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3 **Utilizing an Eight-Step Work Study Framework to Understand and Improve Railroad Cyclical**
4 **Track Program Curve Rail Replacement Processes in Busy Suburban Commuter Environments**
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ABSTRACT

The eight-step framework consisting of organization, procedure, personnel, time study, rate analysis, utilization analysis, rightsizing, and benchmarking is used to understand and improve productivity and efficiency of railroad cyclical curve rail replacement processes at a major Northeastern commuter railroad. The Railroad is organized into eight geographical maintenance subdivisions supplemented by systemwide track gangs performing capital replacement and reconstruction work. Curve rail replacement work under continuous track outage in catenary electrified territory requires thirty-four distinct steps and eleven machines types. Normally one operator is assigned per machine. Lagers and spike pullers are slowest and sets work pace. Gang can replace about fifteen linear rail feet per minute if extra machines are provided to allow operations at a robust and steady average rate. Root cause of low machine utilization in this setting are the daily setup/preparation and tear down burden, and mobilization and demobilization at each site. Vacation and legitimate personnel unavailability drives requirements for spare employees, requiring 61 heads to fully staff the 45-position gang. Three major recommendations result from this study: (1) consider task-specialized gangs to ensure optimal machine and personnel mix; (2) plan cyclical curve rail replacement sequentially to improve machine utilization; (3) consider establishing extra lists based on craft rather than providing coverage within each gang.

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INTRODUCTION

This paper describes a structured eight-step framework for understanding and improving the productivity and efficiency of railroad maintenance or capital reconstruction processes at a detailed level. It is applied to cyclical curve rail replacement task, as a case study of utilizing this framework, and also serves as a primer for railway engineering and management students to achieve a better understanding of how railroad maintenance is actually performed in a busy suburban environment.

The work study effort aims to provide a detailed understanding of each procedural step required to perform the activity, enumerate all constraints and likely field conditions—then, only when that knowledge is obtained, we analyze resource requirements and asset deployment to optimize the process to maximize productivity and improve efficiency in ways that are feasible and implementable, without violating constraints relating to existing field operations.

Productivity means different things to different people. In this paper, we are looking at process efficiency—essentially scheduling and sequencing of work assignments to maximize work output within given constraints by maximizing utilization of resources (equipment, manpower, track outage, and materials) and by varying inputs, minimizing resource idle time, avoiding duplicative work, and parallelizing processes where possible. This paper does **NOT** examine cost-efficiency through restructuring labour agreements, contracting out, or other variations on that theme which involves paying less money for the same work. Point is here to work smarter to do more, and not to work cheaper or harder.

LITERANTURE REVIEW

Efficiency studies are rarely published. Productivity studies typically relate to one very specific set of circumstances and sometimes relate to one-off solutions that happen to work. Many work studies are also considered proprietary to sponsor, as private firms rely on production process advantages to compete in the marketplace. Restructuring literanture is commonplace (e.g. (1-3) are typical), but they rarely dive into specifics of exactly what was done operationally, and the work of corporate turn-around artists often relate to realizing value within an inherently profitable underlying business process by sizing inputs and outputs appropriately (e.g. shedding unprofitable lines of business, renegotiating leases or labour contracts) or through creative financing, rather than making operational process improvements.

However, famous productivity studies have been published (e.g. (4)), with generalized conclusions helpful as organizational management theory relating to typical business processes in large firms, but do not relate specifically to railroad maintenance processes. Much of this work (e.g. discussed in (5)) relate to controlled factory environments where task, tooling, constraints, and resourcing do not vary on day to day basis. When new production lines are set up, much work is required in fine-tuning it prior to achieving optimal outputs. This differs significantly from challenges faced by track maintenance supervisors. It is helpful to think of suburban railroad maintenance as a production line many miles long, multiple tracks wide, and has trains running though every half hour or less—all while infrastructure production is ongoing between trains.

F.W. Taylor is considered a pioneer in this field; the eight-step framework can be considered an adaptation (and extension) of principles espoused in his treatise (6). However, present work differs significantly from classical Taylorism by recognizing explicitly that efficiency innovations depend on teams of employees willing to collaborate, test, and carry out proposed improvements in processes.

1 Ideas that may be theoretically efficient, but cause operational problems or difficulties in team
 2 dynamics, are deemed infeasible and not explored further.

3
 4 Standard railway engineering textbooks (7,8) usually have chapters dealing with engineering economy,
 5 work planning, and work processes. These materials often describe processes without providing
 6 empirical data on production rates at sufficient level of granularity and detail to determine resource
 7 requirements or production line queuing dynamics; aggregate production rates quoted and means and
 8 methods described can be unsuitable, inapplicable, or may require substantial modification to adapt to
 9 busy electrified suburban environments. These data were updated somewhat in recent American
 10 Railway Engineering & Maintenance-of-Way Association (AREMA) manuals (9), but focus continue to
 11 be single-track un-electrified mainlines. By far best resource on cyclical track production work process
 12 is actually training manuals intended for track gang foremen and supervisors (10), although regrettably
 13 this was a private publication and not widely available. Interestingly some great sources for track
 14 maintenance processes turn out to be documentaries (11) and amateur videos (12,24) of track gangs at
 15 work.

16
 17 With this background, this paper describes cyclical curve rail replacement process at a high level and
 18 show how they might be optimized using formal techniques.

19
 20 **METHODS: THE EIGHT STEP FRAMEWORK (THEORY)**

21 Basic eight-step framework consists of following steps:

22

23	1. Roles, responsibilities, and organization	27	5. Production rate matching analysis
24	2. Work process and procedure	28	6. Schedule and utilization analysis
25	3. Current personnel assignment	29	7. Rightsizing
26	4. Time study	30	8. Benchmarking

31
 32 Details of each step follows.

33
 34 ***Step 1: Roles, Responsibilities, and Organization***

35 When studying production processes, roles and responsibilities of each level, title, craft, subdivision, and
 36 department must be understood. In production, typically titles are organized along craft lines, with clear
 37 lines of accountability and promotional opportunities within each craft, but most work tasks requiring
 38 coordination and joint planning amongst different crafts. Existing labour agreements can reveal what
 39 prevailing constraints are and their rationale (e.g. different levels of skills, pay, terms of employment,
 40 local labour market subtleties, or historical reasons). It is also important to understand scope of each
 41 group within the organization—sometimes geographical, or maybe organized along business sectors or
 42 other arbitrary jurisdiction. Maps of the territory (22), and organizational charts (15) of relevant
 43 departments are excellent tools for this step.

44
 45 ***Step 2: Work Process or Procedure***

46 Typical railroad industry production processes are documented at varying levels of detail. Extremely
 47 precise and technical standards and requirements are common (e.g. (26)), but these are often engineering
 48 specifications to be met in finished products (17), rather than descriptions of required work steps to
 49 achieve these standards. Prescriptive procedures designed to ensure safe operations, like rules defining
 50 how to take track segment out of service (19), or prohibiting certain employee behaviours, are also
 51 customary. Individual owners’ manuals detailing technical steps necessary to operate and service each

1 machine or component (18,25) are usually available. Higher level project scopes together with design
2 drawings can sometimes be found for specific projects, and project documents may include descriptions
3 of means and methods—however, this is unlikely for cyclical program work, to restore infrastructure to
4 as-built condition or meet latest standards, rather than to additional capabilities or new infrastructure.
5

6 Often missing in this mound of documentation is stepwise descriptions of how to accomplish specific
7 tasks—normally taught as on-the-job training, and part of the mystery of the craft. When interviewing
8 subject matter experts, they often state, “it depends on the situation.” Goal of this step is to enumerate
9 high level work processes, with sufficient detail to distinguish between situations that significantly affect
10 resourcing, work pace, or sequencing, without diving into every plausible scenario and covering each
11 technical eventuality.
12

13 Classic process mapping tools like swimlane charts (16) can be utilized to determine procedural
14 dependencies, especially amongst different departments or workgroups that must support each other to
15 ensure smooth work process.
16

17 ***Step 3: Current Personnel Assignment***

18 Budgeting or administrative systems showing authorized positions, daily timecards, work order systems,
19 and punch in/out records is a good place to start understanding existing personnel assignment.
20 However, they often focus on administrative needs of keeping individuals accountable for hours worked
21 and generally don’t capture detailed relationships between headcount and procedural steps performed,
22 especially amongst substitutable/relief/mobile personnel. In railway environments, assignment sheets
23 are usually issued each morning listing available personnel, equipment/workstation/location/gang
24 allocation, and tasks assignment. In some locales, this “sheet” may actually be moving magnets on
25 whiteboards, or handwritten symbols on chalkboards. Obtaining copies (or photos) of this sheet can
26 help determine assignments (e.g. Figure 1(a)). Field observations that day can then note what work is
27 being performed by each named individual, which may vary over course of the day. Performing
28 observations over number of days where gang work assignment is similar provides an aggregate
29 “typical” picture of personnel assignment within gang for that task. Clarification and casual
30 conversations with foremen or supervision can yield details (often not shown on administrative
31 documentation) necessary to understand the entire operation. During observations, “minimum operable
32 team” for each procedural task should be determined. This number is often observable when gang is
33 short-staffed. Typical output for this step, shown as stick-figure diagrams, is given in (10).
34

35 ***Step 4: Time Study/Production Rate (or Work Pace) Measurement***

36 Classical methodology (e.g. described in (5,6), etc.) can be followed for this step, utilizing stopwatches,
37 clicker-counters, and clipboards to keep track of production rates. Each discrete part of work procedure
38 should be timed separately, and outputs measured in terms of minimum countable units. For trackwork,
39 it is convenient to count crossties or fasteners installed; where length measurements are required,
40 crossties is convenient for tracking distance (edge of one tie, to same edge on next tie = 19½” in wood
41 tie territory). If necessary, marking chalk, survey strings, measuring wheels, and GPS technology can be
42 utilized to supplement manual counting. In our experience, due to hazardous nature of railroad rights-
43 of-way with active adjacent high-speed tracks, we found simpler data recording technologies (i.e. pen &
44 paper) are safer and less likely to divert attention from train and machine movements.
45

46 Time-of-day should always be noted when timing each step, to allow later analyses of waiting time (for
47 other processes to complete) prior to starting work. We collected sample data every 1~2 or every five
48 minutes in this study, measuring average work pace but also production rate variability due to random

1 field conditions. If unusual conditions arise (e.g. machine workhead jams, requiring operators to stop
2 work and troubleshoot), time when continuous process stopped and when process resumed was
3 recorded, along with reasons for delay (Figure 1(b)). Allocation of time to different activities and
4 theoretically possible production rates could thus be calculated.

6 ***Step 5: Production Rate Matching Analysis***

7 Railroad is a linear production environment. Machines generally cannot leapfrog each other (except by
8 “bumping” along, where front machine(s) would skip a fraction of work, allowing rear machine(s) to
9 fill-in incomplete pieces), and tasks cannot be performed out-of-order since previous step is generally
10 prerequisite for next. In this environment, with constraint that most employees arrive and leave worksite
11 together, work rate and efficiency of entire process is limited by slowest step along the production line.
12 (cf. maximum end-to-end throughput of double-track railways under current-of-traffic rules is limited by
13 longest signal block.) Goal is therefore to identify such “bottleneck” processes and add parallel capacity
14 or advanced machines therein, to achieve throughput improvements in the entire production line.
15 Alternatively, if bottlenecks prove impossible to speed up, other processes could be derated by having
16 resources unassigned until their rates match the slowest step. General goal here is to minimize idle time
17 within production cycle.

19 ***Step 6: Schedule and Utilization Analysis***

20 Railroad is a field production environment. All production “lines” must be mobile: set-up from scratch
21 when job starts, and put away properly when job is done. This step concerns analyses of time taken as
22 each shift begins, to get production moving at full capacity, and conversely to shut down and immobilize
23 all machines at shift’s end. Another related issue is time taken to set-up upon arrival at site, and
24 dismantling when work is complete. Typically, both issues can be examined by enumerating daily
25 production schedules—by fractionating time from reporting for duty to punching out at day’s end into
26 broad categories like productive work, travel, waiting to start work (or waiting after finishing), and
27 overhead activities like daily machine inspections, gathering supplies, fueling, contractually-mandated
28 comfort breaks, etc. Actual categories used can be somewhat flexible, but should always include a
29 category representing idle time to be minimized (e.g. waiting to start—ready to work but not actually
30 engaged in production), and also a category representing those parts of overhead that could be
31 influenced by changing work location sequencing (e.g. travel to/from job site). For those with train
32 scheduling background, these two categories are analogous to terminal dwell time (waiting to start), and
33 deadheading (moving to & from work site).

34
35 To understand those issues quantitatively (and to identify areas likely to yield improvements), utilization
36 statistics can be computed, i.e. productive hours as fraction of total hours. For track work, this is
37 typically examined at machine level (since track machines can be expensive, goal is to maximize
38 utilization where possible), operator level (machines might be specialized to one task, whereas operators
39 aren’t necessarily so), and also workgroup level (larger gangs can be split into smaller workgroups and
40 work separately if certain parts of gang are consistently underutilized). Classic construction project
41 management tools like Gantt charts (see, e.g. (20)) can be used to identify critical processes and any
42 possible process parallelism that isn’t currently being exploited to improve production.

44 ***Step 7: Rightsizing***

45 In this context, “rightsizing” is not an excuse to reduce budget. It is resource assignment based on (a)
46 optimal work rate derived in Step 5 (to minimize within-production idle time) and (b) necessary
47 schedule and work plan determined in Step 6 (to maximize utilization and minimize set-up/teardown
48 idle time) to create future staffing plans that can properly execute work scope without undue delay but

1 also without extraneous resources. Contingencies are also determined here, e.g., if extra machines are
2 needed to “protect” critical steps that could cause hiccups or severe delays, or if extra personnel with
3 specific skillsets are needed in case key staff are sick or otherwise unavailable. Required size of
4 contingency personnel could be thought of as “extra board” (e.g. discussed in (14)) or “spare list”, and
5 proper resourcing levels could be determined using probabilistic binomial methods where the required
6 coverage (in terms of probability of “stockout” events) can be selected based on the criticality of the
7 class of personnel to the overall efficiency of the production line, and balanced against the cost of
8 carrying spares. Other overhead or non-operational needs for personnel should also be considered at this
9 stage; typical overhead personnel includes resident mechanics who might be needed to ensure machines
10 are functioning, safety (e.g. adjacent track flaggers), other supervisory or management personnel, and
11 instructor and student personnel who are required to ensure the continued technical viability of the gang
12 (i.e. to ensure that craft skills are retained as experienced personnel retire, as-in succession planning.)
13

14 ***Step 8: Benchmarking***

15 This is often the eight-step framework’s least useful step, for two very basic reasons: (a) complex track
16 maintenance processes are usually subject to local constraints, all of which would have been discovered
17 and documented in prior steps; it will be difficult to locate comparable situations, limiting usefulness of
18 benchmarking to higher level performance indicators (see, e.g. (21), although in many cases subtle
19 differences in measurement definitions might limit usefulness and comparability also), and (b) where
20 comparable processes are found, e.g. via worldwide searches or management peer-to-peer industry
21 benchmarking organizations, incentives for organizational leaders to present their best statistics and/or
22 idealized case studies are tremendous, rendering results less-than-useful in real world conditions.
23

24 Two situations exist where benchmarking is invaluable: (a) to gather fresh ideas on how existing
25 processes can be incrementally improved—great deal of efforts must be expended in adapting “foreign”
26 processes to prevailing constraints by process specialists, including a locally acceptable path to be
27 charted out for getting from where we are now to where we want to be, and (b) in the limited case of
28 industry-standard subprocesses where, after benchmarking reviews, many organizations were found to
29 employ basically the same technology under virtually identical circumstances, resourcing levels and
30 work rate could be directly compared and benchmarked for that subprocess only (good example of this
31 is Thermit welding processes used to join continuous welded rail (CWR)).
32

(a) RAIL GANG

DATE 10/5/16

DAY wednesday

FOREMAN _____

SPIKE PULLER Morris

SPIKE PULLER James

SCRAP MACH King

GROVE Dick

CRIBBER James

ADZBR Morris

SLED James

GROVE Dick

TAMPER James

CLIP CART James

GAGE SPIKER R

DRILL James

DRILL James

LAGER James

LAGER James

LAGER James

BOMB James

CLIP APP James

CLIP APP James

MOTOR CAR _____

TIE HANDLER _____

OPER BUS _____

TRK BUS _____

PICK UP _____

B-TRUCK _____

SUB5394 _____

HI-RAIL _____

VAC, SICK AND OUT _____

BACK ON TIME _____

Rule 22

16.3

4K2

1/31/13

CP 112 - 115

(b) Railroad
SOIFA Unit Data Collection Form-Event Log

Process Name: Spike Puller SP6002

Data Collector: _____

Date: 9/17/17 Page: 3 Total Pages: 3

Seq #	Time	Start/stop	# Done*	# Rework*	Notes/Reason for Stop**
1	12:55:26	S	449	285	12 up - Hydraulic leak noted - Need to get Part - stopped to fix hydraulic leak
2	01:05:26	P	449	319	
3	1:11:31	P	503	319	
4	1:18:34	S	526	336	None up
5	1:24:38	S	545	353	
6	1:29:53	P	545	355	stopped to fix hydraulic change battery on hose.
7	1:38:15	S	569	371	
8	1:48:35	P	580	386	stopped to replace clamp
9	1:48:47	S	610	401	
10	1:53:47	S	636	411	Finished
10	:	S			
10	:	P			

* Note cumulative counts, do not reset counter between events
** Note any special field conditions

Notes
Fouling Track: _____
Materiel Req.: _____
Manpower: _____

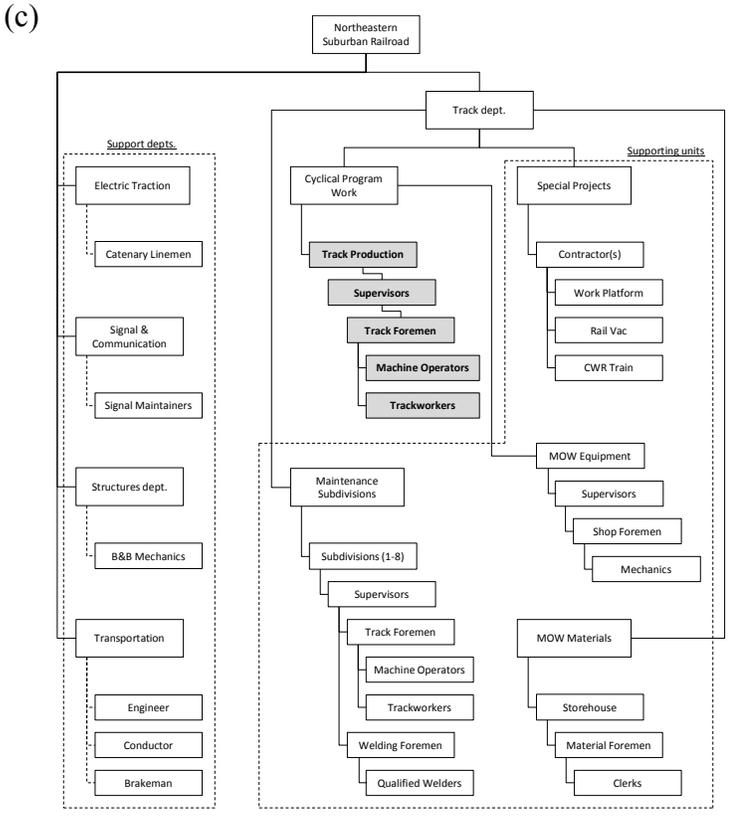


FIGURE 1 Tools of the trade: (a) "morning sheet"; (b) data collection instrument; (c) organizational chart showing departments involved in Track Production.

1
2 **RESULTS: APPLICATION TO CURVE RAIL REPLACEMENT (PRACTICE)**

3 Each curve in railroad track has a balancing speed when lateral forces required to change train's travel
4 direction is exactly balanced by the component of gravitational force parallel to carbody floor (due to
5 elevation of outside rail in the track structure). Typically, by design, balancing speed is lower than
6 curve's maximum authorized speed, resulting in an underbalance. When train travels through curve
7 with underbalance, outside rail provides additional lateral forces to change train direction; during this
8 process, outside wheel flange contacts gauge face of outer rail, resulting in wear to outside (high) rail.
9 In the opposite case, when heavy freight trains travel at below balancing speed, track elevation tends to
10 push inside wheel flange against gauge face of inner (low) rail, resulting in accelerated wear. Curve rail
11 therefore requires maintenance or replacement more frequently than other rail (for detailed explanation
12 of train dynamics and wheel-rail interface, see (23)). As a case study, this section details work-study
13 findings of applying eight-step framework to CWR replacement process on curve track sections at a
14 major Northeastern commuter railroad (hereinafter, "the Railroad").

15
16 ***Production Track Gang, Subdivision Forces, and Support Crafts***

17 The Railroad, like many Class I railroads, has a dedicated track gang for performing cyclical track
18 rebuilding work (hereinafter, "Production Gang"). The gang controls its own machines, vehicles, and
19 most of its own personnel. It also mostly provides its own support functions, including track materiel
20 delivery to work site from a centralized material depot, and adjacent-track flagging.

21
22 Production Gang relies on local maintenance "subdivision" forces for certain specific functions. The
23 gang has no rail welders, thus relies on local subdivision for all welding tasks. The gang has no rotary
24 dump trucks or ballast cars, and relies on subdivision or Transportation's Train & Engine (T&E)
25 employees to deliver stone. Gang has no CWR train and relies on outside contractors working with
26 T&E employees to deliver CWR. Finally, gang doesn't control larger or more specialized machines like
27 Continuous Work Platform (CWP), Loram rail vac, rail grinder, undercutter, etc., although CWP support
28 is available on request if requested. Production Gang does have full surfacing capabilities including
29 production tampers, ballast regulators, and dynamic track stabilizers. Gang doesn't control Mechanics
30 assigned to repair its track machines, although normally one dedicated Mechanic is assigned to travel
31 with the gang.

32
33 The Railroad's track function is organizationally divided into Maintenance, Program Work, and
34 Engineering with senior officers overseeing team of managers and engineers responsible for each area.
35 Production falls under the Program Work area, and Production Gang is overseen by a Supervisor and
36 two Assistant Supervisors, who occupy the highest title within agreement ranks. They are responsible
37 for job planning, quality, and oversee a team of Foremen that run the job site. Foremen in turn are
38 responsible for safety, coordinating site work, and running the group of Track Workers, Machine
39 Operators, and other skilled crafts assigned to them. To the extent that support is necessary from Power,
40 Signal, and Structure depts., Third Railmen, Catenary Linemen, Signal Maintainers, and Bridge &
41 Building Mechanics report to their own Foremen, although Foremen from other depts. are not normally
42 on-site.

43
44 Track maintenance responsibilities on the Railroad are divided geographically into eight subdivisions,
45 each having its own Supervisor and Assistant Supervisor. Subdivisions have Track Foremen and Track
46 Workers assigned to perform routine inspection and spot maintenance work. Larger Subdivisions also
47 have Welding Foreman and Welders assigned to perform specialized work. Each subdivision is
48 responsible for between 20 and 150 miles of mainline tracks, with smaller subdivisions also responsible

1 for major yards or terminals. Figure 1(c) shows simplified organizational chart summarizing these
2 relationships.

3 4 ***Thirty-Four Steps and Eleven Machines to Change Curve Rail***

5 Changing out curve rail under continuous track outage in catenary electrified territory (together with
6 fastener upgrade from cut spike to Pandrol clip) consists of basic steps shown in Figure 2(a). Pictures
7 for some procedural steps are shown in Figure 3.

8
9 In essence, process starts with preparatory work including planning, site survey, material delivery, and
10 removing all signal and power installations from the track itself. Once equipment and trackmen arrive
11 on site, first Grove crane are used to move new rail to exact location to be installed, and new tie plates
12 are delivered, one per crib (i.e. space between adjacent ties). Old rail is unfastened (i.e. rail anchors and
13 cut spikes removed and picked up by scrap machine), then removed (threaded out) by crane.

14
15 Ties are prepared to receive new fastening system and rail: first old tie plates are removed, then wooden
16 plugs are inserted into square holes (where spikes were) and tamped down. Adzer/cribber machine then
17 adzes ties (i.e. cut sideways with rotating blades) to provide flat surface. Replacement (new) tie plates
18 are put into position, aligned, and rail is threaded in on top of it. Some adjustments may be needed (as
19 plates are not yet fastened down), and then junior tamper tamps (i.e. vibrate and shove with heavy metal
20 workheads to force ballast from the crib beneath the tie, thereby causing ties to move upwards) ties up to
21 rail position.

22
23 Two rails are gauged (measured with gauging rod and adjusted by teams of Trackworkers using lining
24 bars) to ensure they are exactly 4'8½" apart. Pandrol plates are manually spiked down (with spike
25 maul) every eight ties to retain gauge, then holes drilled into ties with quaddrill. Lagger is used to lag
26 each hole in turn; all four lags are installed on each tie plate in curve rail segments. Prior to adjusting
27 rail temperature, a few Pandrol clips are set but not fully fastened. When rail is below neutral
28 temperature, rail heater is used to heat rail up to correct temperature, and rail encouraged to expand to
29 proper length by tapping on plates with spike maul. When rail is at proper length, Pandrol clips are fully
30 fastened to prevent further movement.

31
32 Foreman and Supervisor then conducts quality check prior to turning completed track over to Power
33 dept., who measures trolley wire height above rail and adjusts the catenary accordingly. Signal dept.
34 then re-installs impedance bonds (required to separate track circuits while allowing traction return
35 current to return to substations), connects track circuits and cab signal system to new rail (unrusting new
36 rail as necessary), and tests the entire system prior to allowing track back in service. As time permits,
37 machines and track workers return to site to complete scrap material removal (temporarily stored on the
38 wayside). Stick-figure representation of this process together with required machines and typical
39 manpower is shown in Figure 4.

40

- (a)
1. Pre-work inspection
 2. Marking out
 3. Remove track from service
 4. Prepare work site (S)(P)
 5. Unload rail nearby [Figure 3(a)]
 6. Bulk material delivery
 7. Drag rail into place
 8. Drop new tie plates
 9. Remove rail anchors
 10. Remove spikes [Figure 3(b)]
 11. Pick up scrap
 12. Thread rail out [Figure 3(c)]
 13. Remove tie plates
 14. Plug ties [Figure 3(d)]
 15. Tamp down tie plugs
 16. Clean out crib and adze ties
 17. Position replacement tie plates
 18. Align new plates [Figure 3(e)]
 19. Thread rail in
 20. Adjust tie plates
 21. Tamp ties up to rail [Figure 3(f)]
 22. Drop Pandrol clips
 23. Gauge rail [Figure 3(g)]
 24. Drill holes
 25. Lag plates to tie [Figure 3(h)]
 26. Set Pandrol clips
 27. Adjust rail temperature [Figure 3(j)]
 28. Fasten Pandrol clips
 29. Quality inspection (Track dept.)
 30. Adjust catenary clearance (P)
 31. Reinstall impedance bonds and track circuit connections (S)
 32. Test and re-qualify track for service (S)
 33. Place track in service
 34. Collect scrap rail and spike plates

Note: (S) = Signal dept., (P) = Power dept.; Corresponding illustrative figure shown in square brackets.

(b)

Work Step	Equipment	Foremen	Operators	Trackwrkrs	Welders
Fuel Machines	1 Fuel Truck	1	1	–	
Drag Rail	2 Grove Cranes	1	2	2	
Deliver Tie Plates	1 Logging Truck	–	2	–	
Drop Tie Plates	1 Motor Cart, 1 Flat Cart	1	1	2	
Remove Rail Anchors		–	–	1	
Remove Spikes	1 Spike Puller	–	1	–	
Pick Up Scrap	1 Scrap Machine	–	1	–	
Empty Scrap Bin	1 Logging Truck	–	2	–	
Unbolt Existing Rail		–	–	1	
Thread Rail Out	1 Grove Crane	1	1	1	1+1*
Cut Old Rail		–	–	–	1+1*
Remove Tie Plates		–	–	1	
Plug Ties		–	–	1	
Tamp Down Plugs		–	–	1	
Adze/Crib	1 Adzer/ Cribber	–	1	–	
Lay New Tie Plates		1	–	2	
Gauge Tie Plates	1 Plate Gauger	–	–	2	
Joint Bar to Existing Rail		–	–	2	
Thread Rail In	1 Grove Crane	1	1	2	
Joint Bar to Old Rail		–	–	2	
Tamping Ties to Rail	1 Junior Tamper	–	1	–	
Drop Pandrol Clips	1 Clip Cart	–	–	1	
Adjust Plates		–	–	1	
Gauge Rail	1 Push Cart	1	–	4	
Drill Holes	1 Quadrill	1	1	–	
Lag Plates to Tie	1 Lagger	–	1	–	
Set Pandrol Clips		–	–	1	
Adjust Rail Temp.	1 Rail Heater	1	1	2	
Fasten Pandrol Clips	1 Clip Machine	–	1	2	

* **Note:** “1+1” indicates 1 Qualified Welder and 1 Welding Foreman is required.

FIGURE 2 Curve rail replacement: (a) work procedure; (b) minimum operable manpower by craft in each step.



FIGURE 3 Work in progress: (a) unloading rail; (b) spike puller; (c) threading rail out; (d) plugging ties; (e) plate gauger; (f) junior tamper; (g) rail gauging; (h) logger; (j) rail heater. Due to space considerations various intermediate steps not shown.

Photo 2(a) courtesy of Jay Wendt.

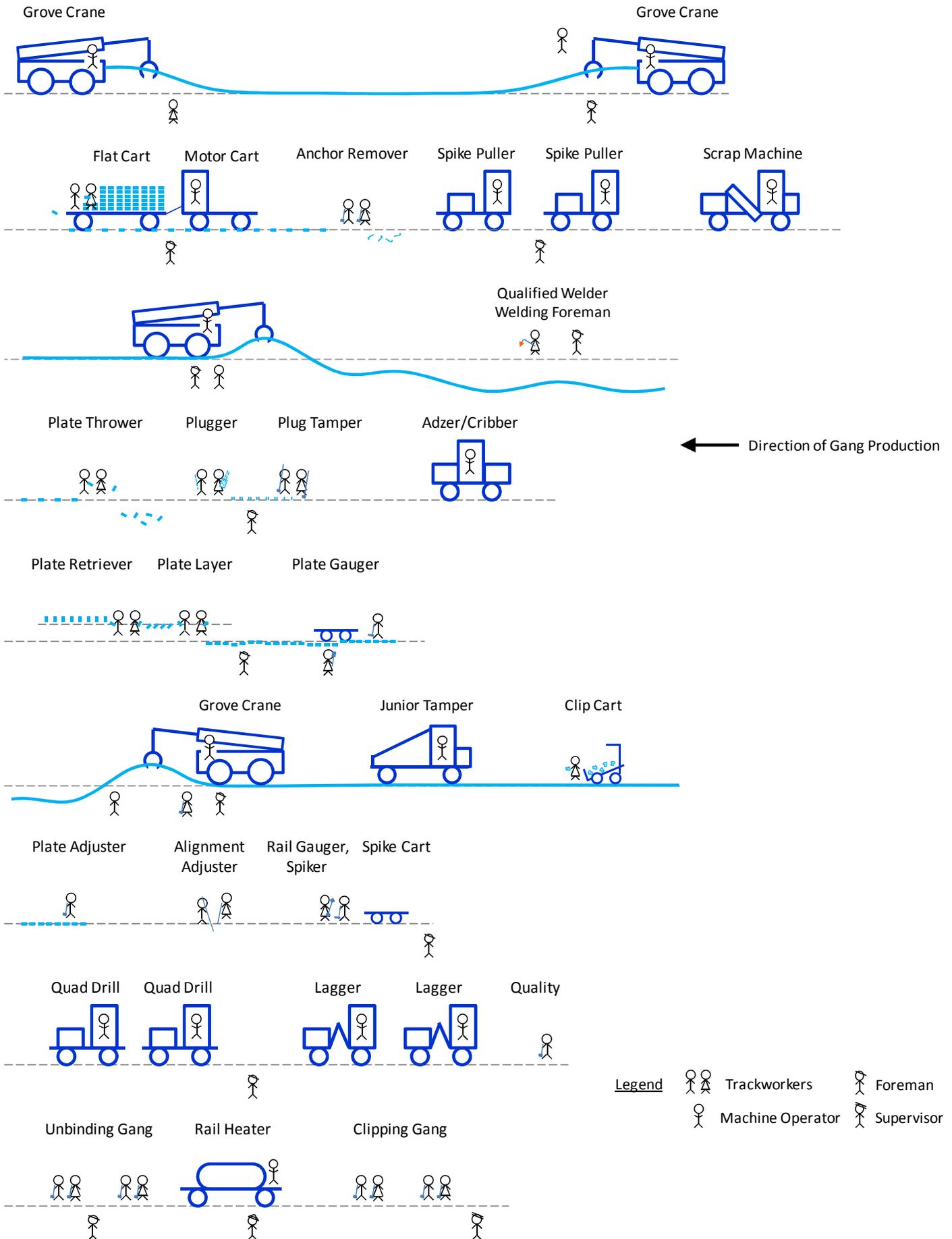


FIGURE 4 Schematic representation of curve rail gang with typical manning levels and machine assignments.

1
2 ***One Operator per Machine—But the Whole Gang is a Team***

3 The Railroad operates in a busy but small and heavily built-up suburban territory where significant
4 constraints often exist for staging, unloading, storage, and vertical clearance obstructions for crane
5 operation. Because of high train volumes, it is routinely necessary to remove machines at short notice,
6 vacate occupied tracks not under active reconstruction, to allow track space to be utilized for running
7 revenue trains. For those reasons, the Railroad's policy is to assign dedicated Machine Operators to
8 each machine leaving the Maintenance-of-Way (MOW) yard. Unlike Class I railroads, whose track
9 gangs travel in dedicated trains equipped to unload machines from flat cars at job site, the Railroad's
10 machines are normally driven from MOW yards to work location, perform day's work, then moved back
11 to yard at the workday's end. Since all machines identified are required for curve rail replacement
12 activity, only variable here is duplicate machine counts assigned to speed up each step, discussed later.
13 One logical consequence of this policy is that overtime is mandatory for Machine Operators; if machine-
14 qualified employee don't wish to accept overtime assignment, they are assigned as Trackworker that
15 day, so no machines are left in limbo when scheduled tour of duty ends, and overtime begins.

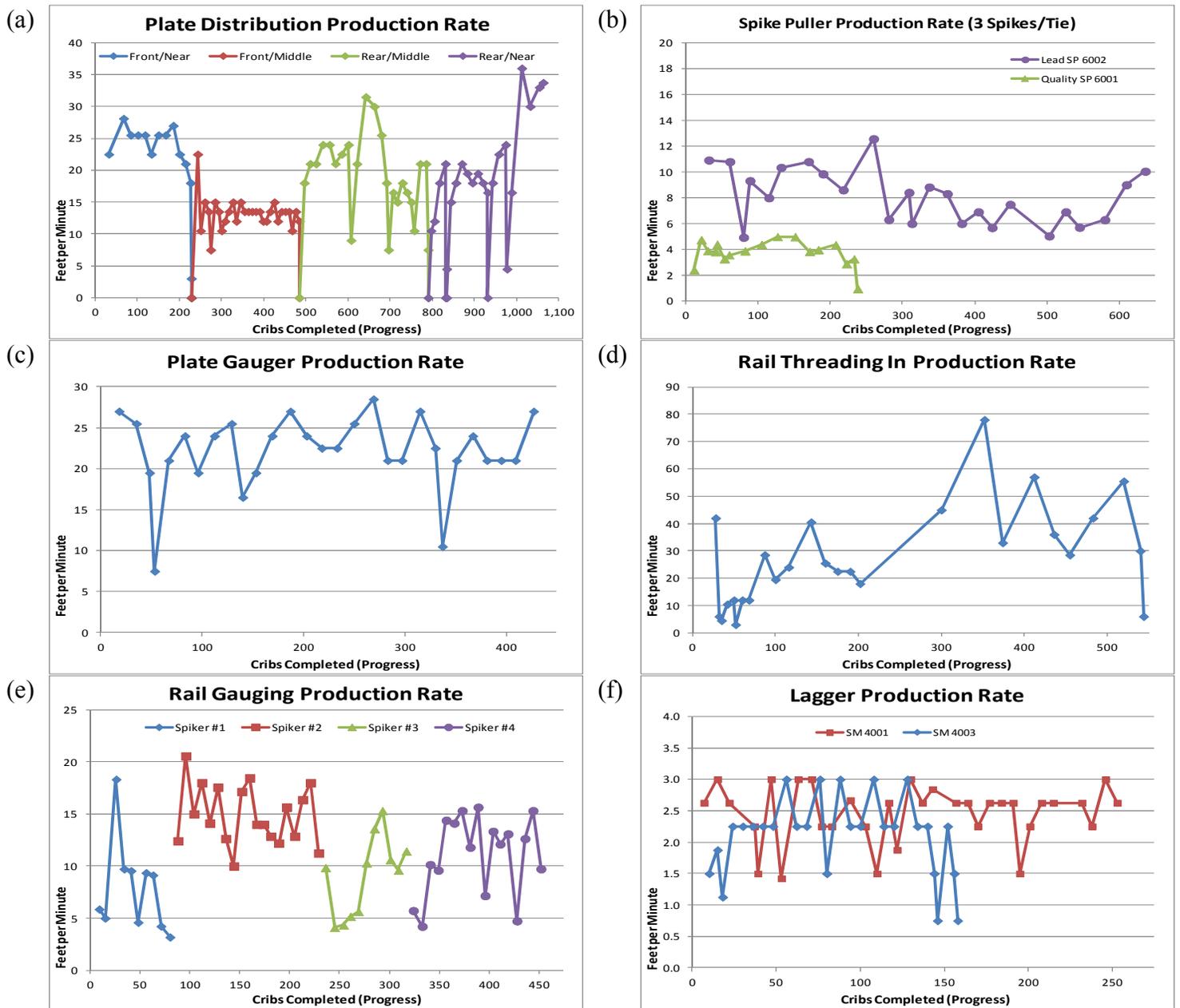
16
17 Unlike Machine Operators who are captive to their machines, Trackworkers and Foremen are mobile
18 and can be utilized throughout the day in different groups. Those at gang's front end, who completed
19 their daily work, typically move to the gang's rear end to assist those still working. Through training
20 classes and on-the-job instruction by Foremen and senior Trackworkers, all Trackworkers on the
21 Railroad are basically competent in performing all manual tasks required in any part of gang. Minimum
22 operable manpower shown in Figure 2(b) assumes all steps of curve rail replacement process are carried
23 out simultaneously, and work is done as an idealized continuous process where each employee performs
24 only one role. However, it is important to note Production Gang doesn't actually work that way, and
25 factor this into account when assessing utilization and resource assignment.

26
27 ***Lagger and Spike Pullers Need Time to Work***

28 Figure 5(a) shows many factors affect production rates even in deceptively simple tasks like dropping
29 tie plates from moving track carts. In "Front/Near" mode, Trackworker picks up tie plates and drops it
30 off the cart's front end. As front-end tie plate inventory is depleted, gang changes to "Front/Middle"
31 mode where another Trackworker must pass plates to the first Trackworker, who tosses them overboard.
32 Whole process is reversed for plate inventory in the cart's rear half, but now tossing operations is more
33 complex because Trackworkers must drop plates precisely between flat cart and motor, and coordinate
34 with motor cart operator to ensure proper speed is set. It is thus important to time entire work process
35 through its various phases; when utilizing average rates, variability between slowest and fastest modes
36 of operation must be considered.

37
38 Figure 5(e) shows individual variability between experienced and somewhat less skilled employees.
39 Spiking ties is an acquired skill. Highly skilled Trackworkers utilize windmill motions (27), allowing
40 spike maul's weight to do most of the hard work, and can insert one spike into new wood tie in about 10
41 hits. Other Trackworkers find it difficult to precisely align spike maul with the spike, and must utilize
42 chopping motions, requiring up to 20 hits to fully insert a spike. This further illustrates importance of
43 considering individual variability in work pace as well as average rates.

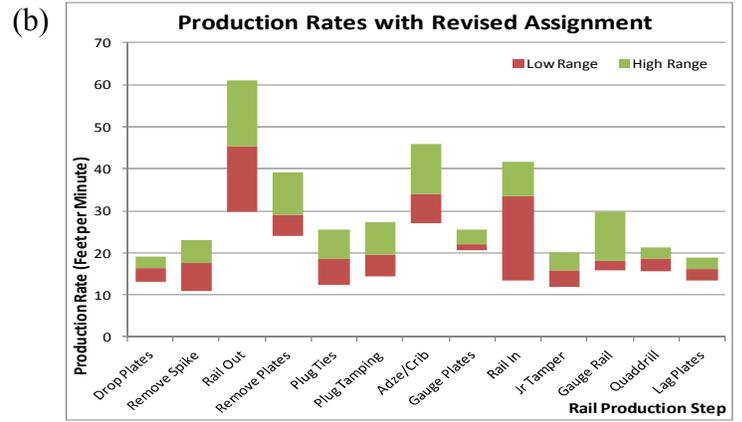
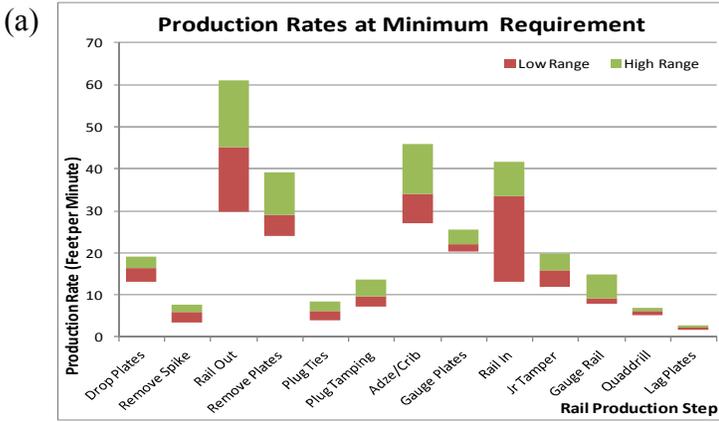
44
45 Based on each individual step's time study results reduced down to minimum operable teams, Figure
46 5(g) shows machines with slowest natural paces are: spike puller, quaddrill, and lagger. This explains
47 why in Figure 4's typical Production Gang configuration, two of each machine is provided, allowing the
48 team to work at approximately double rate.



(g)

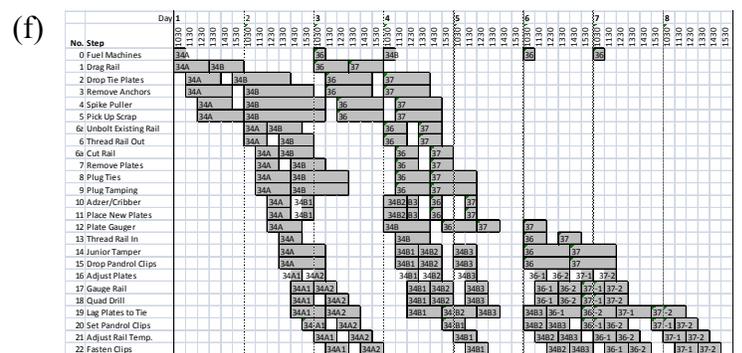
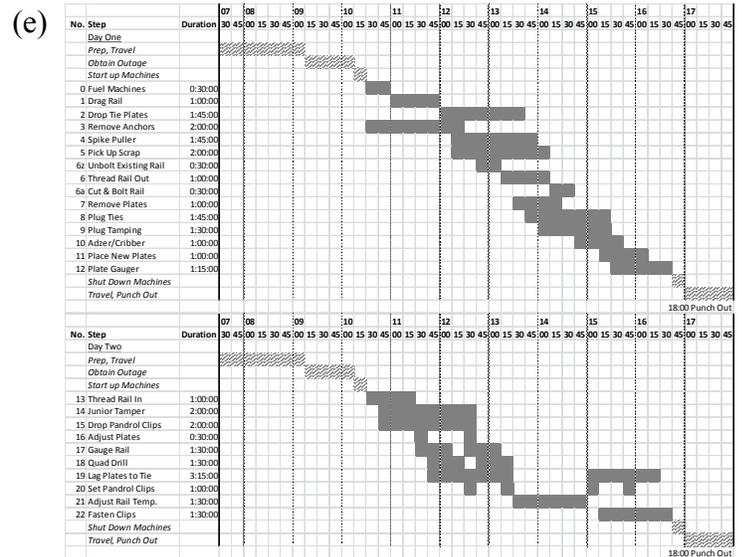
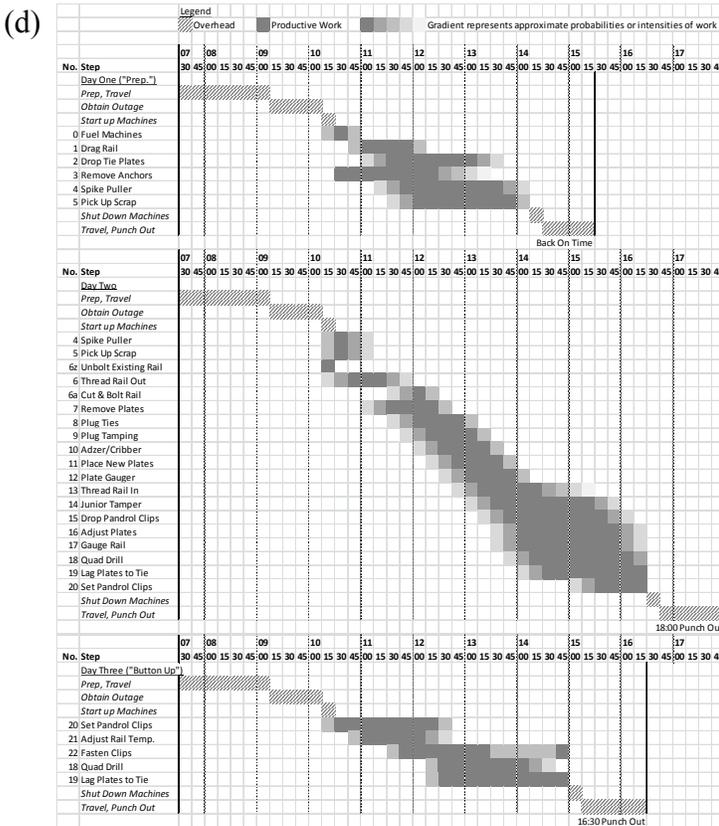
Work Step	Machines	Sample		Production Rates (Ft./Min.)		
		Size (Feet)	Interval	Low	Wt. Avg.	High
2-Drop Tie Plates		1,595	1 Min.	13.2	16.4	19.1
4-Remove Spikes	SP 6001, 6002	1,308	2~5 Min.	3.6	5.9	7.7
6-Thread Rail Out	CH 2201	1,179	1 Min.	29.7	45.3	61.0
7-Remove Tie Plates		147	<1 Min.	24.1	29.1	39.3
8-Plug Ties		233	1~2 Min.	4.1	6.2	8.5
9-Plug Tamping		225	1 Min.	7.2	9.8	13.6
10-Adzer/Cribber	KA 1001	1,109	Cat. Pole	27	34	46
12-Gauge Tie Plates		641	1~2 Min.	20.5	22.1	25.6
13-Thread Rail In	CH 2002	714	1 Min.	13.3	33.6	41.7
14-Junior Tamper	MJ 3002	806	1 Min.	12	15.8	20
17-Rail Gauging		678	1 Min.	7.9	9.1	14.9
18-Drill Holes	TY 1205	461	2~5 Min.	5.2	6.2	7.1
19-Lag Plates to Tie	SM 4001, 4003	310	2 Min.	1.9	2.3	2.7

FIGURE 5 Time study results for rail replacement processes: (a)-(f) selected individual task data; (g) summary.



No.	Step	Curr. Assign. (Teams)	Revised Assign. (Teams)	Old Work Rate (Ft./Min.)	New Work Rate (Ft./Min.)	New Machine Utiliz.* (%)
4	Remove Spike	2	3	11.8	17.7	8%
17	Gauge Rail	1	2	9.1	18.2	—
18	Quaddrill	2	3	12.4	18.6	7%
19	Lag Plates	3	4	6.9	9.2	15%

* Note: (Machine Utilization %) = (Utilized Machine Hours) ÷ (Available Machine Hours).



Note: (d)-(f) intended to show general shape of grey area only, details not pertinent to present discussion.

(g)	Overhead**	Work	Wait	Total
Traditional Plan	102:15 (46%)	27:27 (12%)	91:48 (41%)	221:30
Pipelined Plan	53:15 (54%)	18:42 (23%)	27:17 (33%)	99:15
Difference	-49:00 (-48%)	-8:44 (-32%)	-64:30 (-70%)	-122:15 (-55%)

** Note: Overhead includes travel to work site, machine servicing, job preparation, and mandatory rest breaks.

FIGURE 6 Process analysis for rail replacement: (a)-(b) overall production rates; (c) machine utilization; (d)-(f) work plan alternatives; (g) overhead, productive work, and within-production wait time fractionation.

(a)

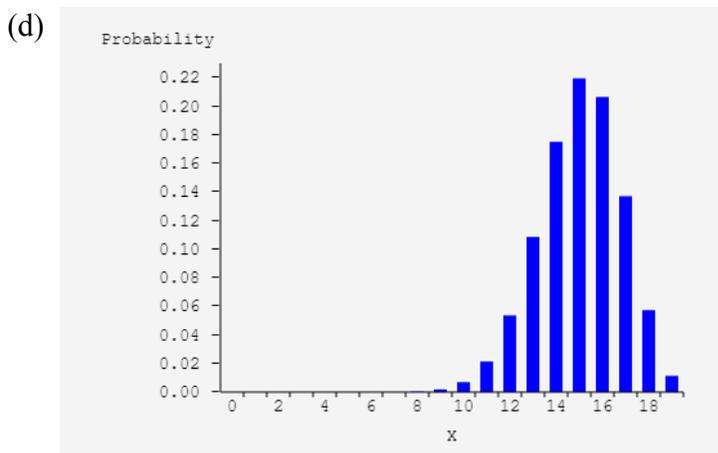
Category	Total Workdays	Coverage Required	Relief not Req'd
Days in a Year	365		
Rest Days	-102		
Holidays	-10		
Vacation Days		-25	
Sick Days		-12	
Personal Days		-3	
Training*		-3	
Discipline*		-3	
Bid Out Status*		-7	
Annual Total	253	-53 (21%)	200 (79%)

(b)

Emp. Avail.	Emp. Unav.	Prob.	Total Prob.	Days	Total Days
19	0	0.0113	1%	3	3
18	1	0.0573	7%	14	17
17	2	0.1371	21%	35	52
16	3	0.2065	41%	52	104
15	4	0.2196	63%	56	160
14	5	0.1751	81%	44	204
13	6	0.1086	92%	27	232
12	7	0.0536	97%	14	245
11	8	0.0214	99%	5	251
≤10	≥9	0.0092	100%	2	253

(c)

Nos.	Position
1-19	Regular Machine Operators
20-25	Relief Machine Operators
26-27	Extra-Extra Machine Operators
28-39	Regular Trackworkers
40-42	Protect Trackworkers
43	Extra-Extra Trackworker
44	Qualified Welder
45-48	Regular Track Foremen
49-50	Extra Track Foremen
51	Extra-Extra Track Foreman
52	Welding Foreman
53	Track Machines Mechanic
54	Machine Instructor
55-57	Bus Driver, Rule 22 Flaggers
58	Protect Bus Driver & Flagger
59	Timekeeper
60-61	Assistant Supervisor, Supervisor



Note: This chart is generated by David M. Lane's *Binomial Distribution Calculator* (http://onlinestatbook.com/2/calculators/binomial_dist.html).

FIGURE 7 Rightsizing results: (a) relief coverage requirements; (b) binomial unavailability model for 19 operators; (c) curve rail gang roster for traditional work plan; (d) graph of binominal distribution.

Uniform Pace of About Fifteen Feet per Minute

Our initial thoughts on process improvements is to minimize wait time within production cycle, by managing capacities such that all steps operate at a robust and steady average rate (i.e. near lower bound) of faster and more variable-pace/finicky processes (e.g. threading rail in), by adding sufficient capacity to slower and more consistent processes (e.g. spike puller, quaddrill, lagger). Figure 6(a) shows relative production rates of all steps with minimum operable teams. ‘Highest reasonable pace’ was deemed to be about 15~20 linear feet of track production per minute.

However, to enable this rate, analytical results (Figure 6(b,c)) showed that dramatically more lagger capacity is required compared to typical Production Gang, to match lagger’s work pace (and to lesser extent, spike puller’s) with remaining machines. Adding new capacity also drove down lagger and spike puller fleet utilization as a whole, because same amount of work is shared by more machines operating in parallel. Within curves, the Railroad’s track maintenance standards require each Pandrol plate to be lagged down with four lags, resulting in peaking work load for these machines in curve sections. In tangent (straight) sections, only two lags are required, rendering additional capacity surplus when working in other areas. Because the Railroad didn’t have sufficient track mileage to justify a dedicated

1
2 year-round ‘curve rail gang’, and Production Gang must cover all track and tie renewal work, it was
3 determined that additional machines may not be a great investment.
4

5 Increase in machine capacity could result in reducing typical time to install one 1,600 ft CWR string
6 from three to two days. Substantial overtime is required on those two days to complete work, and we
7 didn’t think continuous work at this overtime utilization level was sustainable, prudent, or realistic at the
8 Railroad. Study effort was redirected towards finding low machine utilization’s root causes, i.e. finding
9 non-work time outside of regular production cycle.
10

11 ***Root Cause of Low Utilization: Start Up and Tear Down***

12 At the Railroad, two types of activities contribute to non-productive time: (1) recurring daily is time
13 required to prepare for work, perform service and maintenance on track machines, load materials, travel
14 to & from work site, and obtain track outage & power off (termed “daily overhead”); (2) recurring for
15 each job is time required to start each step and ramp up machines to full continuous capacity, and when
16 job is finishing, time is required to wait for all machines to complete work and shut-down production
17 line (i.e. “job overhead”).
18

19 Regarding daily overhead, existing labor agreements state track employees are entitled to short lunch
20 break, report to central locations at beginning of workday, punch-out at same location at day’s end, and
21 have defined tours-of-duty providing for same start time every workday and two consecutive rest days
22 per week. Numerous reasons exist for this arrangement relating to workforce accountability and control,
23 past practice, and lack of suitable reporting locations at work sites due to abandonment or sale of fixed
24 field facilities inherited from predecessor railroads. Revenue train schedules negotiated between the
25 Railroad and funding partners constrain daily work window on mainlines to basically between 1000 and
26 1430 hours, with extension to 1600 subject to additional approval when required. Interaction of these
27 long-term constraints result in maximum theoretical machine (and personnel) utilization of 50% without
28 overtime, and 60% with maximum overtime. Due to nature of these constraints (requiring negotiation
29 with both labor unions and two major funding partners), daily overhead is outside this study’s scope and
30 60% utilization should be regarded as theoretical maximum for this exercise.
31

32 Au contraire, job overhead lies within management short-term control to a large extent. As typical in
33 productivity studies, production line is at peak efficiency when operating in continuous and repetitive
34 fashion. Current policy of working on one curve (up to three 1,600 ft CWR strings, working limits of
35 ~1½ miles) at a time results in workplans requiring three days of carrying out different types of work
36 (simplified Gnatt chart in Figure 6(d)), net result being the production line never really gets going, and
37 when assessed in aggregate, up to two-thirds of all machines essentially sit idle waiting for either their
38 portion of process to begin, or waiting for remainder of gang to complete their part. Even with strategic
39 addition of machine capacities and overtime, process can be driven down to two-day duration (Figure
40 6(e)), but even then, much waiting-to-start and waiting-to-be-done (i.e. white space on Gnatt charts)
41 continue to exist.
42

43 Potential solution here is to schedule curve rail replacement work as contiguous sequence of curves
44 between interlockings (known as “pipelined plan”, Figure 6(f)). This method is typical for track gang
45 deployment on Class I freight carriers, which work predominately in single-track territory with trains
46 detoured over other lines. On the Railroad, however, revenue train scheduling requirement dictates that
47 only one track for one signal block (interlocking to interlocking) can be removed from service for
48 prolonged periods at any one time. Typical block spacings are 4~12 miles, but due to the Railroad’s
49 curvaceous nature, multiple curves can be present within one block. Working continuously on multiple

1 curves from west to east, gang's frontend might have progressed to preparing Curve #3 by the third day,
2 whereas middle of gang would be working on Curve #2, and rear could be buttoning-up Curve #1. On
3 days when full simultaneous work is possible, fewer parts of gang is waiting on others, and gang
4 utilization could approach 50% of the theoretical ceiling dictated by current agreements.

5
6 Based on our calculations (Figure 6(g)), block containing four typical curves on the Railroad totalling
7 11,300 ft would have taken 23 workdays (221½ hours) using traditional methods, could be condensed
8 into 12 days (99¼ hours) with typical authorized overtime. Operational problems remaining to be
9 solved in utilizing pipelined plan include necessity to spread out the gang over working limits of up to
10 five miles, together with normal concerns of personnel and materiel logistics, communications,
11 adequacy of supervision, safety, and delays to passing trains which must operate at 30 mph through the
12 entire work zone. The Railroad is currently exploring possibility of planning consecutive curve rail
13 replacement work this way.

14 ***Extra Board Requirements Drive Gang Size***

15
16 Rightsizing computations for gang personnel turns out to be fairly complex. Starting with the one-
17 operator-per-machine rule, Machine Operators are assigned. The Railroad's track gangs are internally
18 supported, meaning all absences and otherwise unavailable personnel must be covered by reassigning
19 other employees with appropriate qualifications from within the same gang, sometime resulting in
20 cascading reassignments leaving least operationally-critical position(s) uncovered. The Railroad has
21 vacation and sick leave policies largely consistent with area suburban railroads (and predecessor private
22 railroads) plus features of collective bargaining processes (bid out status, discipline, and training) that
23 result in probabilistic total of 21% unavailable person-days requiring relief coverage (Figure 7(a)).
24 Modelling results based on random distribution of unavailability patterns (Figure 7(d)) show that to
25 achieve 100% availability on 92% of workdays for 19 Machine Operators, six extras must be carried on
26 payroll (Figure 7(b))—and because these six extras are themselves are entitled to same benefits and
27 subject to vagaries of agreement processes, additional two extra-extra positions are required to provide
28 coverage for extra positions.

29
30 Trackworkers are next to be assigned. However, because Trackworkers can currently cycle during the
31 day from gang's frontend to the back (if "pipelined plan" is not utilized), fewer positions are required.
32 And because unavailable Trackworkers can be covered from Machine Operator spare list, fewer extra
33 Trackworkers are needed to provide complete coverage. To this basic gang, other workers like
34 Qualified Welders, Mechanics, and Foremen are added, together with extras where necessary. Overhead
35 positions like Instructors, Trainees, Supervision, and Adjacent Track Flaggers are then added to roster.
36 Results show that 61 total positions are required to staff Production Track Gang operating in traditional
37 curve rail mode. This result is actually three heads more than personnel that the Railroad currently
38 assigns to this gang, however, current practice also calls for Welding Foreman, Welder, and Mechanic to
39 be borrowed from local subdivision and mechanical support shop as needed.

40
41 One interesting insight from this exercise is extent to which leave benefits (whether paid or unpaid,
42 positions still need to be properly covered for gangs to work) and agreement process contribute to
43 headcount. Of 61 positions, 16 employees (or 26%) are actually relief positions (8 Machine Operators,
44 4 Trackworkers, 3 Track Foreman, and 1 Flagger; Figure 7(c)). We believe this staffing ramification
45 was not understood when benefits packages were originally negotiated by predecessor railroads more
46 than five decades prior. Net result is, on more than half of all workdays, extra personnel could be
47 observed assisting other workers or learning to operate machines on site. Unlike T&E service tradition
48 where extra board personnel are paid to stay home and called to protect specific assignments, spare
49 maintenance personnel actually put in full workdays at the jobsite.

1
2 Our recommendation to the Railroad is to explore establishing extra lists for maintenance personnel
3 solely based on craft and reporting location, rather than internally covered within each gang. However,
4 benefits may not be as significant as it first seems since most locations have only 2~3 gangs reporting
5 and some locations have only one gang. If systemwide extra list were to be established, with
6 deadheading necessary between locations to fill relief positions, complex crew calling systems must be
7 setup for maintenance personnel, which would involve collective bargaining negotiations,
8 commissioning new computer systems, and implementing new business processes.

10 DISCUSSION

11 Eight-step review of cyclical track program demonstrated most important area of efficiency
12 improvements is in sequencing of jobs. Rate studies show typical machine assignments are fairly well
13 matched in terms of work pace, except for spike pullers and ladders, which must perform extra work on
14 curves for extra fasteners needed compared to plain line. Timing studies showed 12 hours' of
15 continuous on-track work is required to change out one 1,600 ft length of rail, assuming sequential work
16 by each machine overlapping within one rail string to maximum extent feasible. Traditional method of
17 changing out curve rail under track-time-constrained situations involves breaking required work down to
18 three workdays of 4~6 hours of on-track time each. More efficient method could be utilized to complete
19 work in two six-hour days, but requires extra machines that only achieves low utilization due to nature
20 of peaking demand within the day's work sequence. To fundamentally improve efficiency in rail
21 replacement processes, work must be planned such that curves within same signal block is replaced at
22 the same time and in sequence, allowing all machines to be utilized within entire production cycle,
23 rather than working one day at a time, one curve at a time.

24
25 Sequencing of jobs is subject to external constraints, including major capital jobs elsewhere on-line (e.g.
26 movable bridge replacement, hurricane damage restoration), which dictates signal blocks available for
27 rail replacement work, and overall rail replacement program dependent on curve rail existing conditions
28 and typical wear rates (which in itself is dependent on physical characteristics of track segment,
29 operating speeds, traffic density, and traffic mix). These interactions are complex and it may not always
30 be possible to work on each curve in sequence without replacing some curve rails prematurely. Cost of
31 foregone materiel lifecycle versus productivity gains of sequentializing cyclical rail replacement could
32 be subject to further research.

33
34 Whereas typical budget-driven rightsizing initiatives might strive to assign each position to one specific
35 production line job, analysis herein demonstrates a many-to-one relationship exists between them.
36 "Spare" personnel is integral to keeping track gangs at full production in spite of legitimate absences and
37 unavailable employees where they occur. Zero-based budgeting efforts should avoid "cutting to the
38 bone" and thereby placing track gangs in situations where any unavailability deeply affects entire gang's
39 productivity.

40
41 Compartmentalization and regionalization of commuter rail service that occurred (28) due to Northeast
42 Rail Services Act (1981) may have resulted in balkanization of track renewal functions (limiting scope
43 of each production gang geographically, versus Class I-style systemwide travelling gangs), consequently
44 rendering it impossible to develop specialized curve rail-, yard/mini tie-, and mainline tie-gangs where
45 equipment and manpower is matched precisely to routine tasks. Consolidative economy of scale may
46 have been lost with potentially adverse consequences in productivity.

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CONCLUSION

Eight-step analysis framework performed well in identifying root causes of potential productivity constraints within curve rail cyclical replacement program. While each efficiency analysis situation is different, by utilizing the eight-step approach, analytical efforts could be targeted in areas requiring further refinement and improvement while ensuring all bases are covered and that most leveraged area in terms of improvement possibilities are systematically identified.

Based on this study, our recommendations are as follows:

- Consider creating specialized tie gang and curve rail gang, to ensure optimal machine and manpower resources are assigned to each gang and work pace of all steps are well-matched.
- If deemed feasible within prevailing operational constraints, consider planning cyclical curve replacement sequentially to improve machine utilization under “pipelined” work plan.
- After further analysis of cost and benefits, consider establishing extra lists for maintenance personnel solely based on craft (and maybe reporting location) rather than assigned to each gang.

Our suggestion to other railroads engaged in similar cyclical track rehabilitation activities is to utilize eight-step framework to determine bottleneck processes in their operations and generate ideas for productivity improvements. We encourage others in the industry to publish results of their studies as to contribute to body of knowledge, document critical processes in detail for succession planning, and educate a new generation of railroaders.

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REFERENCES

(1) Posner, Henry III. *The RDC Story, in Perspective—Iowa Interstate and Beyond*. Retrieved from http://www.rrdc.com/speech_Cedar_Rapids_NRHS_062212_print.pdf on May 26, 2017.

(2) Walker, Karen. Turnaround King: Seabury Takes on Even the Toughest Airline Financial Challenges. In *Air Transport World*, June 2015. Retrieved from <https://www.seaburycapital.com/wp-content/uploads/2015/11/Air-Transport-World-June-2015.pdf> on May 26, 2017.

(3) Carter, Christopher. Fixing First South West. In *BUSES*, July 2016.

(4) Roethlisberger, F. J., & Dickson, W. J. *Management and the Worker: An Account of a Research Program Conducted by the Western Electric Company, Hawthorne Works, Chicago*. Harvard University Press, Cambridge, Mass. (1939).

(5) Barnes, R. M. *Motion and Time Study: Design and Measurement of Work*. John Wiley & Sons, Inc., New York, N.Y. (1964).

(6) Taylor, F. W. *Shop Management*. Presented to the American Society of Mechanical Engineers, Saratoga Springs, N.Y. (1903).

(7) Hay, William. Chapter 29: Conduct of Work. In *Railroad Engineering*, 2nd Edition, John Wiley & Sons, New York, N.Y. (1982).

(8) Cope, G. H. Chapters 28-30. In *British Railway Track: Design, Construction and Maintenance*, 6th Edition, the Permanent Way Institution, London, U.K. (1993).

(9) American Railway Engineering and Maintenance-of-Way Association (AREMA). Chapter 16, Economics of Railway Engineering and Operations (Part 9—Program Work). In *AREMA Manual for Railway Engineering*, AREMA, Lanham, Md. (2013).

(10) Ford, Bacon, and Davis Inc., Engineers. *Maintenance of Way Training Manual Book VIII: Maintenance Gang Procedures*. Prepared for Penn Central Transportation Company in Cooperation with United States Railway Association; Disseminated by Consolidated Rail Corporation, Philadelphia, Penn. (1976).

(11) Pentrex, Inc. Norfolk Southern Tie Replacement and Surfacing Gang at New Baden, Ill. In *Workin' on the Railroad* (DVD), Indianapolis, Ind. (1999).

(12) CSXT Grain Express. CSX Replacing Railroad Ties on the CE&D Subdivision between Princeton and Vincennes, Ind. Retrieved from <https://www.youtube.com/watch?v=CP8Gn6m9re8> on May 27, 2017.

(14) Schwarcz, S. and Bernstein, J. Metro-North Railroad Workforce Planning Model: Trade-Offs Between Straight Time, Overtime, and Lost Revenue. In *Transportation Research Record: Journal of the Transportation Research Board 2353* (2013).

- 1 (15) Rosenthal, C. Big Data in the Age of the Telegraph. In *McKinsey Quarterly*, March 2013.
 2 Retrieved from [http://www.mckinsey.com/business-functions/organization/our-insights/big-data-in-the-](http://www.mckinsey.com/business-functions/organization/our-insights/big-data-in-the-age-of-the-telegraph)
 3 [age-of-the-telegraph](http://www.mckinsey.com/business-functions/organization/our-insights/big-data-in-the-age-of-the-telegraph) on May 29, 2017.
 4
- 5 (16) Rummler G.A. and Brache A.P. *Improving Performance: How to Manage the White Space on the*
 6 *Organization Chart*. The Jossey-Bass Management Series, Anytown, U.S.A. (1990).
 7
- 8 (17) Penn Central Transportation Company, Office of the Chief Engineer. *Manual for Construction and*
 9 *Maintenance of Track* (MW-4). Philadelphia, Penn. (1974).
 10
- 11 (18) Pennsylvania Railroad, The. *Manual of Instructions—Maintenance of Way Equipment* (M.W. 52).
 12 Philadelphia, Penn. (1943).
 13
- 14 (19) New York Central System. *Rules for the Government of the Maintenance of Way Department,*
 15 *Effective October 1, 1942*. New York, N.Y. (1942).
 16
- 17 (20) Wilson, J.M. Gantt Charts: A Centenary Appreciation. In *European Journal of Operational*
 18 *Research*, No. 149, pp. 430–437 (2003).
 19
- 20 (21) Reddy, A.V., Lu, A., and Wang, T. Subway Productivity, Profitability, and Performance: A Tale of
 21 Five Cities. In *Transportation Research Record: Journal of the Transportation Research Board 2143*,
 22 pp. 48-58 (2010).
 23
- 24 (22) Wei, X.J., Lu, A., Kennard, J.E., and Fogel, D. Enterprise GIS in a Commuter Rail Environment:
 25 State-of-Practice at a Major Northeastern Carrier (Paper #16-2121). Presented at *Transportation*
 26 *Research Board 95th Annual Meeting*, Washington, D.C. (2016).
 27
- 28 (23) Armstrong, J.H. *The Railroad What It Is What It Does: The Introduction to Railroading*.
 29 Simmons-Boardman Books, Omaha, Neb. (1990).
 30
- 31 (24) Ochi, T. 東海道本線 富士川—新蒲原間 上り本線山側ロングレール交換作業 (*Tokaido*
 32 *Main Line, Fuji River to Shin Kambara Section, Up Main Line, Mountain Side, Continuous Welded Rail*
 33 *Exchange Operations*). Retrieved from <https://www.youtube.com/watch?v=FtHtci6NucY> on June 30,
 34 2017.
 35
- 36 (25) Nordco Inc. *Spike Puller SP2R Model A Operation and Maintenance Manual*, Oak Creek, Wisc.
 37 (September 2015). Retrieved from [http://www.nordco.com/Media/Maintenance-of-Way-](http://www.nordco.com/Media/Maintenance-of-Way-Equipment/Spike-Pulling-Machines/Manuals/Spike-Puller-Two-Rail---SP2R/SN-310001-310007-/SpikePullerTwoRailSP2RModelAOperationManual49453100.pdf)
 38 [Equipment/Spike-Pulling-Machines/Manuals/Spike-Puller-Two-Rail---SP2R/SN-310001-310007-](http://www.nordco.com/Media/Maintenance-of-Way-Equipment/Spike-Pulling-Machines/Manuals/Spike-Puller-Two-Rail---SP2R/SN-310001-310007-/SpikePullerTwoRailSP2RModelAOperationManual49453100.pdf)
 39 [/SpikePullerTwoRailSP2RModelAOperationManual49453100.pdf](http://www.nordco.com/Media/Maintenance-of-Way-Equipment/Spike-Pulling-Machines/Manuals/Spike-Puller-Two-Rail---SP2R/SN-310001-310007-/SpikePullerTwoRailSP2RModelAOperationManual49453100.pdf) on June 30, 2017.
 40
- 41 (26) Rail Safety and Standards Board. *Standards Catalogue*. Retrieved from
 42 <https://www.rssb.co.uk/railway-group-standards> on June 30, 2017.
 43
- 44 (27) Babila, J. *Three Ways to Drive a Spike*. Retrieved from [https://www.youtube.com/watch?v=9Brg-](https://www.youtube.com/watch?v=9Brg-K0J_2U)
 45 [K0J_2U](https://www.youtube.com/watch?v=9Brg-K0J_2U) on July 4, 2017.
 46
- 47 (28) Allen, J.G. and A. Lu. Organizational Regimes for Commuter Rail: Improving Train Service
 48 Worldwide. In *Transportation Research Record: Journal of the Transportation Research Board 2146*,
 49 pp. 100-108 (2010).