to exploratory research and description. Formal exchange programs could be initiated as a next step.

Key Observations

TRA's operations are rooted in classic railroads of yesteryear, and are likely familiar to commuter rail audiences. Many railroads utilize similar designs and practices, especially in isolated cases where capacity or geographic constraints require non-standard solutions, or historical workarounds at specific locations ("hacks") continue – e.g., Long Island Rail Road (LIRR) towerpersons hoops handwritten train orders to passing engineers at Babylon, even though train radios are available; Chicago's South Shore Line uses simple yet effective sliding notches to issue onboard tickets (*21*).

In a rush to automate and standardize, some railroads have inadvertently lost much of once-commonplace multi-disciplinary operating skills (*24*,*25*). Ingenious low-tech solutions slowly disappear, whether or not automated replacements add much value (*21*). Managers resort to following rigid standards. Labour crafts often have narrowly defined functions, while "broadbanding" efforts are fraught with difficulties (*25a*). Both sometimes hesitate to think outside the box, are fearful of exceptions and concerned with repercussions. Systemwide compromises attempting to accommodate all situations sometimes result in complex machines that still don't quite meet all requirements. Fragmented and inflexible job functions could easily reduce organizational capabilities to respond to operational problems in an integrated, commonsense fashion.

Conversely, TRA's management embraced these "hacks" and updated them with modern technology. Designs make more cost-feature tradeoffs for one specific application (value-engineering) rather than follow systemwide standards. Staff is tolerant of diverse working methods and equipment, requiring human skills and initiatives while keeping machines simple. Over time, a nimble and multi-skilled workforce prepared to react to day-to-day operational snafus (incidents) with efficiency and speed has developed, perhaps attributed to daily interaction with a diverse range of problems. TRA is like a diner short-order cook, producing a big menu from a large collection of simpler (but varied) equipment – and quite unlike a fast food worker, who relies on complicated (but regimented) machines to produce standard offerings.

NETWORK DESIGN & REAL ESTATE

TRA's network and services reflect strong centralized planning. Although TRA is one of many passenger transport operators, its infrastructure allows multiple and convenient connections between modes. Joint transportation and land-use planning make railway projects effective land-development tools.

Mainline Tunnelling

The Japanese planned Taipei's railway tunnel prior to WWII. Their main impetus was the major Chung-Hwa Road (Route 1) trunk highway crossing. Taipei's Railway "Undergroundization" Project (Phase I) was approved in 1979, including Taipei Main Station (TMS), 2.8-miles of two-track underground railway, and Banqiao and Nankang yards. Completed in 1989 and costing US$600 million (*26*), it replaced the historic Japanese-era Taipei-*eki* (台北駅) and Hwashan yard, eliminated grade crossings in Taipei's congested Wanhua/Manga (萬華/艋舺) neighbourhood, providing operating efficiencies. Like New York's Penn Station project (*27*), which buried 5.5 route-miles between North Bergen, N.J. and Hunterspoint, Queens by 1908, TMS catalyzed urban redevelopment. Development was extensive but not without cultural costs (*28*). Modern office towers and underground malls replaced Japanese-era wooden shanties and wholesale outlets (*29*), but historic temples were preserved.

Later phases completed the four track mainline tunnels, relocated yards to permit transit-oriented development (TOD), and provided a corridor for a much-needed crosstown expressway (Civic Boulevard). By 2008, US$5.8 billion were invested: Banqiao-Xike (16.0 miles) was tunneled, including all trackage within Taipei City, and Xike-Wudu (3.1 miles) was elevated (*30*). Nankang's Software Park, Exhibition Centre, and Xike's Science Park were developed around this time.

Run-Through Services

Taipei is Taiwan's capital and ultimate destination for TRA's mainlines. Explosive growth since 1980 made Taipei a 10-million population metropolis sprawled over four counties. To accommodate suburban commuters, and to serve passengers travelling to/from suburban business districts (Figure 2(c)), Taipei was envisioned as a through station, allowing West coast trains to operate to Taipei's eastern suburbs, and vice-versa.

Like Philadelphia's Center City Tunnel (*31*), through-running reduces platform occupancy times, maximizes one-seat rides, and distributes passengers over multiple stations (*32*), reducing crowding (Figure 2(b)). Trains can be moved through Taipei's terminal district in arrival sequence, providing some delay absorption capability. Only ~20% of passenger trips originated/terminated at TMS (compared to ~50% at New York's Grand Central); 98% of scheduled trains run through (~4% at Penn Station). Trains are turned at outlying yards (where turnback tracks are expressly provided), minimizing conflicting movements (*33*). Observation at Banqiao revealed substantial transfer activity between TRA and metro.

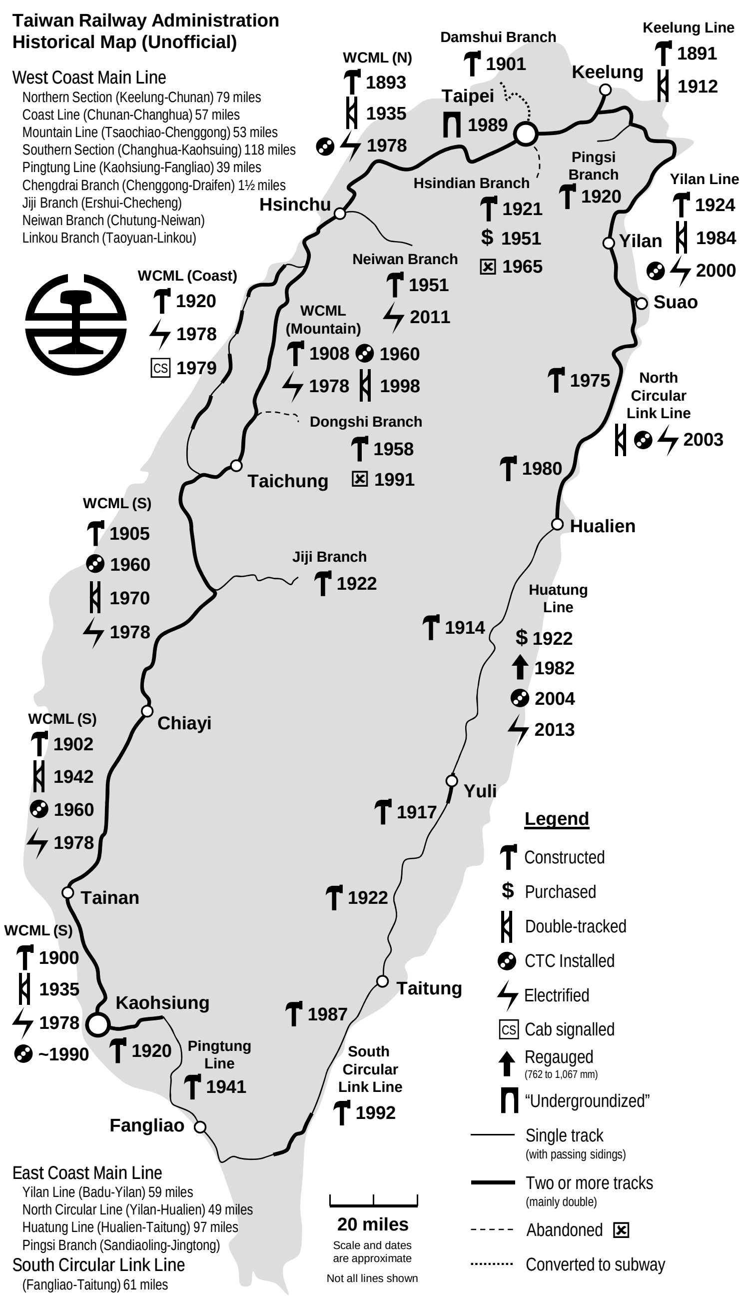
In the 1990s, ECML trains terminated at Banqiao; WCML trains terminated at Nankang/Keelung. All trains thus operate over the busy Banqiao-Nankang (Bannan) section, effectively providing urban transportation by utilizing surplus capacity on longer-distance through trains. Commuter trains made all suburban stops, while Amtrak-like expresses stopped only at major hubs.

Railway Facility Relocation

To support metropolitan growth, Banqiao yard moved west to Shulin, and Nankang yard east to Qidu (Figure 2(a)) during the mid-2000s, extending through operations to approximately 10 miles either side (Figure 1(b)). Banqiao, Taipei, and Nankang became major interchanges. Like Boston's NorthPoint project (*35*) planned for a Boston & Maine yard, the former Banqiao yard is now Banqiao station and a successful TOD site (*26*). Like the CREATE (Chicago Region Environmental and Transportation Efficiency) plan (*36*), through-running allows yards and freight facilities to move from center city (Hwashan, Songshan) to suburbs (Shulin, Qidu), with cheaper land and better highway access.

Rapid Transit as TRA's Feeder

Taipei's metro shows substantial integration with TRA's network, reflecting Taipei's close municipal-central government relationship. Taipei Rapid Transit Corporation's (TRTC) Red Line was converted from TRA's Damshui branch (*29*), while Blue (Bannan) and Green Lines roughly follows TRA's mainline (*37*) and the former Hsindian branch. TRA accepts metro farecards within metropolitan Taipei. Four metro lines converge at TMS, making subways TRA's local distribution system. New intercity bus terminals were constructed near TMS in 2009 (*34*). Like NJTransit's Newark and LIRR's Jamaica stations, Banqiao and Nankang interchanges afford TRA penetration into western and eastern neighbourhoods without long hackney rides or backtracking.



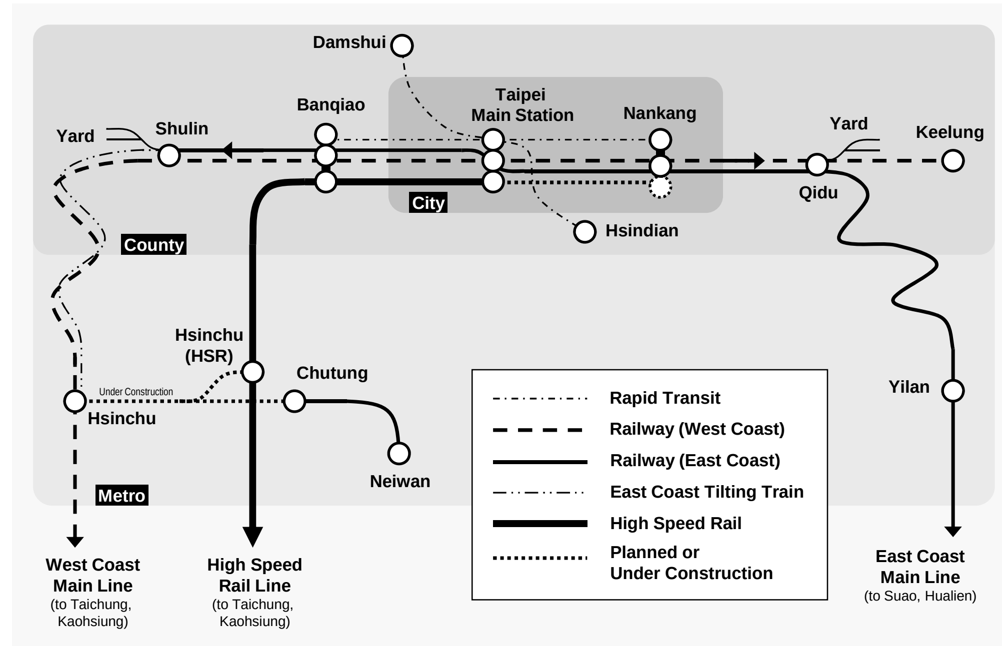


FIGURE 1 TRA's network reflects a combination of legacy infrastructure and "big picture" transportation system planning: (a) Taiwan's railways had been continuously modernized and improved since the completion of the West Coast Mainline in 1908; (b) through-running services in the Taipei metropolitan area.

Note: The base map in Figure 1(a) is loosely based on Taiwan MOTC's official "TRA tourism express travel guide map," edited by Sungho Culture Company Limited (2009), supplemented with historical and technical information from other publicly available sources, including "Taiwan Railway Maps" by Matthew Kirby and Paul Holmes (2006), Taiwan Railways Administration's Trackway History Table: Construction Year ("軌道歷史表 – 光緒13年~民國62年"), and track diagrams compiled by the National Chiao-Tung University Railway Research Association. English translations of station names reflect (where available) those in TRA's passenger rail timetables, which shows a mixture of Wade-Giles (historical and popular usage, particularly outside Taipei), Tongyong Pinyin (former standard and still visible on many official signage), and Hanyu Pinyin (current official Taipei City standard).

Commuter Rail and HSR

TRA's maximum commercial speed is 130 km/h (81 mph) whereas HSR operates up to 300 km/h (187 mph). Although TRA's long-distance services potentially competes with HSR, Taiwan's HSR is focused on origin-destination markets over 100 miles (*38*) like Taipei-Taichung (HSR – 50 minutes; TRA – 110 minutes), whereas TRA serves shorter-haul trips like Taipei-Hsinchu (35 versus 60 minuets). HSR serves Taipei and Banqiao TRA interchanges via shared corridors; a Nankang extension is under construction. Except for Taipei, HSR stations are located out-of-town, minimizing environmental impacts and property acquisition, maximizing economic development potential, and allowing low-curvature alignments (*39*). Commuter rail connects HSR with established provincial downtowns, solving "last mile" problems.

In Hsinchu, HSR and TRA stations are three miles apart. Parts of TRA's Neiwan branch is being electrified and rebuilt as a modern commuter railroad, costing US$280 million to connect Hsinchu's historic downtown with HSR (*26*). Connections generate benefits for both modes and catalyze development near HSR stations, much as Interstate interchanges attracted economic activity. This is a transit-oriented version of Beltway success stories played out across 1980s America.

Tilting Trains

TRA purchased six sets of Hitachi 8-car 130 km/h (*40*) tilting trains (Figure 2(d)), based on JR Kyushu's 885-series design, for US$85 million (*41*), to provide accelerated East coast services, where no HSR exists. Locally called "Taroko trains," they operate on ECML northbound, then WCML southbound, offering one-seat rides in cross-island flows like Yilan-Hsinchu, providing cross-metropolis links between edge cities. Operationally, through-running maximizes Taroko utilization, eliminating terminal recovery time in both segments. This relatively modest investment improved ECML services substantially, although timings are still not quite competitive with express buses using the shorter highway tunnel.

[Figure 2 shown next page]

FIGURE 2 (top) TRA's underground urban trackage and run-through services make efficient use of assets and available track capacity: (a) An Italian Società Costruzioni Industriali Milano (SOCIMI) EMU300 trainset being prepared at Qidu carbarn; (b) TMS's less-crowded underground platform with a British Rail Engineering Limited (BREL) EMU100, delivered in 1978 for the original West Coast Electrification programme (*41a*); (c) Taoyuan commuters wait for a through-running South African Union Carriage & Wagon EMU400 to Qidu; (d) TRA's tilting Japanese Hitachi TEMU1000 trainsets, locally the "Taroko Train".
(bottom) TRA's infrastructure designs are targeted towards specific scheduled movements, including provisions for service recovery: (e) an empty unit coal train with an American Electro-Motive Division (EMD) G12 (TRA R20-class) locomotive is stored on Taoyuan's bypass track, likely recently returned from the Linkou coal-fired power plant; (f) South Korean Daewoo's EMU500 commuter unit being prepared on Hsinchu's middle track while an intercity train departs; (g) terminating Japanese Tokyu DR3000 DMU departing from Shulin station, using crossovers for yard access; (h) express train (orange, streamlined E1000) passing local train (blue) using outside bypass tracks at Kueishan (Turtle Mountain) station on the Yilan Line.


(a)
5
4
3
2
1
(b)
(c)
No Crossing
(d)
(e)
R28
(f)
2月台 地下道↑
Platform2 Underpass
(g)
(h)

INFRASTRUCTURE AND SCHEDULING

TRA's infrastructure might be described as making up for lower track miles with sidings. TRA operated single-track sections on busy mainlines until 1998. Double-track sections can accommodate trains at different speeds; passing movements don't interference with opposing traffic, allowing scheduled throughputs of ~15 trains per hour per direction. Scheduling practices assume staff can respond to unforeseen delays and out-of-sequence trains by dynamically utilizing available infrastructure.

Passing Tracks at Local Stations

Double-ended sidings (loops) good for typical passenger trains (10~12 cars) are provided at 3~8 mile intervals, at local stations. Some stations have an island platform serving middle siding tracks (Figures 2(h), 3(a)), and straight-through outside bypass tracks. Schedules provide extra dwell time for trains to hold until an express passes, also serving as en-route recovery time, improving reliability. Some stations in single-track territory feature three passing tracks (Figure 2(f)), allowing freight or other equipment to be stowed while opposing passenger trains pass one another. Close proximity of sidings allow TRA to squeeze 5~6 tph (both directions, mixed traffic) out of single-tracks (*42*).

Double Island Platforms at Transfer Stations

Train terminations and transfers (express/local, branch/mainline) occur at strategic interchanges where double island platforms and full crossovers are provided. Platforms between siding and mainline provide cross-platform transfers, and allow staff to clear terminating trains without obstructing mainline. Where many trains originate/terminate, additional platforms are provided. Crossovers allow convenient layover access and easy multiple-unit (MU) reversals (Figures 2(g), 3(c)).

Side Platforms and Through Tracks

Island platforms are not ideal for vertical passenger flow. Side platforms allow direct access from stationhouse through fare control. Through track serves the stationhouse at major stations (Figure 3(d)), where most expresses stop. Middle bypass tracks are available for switching, temporary equipment storage, train preparation (Figure 2(f)), and allows passenger trains to pass freights (Figure 2(e)). Stationhouses are usually on the northbound side (up direction, to Taipei), where originating passengers are voluminous (Figure 2(c)). At minor stations, mainline serves the island platform; locals serve the stationhouse while waiting for overtaking expresses (Figure 3(e)).

Explicit Scheduling and Dispatching Priorities

Like classic American railroads, TRA's published timetable specifies train class (thus dispatching priority). Premium-fare expresses, like Tze-Chiang, have highest priority and almost never take sidings (*33*). Customers understand the system, and aren't surprised when lower priority trains are held, allowing others to pass. Dispatching decisions are fairly straightforward; even when trains are out of sequence, stationmasters wouldn't hesitate to hold trains if releasing them could delay a subsequent Tze-Chiang. Close proximity of sidings mean unscheduled holds are likely short, usually <5 minutes.

Schedule, Ridership Pattern, and Demographics

TRA's schedules are not tightly constrained by clock face patterns or policy headways. Extra trains and cars are added on peak travel days to accommodate holiday traffic. 6~8% more departures are scheduled on Fridays, Saturdays, and Sundays. TRA riders span the full gamut including lower-income (students, military) and minorities (Hakka, aboriginal Polynesians) but also choice riders (vacationing families, foreign tourists, monthly commuters). Elderly passengers are common, but wheelchair passengers are rare; not all stations are handicap accessible and not all rolling stock are level-boarding. Fare differentials between expresses and locals provide market differentiation. HSR ridership is observably more affluent, capturing many former airline passengers (*43*).

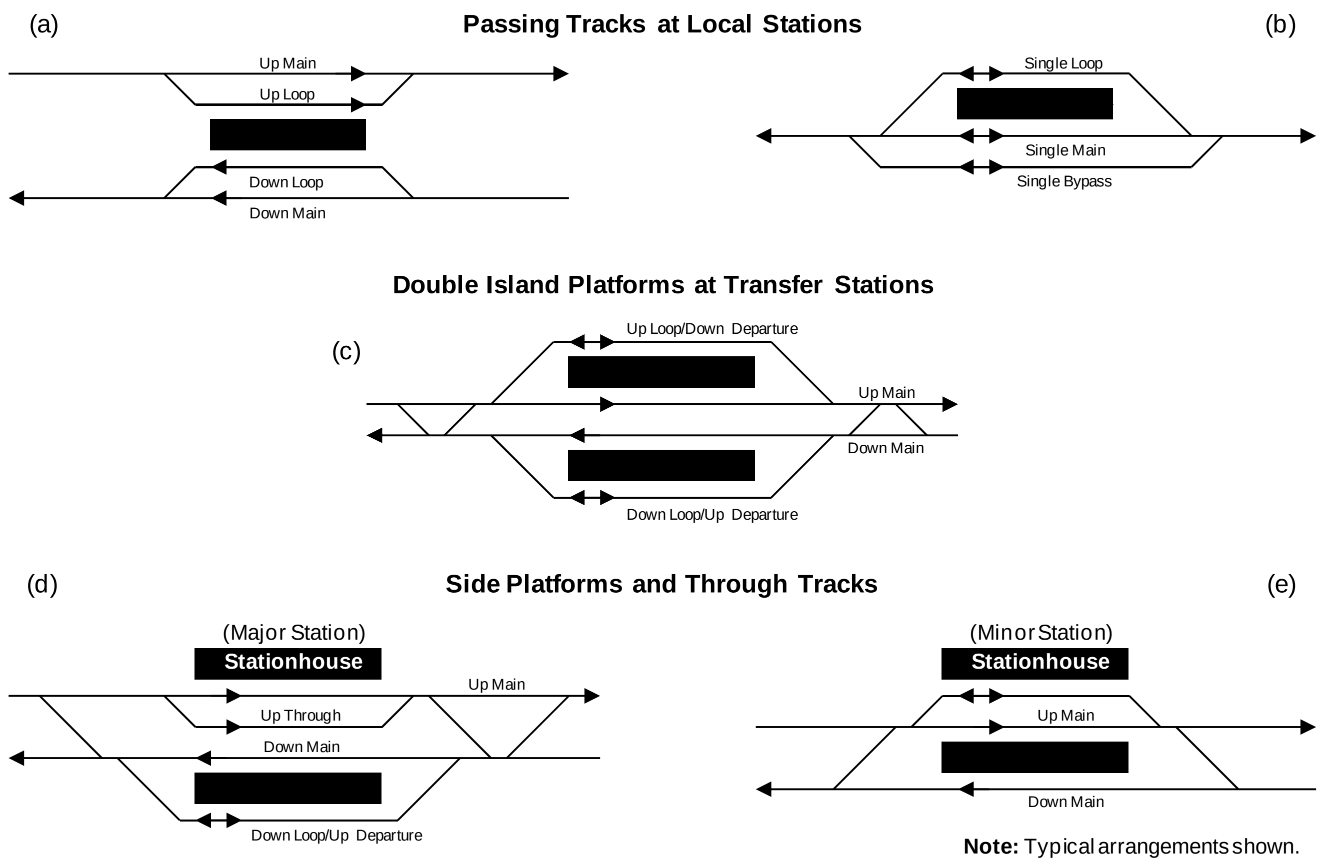


FIGURE 3 TRA's typical track layouts: (a) Island platforms serving middle siding tracks with straight-through outside bypass tracks allows locals unexpectedly operating ahead of expresses take the siding at next local stop, limiting express delays to 2~5 minutes (typical running time differential between sidings); sidings are further apart in geographically challenging areas (e.g. where right-of-way construction requires mountain rock blasting). (b) Some stations in single-track territory feature three passing tracks. (c) Double island platforms with full crossovers facilitate easy train terminations and transfers. (d) At major stations, through track serves the stationhouse; failed equipment is sometimes stored on the middle by-pass tracks, improving network reliability. (e) At minor stations, locals serve the stationhouse while waiting for overtaking expresses.

OPERATING PRACTICES

Operations on different railroads are variations of same general principles. TRA's practices are like JR's – somewhat labour intensive, but immediate on-site accountability and close supervision contribute to high service quality, good delay-recovery capabilities, skills to execute complex maneuvers, and throughputs closer to theoretical line capacity than otherwise achievable.

Stationmasters, Train Regulation, and Dwell Process

Many TRA stations have “stationmaster duty offices.” Stationmasters (their deputies, or platform staff) perform train regulation and signalling functions right from the platform (Figure 4(f)), and provide train crew oversight. Two station crewmembers work busy locations, one per direction. They sound a whistle to warn waiting passengers of imminent arrivals. Passengers standing in yellow danger zones are asked to step back. As trains approach, they hand-signal drivers (Figure 4(b)). Unreserved trains (without assigned cars) berth close to fare control, while expresses berth according to platform car markers, minimizing onboard baggage-carrying by passengers looking for assigned seats. Stationmasters may indirectly reduce overruns by providing immediate accountability.

TRA’s stationmasters and conductors jointly manage dwell time, like their counterparts at LIRR’s Jamaica. Stationmasters regulate trains by enforcing correct train sequences and departure times; holding to time is actually a legal requirement (*43a*). At transfer locations, they manage connections. About ½-minute prior to departure, stationmasters sound platform bells to signal impending departure. When trains are late, bell is given sooner, shortening dwell times. Once conductors close train doors, stationmasters give the “right away” using platform-mounted equipment (Figure 4(a)). After departure, stationmasters remain on platforms, visually inspecting departing trains.

Conductors as Captains

Onboard, conductors’ primary responsibilities aren’t ticket examinations – station fare controls provide coverage. Instead, conductors operate doors and announcement systems, ensure onboard safety, sell onboard tickets (Figure 4(g)), provide customer information and assistance, supervise onboard crews, perform emergency procedures, and troubleshoot equipment where possible. The position’s multi-disciplinary nature is reflected in Asian terms for “conductor” – 列車長 (Mandarin *lieh che jhang*), 車長 (Cantonese *che jeung*), or 車掌 (Japanese *sha-shou*, still informally used on TRA) – which transliterates as “consist manager” or “train handler.” They have overall responsibility for smooth onboard operations and customer experience, actively directing cleaners, attendants, even bento-box vendors.

Onboard Services

On TRA expresses, cleaners periodically move through the train to remove trash, even proactively asking passengers if visible food items are finished (Figure 4(e)). Train attendants offer bento boxes, drinks, souvenirs, and Sun Cakes (traditional gifts for visiting friends) from small carts. The onboard atmosphere is much like Amtrak’s Downeaster.

[Figure 4 shown next page]

FIGURE 4 (top) Although TRA’s operating practices may be labour intensive, the resulting service quality is high: (a) a stationmaster’s controls: departure bell switches, schedule simplifiers, and “good to go” plungers; (b) Hsinchu’s stationmaster at the 11-car marker; (c) Jingtong station is the terminus of the Pingsi branch; (d) EMU operator and relief operator on Yilan’s departure track; (e) TRA’s cleaners move through the train while in-service to collect trash from passengers; (f) Sandiaoling’s stationmaster exchanging tokens (movement authorities) with Pingsi branch’s diesel railcar operator.
(bottom) TRA’s fare control occurs at origin, destination, and en-route. Turnstiles, mobile terminals, and slam gates are used: (g) TRA’s conductor using a portable thermal ticket printer to sell an onboard fare; (h) delay machines print receipts showing recent train delays; (j) delay receipt shows Train 1015 was delayed only 27 minutes despite substitute equipment having to be found; (k) Hsinchu’s exit-only control area (unpaid side) with modern faregates and volunteer customer assistance staff; (m) Suao still has a traditional fare control area reliant on manual ticket examination.


(a)
(b)
(c)
菁 桐
Jingtong
(d)
45EMC551
(e)
(f)
(g)
(h)
PUSH
自助式晚分證明列印機
Delay Certificates
(j)
台灣鐵路管理局新竹車站
<<列車晚分證明>>
99 年02 月07 日 12:46
1008 次 較原定11:28 晚002 分
1015 次 較原定11:34 晚027 分
12 次 較原定11:41 晚007 分
2464 次 較原定11:46 晚005 分
19 次 較原定11:53 晚008 分
1017 次 較原定12:09 晚007 分
3307 次 較原定12:24 晚005 分
2113 次 較原定12:31 晚002 分
(k)
(m)

Incident Management

TRA operations staff seem well-practiced in incident management. The authors observed three incidents with major delay potential, but TRA responded effectively to avert possible delays:

1. Remote control of a mainline power switch was lost at an important junction. A staff member at the station walked to the switch to operate it manually. The quick response limited delays to all four affected trains to <15 minutes, despite the token dispatching system (Figure 4(f)) requiring specific branch line train sequencing.
2. An older trainset developed problems in service but already passed major yards. It was dumped at the next island platform siding. Another trainset picked up stranded passengers 27 minutes later. Figure 4(j) shows incident Train 1015 and delays to other services, limited to <8 minutes despite the blocked siding.
3. A "retired" EMU100 trainset (in regular service covering car shortage from general overhauls) suffered a power failure. A rescue engine was coupled behind the trainset, getting the train moving within 15 minutes. The consist continued in regular service to its final destination, arriving only 7 minutes late.

FARE COLLECTION & CONTROL

TRA's tickets were printed on traditional Edmondson presses until Japan's NEC supplied a computerized ticketing and reservation system in the late 1980s. Almost all stations are divided into paid (platform) and unpaid (waiting room) areas. Normally, ticket examiners (Figure 4(m)) govern platform access, checking and punching tickets as passengers enter. Conductors perform onboard ticket checks near peak load points or every ~100 miles, verifying that passengers hold train-class appropriate tickets, and dispense step-up and zone extension fares from portable ticket printers (Figure 4(g)). Examiners also control access to unpaid areas at destinations, ensuring all passengers paid full distance-based fares. Used tickets are collected and not returned to passengers unless cancelled by stamps (similar to postmarks). Those arriving without appropriate tickets (i.e. requiring "fare adjustments") are assessed 50% penalties, giving passengers incentives to find conductors onboard to purchase step-up fares. Tickets are validated at origin, destination, and sometimes en-route; evasion thus would require elaborate two-ticket schemes or exiting from paid area without going through fare control. Fare evasion rates are thought to be low. Proof-of-payment methods are not used.

Fare Structure

TRA's passenger fares are highly regulated and strictly distance/train-class based (short trips <6.3 miles require 34~73 cents minimum fare.) Express fares are 11.7 cents (per passenger-mile); locals are 5.5 cents (*44*). Within Taipei municipal zone, single trips are 58 cents regardless of distance/class. Unlike HSR, no time- or demand-based off-peak discounts are offered. Periodic (limited-ride) commutation tickets and multi-ride carnets are available. Fares are generally competitive with private commuter and intercity buses. Express trains operate with higher load factors and are more profitable.

Magnetic Ticket Stock and Mechanical Faregates

Fare validation requires substantial infrastructure (paid/unpaid areas), labour-intensive manual ticket examinations, and consequent speed-accuracy trade-offs. During the 2000s, TRA incrementally replaced older thermal ticket printers with automated fare collection (AFC) devices using magnetic-backed stock (Figure 4(k)). Busy stations have faregates to speed up validation. Tickets can be inserted in any orientation. Gates align, check, and mechanically punch tickets prior to opening. Validations are fast and can be "pipelined" or "stacked" (i.e. following passenger can insert ticket while previous passenger is proceeding through the gate). Passenger counting sensors quickly close gates when as many passengers entered as valid tickets processed. When exiting, faregates collect and cancel single trip tickets.

AFC-Induced Ticket Examiner Changes

Many locations still use heat-sensitive tickets (and TRA's tourist branches still use Edmondsons), requiring one ticket examiner per fare control. Examiners punch and collect non-magnetic tickets, provide customer information and assistance, troubleshoot AFC malfunctions (e.g. mutilated tickets), and return cancelled (stamped) tickets to passengers requiring proof-of-travel for expense claims. TRA volunteers (Figure 4(k), yellow vest) staff some gates. Volunteers, like America's auxiliary police and volunteer firefighters, include carefully selected and specifically-trained members of the public, and retired industry personnel (*45*). They assist passengers, sometimes exercising Japanese or English language skills (*46*), and report turnstile jumpers and AFC malfunctions to employees. Station management has considerable latitude in determining work scope of volunteers (*47*).

TICKETING PROCESSES

Most TRA stations feature staffed ticket offices, supplemented by ticket vending machines (TVMs) at busy locations. Unreserved single or day-return tickets must be purchased on the day of travel (to prevent ticket reuse), leading to ticket queues at peak commuter periods. Passengers purchasing advance tickets can delay entire queues, causing imminent train departures to be missed. To maximize passenger throughput, separate ticket windows provide train information, today's tickets, and advance or commutation tickets (Figure 5(d)). Some daily ticket windows only accept cash, further decreasing transaction times. Ticket windows at busy stations can be dynamically switched between different functions, minimizing daily ticket queues.

Fare Vending Machines

Early machines designed primarily for commuters (Figure 5(b)) are essentially receipt printers, accepting only coins (no bills) and prepaid magnetic TransitChek-like cards – not credit cards. Passengers must first insert coins (amount deposited is displayed), then press numerous lighted buttons sequentially to specify traveller count, train class, single/return/concessionary, and destination. Buttons light up only when adequate coins are inserted. TVMs sell only unreserved single/round-trips to local destinations (<50 miles) from the current station. Earlier button presses constrain subsequent choices: destinations for which insufficient fares were paid (in selected train class) do not activate and have no effect.

This machine's target audience is regular travellers who already know required fares. Passenger experiences for first-time customers can be confusing, but once customers learn this TVM, unreserved day ticket transactions are processed much faster than on typical full-feature machines. Machines need only electricity (not network connections) and staff to replace ticket stock, remove coins, and clear jams. Like soda machines, they're robust, self-contained, and have been deployed to remote locations.

Long distance TVMs selling advance-purchase, reserved-seating, and prepaid internet/phone tickets were developed later (Figure 5(a)). These more complex machines, functionally similar to Amtrak's Quik-Trak, are available at principal West coast stations.

Contactless Smartcard Fare Payment

TRTC pioneered transitcards in 2000 via affiliate Taipei Smart Card Corporation, which performs backoffice functions for TRTC, Taipei's Lian-Ying (market-sharing conference) group of bus companies, and other EasyCard merchants. In 2008, TRTC assisted TRA in implementing entry-exit smartcard fare collection (*48*) for local travel within Taipei's metropolitan zone (Keelung-Chungli), offering 10% discounts from regular local train fares. Smartcard holders can travel on regular local and express trains, but not Tarokos, sightseeing specials, nor in business class. When travelling on expresses, smartcard seats are unreserved. As expresses are often sold out, EasyCard offers de-facto standee discounts.

Origin/destination validation and existing fare control areas made smartcard implementation easier. Instead of punching tickets to enter and relinquishing tickets to exit, users tap-in and tap-out. Faregates are replaced with newer integrated designs as funding allows. In the interim, ticket collectors visually verify each transaction on low-cost stand-alone terminals, allowing rapid deployment.

Smartcard development in Taiwan is currently fluid. With 13 million cards issued, readers for Mifare Classic-based EasyCard are already installed at convenience stores like Family Mart (Figure 5(c)). Legislation authorizing "Third Generation e-Purse" (stored value limit ~US$300) was passed in March 2010, allowing smartcard payments for low-value non-transportation items, like Hong Kong's Octopus Card. Three major competitors hold regional subway/bus fare collection franchises (Taipei's "Youyoka" EasyCard, Mid-Island's Taiwan Easy Go "TaiwanTong", and Kaohsiung's "I Pass"), and TRA has active pilots with both EasyCard and TaiwanTong. Taiwan's MOTC expects to eventually integrate all electronic farecard systems nationwide (*49*).

[Figure 5 shown next page]

FIGURE 5 (top) TRA's ticketing process is advanced and efficient, but uses many dedicated special-purpose terminals and vending machines: (a) advance-purchase ticket machines, with touch screens, reservations, and credit card capabilities similar to Amtrak's Quik-Trak; (b) commuter ticket machines are simple prepaid card and cash-only receipt printers; (c) Family Mart (a convenience store) now accepts Taipei metro's EasyCard; (d) the Buddhist monk is purchasing daily tickets at Hsinchu station, skipping long queues at "advance purchase" windows; (e) Suao's ticket office has an older acrylic schedule board (like those at old-fashioned movie theatres) giving departure times.
(bottom) Taiwan Railways Administration's array of onboard and wayside passenger information systems: (f) Suaosin (functionally "Suao Junction") station's dot-matrix platform LED display provides next train's destination (Hsinying), route (Mountain line), train class (Chu-Kuang express), scheduled departure time, and uses the scrolling textbox for en-route station stops, delay information, delayed train's current location (e.g. "Train now between Nan-ao and Dong-ao"), special event messages (e.g. discounted student tickets available during Winter break), public service announcements (e.g. Operation Lifesaver or H1N1 flu prevention messages), and identity of train-after-next (e.g. "16:52 Shulin local follows"); (g) Rueifang station's platform showcase a variety of customer information devices; (h) onboard stop announcement system from a newer EMU700 identifying prior stop (Wudu), next stop (Baifu), and following stop (Qidu); (j) flexible scrolling LED display from an older push-pull E1000 set identifies the train (e.g. "Keelung-bound, Train 1006, Tze-Chiang express"), route ("via Coast Line"), stops ("stopping at Taoyuan, Banqiao, Taipei, Songshan, and Qidu"), and special event and public service announcements similar to platform displays; (k) Taipei Main Station's airport-style departure monitor.


(a)
臺灣
對號列車自動售票機
1
2
(b)
36
(c)
Stay on the Wellness Track
悠遊卡 EASYCARD
(d)
(e)
自動售票機
ATVM
3
2
1
(f)
開往 DESTINATION 新營
經由 VIA 山線
TRAIN TYPE 莒光號
DEPARTURE TIME 16:32
第 PLATFORM 1A 月台
本車在 南澳-東澳區間
蘇澳新
Suaosin
8
(g)
9:15
(h)
五堵 Wudu
百福 Baifu
七堵 Qidu
(j)
1
第1006次,自強號,
PPC 1448
(k)
TAIPEI STATION
North Bound
TIME 08 : 20
DESTINATION NO. TYPE TIME PLAT. REMARK
SU AO 3356 LOCAL EXP. 08:24 4A ON TIME
HUA LIEN 1000 TZU CHIANG 08:30 4B ON TIME
SU AO 2719 LOCAL 08:37 4A ON TIME
KEE LUNG 3044 LOCAL 08:50 4A ON TIME
KEE LUNG 2124 LOCAL 08:57 4B ON TIME
NORTH BOUND

PASSENGER INFORMATION SYSTEMS AND SIGNAGE

TRA takes a holistic and comprehensive approach towards passenger information. Devices used (in both English and Chinese) range from schedule posters, fixed signage to departure monitors and next-train displays.

Solari-like "flippy-flippies" boards, monitors (Figure 5(k)), or smaller LED displays are provided at major terminals and principal stations. One display per control area shows boarding times and track assignments. Delays as short as one minute are posted. Large acrylic signboards show departure times and fares at smaller stations (Figure 5(e)). Ubiquitous clocks throughout stations and facilities make it difficult to find spots where fewer than two clocks are immediately visible.

Platform Signage, Next Train Identifiers

Backlit acrylic signs (airport-style with iconic representations) identify platform and carriage numbers, and provide directions to facilities like restrooms and elevators (Figure 5(g)). Boxes display schedules, tourist information, and service change notices. Large signs (legible from passing trains) indicate station names, and distances to previous/next stations, for use by passengers and crew. Platform LED displays (Figure 5(f)) provide next train identity, departure time, delay information, and context-sensitive messages, including public service announcements.

Onboard Displays and Announcements

TRA's mixed fleet ranges from 1960s hauled stock to new Tarokos and commuter MUs. Newer trains feature automated display/announcement systems (Figure 5(h)) with high-density dot-matrix LEDs like Taipei's metro. On long-distance coaches with longer time between station stops, scrolling displays (Figure 5(j)) are used. Like in Continental Europe, automated onboard announcements are multilingual. Announcements are in four major languages (Mandarin, Formosan, Hakka, and English). In rural areas, announcements are also made in local aboriginal languages; Huatung Line has the Pangcah/Amis tribal dialect. In unusual situations, conductors can usually make announcements in at least two languages.

Trains lacking automatic train location features are not simple to retrofit. TRA devised low-cost multi-lingual "announcement boxes" connected to the public address system, manually triggered by conductors on approach to stations.

Exterior Train Identification

Identifying arriving trains quickly and accurately is equally important to employees and passengers. Classically, lighted acrylic destination signboards are manually changed at terminals. Recent modernization efforts provided exterior LED displays showing destination, route, train number, and class. Newest cars have bilingual flexible displays built-in. Train numbers are especially important on expresses, helping customers identify seat reservations.

FURTHER RESEARCH FOR COMMUTER RAILROADS

The U.S. commuter rail industry has undergone record growth within last thirty years. Ridership reached new heights on revitalized older systems. Entirely new systems were created in smaller cities. Some railroads introduced innovative business models and operating practices from Europe and airlines, while established systems maintained traditional but nonetheless effective operations. Specifically, how could TRA's philosophy contribute to North American practice?

Designing to Expect Disciplined Operations

TRA's infrastructure is not foolproof. Track layouts are designed for a limited set of normal operations, simplifing service recovery decisionmaking by reducing ambiguity and constraining available choices. Accurate train planning and operational precision is expected. Designs neither accommodate simple working methods nor tolerate sloppiness, allowing less wiggle-room for errors. The unforgiving plant and appropriate training seem to create a "getting it right the first time" culture amongst staff.

Scheduling for Priority and Reliability

TRA designed plant and schedules to require en-route "checkpoints" and absorb uncontrollable disruptions. Where capacity constrains express operations in America, third tracks are often proposed, but TRA's two tracks with local station sidings might be considered instead. Scheduled holds improve local service reliability, serving as "recovery time," allowing trains to regain scheduled paths. Similar scheduling and train regulation concepts are found in Japan and Europe (*50*).

Empowering Local Supervision with System Responsibility

Effective use is made of constrained infrastructure through significant on-site supervision, teamwork, peer camaraderie, interpersonal communications, and hands-on operations. Although CTC covers most TRA lines, increasingly remote control did not lead to local personnel's functional obsolescence or centralized micro-management. Operations are precisely choreographed, but their execution requires greater range of responses and broader knowledge base. The greater sense of personal responsibility amongst field employees is evident from observing their attitude and approach towards operational problem-solving.

Appropriate Standardization

TRA's standardization efforts are tempered by specific local adaptations and procurement policy. Rather than rigidly define historic business practices and require vendor compliance, TRA seem flexible in adopting foreign industry standards while ensuring its functional needs are met, as evidenced by 'oddball' solutions and varying designs found systemwide. Tolerating some diversity and purchasing off-the-shelf products may reduce overall costs and improve effectiveness. TRA's smaller orders produced designs tailored for specific applications and incremental improvements between each equipment generation. Station designs and scheduling seem sensitive to passenger volumes and adapted to individual communities. Trade-offs between design, construction, and ongoing operating and maintenance costs should be explicitly considered, including costs of maintaining consistent designs and policy service.

Technology as Workplace Assistance, not Functional Replacement

TRA's automation seem to be accomplished without compromising employees' skills or flexibility. Rather than seeking to replace field personnel, machines enable employees to perform duties better, faster, to multi-task, or backstop inevitable human errors without allowing complacency. Employees with more automated job functions focused on actively troubleshooting, maintaining, monitoring new technology, and assisting customers. TRA also seem willing to accept incremental or partial (probably cheaper) automation solutions, where machines provide "computer assist" not full functional replacement. Similarly, LIRR's train-tracking system assist, not automate, dispatching (*51*); decisionmaking authority remains firmly with dispatchers while information and intelligence gathering is automated, giving staff more time to manage the railroad while spending less time on recordkeeping and executing operational processes.

Prioritizing Investment Based on Technology Characteristics

TRA's capital projects are ranked by each technology's specific impacts on operations. Double-tracking and electrification began in busy suburban areas, followed by farmland, completing difficult and expensive mountainous sections last (*52*). CTC was first installed in farming regions where freight switching moves were once frequent. Alternating single- and double-track mainline sections where overruns could cause dangerous head-on collisions got cab signals first. Branch lines with low train densities retain simple-yet-effective token signalling, which take longer to issue movement authorities but are almost as successful at collision prevention. In America, LIRR's busy suburban Babylon Line has CTC with cab signals, electrification, and full grade-separation, while its (less populated) connecting Montauk Line retains train-order operations east of Speonk.

Fare Control Automation

U.S. commuter railroads have deadlocked over fare control automation for 30 years (*53*) because of technology and staffing issues (*54*), even though Illinois Central Railroad (now Metra Electric) implemented fare barriers in 1966 with some success (*55*). Taiwan and Japan implemented faregates to improve passenger throughputs rather than to remove human presence. Conductors and ticket examiners continue to manage fare collection, while low-volume stations remain barrier free. TRA's willingness to tolerate fare system complexities by mixing smartcard, magnetic, paper, onboard tickets, and turnstile/manual validation contributed to a successful and incremental AFC implementation on a limited capital budget. Railroads should examine how their skilled workforce can be utilized to improve customer experience and actively operate new AFC technology, instead of seeking rationalization. Recently, Baltimore-Washington's MARC kept agents at Odenton station even after installing automatic ticket machines (*56*) because regular riders petitioned for their retention.

Metropolitan Terminals

Although pioneered by the Pennsylvania Railroad, run-through railroad services remain rare in U.S. cities. Taipei's downtown tunnel offers insight into how such projects can be environmentally and politically justified – not for reduced journey times or improved equipment utilization, but for grade-crossing elimination, property development, and civic pride. New York's Access to the Region's Core project might have created through service between New Jersey, Long Island, and Westchester (*57*), but ultimately may never bridge the last mile between West Midtown's Penn Station and Eastside's Grand Central.

Integrated Transportation Planning

TRA's seamless passenger experience across jurisdictions demonstrate an island-wide, strategic, "joined-up" thinking that provided benefits to many stakeholders, while project delivery was phased to make scope, funding, and environmental impacts more manageable, enabling sustained expansion, reconstruction, and modernization during the last forty years. It's as if Robert Moses' powerful visions as "master builder" of New York's parkways were applied to Taiwan's railways!

THE FAR EASTERN PHILOSOPHY

The goal of this research was to pique interest in Taiwan's railways and identify areas for further exploration. More research is required to determine if these ideas are adaptable to North America.

TRA tends to favour simple, robust, single-purpose machines – like separate power generation cars for air-conditioning in diesel territory, and power changes instead of dual-mode locomotives. Complex functions are modularized, like having separate faregates for magnetic tickets and smartcards. Operating and maintaining these machines requires a multi-skilled, multi-tasking workforce – not multi-functional gadgets with narrow crafts of employees. Expectations of system knowledge extend to customers; users must find the right machine for their needs. This philosophy results in a generally more quirky railway, with steeper learning curves for the public and employees alike. Customers and staff have clearly "learned the plant," as evidenced by precise and speedy regular operations.

TRA's approach makes railway hardware fairly basic, while implementing much of service delivery and recovery "in software" with operating practices. The idea that different procedures can permit higher and more flexible utilization of infrastructure is evident throughout TRA's designs.

The Oriental philosophy isn't always right, and may not be applicable in the New World, but it's interesting and different. While multiple standards, vendors, designs, workarounds, and complex operating processes might seem complicated and confusing, over-automation can result in barely maintainable machines operated by human drones. Without compromising safety, is there room in North America for a little within-system technological diversity?

ACKNOWLEDGEMENTS

Authors gratefully acknowledge field assistance provided by Prof. H.Y. Lu and Prof. Angela Chen (NSYSU), Jennifer Hou (ITRI), Attorney Joanne Hsiao (K&L Gates) during a fact-finding visit to Taiwan. Additionally research support from C.C. Young (BOTHSR), Prof. T.C. Kao, Prof. Y.C. Lai, Powen Huang, and K.C. Liu (NTU), Dr. S.T. Chan, Sally Kao, and Kevin Yeh (TRTC) were immensely helpful and much appreciated. Responsibility for errors or omissions remains with the authors. The views are the authors' and do not reflect official policies of aforementioned Taiwan organizations, Metropolitan Transportation Authority, or New York City Transit. No public funds were expended for the research leading to this paper.

REFERENCES

(1) Hung, Chih-Wen (洪致文). Shooting the Breeze on the Taiwan Railways ("台灣鐵道趣味漫談", ISBN 957-13-2101-X). Taiwan Living Series No.44, Taiwan Times Publications, Taiwan, 1996.

(2) Taiwan Bureau of Tourism, Ministry of Transportation and Communications. Chapter 9, *Taiwan Development History* ("臺灣發展史"). In *Tourism Training Material*, Bureau of Tourism, Taipei, Taiwan. Retrieved from *http://61.60.100.220/台灣發展史/chop09-1.htm* on April 15, 2010.

(3) Kuan, Renjian (管仁健). Taiwan's Chinese Education and Japanese Railroads ("台灣的中國教育與日本鐵路"). In *The Taiwan You Don't Know* (Blog). Retrieved from *http://mypaper.pchome.com.tw/kuan0416/post/1281895810* on July 9, 2010.

(4) Taiwan Railways Administration. *Museum Pages: Taiwan Railways Development Timeline*. ("博物館： 臺灣鐵路發展時段") Retrieved from *http://www.railway.gov.tw/i/i2_01.htm* on July 9, 2010.

(5) Abbott, James (ed.) Jane's World Railways, 38th Ed., Coulsdon, Surrey, England, 1996.

(6) Taiwan Railways Administration, Ministry of Transportation and Communications. *TRA Signalling Equipment Maintenance Inspection Standard Operating Procedures* ("交通部台灣鐵路管理局號誌裝置養護檢查作業程序"), Banqiao, Taiwan, 2003. Retrieved from *http://www.railway.gov.tw/admin/upload/kay00/號誌/號誌裝置養護檢查作業程序_公開.doc* on February 16, 2010.

(7) Railway Reconstruction Bureau, Taiwan Ministry of Transportation and Communications. *2007 Annual Report Summary* ("2007交通部鐵路改建工程局局務概況"). Retrieved from *http://www.rrb.gov.tw/upload/documents/pubGov/鐵工局2007局務概況.pdf* on July 11, 2010.

(8) Wang, Shufen (汪淑芬). Government Rescues Taiwan High Speed Rail – Chen Shiyi Suggests Concession Extension. ("政府救高鐵 陳世圯建議延長特許期"). In *Epoch Times*, September 21, 2009. Retrieved from *http://www.epochtimes.com/b5/9/9/21/n2663863.htm* on July 13, 2010.

(9) Ministry of Transportation and Communication, Taiwan Railways Administration, Accounting Office. *2008 Statistical Annual Report*. Banqiao, Taiwan, 2008. Retrieved from *http://www.railway.gov.tw/intro/introduction-7.aspx* on March 15, 2010.

(10) Rail News Speed Report. Typhoon Parma Impacts. In *Taiwan Rail News*, Volume 192, Page 30, Sanchong, Taiwan, November-December, 2009.

(11) Su, Jiao-Shi (蘇昭旭). Taiwan Railways Station Pictorial ("台灣鐵路車站圖誌", ISBN 986-791609-9). JJP Publishing, Taiwan, 2002.

(12) Chen, Shiyi, and F.J. Huang (陳世圯, 黃豐鑑). *Government Should Proactively Promote Railroad Reform Bill to Assist TRA in Overcoming Financial Operating Difficulties* ("政府應積極推動鐵路

法修正案以協助台鐵渡過經營困境”). National Policy Research Foundation, Analysis Report 097-014. Retrieved from *http://www.npf.org.tw/post/3/5178* on July 13, 2010.

(14) Tseng, Tsingnaw (曾鴻儒). Plentiful En-route Real Estate Revitalization and Economic Development/Urban Renewal Helps Taiwan Railways Administration to Recoup Losses (“沿線土地多活化啟生機／都市更新 救台鐵虧損”). In *Liberty Times*, June 10, 2010. Retrieved from *http://www.libertytimes.com.tw/2010/new/jun/10/today-life7.htm* on July 13, 2010.

(15) Reddy, Alla, A. Lu, and T. Wang. Subway Productivity, Profitability, and Performance: A Tale of Five Cities. In Press, TRB Paper No. 10-0487. In *Transportation Research Record 2143*, Transportation Research Board of the National Academies, Washington, D.C, 2010.

(16) American Public Transit Association. The First Steps to TransitVision 2050 – APTA 2010~2014 Strategic Plan, Washington, D.C., 2009.

(17) Harrington-Hughes, Kathryn. International Transit Studies Program Report on the Spring 2009 Performance Measures and Outcomes Study Mission to Southeast Asia. In *Transportation Cooperative Research Program (TCRP) Research Results Digest*, National Academies, 2010.

(18) Grynbaum, Michael M. and R. Gebeloff. 95% of Trains Are on Time? Riders Beg to Differ. In *New York Times*, N.Y. Region, July 26, 2010.

(19) LIRR Commuters Campaign. The On-Time Performance Fraud. Retrieved from *http://www.lirrcommuters.org/* on October 26, 2010.

(20) Haynes, Michael. That Which is Measured, Improves – Measuring Five Years of Bus Bunching, Big Gaps and On-Time Metrics. Presented at the *APTA Multimodal Operations Planning Workshop*, New York, N.Y., 2010.

(21) Zelchenko, Peter. Appropriate Technologies in Surface Scheduling. Presented at *Transport Chicago* Conference, 2004.

(22) El-Alj, Yasmine, C.D. Martland, and J. Sussman. *Performance-Based Technology Scanning for Railways*, MIT/UIC Working Paper WP-2001-01. Union Internationale des Chemins de fer (UIC, International Union of Railways) and Massachusetts Institute of Technology, Cambridge, Mass., 2001.

(23) Hood, Christopher P. Ch.1: Introduction, Page 5. In *Shinkansen – From Bullet Train to Symbol of Modern Japan*. Oxford, 2006.

(24) Karkera, Kiranraj. Countering the Threat of Lost Knowledge. In *Infosys Perspective*, White Paper, Lisle, Ill., September 2006.

(25) Di Pietrantonio, Loris, and J. Pelkmans. *The Economics of EU Railway Reform*, Bruges European Economic Policy Briefings No. 8, College of Europe, Burges, Belgium, September 2004.

(25a) Allen, John G. From Commuter Rail to Regional Rail – Operating Practices for the 21st Century. In *Transportation Research Record 1623*, Transportation Research Board of the National Academies, Washington, D.C., 1998.

(26) Railway Reconstruction Bureau, Taiwan Ministry of Transportation and Communication. *Taipei Main Station, Songshan, Wanhua-Banqiao, Nankang, and Hsinchu-Naiwan Project Briefs*. Retrieved from *http://www.rrb.gov.tw/04000.aspx?lan=en* on March 14, 2010.

(27) Vantuono, William C. Reconquering Gotham. In *Railway Age*, April 2010.

(28) Chen, Wai-Shu (陳韋臻). To Residents Outside Wanhua: Urban Renewal May Someday Demolish Your Home. In *POTS Weekly* ("破週報"), Taipei, Taiwan. Retrieved from *http://www.pots.com.tw/node/6450* on October 26, 2010.

(29) Lee, Tung-Ming (李東明). *The Forever Taipei-Damshui Branch* ("永遠的北淡線"). Tipi Press, Taipei, Taiwan, 2000.

(30) Sungho Culture Company Limited. Taiwan Ministry of Transportation and Communication, TRA Tourism Express Travel Guide (Map), Taipei, Taiwan, 2009.

(31) Kozel, Scott M. Center City Commuter Connection. In *Pennways*, May 26, 1998. Retrieved from *http://www.pennways.com/Commuter_Tunnel.html* on October 24, 2010.

(32) Lu, Lexcie. Ch.5: Downtown Access Design. In *The Vital Role of Metropolitan Access in Commuter, Regional, Intercity and Overnight Rail Passenger Transportation – and Its Relationship to Technology*. MIT Thesis, Cambridge, Mass., 2003.

(33) Taiwan National Chiao-Tung University Railway Research Association (國立交通大學鐵路研究會). *Taiwan Railways Operation Diagram (Stringline Chart)*, Version 5. Hsinchu, Taiwan, June 16, 2009.

(34) Mo, Yan-Chih. Taipei Bus Station Opens Amid Fears of Heavy Traffic. In *Taipei Times*, Taipei, Taiwan, August 20, 2009. Retrieved from *http://www.taipeitimes.com/News/taiwan/archives/2009/08/20/2003451564* on April 19, 2010.

(35) McKim, Jenifer B. Magic Touch? New Developers Take Over NorthPoint. In *Boston Globe*, September 9, 2010.

(36) CREATE Program Final Feasibility Plan, August 2005. Retrieved from *http://www.createprogram.org/pdf/final_feasibility_plan.pdf* on October 31, 2010.

(37) Kirby, Matthew and P. Holmes. *Taiwan Railways Alignment and Station Maps*. Retrieved from *http://www.taiwanrailways.com/* on May 11, 2010.

(38) Bureau of Taiwan High Speed Rail, Ministry of Transportation and Communication. *Taiwan North-South High Speed Railway Plan* (Unpublished Presentation). Banqiao, Taiwan, January 2010.

(39) Bureau of Taiwan High Speed Rail, Ministry of Transportation and Communication. *Taiwan South-North High Speed Railway – Introduction to Mechanical and Electrical Systems Engineering*. Banqiao, Taiwan, August 2008.

(40) Taiwan Railways Administration. *Introduction to Taiwan Railways' New Taroko Express Trains* ("台鐵新購太魯閣列車簡介"). Retrieved from *http://service.tra.gov.tw/Hualien/CP/11863/tarokoexpress.aspx* on October 24, 2010.

(41) Taiwan Railways Administration (TRA) Orders Tilting A-Train Concept EMUs from Hitachi, in *International Railway Journal*. December 1, 2004.

(41a) Huang, Powen (黃柏文). *The Patriarchal EMU100* ("元老級的自強號"). In *Train Collection*. Retrieved from *http://emu300ct.myweb.hinet.net/index/tramus/EMU100.htm* on October 27, 2010.

(42) Taiwan Railway Company LTD. *"How One" Taiwan Travel Passport (Taiwan Railways Administration Passenger Schedule),* Version 9. Banqiao, Taiwan, January 15, 2010.

(43) Agence France-Presse. Airlines Hit as Taiwan Bullet Train Takes Off. In *The Standard*, Hong Kong, July 19, 2007. Retrieved from *http://www.thestandard.com.hk/news_detail.asp?art_id=49277&con_type=1* on October 26, 2010.

(43a) Law and Regulations Database of the Republic of China. Transportation Law, Railroad Operating Code (交通法規/鐵路目/鐵路行車規則), Title II: Conventional Railways, Chapter 4: Operations, Section 2: Consist Operations (第二編 一般鐵路/第四章 運轉/第二節 列車運轉), Regulations 65~66, as amended August 21, 2008, Taipei, Taiwan. Retrieved from *http://law.moj.gov.tw/LawClass/LawAll.aspx?PCode=K0030005* on November 11, 2010.

(44) Taiwan Railways Administration. *Ticket Policy Information: Fare Computation Principle*. ("車票資訊 – 票價計算原則") Retrieved from *http://service.tra.gov.tw/tw/CP/11333/tickets-1.aspx* on October 24, 2010.

(45) Tsay, Bai-Ling (蔡百靈). 93 Years Old Deng Yo-Tsai, Taiwan Railways' Oldest Ticket-Punching Volunteer ("93歲鄧有才 – 台鐵最老剪票志工"). In *Liberty Times*, Hualien, Taiwan, September 12, 2010. Retrieved from *http://www.libertytimes.com.tw/2010/new/sep/12/today-life12.htm* on October 24, 2010.

(46) User e88111 from Kaohsiung. Taiwan Railways Volunteer (Poem). In *Nameless Station* (Blog), December 17, 2008. Retrieved from *http://www.wretch.cc/blog/e88111/11635670* on October 24, 2010.

(47) Railway Culture Discussion Participant. Taiwan Railways Administration Volunteer Work. In *Taiwan Deep Blue United Student Bulletin Board System* ("台灣深藍學生聯合論壇"). Retrieved from *http://www.student.tw/db/showthread.php?t=220410* on October 24, 2010.

(48) Taipei Rapid Transit Corporation. *Annual Report 2008.* Taipei Rapid Transit Corporation, Taipei, Taiwan, 2009.

(49) Shan, Shelley. EasyCard Plan Steaming Ahead. In *Taipei Times*, Taipei, Taiwan, August 8, 2008.

(50) Network Rail (of Great Britain). Rules of the Route and Rules of the Plan, 2011 Timetable, Version 4.1. Retrieved from *http://www.networkrail.co.uk/browse%20documents/Rules%20Of%20The%20Route/Roprhome.pdf* on October 31, 2010.

(51) Hucks, Eugene. I-TRAC – A Foundation for Subways to Build On. In *At Your Service*, New York City Transit Employee Newsletter, March/April, 2010.

(52) Taiwan Railways Administration. *Trackway History Table: Construction Year* ("軌道歷史表 – 光緒13年~民國62年"). Retrieved from *http://service.tra.gov.tw/tw/CP/11476/railhistory-1.aspx* on October 24, 2010.

(53) Nelson, David and T. Blakey. Commuter Rail: Concerning One-Person Train Operations and the Self-Service Economy. TRB Paper #09-1954. In *Proceedings of the 88th Transportation Research Board Annual Meeting*. CD-ROM. National Academies of Science, Washington, D.C., 2009.

(54) Rainville, Lydia, V. Hsu, and S. Peirce. Electronic Fare Collection on Commuter Railroads: Case Studies and Lessons Learned. TRB Paper #10-0808. In *Proceedings of the 89th Transportation Research Board Annual Meeting*. CD-ROM. National Academies of Science, Washington, D.C., 2010.

(55) Illinois Central Magazine. Illinois Central Electric to have Automatic Fare Collection, Chicago, Ill., December, 1966.

(56) Vernon, Wes. Ticket Agents: Gone Forever? City Rail, *TRAINS Magazine*, Volume 70, Issue 6, Waukesha, Wis., June 2010.

(57) Metropolitan Transportation Authority, NJ Transit, and the Port Authority of New York and New Jersey. Access to the Region's Core 1995 Major Investment Study – 2003 Summary Report. Retrieved from *http://www.arctunnel.com/pdf/library/ARC_MIS_Summary_Report.pdf* on October 31, 2010.