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Executive Summary

Equipment readiness is central to the training and deployment of Army National Guard (ARNG) units. The Department of the Army assesses the mission readiness of a unit's required equipment portfolio as of a designated reporting day each month. The equipment readiness metric is calculated based on the amount of time a unit's equipment is "mission capable" and available for use. Maintenance facilities staffed primarily by dual-status military technicians (MilTechs) perform the vast majority of inspections, repairs, and upgrades required to generate and maintain equipment readiness in the ARNG.

In this research, we quantify the causal effect of changes in ARNG MilTech maintenance personnel on ground equipment readiness. In particular, we measure the effect of maintainer staffing levels on the length of time required to complete work on vehicles and electronic equipment at Field Maintenance Shop (FMS), Combined Support Maintenance Shop (CSMS), and Maneuver Area Training and Equipment Site (MATES) facilities. We find that additional MilTech vehicle and electronics maintainers result in economically meaningful and statistically significant reductions in the length of time ground equipment remains in a mission-incapable state.

Methodology and Data

We use survival analysis regression to estimate the marginal effect of additional MilTechs on average equipment downtimes. Equipment readiness ratings are compiled at the battalion level, but equipment maintenance for battalions commonly occurs at more than one maintenance shop, each of which often serves multiple battalions. This makes clean association of shop-based maintenance personnel with battalion-level readiness ratings impossible. We therefore focus our analysis on maintenance shop performance where we can accurately match work to workers and calculate how changes in staffing impact the time to complete work orders. Results can be expressed as changes in the time-denominated equipment readiness ratings used by the ARNG.

Information for this research is drawn from ARNG ground equipment maintenance work orders and from uniformed and civilian personnel administrative records for the period from October 2010 to June 2015. We focus on vehicles and electronics equipment to reduce variation in the type of work completed, improve our ability to match work with the relevant maintainers, and obtain a population size large enough to provide reliable estimates. We define "vehicles" as both tactical and combat vehicles. While significant differences exist between these equipment types, the personnel data do not distinguish between tracked versus wheeled mechanic maintainers. Electronics work orders include items such as night vision goggles, radios, and other communications security equipment. Because the volume of electronics work received by FMS facilities is insufficient to support analysis, we examine electronics work orders submitted to CSMS and MATES facilities only.

We analyze 564,000 ARNG MilTech person-months worked by 16,000 individuals at maintenance facilities. We are unable to analyze work occurring in the states of Montana, New Mexico, Utah, and Vermont, as the administrative practice of accounting for maintenance facility staff in Joint Force Headquarters (JFHQ) units alongside non-maintenance staff prevents matching of MilTechs to maintenance facilities for these states. From the total set of in-scope records, we capture 74% of ground maintenance MilTech-months and 70% of work orders, covering 472 FMS and 81 CSMS/MATES facilities.

Facilities differ in their buildings, equipment, maintainer types, work complexity, and portfolio of equipment types serviced. FMS facilities primarily handle routine mechanical vehicle maintenance, and account for 53% of the MilTechs in the analysis. CSMS and MATES facilities are equipped to address both standard and complex maintenance tasks across a variety of equipment categories including vehicles, small arms, electronics, and artillery. We treat distinct combinations of facility type and equipment category separately, controlling for individual facility features.

Results

The direct effects of MilTech manpower investments at FMS, CSMS, and MATES facilities on ARNG vehicle readiness are substantial and statistically significant, and indicate that leaders who desire to improve levels of ground equipment readiness can do so by adding vehicle maintainers to FMS facilities and vehicle and electronics maintainers to CSMS and MATES facilities.

We find that an additional vehicle maintainer decreases the average FMS vehicle work order duration by between 0.8 working days per work order, or an average production of 167 additional ready equipment days per shop year, respectively. The addition of one vehicle maintainer to each of the 472 FMS facilities studied would produce approximately 79,000 additional ready equipment days each year across the ARNG, holding constant all other staffing and features. Personnel managers with limited budgets should focus staffing additions in locations with an average to high level of workload per maintainer. At such shops, an additional vehicle maintainer produces 210 additional ready equipment days per shop year. Given approximately 260 working days per MilTech year, an additional ready days payoff of 210 for an investment of 260 MilTech working days represents a high rate of readiness return and suggests that personnel constraints currently hamper the timely maintenance of equipment.

Estimated impacts of maintenance personnel on vehicle work orders at CSMS and MATES facilities are also large, positive, and statistically robust. We find that an additional vehicle maintainer decreases the average CSMS and MATES vehicle work order duration by 0.4 working days per work order, or an average production of 121 additional ready equipment days per shop year. Likewise, an additional electronics maintainer decreases the average CSMS and MATES vehicle work order duration by 0.7 working days per work order, or an average production of 191 additional ready equipment days per shop year. Adding one vehicle and one electronics maintainer to each CSMS and MATES facility studied—or 162 FTEs total—would produce approximately 25,000 additional ready equipment days each year across the ARNG, all else equal.

Unlike the vehicle work duration results, our analyses of CSMS and MATES electronics work suggest that factors influencing electronics repair productivity and correlated with staffing levels at the facilities studied are confounded with features not accounted for in our data or model. Additional data, or more thorough modeling of total workload, may more precisely identify returns to electronics maintainer investments for the electronics workload.

In addition to the main results on MilTech productivity, we confirm that work proceeds significantly faster for equipment owned by units approaching deployment—particularly in the four to nine months prior to deployment—and slower for units already deployed. This additional productivity appears related to investments in Active Duty for Operational Support, Reserve Component (ADOS-RC) manpower, confirming that ADOS-RC maintenance tours are used to fill surge labor needs.

We briefly explore the impact of selected personal characteristics of maintainers and additional shop features on productivity: maintainer tenure, average Armed Forces Qualification Test (AFQT) score, and supervisor ratio. We are unable to identify the impact of tenure on time to work completion because low levels of variation in tenure and high median experience combine to limit statistical power. In our analyses of the supervisor-to-line worker ratio, we find that FMS facilities with relatively more supervisors complete work slightly more slowly (with work orders requiring an economically insignificant 0.8% more working days to complete). This may result from the formation of slightly smaller-than-optimal teams, due to small overall staff size in FMS facilities, or from the loss of a line worker when an individual is called upon to perform supervisory activities. Adding more vehicle maintainers to FMS facilities—not cutting supervisors—would most effectively address this matter. Finally, we observe that AFQT score appears to have little impact on productivity, despite a fairly large amount of native variation in the data. Exploration of whether selection may confound identification of any AFQT impact is beyond the scope of this research.

In sum, this research documents economically robust and statistically significant equipment readiness returns to investments in maintenance personnel at ARNG FMS, CSMS, and MATES facilities. Our results suggest that personnel constraints currently hamper the timely completion of equipment maintenance and impact overall equipment readiness levels in the ARNG.

Contents

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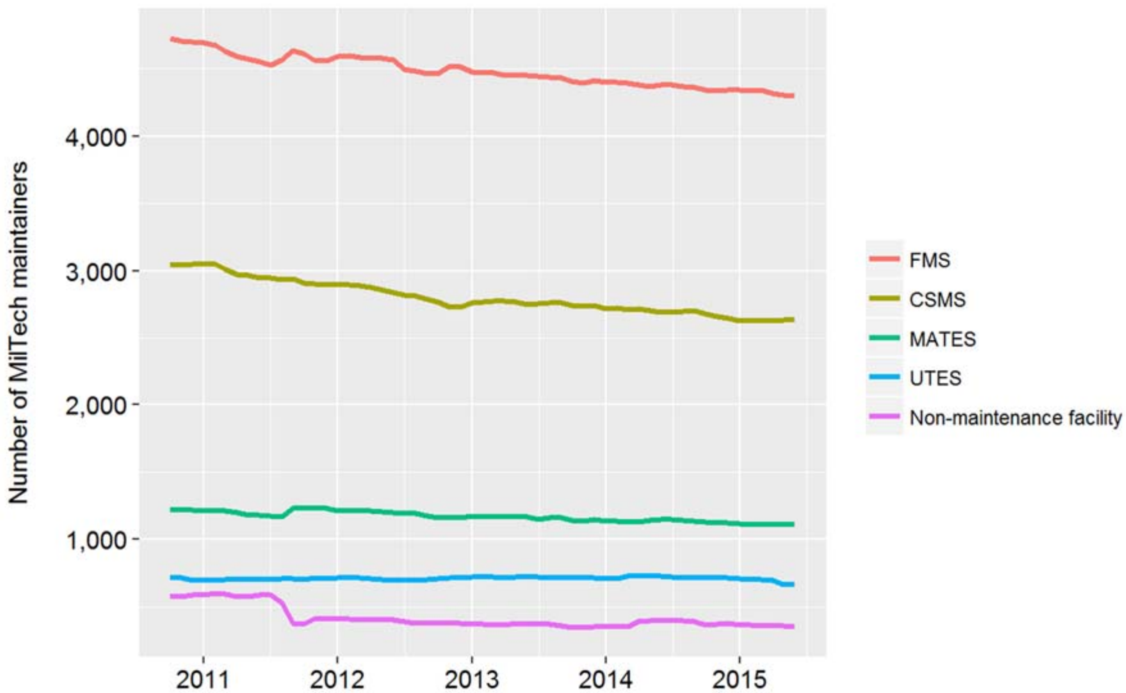
1. Introduction

Equipment readiness is central to the training and deployment of Army National Guard (ARNG) units. The Department of the Army assesses the mission readiness of a unit's required equipment portfolio as of a designated reporting day each month. The equipment readiness metric is a direct function of the amount of time a unit's equipment is "mission capable" and available for use. Maintenance facilities staffed primarily by military technicians (MilTechs) perform the vast majority of inspections, repairs, and upgrades required to generate and maintain equipment readiness in the ARNG.

We quantify the causal effect of changes in ARNG MilTech maintenance personnel on ground equipment readiness. All ground equipment, including vehicles, small arms, and electronics, falls under the purview of Field Maintenance Shop (FMS), Combined Support Maintenance Shop (CSMS), Maneuver Area Training and Equipment Site (MATES), and Unit Training Equipment Site (UTES) facilities. We estimate survival analysis regressions to measure the impact of maintainer staffing levels on the length of time required to complete vehicle and electronics equipment work orders at FMS, CSMS, and MATES facilities. Overall, we find that additional MilTech vehicle and electronics maintainers result in economically meaningful and statistically significant reductions in the length of time ground equipment remains in a mission-incapable state.

Survival analysis is more appropriate to this context than alternatives, such as a direct assessment of equipment readiness ratings or facility throughput analysis. Equipment readiness ratings are compiled at the battalion level, but equipment maintenance for a given battalion commonly occurs at multiple maintenance shops, which often serve multiple battalions. This makes clean association of shop-based maintenance personnel with battalion-level readiness ratings impossible. We therefore focus at the maintenance shop level to cleanly match work to workers, and calculate how changes in staffing impact the time to complete work orders. This approach produces results that can be expressed as changes in the time-denominated equipment readiness ratings used by the ARNG. Because survival analysis can accommodate a highly disaggregated level of equipment classification, it is suitable to the context of maintenance shops that service a broad variety of equipment items with variable frequency. By contrast, throughput analysis is more appropriate to evaluating either the completion rates of high-volume equipment types or representative bundles of heterogeneous work orders. Survival analysis estimates a short-run effect, as compared to throughput analysis, which would measure the new long-run steady state that results from adding another maintainer at a maintenance facility. To the extent that work order congestion causes delays to newly submitted work orders and that additional maintainers reduce work duration, the extrapolated short-term duration effect will be a lower-bound estimate of the long-run reduction in time required to complete repairs across many work orders. Because manning levels and workloads both change within shops over time, we investigate whether productivity depends on work order backlogs. During the period of analysis from October 2010 to June 2015, we observe a slight decline in the number of MilTechs in maintenance-relevant occupation codes whose facilities appear in our eligible set (illustrated in Figure 1), which coincides with declines in ARNG force structure and total drilling soldier headcount over the period.[1] This gradual decrease in MilTechs contrasts with a highly variable total work order volume over the period, as shown in Figure 2. Note that there is also a decreasing trend in work order volume, consistent with a decrease in deployment incidence over the period.



Note: The counts presented here represent MilTech maintainers found in the Corporate Management Information System (CMIS) after removing all aviation maintenance facilities and all individuals located in Guam, Puerto Rico, and the U.S. Virgin Islands.

Figure 1. MilTech Maintainers by Maintenance Facility Type

[1] The number of eligible MilTech maintainers in the ARNG slightly declines over the period of analysis, from 8,520 in October 2010 to 7,604 in June 2015. Between 2008 and 2015, we calculate a 3% decline in the total number of MilTechs in all roles (maintenance and non-maintenance), and a 1% decline in the number of uniformed ARNG members.

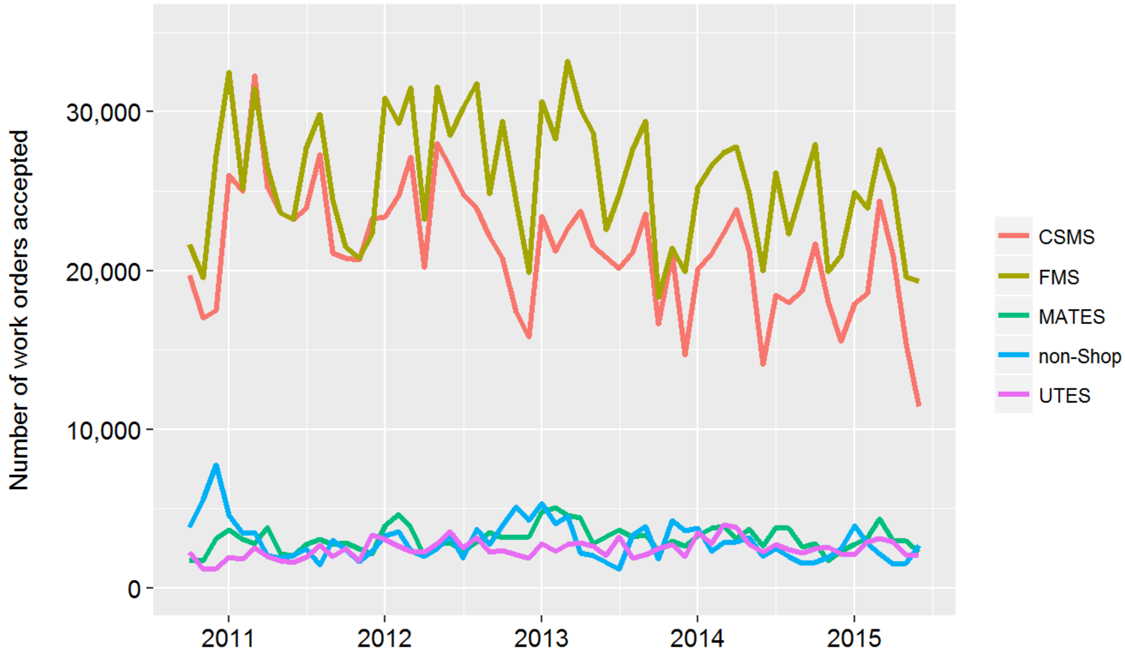


Figure 2. Work Order Volume by Facility Type

For FMS facilities, we find that vehicle maintainers have a large and statistically robust impact on vehicle work completion times. An additional vehicle maintainer produces an average of 167 additional ready equipment days per shop year. Adding a vehicle maintainer to each of the 472 FMS facilities studied would result in an additional 79,000 additional ready equipment days each year across the ARNG.

For CSMS and MATES facilities, we find that an additional vehicle maintainer produces an average of 121 additional ready equipment days per shop year, and that an additional electronics maintainer produces an average of 191 additional ready equipment days per shop year, on average. Adding one vehicle and one electronics maintainer to each of the 162 CSMS and MATES facilities studied would produce approximately 25,000 additional ready equipment days each year across the ARNG, all else equal.

Unlike the vehicle work duration results, our analyses of CSMS and MATES electronics work suggest that factors influencing electronics work order productivity and correlated with staffing levels at the facilities studied are confounded with features not accounted for in our data or model. Additional data, or more thorough modeling of total workload, may more precisely identify returns to electronics maintainer investments for the electronics workload.

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2. ARNG Maintenance Environment, Scoping, and Descriptive Statistics

When a piece of ARNG equipment requires maintenance that the owning unit is unable to provide, the unit submits the equipment to a maintenance facility, where a work order is opened to record the maintenance performed. Information for this research is drawn from ARNG ground equipment maintenance work orders and from uniformed and civilian personnel administrative records for the period from October 2010 to June 2015.

A. Maintenance Facility Types

The ARNG has four types of maintenance facilities: FMS, CSMS, UTES, and MATES. In this analysis, we combine CSMS and MATES facilities in the same analysis pool because the work volumes and staffing profiles at these facilities are similar, as illustrated in Table 1. MATES and UTES facilities are similar to CSMS facilities in the level of support they provide, but unlike CSMS facilities, they either act as the owning unit of specific equipment for use by visiting units during training exercises, or store equipment on behalf of other units.

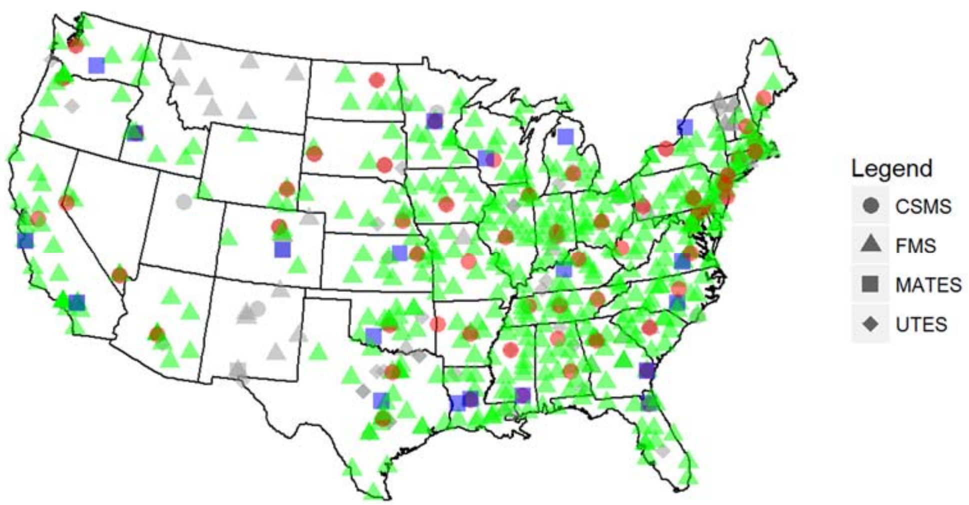
Maintenance conducted at FMS facilities primarily involves inspections and mechanical repairs of vehicles, consistent with the skills typically on staff shown in Table 1. FMS facilities are not usually equipped to provide all levels of maintenance on vehicles or other types of equipment requiring other skill sets. When an FMS encounters a piece of equipment or set of repairs that it cannot complete, it may evacuate the equipment to another support facility. Usually, an FMS sends such equipment to a CSMS.

CSMS facilities are staffed and equipped for a broad variety of standard and complex maintenance tasks, including non-routine or complex work “evacuated” from FMS facilities. Staffing levels are higher, and the profile of supported equipment is more varied at CSMS facilities than at FMS facilities, with CSMSs servicing small arms, artillery, electronics, and other specialized equipment. Figure 3 displays the locations of ARNG maintenance facilities.

Table 1. Average Shop-month Staffing and Workload Levels by Maintenance Facility Type

	CSMS	FMS	MATES	UTES
Maintainers	**37**	**8**	**46**	**20**
Mobile	22	8	36	18
Electronics	8	0	6	2
Other	7	0	4	1
Open WOs	**994**	**186**	**545**	**215**

Note: The *other* category includes maintainers with a variety of occupations, including welding, painting, and working with specialized equipment, like artillery. The sum of the mobile, electronics, and other categories may not equal the total maintainers for each maintenance facility type due to rounding.



Note: All maintenance facilities present in the full CMIS population are plotted. Maintenance facilities not retained in the regression set are in gray.

Figure 3. Geographic Locations of Maintenance Facilities.

B. Factors Expected to Impact Maintenance Work Order Duration

Many factors beyond staffing levels are expected to influence work order duration. Some may be confounded with observed staffing features. To parse the impact of staffing levels from the influence of non-staffing factors on work order duration, we control for features such as work difficulty and type; priority; the annual and event-based ARNG operating schedule and other workflow considerations; and shop features.**Error! Reference source not found.** Figure 4 describes the typical path of a ground equipment maintenance work order.

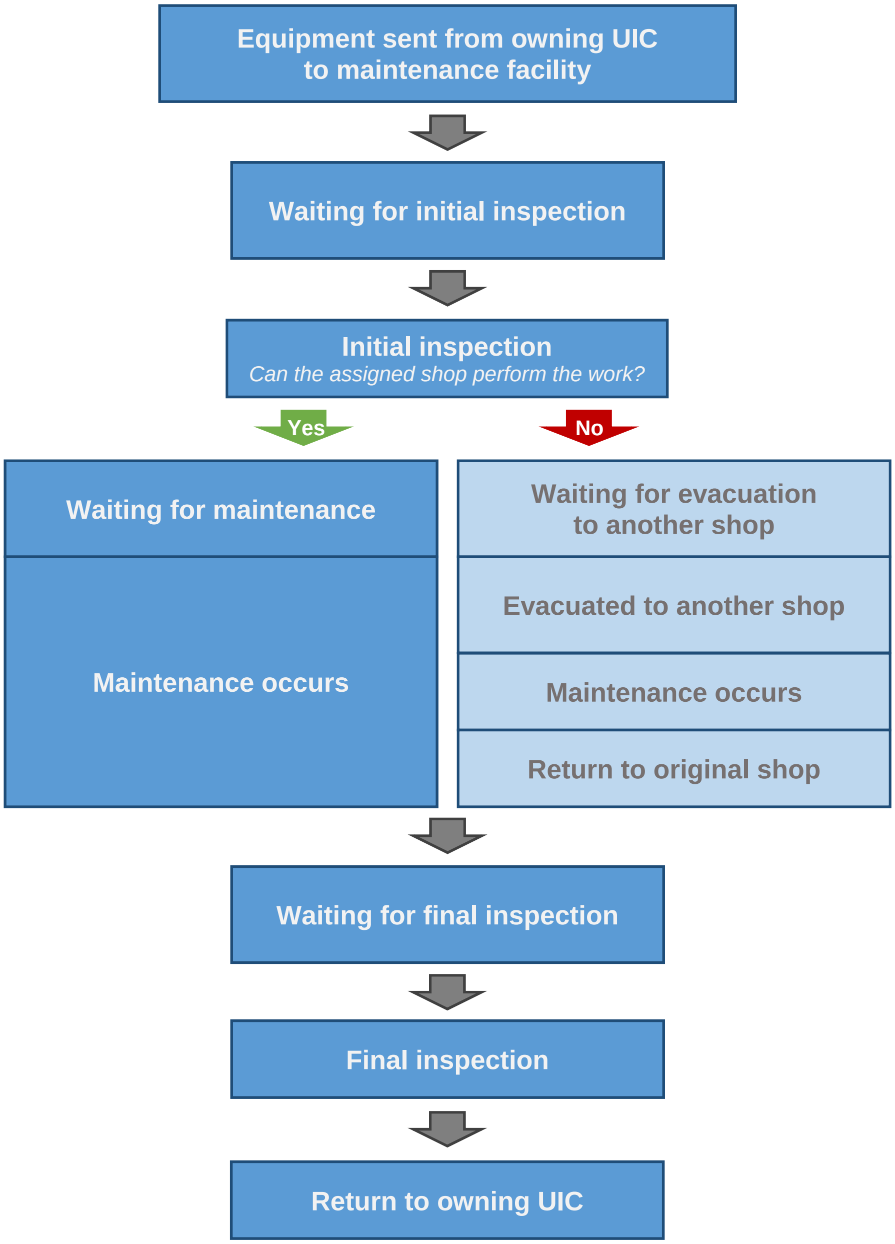


Figure 4. Typical Ground Equipment Maintenance Work Order Path

1. Work Difficulty

Unobservable differences in work difficulty threaten to attenuate the estimated returns to labor investments if work difficulty is positively correlated with shop staffing levels, seniority, managerial intensity, or skill diversity. We can partially control for work difficulty through observed equipment characteristics, such as type and model, and work features, such as whether the work requires transfer to a different facility. If equipment-owning units vector tasks to specific shops based on the unit's information about the task's nature and difficulty and how well particular shops are suited to the task, then work complexity will correlate with assigned facility type and staff composition. The presence of multiple skills at a facility suggests that this facility may see a more complex workload. For instance, a facility supporting vehicle painting might have longer-than-average work completion times because of paint booth capacity constraints and the time required for the painting and drying process. A facility with maintainers who specialize in welding or machine work may receive more complex or involved repair projects. Shares of facility months with one or more maintainer specialties present are presented in Table 2.

Table 2. Share of Facility Months with Advanced Capabilities

	One Complex Task Capability	Two or More Complex Task Capabilities
FMS	10%	1%
CSMS	92%	82%
MATES	88%	58%

Note: Includes eligible facility-months that receive eligible work orders. Complex task capabilities include painting, welding, machining, woodworking, fabric work, optical work, armament, and small arms.

The expected time required to complete each work order depends on the type of work required and the shop's relative proficiency in and capacity for completing that type of work. We group equipment items by type using equipment category codes (ECCs) to control for overall system complexity. ECCs consist of two digits: the first identifies equipment family (e.g., tactical vehicles), and the first and second combined identify specific equipment type (e.g., 1.5 ton utility trucks). We use ECCs to partition the analysis by equipment family and to control for equipment type within each family.

The complexity of the required work also impacts work order duration. Information on work complexity resides in a free-text field containing a brief description of the work required. This field sometimes contains information such as a description of the piece of equipment in need of repair (e.g., "repair axle"), and sometimes contains a description of the work performed (e.g., "reset"). We use these descriptions to classify work into six categories: reset (approximately 6% of work orders in the regression set), update (3%), turn-in (6%), service (31%), inspection (2%), and unknown (53%). These classifications enable us to control for processes expected to require different amounts of time for maintenance. "Reset" is an involved process, commonly involving major upgrade or revamp after deployment. By contrast, "service" usually refers to routine maintenance required at regular intervals. Sometimes these routine procedures require a number of time-consuming steps that must be completed in a given sequence, or require multiple people to coordinate a procedure. Occasionally, the maintenance facility receiving an equipment item cannot provide the specific type or level of maintenance required, or lacks the capacity to repair the item in the needed timeframe. Such work is evacuated from the original maintenance facility to a different facility, which opens a second work order.

2. Timing Effects

Time-related factors, such as training and deployment schedules, may impact work order duration. Only some of these elements are directly observable in this research.

Annual training events for equipment-owning units frequently occur in the summer months, which drives distinct seasonal differences in workloads. Annual training contributes to higher maintenance workloads, both in the spring (prior to training) and in the summer and fall (to repair items damaged or depleted during training). Workloads are lowest during the winter holiday season.

The timing of monthly drill for equipment-owning units could impact maintenance workload, but is unobservable in this research. Guardsmen in equipment-owning units may use that equipment during drill, perform required equipment inspections leading to identification of maintenance needs, or fulfill training or administrative duties that do not involve their assigned equipment at all. Drilling guardsmen who are themselves employed as maintenance MilTechs in shops may perform maintenance tasks during their monthly weekend drill. This potential weekend labor cannot be captured in this analysis, as it is not recorded centrally.

When an equipment-owning unit receives notice that it will deploy—typically 12 months in advance—it begins preparing its personnel and equipment. During the preparation period, maintenance facilities place higher priority on work for the deploying unit, which often arrives in larger-than-usual volumes. During the deployment of an equipment-owning unit, work order volume generally decreases as the unit's maintenance needs are met in theater and the urgency of the deployed unit's remaining work decreases. Work orders submitted by deployed units take longer to complete. Deployments also impact the staffing levels at maintenance facilities, since dual-status maintainers[2] frequently deploy with their supported unit, leaving the maintenance facility for the duration of the deployment. Following the unit's return from deployment, all of its returning equipment requires "reset" maintenance to return it to its pre-deployment functionality, leading to a large volume of relatively low-priority work, which may be more involved or complex, due to damage sustained in the deployed setting.

At the shop level, trends exist in the day of the week that new work arrives to shops, which may impact work durations due to congestion or other factors.[3] New work arrives most frequently on Wednesdays.

[2] Usually, a dual-status maintainer is a uniformed member of one of the units he or she supports as a state employee in a maintenance facility.

[3] Eleven states—Alaska (AK), Alabama (AL), Colorado (CO), Louisiana (LA), Maryland (MD), New Jersey (NJ), Oklahoma (OK), Rhode Island (RI), South Dakota (SD), Utah (UT), and Washington (WA)—operate on four-day work weeks. Two of these—AK and NJ—have an additional workday each pay period. Eight

Finally, uncertainty about the timing and levels of funding available for repairs arises in some years from delayed passage of the federal budget. Prior to passage, fiscal planners are bound to continuing resolution spending levels, frequently followed by a period of catch-up spending after passage. These fiscal constraints may generate follow-on effects in the arrival rate of new work or the time required to obtain parts.

3. Shop Physical Constraints

Capital assets, such as work bays, lifts, cranes, paint booths, paved and lighted lots, and storage facilities support the capabilities of maintenance facilities and enable the productivity of labor inputs. Shop throughput could be constrained by the number of maintainers it has to accomplish a task, by the limitations of the facility itself, or both. Unfortunately, because shop physical features do not vary over the period of this analysis, we cannot estimate the returns to investments in equipment and infrastructure separately from an overall shop-specific effect. However, a finding that additional MilTechs do have a significant effect on average work order duration would suggest that the physical capital stock is not the binding constraint on work completion.

4. Personnel

Both individuals in equipment-owning units and staff at dedicated maintenance facilities participate in equipment upkeep. Maintenance performed at equipment-owning units generally consists of simple tasks, such as oil changes and routine inspections, and is beyond the scope of this analysis.

a. Dual-status maintenance technicians

ARNG maintenance facilities are predominantly staffed by dual-status MilTechs: federal civilian employees who are required to remain in the Selected Reserve as a condition of their civilian employment.[4,5,6] Although MilTechs may perform maintenance activities during drill in their roles as uniformed soldiers, we do not observe these

states— Florida (FL), Hawaii (HI), Idaho (ID), Mississippi (MS), Nevada (NV), Pennsylvania (PA), Vermont (VT), and Wyoming (WY)—are closed one Monday or Friday per pay period, but otherwise operate on a five-day work week. The remaining states operate Monday through Friday.

[4] Technicians: employment, use, status, Title 32 U.S. Code, Sec. 709(a) 2, 2011 ed., accessed April 2018, https://www.law.cornell.edu/uscode/text/32/709.

[5] Nearly all maintainers are hired into permanent positions, with a one-year probationary period. Approximately 4% of person-months relate to temporary technicians with fixed terms of one to four years.

[6] During our period of analysis, non-dual-status MilTechs were present in the ARNG. While our MilTech data only includes dual-status MilTechs, we believe that non-dual-status MilTechs are rarely, if ever, used to fill maintenance roles. We use “MilTechs” to denote “dual-status MilTechs.”

contributions.[7] Maintainers often specialize in a particular type of equipment or system. Appendix B includes detailed information on MilTechs, organized by occupational series and groups, from the U.S. Office of Personnel Management (OPM).[8] The analysis-relevant MilTechs are those who work both at a maintenance facility and in a maintenance-related occupation. In an average month within the scope of this analysis, we observe 9,897 maintainer MilTechs, with 8,291 (84%) in occupations directly associated with ground equipment. The number of maintainer MilTechs declines slightly over the period.

b. Present, absent, and deployed MilTechs

Table 3 shows the mean monthly fraction of MilTech maintainers in each of the various statuses present in our data. Approximately 4% of maintainers are deployed in a given month, and an additional 5% of maintainers are absent from the shop but not deployed.[9] We exclude absent maintainers from calculations of available manpower, which is relatively constant at the shop level over time.

Table 3. Monthly Average Share and Standard Deviation of MilTech Maintainers in Each Employment Status

	Present	ADOS-RC	Deployed	Non-Deployment Absence
Mean	0.89	0.01	0.04	0.05
Standard deviation	0.042	0.005	0.029	0.012

Note: Means and standard deviations are taken on the monthly share of eligible MilTech maintainers in each of the employment statuses. Non-Deployment Absence denotes a maintainer who is not present for his or her civilian role for a reason other than a deployment (e.g., mobilization).

c. Active Duty for Operational Support, Reserve Component

MilTech labor may be supplemented by individuals on Active Duty for Operational Support, Reserve Component (ADOS-RC) orders. Unlike those acting in a MilTech role, individuals on ADOS-RC orders are not bound to a 40-hour workweek. Maintenance facilities with surge labor requirements may place either MilTechs or traditional guardsmen on ADOS-RC orders during times of peak demand. In the data used for this research, the median ADOS-RC tour lasts four days. We include ADOS-RC tours for individuals with

[7] Also note that a MilTech maintainer's civilian role may or may not involve work in the same maintenance facility that serves the equipment assigned to his or her drilling unit.

[8] Office of Personnel Management, *Handbook of Occupational Groups and Families*, https://www.opm.gov/policy-data-oversight/classification-qualifications/classifying-general-schedule-positions/occupationalhandbook.pdf.

[9] Mobilized maintainers are not specifically excluded from analysis, since a maintainer may be mobilized and still work in a maintenance facility to prepare for a deployment. However, on average, 96% of mobilized maintainers in a month have a pay status indicating an absence from civilian responsibilities, so mobilized maintainers are rarely included as active maintainers.

a maintenance-related primary Military Occupational Specialty (MOS), and assign these personnel to the maintenance facility that supports their drilling units. ADOS-RC data availability determines the beginning of the analysis period for this research.

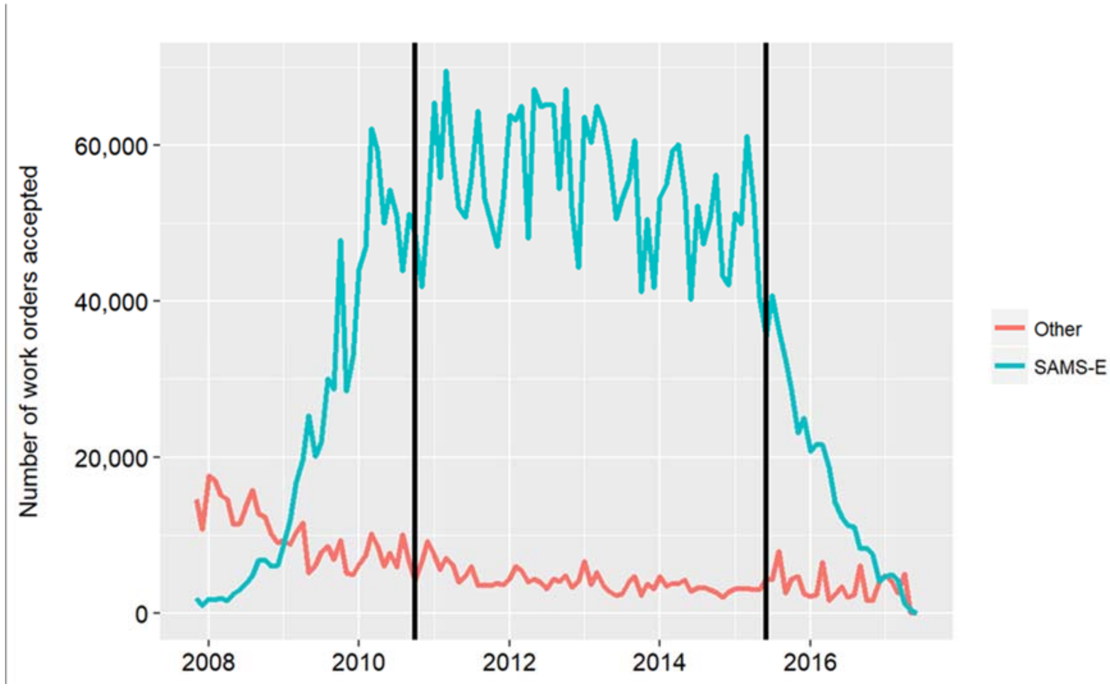
C. Work Order Data

Data provided by the ARNG describe the equipment work orders, their durations, and the equipment serviced by maintenance facilities. Maintenance facilities record these data and transmit them to the U.S. Army Materiel Command Logistics Support Activity (LOGSA) for storage.[10] A total of 3.3 million work orders exist for the period of analysis, primarily generated within the Standard Army Maintenance System-Enhanced (SAMS-E). In 2015, the ARNG began migration from SAMS-E to the Global Combat Support System-Army (GCSS-Army); the resulting decline in captured work orders is visible in Figure Figure 5. We tailor our period of analysis to the period covered by SAMS-E.

In determining the population of research-eligible work orders, we excluded those

- submitted to facilities located in the states Montana (MT), New Mexico (NM), UT, and VT (8.6%) as they cannot be matched to maintenance personnel (see Section 2.D.2);
- submitted to facilities located in Guam, Puerto Rico, or the U.S. Virgin Islands (4.5%);
- submitted to active component maintenance facilities (less than 1%);
- submitted to units not identified as maintenance facilities (5.1%);
- missing information in key fields (5.3%); or
- with duplicate tracking numbers (less than 1%).

[10] We use the WON_R, STATUS_R, ITEM_ALL, and D_UIC tables maintained by LOGSA in this research.



Note: *Other* includes work orders submitted through systems predating SAMS-E. Work orders submitted through GCSS-Army are not represented in this figure. The vertical lines mark the period of analysis.

Figure 5. Work Order Volume by Input System

We measure work order duration by counting elapsed weekdays, and use detailed information on work statuses to identify the periods of time maintainers can contribute to completion of a work order.[11] Information on work order status is available for 80% of eligible work orders. We include the remaining 20% in calculations of shop workload, but do not analyze them directly.

Figure 6 illustrates the average time that work orders in the regression set spend in each status. Vehicles typically wait 15 days for parts. CSMS and MATES vehicle work order experiences are similar to those at FMS facilities. Some statuses—such as waiting for parts—are not in the direct control of the maintainers at the maintenance facility. We remove the time spent in these statuses from our analysis. When calculating work order duration for this analysis, we sum the elapsed working days spent in the following statuses: awaiting initial inspection, in shop, awaiting shop, scheduled maintenance, awaiting parts but work continues, awaiting final inspection, and final inspection. We exclude weekends and federal holidays when computing the number of days elapsed in a given status.

Maintenance may stall while waiting for a part on order. Figure 6 illustrates that waiting for parts differentially impacts the amount of time required to complete work orders across equipment categories. We assume that after identifying an out-of-stock part

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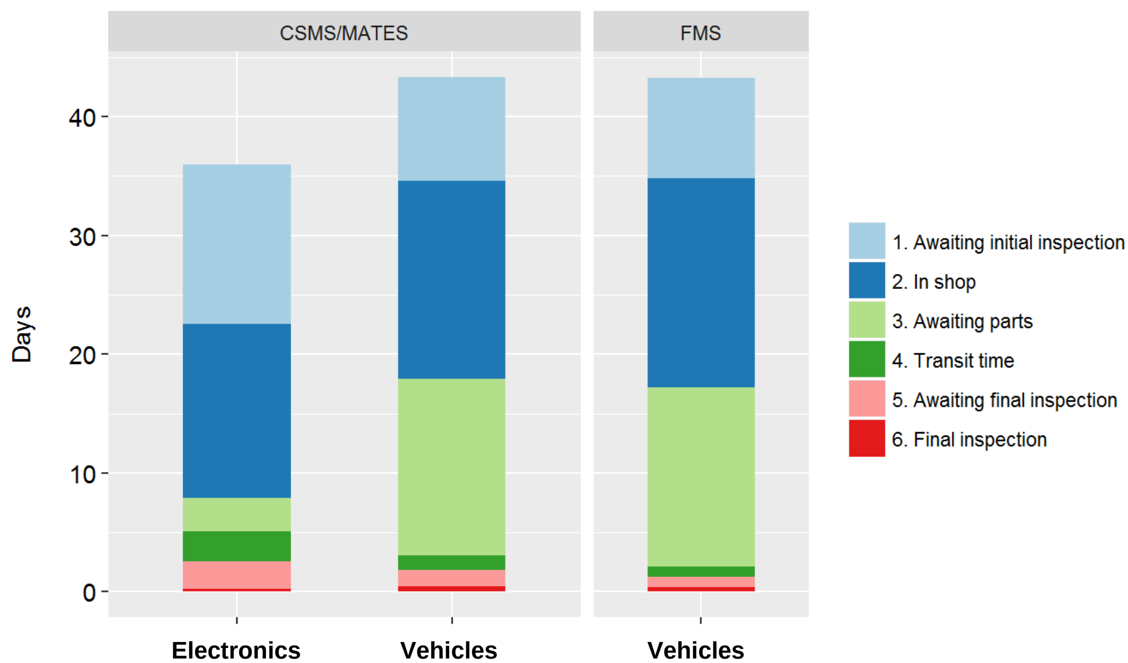
[11] DA PAM 750-8 Table B-21 provides a comprehensive list of these work order statuses and their corresponding descriptions.

need and placing an order, maintenance facility staff are unable to impact the timing of parts arrival, and therefore remove open work days coded as "waiting for parts" from the calculation of working days required to complete the work.

Interpretation of work order durations for shops in states with alternate schedules is somewhat different than for shops in states with traditional 5-day workweeks. For example, in states operating their shops on a 4 days x 10 hours/day schedule, the duration calculation outlined above includes days of the weekend in the computed work duration. We do not remove these days, because shops in alternate workweek states still experience the same number of total working hours in the course of the week. Reducing the number of elapsed days would thus alter the interpretation of the resulting duration.

In the case of work transferred between facilities, we identify and remove time spent in statuses related to an evacuation event from the calculated elapsed days spent at the original maintenance facility.[12]



Note: Chart presents averages for work orders in the eligible set.

Figure 6. Mean Days a Work Order Spends in Each Status

12 Statuses L, M, and N from DA PAM 750-8 Table B-21, which correspond to *EVAC NMCS*, *EVAC NMCM*, and *EVAC Depot*, respectively. Status O, *Awaiting evacuation*, is excluded because work orders appear to transition between other statuses and status O prior to the actual evacuation.

D. Personnel Data

Data provided by the ARNG describe the uniformed personnel using the equipment represented in the work orders, the technicians that staff the maintenance facilities, and the auxiliary military personnel on temporary orders to support maintenance facilities.

1. Uniformed Personnel

The ARNG Personnel Programs, Resources and Manpower Division (ARNG-HRM) Analysis Branch provided data on Uniformed Personnel (UP) for these analyses, drawn from the ARNG G1 Lifecycle Data Warehouse. The UP data consist of approximately 19 million person-month records. From these data, we capture both individual-month-level characteristics of the maintainers who staff the maintenance facilities and unit-month-level characteristics of the customer units submitting work orders.

The UP data provide a comprehensive record of each individual's MOS, including primary, secondary, position, and duty MOS; status as a full or part-time guardsman; Title 32, Title 10, or MilTech status; position title; enlisted or officer rank; and years of service completed in the ARNG. Each record also contains two binary fields indicating whether an individual was deployed or mobilized in a given month.

Unit-level characteristics obtained from the UP data include Unit Identification Code (UIC), state, unit name, and unit type (Modified Table of Organization and Equipment [MTOE] or Table of Distribution and Allowances [TDA]). We calculate the share of personnel in each UIC-level unit deployed in each month, and consider a unit deployed if 70% or more of its personnel are deployed in a given month. Once a unit is considered deployed, we smooth any intervening one- or two-month periods wherein less than 70% of the unit is deployed to produce a single, contiguous deployment.[13]

2. MilTech data from the CMIS

The ARNG-HRM Analysis Branch provided monthly data on the full-time civilian positions of all dual-status MilTechs in the ARNG data for these analyses, drawn from the CMIS. We use the CMIS data to identify which MilTechs are maintainers, and which maintenance facilities these maintainers support. The CMIS data contain approximately 1.9 million person-month records and approximately 52,000 unique individuals in the period of analysis, of which approximately 564,000 person-months and 16,000 individuals are eligible for analysis. From the population of MilTech maintainers, we remove personnel records for individuals

[13] This smooths small variations in deployed headcount as individuals are removed from theater for various reasons, and impacts a small number of records.

- in non-ARNG units (10% of person-month records);
- in aviation maintenance units (16%);
- in Guam, Puerto Rico, or Virgin Islands (2%);
- who cannot be matched to the UP data (1%);
- with duplicated person identifiers (0.1%)[14]; or
- in the states of MT, NM, UT, and VT (4%).

Personnel records in the states of MT, NM, UT, and VT are associated with Joint Force Headquarters (JFHQ) units alongside non-maintenance staff performing standard JFHQ functions. This administrative data-management practice prevents us from attributing MilTechs to maintenance facilities and work orders for these states, forcing us to exclude them from analysis.

The CMIS data contain several fields describing an individual's employment, including OPM's four-digit occupational series characterizing the type of work an individual performs into 83 groups within the eligible set.[15] We use the occupational series field to classify maintainer types. The position title is much more specific than the occupational series and helps us classify any ambiguous occupational series. CMIS also includes a supervisor status field that shows whether a MilTech with managerial responsibilities is a "Supervisor or Manager," "Supervisor (CRSA)," "Management Official (CYSA)," "Leader," or "Team Leader."[16]

The pay status field shows whether MilTechs are present for work in a given month.[17] Approximately 90% of person-months have a pay status code of P, indicating that a MilTech is present in his or her civilian position. A sizeable share of person-months (10%) has pay status U or Q to denote an absence due to military service. It is important to note that the pay status field does not signify when an individual is deployed. CMIS only

[14] Approximately 0.2% of total person-months in the period of analysis have duplicated identifiers, but are not completely duplicated records. Two records with the same identifier typically differ in an administrative field, such as effective appraisal date, or a sequence number used as an index of events. These differences do not carry analytical significance.

[15] Office of Personnel Management (OPM), *Handbook of Occupational Groups and Families.* https://www.opm.gov/policy-data-oversight/classification-qualifications/classifying-general-schedule-positions/occupationalhandbook.pdf.

[16] OPM, *The Guide to Data Standards*. https://www.opm.gov/policy-data-oversight/data-analysis-documentation/data-policy-guidance/reporting-guidance/part-a-human-resources.pdf.

[17] "OPM Pay Status:" https://dw.opm.gov/datastandards/referenceData/1499/current?d-5590585-p=5.

provides information on the civilian position status of MilTechs.[18] Unfortunately, the weekly hours field does not capture any variation in hours worked.

We calculate MilTech tenure using the *Dt Arrived Personnel Office* field in CMIS. As shown in Table 4, the mean MilTech maintainer tenure across all person-months is nine years. Additionally, an individual's date of birth is provided in CMIS, enabling calculation of MilTech age.

3. Active Duty for Operational Support, Reserve Component

The ARNG office of the G-1 provided data from pay tape files on all ADOS-RC tours in potentially relevant type of duty codes (TDCs) during the period of analysis. These data contain approximately 1.1 million ADOS-RC tours associated with approximately 276,000 individuals, and provide start and end dates, TDCs, and a tour mission description.

Traditional guardsmen and MilTechs may be activated on ADOS-RC to serve a variety of purposes. We desire to capture any additional manpower that maintenance facilities gain through these tours in support of work order completion. ARNG G-1 provided a list of TDC descriptions identified as potentially contributing to maintenance activities. Overall, approximately 57% of tours and 80% of individuals in the ADOS-RC data correspond to potentially maintenance-relevant TDCs. The number of new tours peaks in August, September, and October, with November and December consistently containing fewer new tours. Of potentially maintenance-relevant ADOS-RC tours, we consider the approximately 130,000 tours (12% of total tours) completed by MilTech maintainers or by traditional guardsmen with a maintenance primary MOS as the set of maintenance-relevant tours, and attempt to assign them to maintenance facilities. Overall, we match approximately 4,000 ADOS-RC tours representing 52% of the maintenance-related ADOS-RC tour-months to a maintenance-facility-month. While a relatively low proportion of maintenance related ADOS-RC tours are matched to a maintenance facility, matched tours are longer on average (9 days at the median and 48 days at the 75th percentile) than relevant non-matched tours (4 days at the median and 9 days at the 75th percentile).

We identify maintenance-relevant ADOS-RC tours and attribute this labor to maintenance facilities using two methods. Unfortunately, the ADOS-RC data do not contain information on where the subject individual completes his or her tour. For ADOS-RC tours completed by individuals who also serve as maintenance MilTechs, we attribute each tour to the maintenance facility in which the individual performs MilTech duties. Approximately 1,000 (1% of maintenance-relevant ADOS-RC tours) match in this manner.

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[18] Approximately 0.1% of CMIS person-months indicate a pay status of present for civilian duties but correspond to a deployed status in the uniformed personnel data. We assume that individuals are deployed in these months and do not consider them in the analysis.

We also retain tours for traditional guardsmen with a maintenance-related primary MOS, and assign them to the FMS facilities that support their drilling unit. In total, approximately 3,000 tours (2% of maintenance-relevant ADOS-RC tours) match to eligible FMS facilities through the customer units.[19]

Since the ADOS-RC data provide the day of the month that a tour starts and finishes, we count only the fraction of each month an individual was activated on ADOS-RC. For the analysis, a MilTech on ADOS-RC for part of a given month is counted as a regular MilTech for the fraction of the month spent not on ADOS-RC.

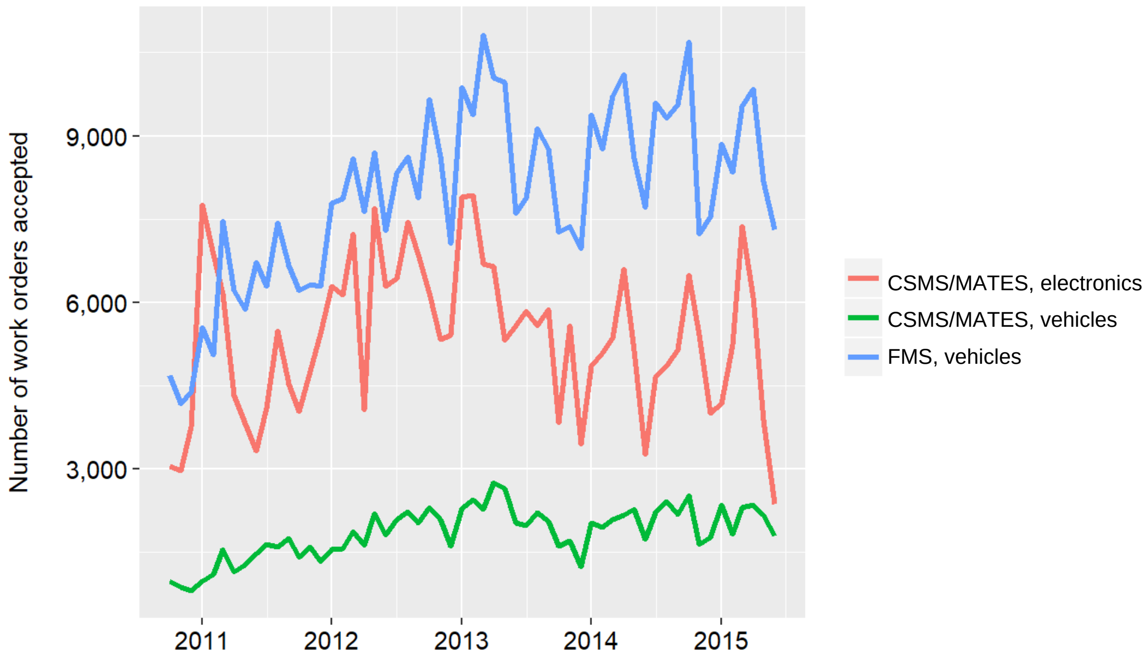

Figure 7. Regression Set Work Orders Receipts over Time, by Subset

E. Scoping by Facility and Equipment Type

The period of analysis spans October 2010 through June 2015, and includes 3.3 million raw work orders across all equipment types and 1.8 million raw MilTech-months. To link the work orders with the personnel completing the requisite work, we merge the work order and personnel data on social security numbers, customer and maintenance UICs, and calendar month. We then scope the analysis by facility and equipment type.

[19] Individuals in a customer unit with a primary MOS that relates to a specific ECC group are assigned proportionally to all supporting FMS facilities with an open work order on the corresponding ECC group. If there is no supporting FMS with work on the corresponding ECC group in an active-tour-month, then this individual is assigned proportionally to all supporting FMS facilities. Likewise, all individuals in a customer unit with a maintenance-related MOS that does not match to a single ECC group are assigned proportionally to each supporting FMS.

To determine the type of each maintenance facility, we parse maintenance unit names. This process yielded 474 FMS, 63 CSMS, 20 MATES, and 37 UTES facilities among eligible records in the period of analysis. FMS facilities are widespread in the ARNG and perform a work volume that is adequate to support analysis without combining with other facility types. However, workloads at the remaining facility types do not, and we therefore consider how the remaining facilities might be most appropriately pooled together for analysis. Because CSMS and MATES facilities are relatively similar along the dimensions of staff skill profile and overall size, we combine CSMS and MATES facilities in the same regression set. The staff skill profile and complement at UTES facilities differentiate them from CSMS and MATES facilities, and the type of work and usual work flow at UTES facilities differentiate them from FMS facilities. As a result we cannot combine UTES facilities with other facility types, and do not include them in this analysis.

We focus on vehicles and electronics equipment to isolate the most comparable subset of work, improve our ability to match work with the relevant maintainer skills, and analyze work order populations of a size sufficient to avoid bias in the estimates. Population size and data consistency concerns led us to exclude small arms, artillery, and other equipment categories.[20] Overall, we retain 74% of ground maintenance MilTech-months and 70% of work orders in the set of records eligible for this analysis.

We define "vehicles" as tactical vehicles, combat vehicles, and tanks (ECC groups H, G, and F, respectively). While significant differences exist between these equipment types, the personnel data do not distinguish between vehicle maintainers for tracked versus wheeled equipment. Analyzing these groups separately is inappropriate because of the expected high degree of overlap in maintenance skill sets required for these items, and relatively small tanks and combat vehicles work order pools. We therefore combine work orders for ECCs H, G, and F into a single regression set.

A large volume of electronics work orders are available in the data, and we expect this work to closely correspond with identifiable maintainer skills. On average, each CSMS has eight and each MATES has six electronics maintainers, as shown in Table 1. Electronics work orders represent more than one piece of equipment in 4.2% and 3.2% of work orders received by CSMS and MATES facilities, respectively. Given the sufficient volume of work orders and robust, identifiable population of relevant maintainers, electronics work orders represent a viable category for analysis of CSMS and MATES facility performance. We exclude electronics work orders submitted to FMS facilities from

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[20] Survival analyses regressions on small populations are likely to produce biased estimates when a large number of categorical variables are present. See Section 3 for discussion. In the case of small arms, recording of the number of items inspected or serviced is inconsistent, both within and across shops over time. This prevents its analysis, despite the significant number of work orders.

the eligible set, as FMS facilities have very few electronics maintainers, and generally send this work to CSMS facilities.

Because many work orders presented at CSMSs have been evacuated from FMSs and are difficult to track back to their customer units, FMS work orders match to customers more frequently than those at CSMS facilities. Linking evacuated work through the referring facility to its original customer, we retain 81% of FMS, 67% of CSMS, and 62% of MATES raw work orders and 75% of maintainer-months in the eligible set (see Table 4 and Table 5). After further limiting the population to work orders with available workflow status, we retain 60% of raw work orders and 74% of raw MilTech-months. Column 4 of Table 4 and column 3 of Table 5 display the eligible set of records. Column 4 of Table 5 further displays the set of eligible work order records following equipment family and shop type restrictions.[21]

The resulting populations of MilTechs and work orders comprise the eligible sets displayed in column 4 of Table 4 and column 3 of Table 5, respectively, with in-scope work orders shown in column 4 of Table 5. The final columns of Table 4 and Table 5 present the regression set, which represents the eligible set after removing case-wise missing observations. Overall, the regression set includes 31% of the raw work orders, 27% of the raw MilTech-months, and 67% of MilTech maintainer-months. Additionally, 87% of FMS, 75% of CSMS, and 69% of MATES facilities observed in the raw CMIS data are retained in the regression set.

[21] The impact of work order restrictions is not shown separately in Table 4, as it reduces the set of included maintainers by a relatively small amount.

Table 4. CMIS Reconciliation Table
Part 1 of 2

	Raw Data	ARNG shops in US States and DC	Eligible States	Eligible Set	Regression Set
MilTech person-months, all records	1,850,044	1,335,541	1,263,899	564,118	492,394
Share remaining	*100.0%*	*72.2%*	*68.3%*	*30.5%*	*26.6%*
MilTech non-ground-maintainer person-months	1,220,603	789,417	740,208	91,526	73,612
MilTech ground maintainer person-months	**629,441**	**546,124**	**523,691**	**472,592**	**418,782**
Share remaining	*100.0%*	*86.8%*	*83.2%*	*75.1%*	*66.5%*
Present for duty in shop	561,078	485,831	465,774	421,886	374,398
ADOS-RC	5,411	4,776	4,581	4,148	3,621
Deployed	27,127	24,214	23,144	20,919	18,054
Otherwise absent	35,825	31,303	30,193	25,639	22,709
Specialty					
Mobile	471,152	437,813	420,048	387,915	340,354
Electronics or communications	89,597	60,245	57,622	46,365	41,850
Other	68,692	48,066	46,021	38,312	36,578
Characteristics					
Age in years	39	40	40	40	40
Years of MilTech Service	9	9	9	9	9
Years of ARNG Service	17	18	18	18	18

Note: From the raw CMIS data, we remove non-ARNG units (5% of maintainer-months), aviation maintenance units (6%), outside the continental United States (OCONUS) territories (2%), and duplicated social security numbers (0.1%). Then, after removing states with poor match rates between CMIS maintenance facilities and WON_R, we exclude MilTechs not matched to the uniformed personnel (1%), maintenance facilities not matched to WON_R (6%), and maintenance facilities without a customer unit (1%) to arrive at the eligible MilTech population. To arrive at the regression set, we drop any maintenance facilities in WON_R without any work orders in a month that match to STATUS_R (1%) and UTES facilities and all other case missing values that are necessarily dropped during modeling (7%). The eligible set excludes all records not matching UP, maintenance facilities in WON_R, or customer units. The regression set excludes work orders not matching STATUS_R, records at a UTES, and all case-wise missing values.

Table 4. CMIS Reconciliation Table
Part 2 of 2

	Raw Data	ARNG shops in US States and DC	Eligible States	Eligible Set	Regression Set
Unique MilTechs	52,481	36,723	34,863	15,703	14,028
Ground Maintainers	17,607	14,531	13,929	12,870	11,865
Non-maintainers	36,649	23,424	22,075	3,420	2,667
Share of ground maintainers remaining	*100.0%*	*82.3%*	*79.2%*	*73.1%*	*67.4%*
Unique MilTechs on ADOS-RC	24,601	18,730	17,719	8,266	7,333
Unique ground maintainers on ADOS-RC	8,979	7,832	7,501	7,024	6,342
Unique UICs of type:	2,274	2,034	1,969	604	553
Field Maintenance Shop	542	529	508	474	472
Combined Support Maintenance Shop	84	81	79	63	63
Maneuver Area Training Equipment Site	26	25	24	20	18
Unit Training and Equipment Site	44	44	43	37	0
Other location	1,471	1,355	1,315	10	0
Mean ground maintainers per shop month at:					
Field Maintenance Shops	9	9	9	10	10
Combined Support Maintenance Shop	40	39	39	43	43
Maneuver Area Training Equipment Site	56	51	53	56	55
Unit Training and Equipment Site	18	17	17	18	0
Other location	1	1	0	2	0

Note: The number of unique MilTechs does not equal the number of unique ground maintainers plus non-maintainers because an individual can change MilTech occupations over time. The number of unique MilTech maintainers on ADOS-RC tours during our period of analysis is greater than the number of maintainer-months spent on ADOS-RC due to the relatively short duration on ADOS-RC tours and the fact that we count the fraction of a month spent on ADOS-RC. Units in CMIS are identified using a combination of the Organization field and the D_UIC table. In particular, the UNT_DESC field in D_UIC is used to retrieve the maintenance facility of each UIC. For UICs without a UNT_DESC in D_UIC, the Organization field in CMIS is used.

Table 5. Work Order Reconciliation Table

Part 1 of 2

	Raw Data	Eligible States	Eligible Set	In-scope Equipment Types	Regression Set: FMS: Vehicles	Regression Set: CSMS & MATES: Vehicles	Regression Set: CSMS & MATES: Electronics
Unique Support Units	891	678	604	600	472	81	81
Unique FMS Support Units	529	492	474	474	472	0	0
Unique CSMS Support Units	72	66	63	63	0	63	63
Unique MATES Support Units	22	20	20	20	0	18	18
Unique UTES Support Units	41	38	37	37	0	0	0
Unique Other Support Units	74	62	10	6	0	0	0
Work Orders and Units							
Total Work Orders	3,339,679	3,076,238	2,358,833	1,371,554	452,784	105,440	305,946
Total Unique Units	7,426	6,640	5,726	5,457	4,301	3,457	3,913
Unique Support Units	891	678	604	600	472	81	81
Unique Customer Units	7,277	6,633	5,131	4,862	3,829	3,376	3,832
Submitted Work Orders							
Median per Support UIC	2,011	2,510	2,431	1,557	855	1,121	2,492
Median per Customer Unit	229	247	270	159	59	8	32
Submitted to:							
FMS	1,496,002	1,420,342	1,222,475	796,100	452,784	0	0
CSMS	1,234,239	1,180,717	831,703	424,917	0	74,462	283,122
MATES	215,749	177,354	135,205	66,301	0	30,978	22,824
UTES	141,987	131,812	117,497	67,228	0	0	0
Other Units	169,629	166,013	51,953	17,008	0	0	0

Note: In moving to the eligible set, we match customer UICs from work orders to personnel data on customer units. Excluded work orders are those that do not match to the personnel data. The regression set consists of three regression populations including vehicle work orders submitted to FMS facilities, vehicle work orders submitted to CSMS and MATES facilities, and electronics work orders submitted to CSMS and MATES facilities.

Table 5. Work Order Reconciliation Table
Part 2 of 2

	Raw data	Eligible States	Eligible Set	In-scope Equipment Types	Regression Set: FMS: Vehicles	Regression Set: CSMS & MATES: Vehicles	Regression Set: CSMS & MATES: Electronics
Work Orders by Type							
Reset	344,410	319,972	248,532	83,750	2,374	1,678	45,266
Service	739,835	684,013	590,005	392,902	168,617	28,507	67,889
Inspection	89,637	82,171	48,179	29,048	7,210	1,300	7,074
Turn-in	311,652	285,723	226,498	107,340	18,344	6,966	30,027
Update	59,789	57,416	48,262	45,242	288	157	22,938
Unknown	1,794,356	1,646,943	1,197,357	713,272	255,951	66,832	132,752
Work Order Completion Time							
Median Elapsed Days to Complete	42	43	43	43	42	47	36
Mean Elapsed Days to Complete	71	72	70	70	71	75	59
Median Working Days to Complete	26	25	25	25	29	32	22
Mean Working Days to Complete	45	44	43	43	49	51	38
Median Days Waiting for Parts	0	0	0	0	0	0	0
Mean Days Waiting for Parts	8	8	9	10	15	15	3
Completion Time by Shop Type							
Median Working Days to Complete							
FMS	25	25	24	26	29		
CSMS	24	23	23	23		33	22
MATES	33	29	31	30		29	33
UTES	26	26	26	29			
Other Units	45	46	81	62			

F. Describing the Regression Set

Table 6 through Table 9 and Figure 7 through Figure 9 present key features of the regression populations.

FMS facilities have smaller staffs than CSMS/MATES facilities, and almost all FMS maintainers specialize in vehicle maintenance, as illustrated in Table 6 and Figure 9. CSMS/MATES facilities are heavily staffed by mobile maintainers, but also include a large complement of electronics maintainers and those with other specialties. On average, ADOS-RC-allocated labor accounts for approximately 8% of total available labor in FMS facilities and approximately 6% in CSMS/MATES facilities. The standard deviation of the mean ADOS-RC allocation is high relative to the mean level, illustrating that ADOS-RC manpower is unevenly used and underscoring its importance as a surge labor source, which any analysis of ARNG maintenance labor productivity cannot safely ignore.

Turning to personnel characteristics in Table 6, we observe that maintainers' years of experience is similar across facility types, with electronics maintainers having on average more experience than vehicles maintainers. The maintainer:supervisor ratio is slightly higher at FMS than at CSMS/MATES facilities, perhaps due to a greater variety of team types at CSMS/MATES facilities. Finally, average AFQT scores for vehicle maintainers are consistent across locations, and notably lower than scores for electronics maintainers.

Each of the regression subsets contains a sufficient number of work orders to support analyses. Figure 7 presents work volumes for the regression subsets over time. Respectively, FMS vehicles, CSMS/MATES vehicles, and CSMS/MATES electronics works orders require on average 71, 76, and 59 overall days to complete, with 34, 36, and 35 days of those periods potentially impacted by maintainer effort. The ratio of maintainer influence days to overall open days varies across regression subset. Based on our categorization of the work order statuses illustrated in Figure 6, approximately 47% of vehicle work order open days and 60% of electronics work order open days are available for maintainer effort. This is consistent with the significantly smaller amount of time electronics work orders spend awaiting parts.

As indicated by Table 6, relatively few work orders in the regression population are submitted by a unit preparing for deployment within the next year. A small amount—5%—of FMS vehicles work is referred to another shop, and almost no work is received from another shop. By contrast, 18% of CSMS/MATES vehicles workload and 46% of CSMS/MATES electronic workload is received from other shops. This is consistent with the CSMS/MATES missions, and reflects their broad skill profiles.

We expect that equipment type will impact the time required to complete repairs. Table 7 displays the most common two-digit ECCs in the regression set. The category of tactical vehicles—trucks, in particular—dominates the vehicle regression pool. Similarly, the infrared surveillance systems category dominates the electronics category.

As shown in Table 9, work order duration is consistent at all duration percentiles across the regression subsets. Since the regression set includes work orders received between October 2010 and June 2015 and the work order data were obtained in 2017, very few work orders are naturally censored. To avoid distortions in the estimated coefficients from outlier work orders open for extremely long time periods, we truncate durations at the ninetieth percentile, noting that the maximum durations are an order of magnitude larger than the 90th percentile values in each regression subset.

Table 6. Regression Set Features

	FMS	CSMS & MATES	
	Vehicles	Vehicles	Electronics
Shop Characteristics			
Shop count	472	81	81
Vehicle maintainer headcount	10.1	31.2	28.2
Electronics maintainer headcount	-	8.0	10.2
Other maintainer headcount	0.4	7.0	9.5
ADOS-RC allocated headcount	0.8	2.7	3.0
Shop open work orders per MilTech maintainer	14.6	13.2	21.5
Maintainer Experience			
Median maintainer tenure in years	7.1	7.7	8.6
Share with < 1 year experience	0.06	0.06	0.05
Share with < 2 years experience	0.12	0.11	0.11
Maintainer:Supervisor ratio	5.8	4.4	4.7
Mean maintainer AFQT score	52.3	52.8	65.3
Work Order Characteristics			
Count	452,784	105,440	305,946
Average open days	70.7	75.5	59.0
Average working days	48.8	50.9	37.6
Average days under maintainer influence	33.6	35.9	34.7
Share for a customer deploying in 1 year or less	0.04	0.04	0.07
Share referred to another shop	0.05	0.02	0.02
Share received from another shop	0.01	0.18	0.46

Note: Statistics are either counts or means taken across all work orders in the respective population

Table 7. Equipment Included in the Regression Populations

	FMS		CSMS		MATES	
Vehicles						
ECC Group H: Tactical Vehicles	**448,226**	***100%***	**72,152**	***100%***	**22,636**	***100%***
Trailers	64,207	*14%*	9,084	*13%*	3,096	*14%*
Trucks, 0.25 - 1.25 tons	194,961	*43%*	33,335	*46%*	8,047	*36%*
Trucks, 2.5 - 10 tons	161,802	*36%*	26,173	*36%*	9,075	*40%*
Other	27,256	*6%*	3,560	*5%*	2,418	*11%*
ECC Group G: Combat Vehicle	**4,336**	***100%***	**2,147**	***100%***	**6,804**	***100%***
Armored recon air assault vehicles	278	*6%*	275	*13%*	1,606	*24%*
Carriers, command post	627	*14%*	400	*19%*	750	*11%*
Personnel carriers	1,618	*37%*	409	*19%*	2,111	*31%*
Self-propelled howitzers	494	*11%*	317	*15%*	689	*10%*
Other	1,319	*30%*	746	*35%*	1,648	*24%*
ECC Group F: Tanks	**222**	***100%***	**163**	***100%***	**1,538**	***100%***
90MM, 105MM, 120MM	171	*77%*	115	*71%*	1,538	*100%*
Other	51	*23%*	48	*29%*	0	*0%*
Electronics (ECC Group J)			**283,122**	***100%***	**22,824**	***100%***
Communications security equipment			14,632	*5%*	1,145	*5%*
Infrared surveillance systems			169,971	*60%*	14,189	*62%*
Operation central communications			28,991	*10%*	1,979	*9%*
Radios			33,864	*12%*	3,922	*17%*
Other			35,664	*13%*	1,589	*7%*

Note: The work orders presented here are included in the regressions. The category names excluding *Other* are referenced from DA PAM 750-8 (2005), Table B-18 and correspond to the list of two-digit ECCs. In particular, the category description *90MM, 105MM, 120MM* is taken directly from the table and does not permit further investigation into the nature of the tanks included.

Table 8. Mean Monthly Work Orders Received, by Facility Type

	All Work Orders	Eligible Set	Regression Set
FMS			
Vehicle ECCs	23	23	20
Electronics ECCs	23	20	0
Other ECCs	22	19	0
CSMS/MATES			
Vehicle ECCs	39	30	25
Electronics ECCs	107	93	81
Other ECCs	145	106	0

Note: Presented statistics are mean submitted work orders taken at the maintenance facility month level.

Table 9. Distribution of Work Order Days Potentially Impacted by Maintainer Effort

Percentile	FMS	CSMS/MATES	
	Vehicles	Vehicles	Electronics
0th	1	1	1
20th	7	9	9
40th	14	18	17
60th	26	30	27
80th	50	54	48
100th	812	768	627

Note: Percentiles are computed on the work order open days available for maintainer effort, for each regression subset. Days available for maintainer effort excludes time spent in transit or awaiting parts.

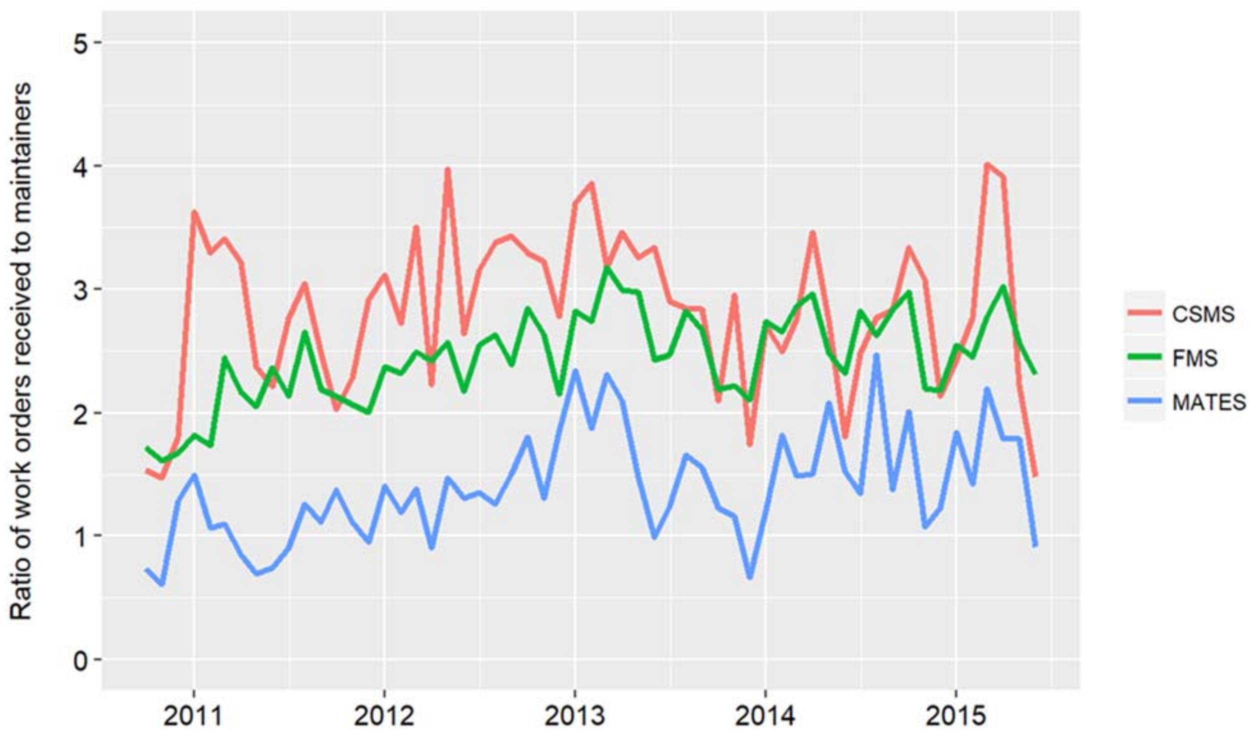
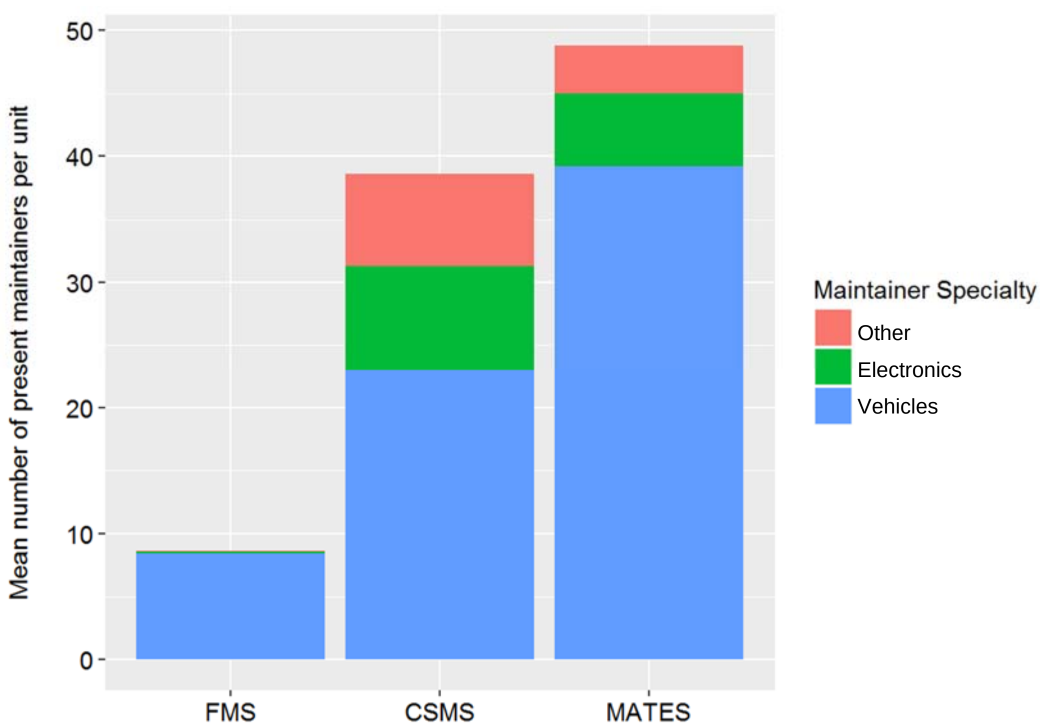


Figure 8. Work Orders Received Per Maintainer Each Month by Shop Type



Note: Means for maintenance facilities in the regression set.

Figure 9. Mean MilTech Maintainer Headcounts by Worker Specialty and Facility Type

3. Estimation Methodology

In this research, we apply survival analysis methods to determine the effect of MilTech manning on ground equipment work order time to completion $T \geq 0$, with time measured in days. We empirically estimate the distribution of time-to-completion *F(t),* as well as the contribution of factors such as MilTech manning levels to the shape of *F(t)*. In this context, "survival" indicates a work order remaining open, as opposed to transitioning to closure.

Two measures of particular interest can be derived from the distribution: the survival function *S(t)* and the hazard function *h(t)*. The survival function measures the fraction of work orders that remain open for at least *t* days. For instance, *S(0)* is equal to 1, since all work orders remain uncompleted by time 0. On the other hand, if *t_median* denotes the median completion time, then *S(t_median)* equals 0.50. Formally, *S(t) = 1-F(t)*.

The hazard function, when formulated in a context of discrete day units, represents the probability of a work order transitioning from open to closed during day *t*, conditional on being open until at least day *t*. In this research, we model time as a continuous variable, but the discrete-time hazard function intuition carries through for continuous time. Formally, *h(t) = f(t)/S(t)*, where *f(t)* is the probability density function. A priori, one might expect the hazard function for work orders to either be constant or increase with time. However, one might instead observe a declining hazard for the overall sample if work orders are heterogeneous with respect to difficulty and the easier work orders are closed first, leaving behind a population of increasingly difficult open work orders as time progresses.

The generalized gamma distribution offers both the most flexible hazard fit possible among standard parametric distributions and the ability to model the linear function:

$$\ln(T) = X\beta + W \tag{1}$$

where X is the covariate vector, β is the corresponding coefficient vector, and W is an error term. This formulation is referred to as an Accelerated Failure Time (AFT) model. The generalized gamma, which is governed by three parameters, nests as special cases the two-parameter Weibull and lognormal distributions, as well as the one-parameter exponential distribution. These nested distributions yield AFT models, but the Weibull and exponential have the distinction of also being proportional hazards (PH) models in which the covariates are restricted to have a duration-invariant proportional effect on the base hazard function.[22] Among PH models, a popular choice is the non-parametric Cox PH model, which estimates the base hazard directly from the data, instead of fitting parametric distributions to the data.

While the non-parametric Cox model is attractive because of the lack of imposed assumptions on the hazard shape, we choose to use generalized gamma instead of Cox as our regression specification for three reasons. First, the three parameters of the generalized gamma distribution allow us to strike a balance between flexibility in modeling the hazard and implicitly imposing the identifying assumption of a smooth base hazard function, thus allowing deviations from a smooth hazard to be attributed to the influence of covariates. Second, the generalized gamma results can be presented in AFT form, whereas the Cox regression results cannot. Third, generalized gamma does not restrict covariates to have a time-invariant proportional effect on the hazard, whereas the Cox model does.

The density of the generalized gamma distribution is parametrized as follows:[23]

$$f(t;\mu,\sigma,\kappa) = \frac{|\kappa|}{\sigma t\Gamma(\kappa^{-2})}\left\{\kappa^{-2}(e^{-\mu}t)^{\frac{\kappa}{\sigma}}\right\}^{\kappa^{-2}} e^{-\kappa^{-2}(e^{-\mu}t)^{\frac{\kappa}{\sigma}}} \quad (2)$$

The parameter μ is modeled as $\mu = X\beta$, where X is the covariate vector and includes the MilTech manpower levels and other features.

We can arrange the generalized gamma in AFT form by expressing $\ln(T)$ as a function of $X\beta$ and error term W, which has density $f(w;\kappa) = \frac{e^{\kappa^{-2}w-e^{w}}}{\Gamma(\kappa^{-2})}$, as follows:[24]

$$\ln(T) = 2\frac{\sigma}{\kappa}\ln(\kappa) + X\beta + \frac{\sigma}{\kappa}W \quad (3)$$

Letting X_1 and β_1 denote manpower and its coefficient, respectively, the effect of X_1 on duration T can be found by taking the derivative of both sides of the above AFT equation with respect to X_1 and rearranging:

$$\frac{dT}{T} = \beta_1 dX_1 \quad (4)$$

Equation (4) holds approximately with non-trivially small changes ΔX_1:

[22] The base hazard is recovered, after estimation, as the hazard that would exist if all covariates set equal to zero.

[23] Cox and Matheson (2014), also "Stata: Release 13. Statistical Software." (College Station, Texas TX: StataCorp LP, 2013). This density is valid when κ is non-zero, which is confirmed in the actual estimation.

[24] This result is found in Kalbfleisch and Prentice (2002) Chapter 2, but with different parameterization. The AFT model presented here has been derived assuming that parameter κ is positive, for ease of exposition. This assumption is confirmed in the actual estimation. See Appendix E for details of the derivation.

$$\frac{\Delta T}{T} \approx \beta_1 \Delta X_1 \quad (5)$$

The interpretation is as follows: a ΔX_1 change in manpower X_1 is associated with a $100 \cdot \beta_1 \Delta X_1\%$ change in duration T. To estimate the vector β, we use the Stata econometric software package, which parametrizes the generalized gamma in the same manner as described previously.

The baseline specification for $X\beta$ that we estimate separately for samples of vehicles and electronic equipment work orders is

$$X\beta = \beta_1 maint_{veh} + \beta_2 maint_{elect} + \beta_3 maint_{other} + \beta_4 ADOS + \delta V \quad (6)$$

where

- $maint_j$ represents the headcount of MilTech maintainers identified as working in occupational area j;
- $ADOS$ captures person-months of available ADOS-RC labor;
- V is a vector of indicator variables including some or all of the following, depending on the specification:
  - Work order sent to another shop
  - Work order received from another shop
  - Work type category
  - Whether the work order was accepted in January – May
  - Equipment type in either five categories (for vehicles) or three (for electronics)
  - Customer deployment: deployed, and each of 1-3, 4-6, 7-9, and 10-12 months prior to deployment
  - Acceptance day of week
  - Maintenance facility

All covariates are time-invariant and fixed in the month the work order is received. Maintainer behavior, constraints on efficiency, and other factors otherwise unobservable are consistent within maintenance facilities. We cluster standard errors at the maintenance facility level.

We also implement variations of Equation (6) to explore potential nonlinearities in returns to manpower investments across variations in staffing and workload. We define "lagged open work orders" for a work order observation as the count of work orders open at the receiving shop in the month before the work order is received. We define "relative workload" on the regression population level as lagged open work orders, divided by the shop-month-level count of all maintainers present at a shop.[25] We then assign shops to tertiles, based on their average relative workload over the analysis period. "High relative workload" shops are in the upper third of the distribution and have the most work per maintainer on average; "moderate relative workload" shops are in the middle third of the distribution; and "low relative workload" shops are in the lower third of the distribution, and have the least work per maintainer on average. We explore potential nonlinearities in manpower returns in a series of specifications using the resulting relative workload tertile indicators, polynomials on labor and lagged open work orders covariates up to the third degree, and combinations of these covariates.

Using work orders as the unit of analysis overrepresents work orders from facilities receiving more work. To make results interpretable at the maintenance facility level, we equally weight the input of each facility's probability weights. We construct the weights at the maintenance facility and equipment family level by dividing the number of vehicle or electronics work orders by the corresponding number of vehicle or electronics work orders received by each maintenance facility during the period of analysis.

Maximum likelihood estimators of the key coefficients of interest are known to be inconsistent when indicator variables are used to estimate fixed effects for subgroups whose size does not scale with the overall sample.[26] The resulting bias on key coefficient estimates is termed incidental parameters bias, and its magnitude decreases as the number of observations per subgroup increases.[27] While the econometrics and statistics literature does not have a widely generalizable guideline on a minimum threshold of observations per subgroup in an unbalanced panel setting, there are two highly stylized examples in the literature that suggest that a threshold of eight per subgroup would be sufficient.[28]

We check that the conditions for non-trivial incidental parameters bias do not exist when adding an initial set of maintenance facility indicator variables, and we also confirm in the next results section that the addition of more indicator variables does not materially change the coefficient estimates, since the overall number of work order observations is

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25 We use lagged open work orders to avoid endogeneity problems arising from considering the examined work order in the total workload term. Cyclicality in work flows and typical work order duration contribute to a high positive correlation in the count of open work orders from one month to the next.

26 An estimator is consistent if it converges to its true value as the sample size increases.

27 Bias is the difference between the expected value of the estimator and the true value of the parameter.

28 Lancaster (2000) surveys this literature and introduces the problem with a simple example in which the bias is equal to the reciprocal of the subgroup size. The common parameter of interest is a function of the incidental parameters and the estimation of the incidental parameters results in a loss of one degree of freedom per equally sized subgroup, thus biasing the common parameter estimate by the reciprocal of the subgroup size. Coupe (2005) runs Monte Carlo simulations with logistic estimation to show that eight observations per subgroup is a minimum threshold for manageable bias.

large. In particular, the maintenance facility indicator variables define a large number of subgroups, but the number of subgroups is fixed, while the size of each subgroup scales with the sample over time as more work orders are added over months and years. We show in Table 10 that the 1st decile of months of work orders received among maintenance facilities is 28 for FMS and 46 for CSMS/MATES facilities, implying slightly greater corresponding work order counts per shop at the 1st decile. Conversely, the month-of-acceptance indicator variables define subgroups that do not scale with the sample over time, but these subgroups are large, thus minimizing any resulting bias in coefficients.

Table 10. Panel Length

		Percentiles on Number of Months Observed Receiving Work Orders				
	Average Months	**0th**	**10th**	**Median**	**90th**	**100th**
FMS	48	1	28	54	57	57
CSMS/MATES	53	5	46	57	57	57

Note: The population is the regression set. Percentiles are formed on the number of months each maintenance facility is observed receiving work orders.

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4. Results: Maintainer Impact on Time to Complete Ground Maintenance Work Orders

We estimate the impact of maintainers on work order duration using variations on Equation (6) from Section 3 and find statistically robust and economically significant marginal impacts of ARNG MilTechs in many roles and facilities. Table 11 through Table 14 present duration regression coefficients, which are interpreted as the percent change in work order duration resulting from a one-unit increase in the given covariate. In all cases, the outcome variable is measured as the number of maintainer-relevant open work order days. We find statistically robust and economically significant marginal impacts of vehicle maintainers on reducing the duration of vehicle work orders in FMS and CSMS and MATES facilities. Table 15 translates these results into the incremental change in open work order days that would result from adding or removing MilTech maintainers of each type from a representative shop in each tertile. We are unable to identify a clear relationship between ARNG electronics MilTech maintainers and the duration of electronics work orders serviced in CSMS and MATES facilities. Appendix D presents complete results for the base regression specification, and plots of hazard functions and Cox-Snell residuals.

A. Vehicle Work at FMS Facilities

Table 11 presents variations on Equation (6), with each column containing coefficients from a separate regression. Specifications (1) and (2) pool maintainer headcounts for all FMS facilities, and do not account for potential nonlinearities in the marginal product of labor. The most basic, specification (1), includes vehicle maintainer and all other maintainer headcounts, ADOS-RC person-months, and indicators for whether the work order was referred in or out, accepted by the shop in months Jan-May, in one of four ECC categories, and individual maintenance facility. All coefficients are significant.

Accounting for customer unit deployment absorbs the statistical significance of ADOS-RC person-months, and confirms that ADOS-RC investments are made to meet surge labor demands related to deployment. Accordingly, we drop the ADOS-RC covariate in specification (2) and keep a set of indicators for time-until-deployment in its place.[29] We observe that work proceeds much faster for equipment owned by units approaching deployment—particularly in the four to nine months prior to deployment, wherein work is completed between 11% and 23% faster—and much slower for units already deployed. Specification (2) also includes indicators for work type and acceptance day-of-week.

[29] In addition to the presented covariates, we explored the potential impacts of state alternate work schedule, the timing of federal budget passage, and whether a shop is capable of handling more complex work. None of these significantly impacted time to work completion. All were excluded from the base specification (2).

Across all FMS facilities, we observe that adding a vehicle maintainer to a typical shop would reduce the working days on vehicle work orders at that shop by 2.4%, or 0.8 working days per work order on average. This result is statistically robust.

Table 11. FMS Vehicle Work Order Duration Regression Results

	(1)	(2)	(3)
Vehicle maintainers in shops from/with:			
All FMS facilities	-0.0271*** (0.00528)	-0.0242*** (0.00522)	
High relative workload			-0.0221*** (0.00740)
Moderate relative workload			-0.0322*** (0.00913)
Low relative workload			-0.0216* (0.0117)
Customer deployed		0.261*** (0.0975)	0.261*** (0.0975)
Customer deploys in 1-3 months		-0.108 (0.0949)	-0.110 (0.0947)
Customer deploys in 4-6 months		-0.235*** (0.0556)	-0.236*** (0.0555)
Customer deploys in 7-9 months		-0.102** (0.0411)	-0.102** (0.0411)
Customer deploys in 10-12 months		-0.0319 (0.0572)	-0.0315 (0.0571)

Note: Each column presents coefficients representing the estimated percent change in vehicle work order duration attributable to various regressors from survival analysis with generalized gamma parameterization. Work order duration is measured as the number of maintainer-relevant open work order days. Column (1) includes vehicle maintainer and all other maintainer headcounts, ADOS-RC person-months, and indicators for whether the work order was referred in or out, accepted by the shop in Jan-May, in one of four ECC categories, and individual maintenance facility. Column (2) includes covariates from column (1) less ADOS-RC person-months and plus indicators for customer unit deployment, work type, and acceptance day-of-week. Column (3) interacts the vehicles maintainer headcount with indicators for shop relative workload tertile, in addition to covariates from column (2).

Note: Statistical significance is displayed using * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

In specification (3), we investigate potential differences in MilTech productivity across variations in shop manning relative to workload by interacting vehicle maintainer headcount with shop-level "relative workload" tertile indicators.[30,31] Returns to additional vehicle maintainers differ slightly with shop workload, and are highest at FMS facilities with relative workloads in the center tertile. At these shops, adding a vehicle maintainer reduces working days on vehicle work orders by 3.2%, producing an additional 217 ready equipment days per shop year. The headcount-by-tertile results are individually statistically significant, but not significantly different from each other. Nonetheless, this slight curvature indicates where managers with limited budgets can invest for greatest impact. It is counterintuitive that returns to additional staffing are highest in the center tertile. As the production of ready equipment requires both capital and labor resources, this result suggests that capital resources may be under greater stress at high-workload FMS facilities.

Table 12 builds upon specification (2) from Table 11 to explore how variations in the personal characteristics of maintainers and additional shop features impact productivity. Specification (1) repeats the main result for reference. Our ability to analyze the impact of MilTech tenure on productivity is limited, due to the fact that the labor pool is very experienced: median tenure of FMS vehicles maintainers is 7.1 years, 94% have one than one year of experience, and 88% have more than two years of experience. High median experience implies that there are likely several seasoned maintainers present for every junior at the shop level. It is, therefore, unsurprising that specification (2) finds no statistically significant negative impact of junior staff on productivity.

Specification (3) of Table 12 includes the maintainer-to-supervisor ratio, or number of line maintainers divided by number of individuals flagged as supervisors in the CMIS data. Here, we observe a statistically significant effect: shops with relatively more line workers per supervisor perform better. This may result from the small overall size of FMS facilities, or the loss of a line worker when an individual is called upon to perform supervisory activities. Finally, specification (4) includes shop mean AFQT score. We do not observe a meaningful impact of higher mean AFQT on time to complete FMS vehicle work orders within the range of scores observed.[32] However, because individuals are assigned to occupations based in part on AFQT scores, we cannot conclude that ability (as measured by AFQT) has no impact on performance.

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[30] Relative workload is defined in Section 3.

[31] In addition to the specifications presented, we explored potential nonlinearities in manpower returns, using polynomials on labor, on lagged open work orders covariates up to the third degree and in various combinations. These specifications identified the same patterns as those in column (3) of Table 11. We present the tertile regression results, as coefficient interpretation is most intuitive.

[32] We impute AFQT to replace missing data for approximately 10% of vehicle maintainers, using the state-by-shop-type mean.

Table 12. FMS Vehicle Work Order Duration Regression Excursions

	(1)	(2)	(3)	(4)
Vehicle maintainers	-0.0242***	-0.0241***	-0.0214***	-0.0241***
	(0.00522)	(0.00524)	(0.00523)	(0.00523)
Electronics maint. share with >1 year tenure		0.0116		
		(0.0900)		
Maintainer-to-supervisor ratio			-0.00817**	
			(0.00365)	
Vehicle maint. mean AFQT score				-0.00102
				(0.00262)

Note: Each column presents coefficients representing the estimated percent change in vehicle work order duration attributable to various regressors from survival analysis with generalized gamma parameterization. Work order duration is measured as the number of maintainer-relevant open work order days. Column (1) includes vehicle maintainer and all other maintainer headcounts, ADOS-RC person-months, and indicators for whether the work order was referred in or out, accepted by the shop in Jan-May, in one of four ECC categories, and individual maintenance facility. Column (2) includes covariates from column (1) less ADOS-RC manmonths and plus indicators for customer unit deployment, work type, and acceptance day-of-week. Column (3) interacts the vehicles maintainer headcount with indicators for shop relative workload tertile, in addition to covariates from column (2).

Note: Statistical significance is displayed using * p<0.1, ** p<0.05, *** p<0.01.

B. Vehicle Work at CSMS and MATES Facilities

Table 13 presents regression results for CSMS/MATES vehicle work orders. Both specifications account for vehicle, electronics, and other labor specialties separately. Specification (1) also includes ADOS-RC person-months, indicators for each maintenance facility, and indicators for whether the work order was

- referred in or out
- accepted by the shop in January through May
- in one of four ECC categories, or
- individual maintenance facility.

All coefficients are statistically significant. Exploration of potential nonlinearities reveals no variation in returns to MilTech maintainer investments at CSMS/MATES facilities, and is not presented.

Across all CSMS/MATES facilities, we find that adding a vehicle maintainer to a typical shop would reduce the working days on vehicle work orders at that shop by 1.2%, or 0.4 working days per work order on average. Likewise, adding an electronics maintainer to a typical shop would reduce the working days on vehicle work orders at that shop by

2.0%, or 0.7 working days per work order on average.[33] Specification (2) adds time-to-deployment indicators. We again observe that ADOS-RC investments at CSMS/MATES facilities are strongly correlated with deployment, with work proceeding significantly faster for equipment owned by units between four to nine months from deployment. All results are statistically robust. Investigation of maintainers' personal characteristics and shop features yields no additional findings (see Table D-2 in Appendix D).

C. Electronics Work at CSMS and MATES Facilities

Table 14 presents duration regression results for electronics work orders received at CSMS and MATES facilities using covariates following the previous analyses. Model fit for the CSMS/MATES electronics work is unsatisfying, with weaker adherence of Cox-Snell residuals to the 45 degree line and lower absolute-value log likelihood than the vehicles regressions (see Appendix D). We observe small and statistically *insignificant* coefficients on all maintainer headcounts. These observations together suggest that factors influencing electronics work order productivity and correlated with staffing levels at these facilities are confounded with features not accounted for in our data and model. A limitation of this analysis is our inability to observe which skill sets or individuals contribute to each work order type, and the relative complexity of each work order. Additional data, or more thorough modeling of total workload, may more precisely identify returns to electronics maintainer investments for the electronics workload.[34] We can draw no conclusions about returns to personnel investments or the appropriateness of observed staffing levels at CSMS/MATES facilities with respect to the electronics workload.

[33] ARNG vehicle maintenance requires a broad array of skill sets, as these vehicles contain many sophisticated systems.

[34] For example, more detailed analysis of how different work types interact to impact manpower productivity is possible with current data (to some extent), and might illuminate interrelationships in productivity by work type.

Table 13. CSMS/MATES Vehicle Work Order Duration Regression Results

	(1)	(2)
Vehicle maintainers	-0.0124***	-0.0124***
	(0.00380)	(0.00372)
Electronics maintainers	-0.0212**	-0.0196**
	(0.00849)	(0.00850)
Other maintainers	0.00958	0.00988
	(0.0102)	(0.0105)
Customer deployed		0.307*
		(0.172)
Customer deploys in 1-3 months		-0.197
		(0.142)
Customer deploys in 4-6 months		-0.293***
		(0.0645)
Customer deploys in 7-9 months		-0.0968*
		(0.0566)
Customer deploys in 10-12 months		0.109
		(0.0718)

Note: Each column presents coefficients representing the estimated percent change in vehicle work order duration attributable to various regressors from survival analysis with generalized gamma parameterization. Work order duration is measured as the number of maintainer-relevant open work order days. Column (1) includes vehicle maintainer and all other maintainer headcounts, ADOS-RC person-months, and indicators for whether the work order was referred in or out, accepted by the shop in Jan-May, in one of four ECC categories, and individual maintenance facility. Column (2) includes covariates from column (1) less ADOS-RC manmonths and plus indicators for customer unit deployment, work type, and acceptance day-of-week. Column (3) interacts the vehicles maintainer headcount with indicators for shop relative workload tertile, in addition to covariates from column (2).

Note: Statistical significance is displayed using * p<0.1, ** p<0.05, *** p<0.01.

Table 14. CSMS/MATES Electronics Work Order Duration Regression Results

	(1)	(2)
Vehicle maintainers	-0.000493	-0.00128
	(0.00555)	(0.00487)
Electronics maintainers	-0.00718	-0.00480
	(0.0180)	(0.0147)
Other maintainers	0.0116	0.0134
	(0.0143)	(0.0108)
Customer deployed		0.0519
		(0.259)
Customer deploys in 1-3 months		-0.447***
		(0.164)
Customer deploys in 4-6 months		-0.560***
		(0.0891)
Customer deploys in 7-9 months		-0.316***
		(0.0806)
Customer deploys in 10-12 months		-0.0526
		(0.112)

Note: Each column presents coefficients representing the estimated percent change in vehicle work order duration attributable to various regressors from survival analysis with generalized gamma parameterization. Work order duration is measured as the number of maintainer-relevant open work order days. Column (1) includes vehicle maintainer and all other maintainer headcounts, ADOS-RC person-months, and indicators for whether the work order was referred in or out, accepted by the shop in Jan-May, in one of four ECC categories, and individual maintenance facility. Column (2) includes covariates from column (1) less ADOS-RC manmonths and plus indicators for customer unit deployment, work type, and acceptance day-of-week. Column (3) interacts the vehicles maintainer headcount with indicators for shop relative workload tertile, in addition to covariates from column (2).

Statistical significance is displayed using * p<0.1, ** p<0.05, *** p<0.01.

D. Change in Vehicle Ready Days from Additional Maintenance Manpower

To understand the economic impact of our vehicle maintenance findings, one must extrapolate across the total volume of work impacted by maintainer headcount changes at the shop level. Table 15 translates marginal percent changes in completion times (that is, coefficients from specification (3) in Table 12 and specification (2) in Table 13) into predicted days saved at the shop level, given maintainer headcount changes of -2 to +2 individuals with the specified skill set. These staffing additions and subtractions assume that all other staffing levels are unchanged; that is, we consider changes in total shop headcount, not reallocations among skill sets. We base these calculations on average facility features within each of the FMS and CSMS/MATES categories. Error bounds presented are the standard error of the predicted difference in mean annual throughput at a facility, which we derive in Appendix E.

Section 1 of Table 15 presents the impacts of changes in FMS vehicle maintainer headcounts among FMS facilities in each relative workload[35] tertile, all else equal, on the completion of vehicle work orders. Estimated impacts of an additional maintainer at high and moderate relative workload shops—those with average and above average workloads per maintainer—are large and statistically robust: a maintainer added to these shops produces an additional 202 and 217 ready equipment days per shop, respectively. Given approximately 260 working days per MilTech person year, investment of an additional vehicle maintainer at these shops results in a high rate of equipment ready days recaptured for the additional MilTech working days. Estimated impacts of an additional maintainer at low relative workload shops are also positive and statistically significant, with an additional maintainer estimated to produce an additional 81 ready equipment days. The addition of one maintainer to each FMS facility studied—or 472 FTEs—would produce approximately 79,000 additional ready equipment days each year across the ARNG, all else equal.

Section 2 of Table 15 presents the impacts of changes in vehicle and electronics maintainer staffing on vehicle work orders at CSMS and MATES facilities, all else equal. Facilities are not divided into relative workload tertiles, as analysis did not identify meaningful non-linearities in returns to staffing at the CSMS/MATES workload and manning levels observed in the data. Adding a vehicle or an electronics maintainer to a CSMS or MATES facility has a large and statistically robust impact on the time required

[35] We define "relative workload" as the count of work orders open at the shop in the month before the work order is received, divided by the shop-month-level count of all maintainers present at a shop. This allows exploration of potential nonlinearities in returns to manpower investments across variations in staffing and workload. We use lagged open work orders to avoid endogeneity problems arising from considering the examined work order in the total workload term. Cyclicality in work flows and typical work order duration contribute to a high positive correlation in the count of open work orders from one month to the next.

to complete vehicles work orders, resulting in 121 and 191 additional ready days each, respectively. The addition of one vehicle and one electronics maintainer to each CSMS and MATES facility studied—or 162 FTEs—would produce approximately 25,000 additional ready equipment days each year across the ARNG, all else equal.

These high rates of equipment ready days recaptured for additional investments in vehicles maintainers would be realized in practice if there is an existing work order backlog that the new maintainer would help to clear over time. To illustrate this mechanism, assume that a hypothetical FMS is in a steady state of work order arrivals and completions and also has a stable backlog of 25 vehicles each day. In this example, 25 backlogged vehicles per day, times 250 work days per year, would contribute a total of 6,250 lost vehicle readiness days. All else equal, the addition of a maintainer to this hypothetical FMS would clear the backlog over time, and bring the FMS to a new steady state in which the aggregate number of duration days saved is at least 6,250, relative to the previous baseline.

Table 15. Days Saved, Given Specified Changes to Maintainer Staffing

	Observed Mean Maintainer Count by Category	Mean Annual Work Orders Per Shop	Days Saved Per Work Order Given Incremental Change in Staffing				Projected Annual Work Days Saved Per Shop with +1 Maintainer
			-2	-1	+1	+2	
1. Impacts of vehicle maintainer changes on vehicle work orders in FMS facilities with							
High relative workload	9	256	-1.6***	-0.8***	0.8***	1.6***	202***
			(0.6)	(0.3)	(0.3)	(0.5)	(67)
Moderate relative workload	8	217	-2.2***	-1.1***	1.0***	2.0***	217***
			(0.6)	(0.3)	(0.3)	(0.6)	(64)
Low relative workload	7	134	-1.2*	-0.6*	0.6*	1.2*	81*
			(0.7)	(0.3)	(0.3)	(0.6)	(43)
2. Impacts of all maintainer changes on vehicle work orders in CSMS/MATES facilities							
Vehicle maintainers	32	275	-0.9***	-0.4***	0.4***	0.9***	121***
			(0.3)	(0.1)	(0.1)	(0.3)	(36)
Electronics maintainers	8	275	-1.4**	-0.7**	0.7**	1.4**	191**
			(0.6)	(0.3)	(0.3)	(0.6)	(81)
Other maintainers	7	275	0.7	0.4	-0.4	-0.7	-99
			(0.7)	(0.4)	(0.4)	(0.8)	(105)

Note: Days saved per work order represents predicted change in time to completion given mean work order and shop characteristics. Error bounds presented are the standard error of predicted difference in mean annual throughput at a facility.

Note: Statistical significance is displayed using * p<0.1, ** p<0.05, *** p<0.01.

5. Conclusions

Equipment readiness is central to the training and deployment of ARNG units. This research quantifies the causal effect of ARNG maintenance personnel on the readiness of ground equipment, proxied by changes in the number of days equipment items are unready due to required maintenance. We estimate survival analysis regressions to measure the impact of maintainer staffing levels on the length of time required to complete equipment work orders at FMS, CSMS, and MATES facilities.

Because equipment readiness ratings are compiled at the battalion level, while equipment maintenance for a given battalion commonly occurs at multiple maintenance shops that also serve other battalions, clean association of shop-based maintenance personnel with battalion-level readiness ratings is impossible. Direct assessment of the impact of ARNG maintenance personnel on ARNG equipment readiness ratings would be confounded by a mismatch between maintenance facilities and readiness-reporting units. These and other complexities in the analytic environment make survival analysis a more appropriate approach than alternatives, such as a direct assessment of equipment readiness ratings or facility throughput analysis.

The direct effects of MilTech manpower investments at FMS, CSMS, and MATES facilities on vehicle readiness are remarkably stable across many different model specifications. We find that an additional vehicle maintainer decreases the average FMS vehicle work order duration by about 0.8 working days per work order, or an average production of 167 additional ready equipment days per shop year. Personnel managers with limited budgets should focus staffing additions in FMS facilities with average and high levels of open work orders per maintainer ("relative workload"). At those shops, an additional vehicle maintainer produces 210 additional ready equipment days per shop year. The addition of one vehicle maintainer to each of the 472 FMS facilities studied would produce approximately 79,000 additional ready equipment days each year across the ARNG, holding constant all other staffing and features.

Estimated impacts of maintenance personnel on vehicle work orders at CSMS and MATES facilities are also large, positive, and statistically robust. We find that an additional vehicle maintainer decreases the average CSMS and MATES vehicle work order duration by 0.4 working days per work order, or an average production of 121 additional ready equipment days per shop year. Likewise, an additional electronics maintainer decreases the average CSMS and MATES vehicle work order duration by 0.7 working days per work order, or an average production of 191 additional ready equipment days per shop year. Adding one vehicle and one electronics maintainer to each of the 81 CSMS and MATES facilities studied—162 FTEs total—would produce approximately 25,000 additional ready equipment days each year across the ARNG, all else equal.

Unlike the vehicle work duration results, our CSMS and MATES electronics work duration results offer no definitive conclusions. Our analyses suggest that factors influencing electronics work order productivity and correlated with staffing levels at the facilities studied are confounded with features not accounted for in our data or model. A limitation of this analysis is our inability to observe which skill sets or individuals contribute to each work order type, and the relative complexity of each work order. Additional data, or more thorough modeling of total workload, may more precisely identify returns to electronics maintainer investments for the electronics workload.

In addition to the main results on MilTech productivity, we confirm that work proceeds significantly faster for equipment owned by units approaching deployment—particularly in the four to nine months prior to deployment—and more slowly for units already deployed. This additional productivity appears related to investments in ADOS-RC manpower, confirming that ADOS-RC maintenance tours are used to fill surge labor needs.

We briefly explore the impact of selected personal characteristics of maintainers and additional shop features on productivity: maintainer tenure, average AFQT score, and supervisor ratio. We are unable to identify the impact of tenure on time to work completion. This likely follows from the fact that the labor pool we examine is very experienced: median tenure is 7.1 years, 94% have one than one year of experience, and 88% have more than two years of experience. The lack of variation in tenure and high median experience combine to limit our ability to understand any tenure/experience tradeoff that may exist. In our analyses of the supervisor-to-line worker ratio, we find that FMS facilities with relatively more supervisors complete work very slightly more slowly (with work orders requiring an economically insignificant 0.8% more working days to complete). This may result from the formation of slightly smaller-than-optimal teams, due to small overall staff size in FMS facilities, or from the loss of a line worker when an individual is called upon to perform supervisory activities. If leaders wish to address this matter, we advise that they do so by adding more vehicle maintainers, not by cutting supervisors. Finally, we observe that AFQT score appears to have little impact on productivity, despite a fairly large amount of native variation in the data. Exploration of whether selection may confound identification of any AFQT impact is beyond the scope of this research.

Appendix A.
Supplemental Information on Data

This appendix contains additional detail on the data used in this research.

Work orders

During the period of analysis, maintenance facilities recorded work order information using the Standard Army Maintenance System (SAMS). SAMS-1 captures information at the maintenance company level and transmits that information to a battalion-level organization or higher. These higher tiers aggregate information received from SAMS-1 locations using the SAMS-2 version of the software, and transmit maintenance records to the Logistics Support Activity (LOGSA) for storage. An updated version of this software, Standard Army Maintenance System-Enhanced (SAMS-E), encompasses both SAMS-1 and SAMS-2. In 2015, the Army National Guard (ARNG) began transitioning from the SAMS platform to Global Combat Support System-Army (GCSS-Army).

Military technicians (MilTechs) recording work occasionally group similar pieces of equipment onto the same work order, which we expect to impact the time required to complete the work order. Subject matter experts in the ARNG inform us that this practice is generally used for routine inspections and updates, and that repairs arising from batch processing events generate new work orders. As batch inspection or processing work is not comparable to other repair actions, in intermediate duration regression specifications, we construct an indicator identifying work orders representing multiple pieces of equipment and find that the coefficient is not statistically significant.

Calculating Maintainer-Relevant Work Order Days

A work order's acceptance day of the week impacts its expected duration, as measured by elapsed calendar days. For instance, if a work order takes five days to complete and arrives on a Monday, it will be completed five days later on Friday of the same week. If, however, that same five-day work order arrives on a Tuesday instead of Monday, it will not be completed until Monday—seven calendar days later—because MilTechs generally do not work weekends. The longer a work order remains open, the greater the difference between elapsed calendar days and elapsed working days. We do not observe time of day for status changes, acceptance times, or completion times. Counting elapsed days approximates the mean acceptance and completion times as occurring halfway through the workday. Because multiple statuses can be opened and closed in the same day, the number of days in each status is computed as the number of working days between the start and end dates of that status. This produces a contribution of zero days for a work order status opened and closed on the same workday, and prevents double-counting of days when adding the durations of each status for a given work order.

In the previous example, a work order opened on Monday and closed on Friday has a duration of four elapsed days. Adding a day to the duration of all work orders to account for what might be characterized as a "lost" day would extend the duration of each work order by a varying percentage, and therefore confound the interpretation of the accelerated failure time model.

Less than 1% of work orders experience a status change on a weekend. As this event is quite rare, we did not adjust our duration measure for presumed weekend work.

Identifying Major Equipment Systems

The ITEM_ALL table maintained by LOGSA provides information about each equipment item on the National Item Identification Number (NIIN) level, and includes the equipment's name, Line Identification Number (LIN), Equipment Category Code (ECC), and Federal Stock Code (FSC). We use a combination of LINs and names of major systems[36] to flag NIINs and merge with the WON_R table to identify work orders corresponding to these high-visibility systems. Performing this identification allows us to confirm that these systems appear in the ECCs included in this analysis.

Master List of Customer Units and Shops

The D_UIC table maintained by LOGSA contains static information on UICs, each associated with a state and a unit name. We use this table as a master list of maintenance facility and customer UICs, and use the names herein to classify the facility as a Field Maintenance Shop (FMS), Combined Support Maintenance Shop (CSMS), Maneuver Area Training and Equipment Site (MATES), or Unit Training Equipment Site (UTES).

[36] Strykers, Bradleys, tanks, and a few other large systems.

Appendix B. Supplemental Tables

Table B-1. Maintainer Matches after Merging Corporate Management Information System (CMIS) and WON_R

State	Maintainer Months	Matched Maintainer Months	Percent Matched
AK	2,349	2,108	89.7%
AL	17,736	17,387	98.0%
AR	11,723	11,232	95.8%
AZ	10,366	8,839	85.3%
CA	22,675	18,950	83.6%
CO	4,511	3,781	83.8%
CT	4,884	3,902	79.9%
DC	2,055	1,760	85.6%
DE	2,557	2,546	99.6%
FL	14,263	14,252	99.9%
GA	11,988	10,801	90.1%
HI	4,046	4,008	99.1%
IA	9,290	9,018	97.1%
ID	10,018	8,719	87.0%
IL	13,213	12,651	95.7%
IN	12,991	12,463	95.9%
KS	14,595	14,441	98.9%
KY	12,097	12,040	99.5%
LA	17,003	16,564	97.4%
MA	9,828	9,793	99.6%
MD	6,032	5,860	97.1%
ME	3,642	3,581	98.3%
MI	14,392	13,165	91.5%
MN	13,138	10,017	76.2%
MO	13,845	11,433	82.6%
MS	26,799	24,295	90.7%
MT	4,272	0	0.0%
NC	18,631	17,922	96.2%
ND	5,717	5,655	98.9%
NE	6,153	5,957	96.8%
NH	2,228	1,875	84.2%
NJ	8,160	7,833	96.0%
NM	3,954	0	0.0%
NV	4,570	4,434	97.0%
NY	17,561	13,766	78.4%
OH	14,373	12,951	90.1%
OK	10,411	9,864	94.7%
OR	10,633	8,012	75.4%

State	Maintainer Months	Matched Maintainer Months	Percent Matched
PA	22,467	21,140	94.1%
RI	3,024	2,724	90.1%
SC	17,473	17,227	98.6%
SD	5,795	5,776	99.7%
TN	16,522	15,616	94.5%
TX	27,527	26,469	96.2%
UT	10,558	0	0.0%
VA	12,892	12,721	98.7%
VT	3,569	369	10.3%
WA	7,784	7,769	99.8%
WI	10,435	10,352	99.2%
WV	5,486	5,284	96.3%
WY	3,278	3,090	94.3%
Total	**280,272**	**241,101**	**86.0%**

Note: This table summarizes the merge between CMIS and WON_R by Unit Identification Code (UIC) and month. The match rate among MilTech maintainers is presented by state.

Table B-2. Impact of Parts on Eligible Work Orders

	Work orders	Impacted by parts	Average days waiting for parts
Tactical Vehicles	687,429	39%	36.7
Communications And Electronic Equipment	653,595	8%	29.1
Small Arms	540,171	19%	27.0
Support Equipment	147,246	30%	34.5
Air Defense Systems	64,848	15%	26.4
Installation/Depot Peculiar Service Equipment	37,982	17%	24.9
Construction Equipment	32,754	41%	38.2
Electronic Test Equipment	25,703	5%	35.8
Material Handling Equipment	23,722	19%	39.9
Combat Vehicles	21,116	30%	35.0
Equipment Not Listed Elsewhere	20,777	13%	41.8
Nontactical Wheeled Vehicles	15,756	14%	30.6
Artillery Weapons	15,362	17%	41.5
Missile Systems Land Combat	10,244	12%	40.3
Floating Equipment	7,571	18%	40.7
Shop Support Equipment	6,890	19%	31.6
Tools Not Listed Else Where	6,133	20%	19.5
Furniture And Appliances	5,718	27%	39.1
Railway Equipment	5,129	14%	38.6
Tanks	3,084	26%	42.0
Medical And Dental Equipment	2,899	6%	40.8
Office Equipment	2,635	11%	45.4
Machine Tools	2,415	6%	33.8
Aircraft	2,236	10%	27.4
Ammunition And Ammunition Equipment	1,886	7%	37.1
Other	1,589	2%	69.4

Note: The population is the eligible set of work orders. The second column presents the share of the work orders in that category that require additional parts. We compute the average days waiting conditional on requiring additional parts. That is, among the 39% of tactical vehicle work orders that require additional parts, the average delay to the work order is 36.7 days.

Table B-3. Share of Work Orders Accepted on Each Day of the Week

Schedule	Su	M	T	W	R	F	Sa	Share of total
1	0%	12%	24%	25%	23%	15%	1%	67%
2	0%	13%	25%	26%	23%	12%	1%	2%
3	1%	4%	26%	28%	26%	15%	0%	14%
4	0%	11%	24%	25%	25%	15%	1%	14%
5	0%	20%	26%	28%	17%	9%	0%	1%
6	0%	19%	28%	20%	23%	10%	1%	2%
All	0%	11%	24%	25%	24%	15%	1%	100%

Note: This table reflects work orders from the eligible set. Schedule information provided by the NG-J85 Division, Property and Fiscal Operations of National Guard Bureau, received December 20, 2017. We attribute work schedules to maintenance facilities within their respective states. Work schedule descriptions:

Schedule 1: Monday through Friday

Schedule 2: Monday through Thursday

Schedule 3: Tuesday through Friday

Schedule 4: Closed one Monday per pay period

Schedule 5: Closed one Friday per pay period

Schedule 6: Open four days per week, with one extra floating day per pay period

Table B-4. Eligible MilTech Occupational Families

Occupational Family	Occupational Series	MilTech Months	Percent of Total
Armament Work Family	Small Arms Repairing	8,853	1.9%
Armament Work Family	Artillery Repairing	3,653	0.8%
Armament Work Family	Miscellaneous Armament Work	2,527	0.5%
Armament Work Family	Ordnance Equipment Mechanic	508	0.1%
Electronic Equipment Installation and Maintenance Family	Electronics Mechanic	36,224	7.7%
Electronic Equipment Installation and Maintenance Family	Electronic Measurement Equipment Mechanic	9,421	2.0%
Electronic Equipment Installation and Maintenance Family	Electronic Digital Computer Mechanic	605	0.1%
Electronic Equipment Installation and Maintenance Family	Electronic Integrated Systems Mechanic	89	0.0%
Electronic Equipment Installation and Maintenance Family	Miscellaneous Electronic Equipment Installation & Maintenance	26	0.0%
Fabric and Leather Work Family	Fabric Working	2,299	0.5%
Fabric and Leather Work Family	Miscellaneous Fabric And Leather Work	81	0.0%
Industrial Equipment Maintenance Family	Powered Support Systems Mechanic	100	0.0%
Instrument Work Family	Optical Instrument Repairing	1,682	0.4%
Machine Tool Work Family	Miscellaneous Machine Tool Work	3,298	0.7%
Machine Tool Work Family	Machining	3,005	0.6%
Metal Processing Family	Welding	6,056	1.3%
Metal Work Family	Mobile Equipment Metal Mechanic	2,934	0.6%
Painting and Paperhanging Family	Painting	4,873	1.0%
Transportation/Mobile Equipment Maintenance Family	Miscellaneous Transportation/Mobile Equipment Maintenance	384,403	81.3%
Transportation/Mobile Equipment Maintenance Family	Automotive Mechanic	296	0.1%
Transportation/Mobile Equipment Maintenance Family	Heavy Mobile Equipment Mechanic	243	0.1%
Transportation/Mobile Equipment Maintenance Family	Mobile Equipment Servicing	39	0.0%
Wood Work Family	Wood Working	1,377	0.3%
	Total	**472,592**	**100.0%**

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Appendix C. Data Challenges and Suggestions for Improvement

The data collection, maintenance, and management protocols that produce the data used in this research introduce challenges that updated processes, organizational structures, and data collection practices might mitigate. Investments in data collection and retention to reduce idiosyncratic differences in data collection and coding, non-standard entries in key fields, practices impeding the identification of deployment effects, inability to directly observe Active Duty for Operational Support, Reserve Component (ADOS-RC) assignments, and production of an historical unit hierarchy would improve the quality of information available to managers and researchers alike.

Heterogeneity in Managerial and Data Practices Between States

Heterogeneity in managerial and data practices between states introduces challenges to Army National Guard (ARNG)-wide analyses. In this context, state-level differences in personnel recordkeeping prevent us from analyzing the entire maintenance military technician (MilTech) and work order populations. In the Corporate Management Information System (CMIS) data, all MilTechs in the states of Montana, New Mexico, Utah, and Vermont are associated with Joint Force Headquarters (JFHQ) units alongside non-maintenance staff performing standard JFHQ functions. As such, we cannot attribute MilTechs to maintenance facilities or match MilTechs with work orders for these states, and therefore must exclude them from analysis.[37]

Another example of cross-state heterogeneity in data practices is illustrated by air defense work orders, which are inconsistently coded into different Equipment Category Codes (ECCs), depending on the state recording the work. These differences impede analysis of the entire work order population. As such, we focus on the largest and most consistent ECCs.

Non-standard Descriptions of Work

The data sources used in this analysis contain several free-text fields that convey critical information. This introduces challenges to categorizing the data and ensuring its

[37] The National Guard Bureau (NGB) or the ARNG should consider standardizing recordkeeping practices for staffing and disbursement of funds across states and units.

accuracy. For example, the unit name at the Unit Identification Code (UIC) level often differs between data sources, resulting from differences in the order of terms, abbreviations, and typographical errors. Consistent or predictable descriptions of the type of work involved in a work order would improve the ability of research to provide actionable findings to decision makers.

Unit relationships

Because units operate within positions in a hierarchy, a clear description of that structure is important to understanding their responsibilities, capabilities, and dependencies on other units. For instance, the readiness of a battalion is a function of the readiness of its subordinate units. Reporting at incongruous or aggregated levels—such as equipment at the battalion level and personnel at the company level—complicates analyses. The relationship between units is partially but inconsistently reflected in the UIC, and therefore cannot be used to reliably identify the unit hierarchy.[38] Efforts to group units or associate people with equipment or various readiness measures, to study organizational behavior before and after deployments, and to better understand the influence of units at different levels of the hierarchy are impeded by researchers' inability to understand the ARNG hierarchy.

Unit hierarchies are recorded in the Force Management System Website (FMSWeb), but the system does not appear to archive hierarchies more than two years old. Fiscal year 2015 was the earliest we were able to obtain a hierarchy from this source.

D_UIC contains unit information, including position in the hierarchy. However, UICs included in D_UIC appear only once, suggesting that the data are static. Changes over time to unit hierarchy, name, or location are not preserved. Although this data source contains all of the work order UICs that appear in the work order data, it does not contain all of the UICs that appear in the ARNG personnel data.

Investments in either standardizing the hierarchy encoding in UICs or other identifiers, or in maintaining a map of all the relationships between units would aid further ARNG studies.

Tracking deployments

The practice of cross-leveling—moving individuals between units—complicates the identification of unit deployments. Understanding deployments in the ARNG is important

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[38] As a notional example of this complexity, let WP4BAA be a battalion-level unit. According to the typical construction of UIC, the unit WP4BA1 would be one of its subordinate units. However, this encoding is not always followed, and may mistakenly associate units. Further, this method does not enable the association of special-purpose units—which are frequently supported by a Table of Distribution and Allowances (TDA) troop command outside of the usual Modification Table of Organization and Equipment (MTOE) hierarchy—with their relevant MTOE hierarchy.

because of the changes in funding, training, and behavior related to the preparation for deployment. Deployments are further complicated by the fact that the relationships between units, including those relationships brought about by the creation of derivative units or combining units, are currently unobservable by researchers.

Tracking ADOS-RC Tours

Maintenance facilities sometimes benefit from additional labor inputs in the form of individuals on ADOS-RC tours. However, almost no ARNG-level administrative data are available on the placement and work of individuals on ADOS-RC orders. This impedes the analysis of their productivity, both in the maintenance context and elsewhere. Visibility into what UIC each individual on an ADOS-RC tour is serving, and the nature of that service, would allow for a more accurate attribution and analysis of manpower outputs.

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Appendix D. Additional Results

The following table displays selected coefficients for the final specification in each modeled population.

Table D-1. Work Order Duration Regression Results

	FMS	CSMS/MATES	
Covariate	**Vehicles**	**Vehicles**	**Electronics**
Vehicle maintainers	-0.0242*** (0.00522)	-0.0124*** (0.00372)	-0.000493 (0.00555)
Electronics maintainers	†	-0.0196** (0.00850)	-0.00718 (0.0180)
Other maintainers	0.0133 (0.0215)	0.00988 (0.0105)	0.0116 (0.0143)
ADOS-RC			-0.00410 (0.00401)
Work order referred out	0.374*** (0.0329)	0.0146 (0.136)	0.0757 (0.133)
Work order referral received	0.0758 (0.0488)	0.204*** (0.0517)	-0.0739 (0.0618)
Reset work order	0.620*** (0.115)	0.539*** (0.0994)	
Update work order	-0.179 (0.230)	-0.403** (0.178)	
Turn in work order	-0.179*** (0.0325)	-0.267*** (0.0670)	
Service work order	0.415*** (0.0203)	0.269*** (0.0477)	
Inspection work order	-0.0742 (0.0540)	-0.247** (0.106)	
Other type of work order	†	†	
Work order accepted in January-May	-0.0700*** (0.0101)	-0.0873*** (0.0171)	0.0151 (0.0381)
Work order accepted in June-December	†	†	†
Trailer	0.0446***	0.0287	

Covariate	FMS Vehicles	CSMS/MATES Vehicles	CSMS/MATES Electronics
	(0.0144)	(0.0355)	
Truck, 5 tons or greater	0.0802***	0.0306	
	(0.0101)	(0.0219)	
Truck, less than 5 tons	†	†	
Other vehicle ECC	0.0449	-0.0603	
	(0.0379)	(0.0532)	
Radio			†
Infrared surveillance system			-0.196***
			(0.0506)
Other electronics ECC			-0.220***
			(0.0430)
Customer deployed	0.261***	0.307*	
	(0.0975)	(0.172)	
Customer deploys in 1-3 months	-0.108	-0.197	
	(0.0949)	(0.142)	
Customer deploys in 4-6 months	-0.235***	-0.293***	
	(0.0556)	(0.0645)	
Customer deploys in 7-9 months	-0.102**	-0.0968*	
	(0.0411)	(0.0566)	
Customer deploys in 10-12 months	-0.0319	0.109	
	(0.0572)	(0.0718)	
Work order accepted on a Monday	-0.0912*	0.0318	
	(0.0473)	(0.115)	
Work order accepted on a Tuesday	-0.0955**	0.0544	
	(0.0472)	(0.107)	
Work order accepted on a Wednesday	-0.0840*	0.0831	
	(0.0471)	(0.110)	
Work order accepted on a Thursday	-0.0479	0.0809	
	(0.0465)	(0.109)	
Work order accepted on a Friday	-0.00327	0.0966	
	(0.0480)	(0.112)	
Work order accepted on a Saturday or Sunday	†	†	
Log-likelihood	-2,918,386	-115,616	-31,032
Observations	452,784	105,440	305,946

Note: Coefficients for maintenance facility indicators are not presented. † indicates an indicator variable excluded as the reference group. Statistical significance is displayed using * p<0.1, ** p<0.05, *** p<0.01.

Table D-2. CSMS/MATES Vehicles Work Order Duration Regression Excursions

	(1)	(2)	(3)	(4)
Mobile maintainers	-0.0124***	-0.0118***	-0.0119***	-0.0124***
	(0.00372)	(0.00367)	(0.00370)	(0.00372)
Electronics maintainers	-0.0196**	-0.0196**	-0.0189**	-0.0195**
	(0.00850)	(0.00842)	(0.00848)	(0.00859)
Other maintainers	0.00988	0.00930	0.0107	0.00999
	(0.0105)	(0.0103)	(0.0104)	(0.0105)
Vehicle maintainer share with >1 year tenure		-0.303		
		(0.225)		
Maintainer to supervisor ratio			-0.0167	
			(0.0165)	
Vehicle maintainer mean AFQT score				-0.00211
				(0.00504)

Note: Each column presents coefficients representing the estimated percent change in vehicle work order duration attributable to various regressors from survival analysis with generalized gamma parameterization. Work order duration is measured as the number of maintainer-relevant open work order days. Column (1) includes vehicle maintainer and all other maintainer headcounts, Active Duty for Operational Support, Reserve Component (ADOS-RC) person-months, and indicators for whether the work order was referred in or out, accepted by the shop in Jan-May, in one of four Equipment Category Code (ECC) categories, and individual maintenance facility. Column (2) includes covariates from column (1) less ADOS-RC person-months and plus indicators for customer unit deployment, work type, and acceptance day-of-week. Column (3) interacts the vehicles maintainer headcount with indicators for shop relative workload tertile, in addition to covariates from column (2).

Note: Statistical significance is displayed using * p<0.1, ** p<0.05, *** p<0.01.

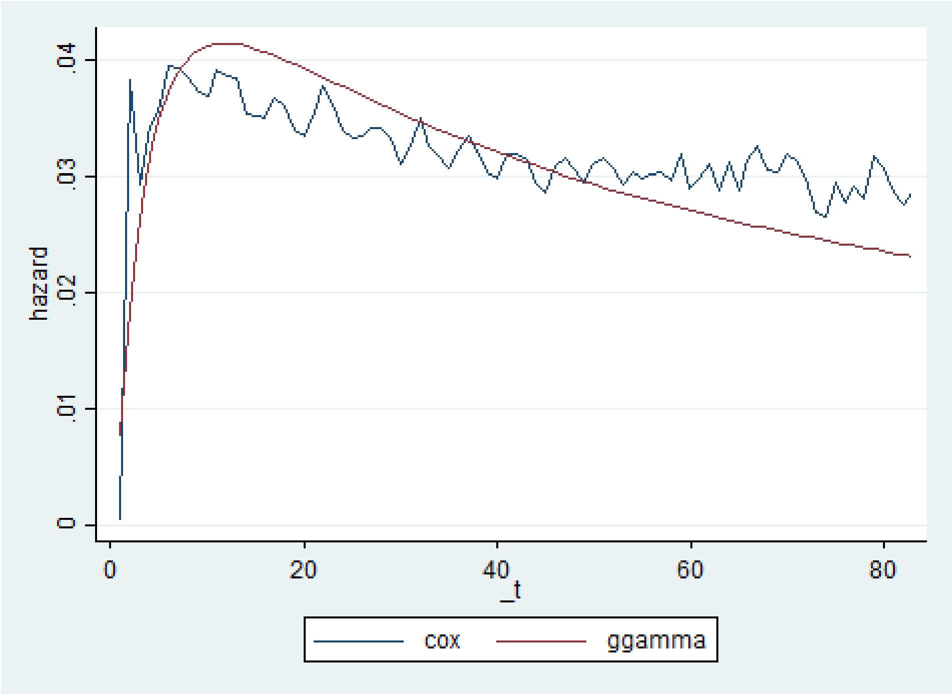

Figure D-1. Hazard Functions for FMS Vehicles Final Specification

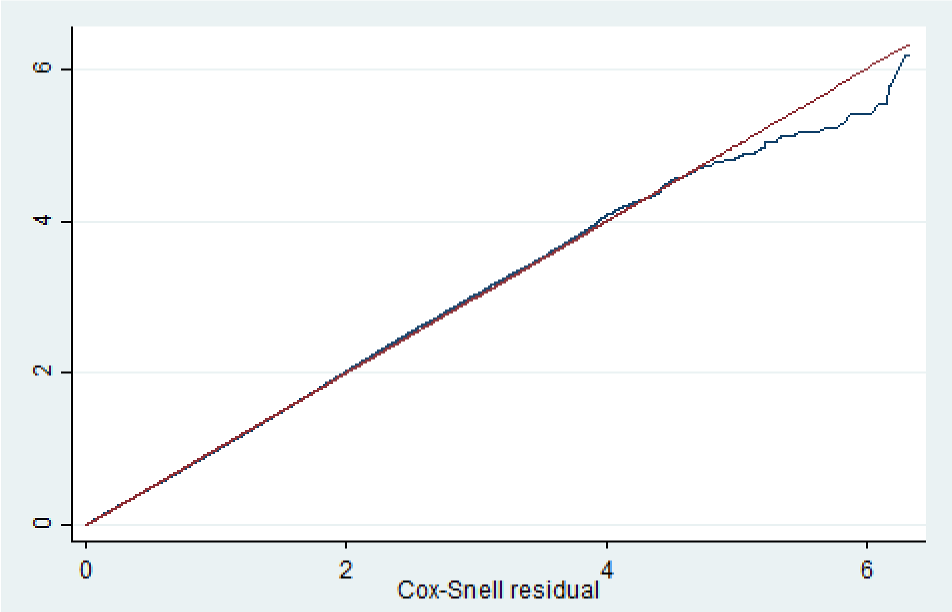

Figure D-2. Cox-Snell Residuals for FMS Vehicles Final Specification

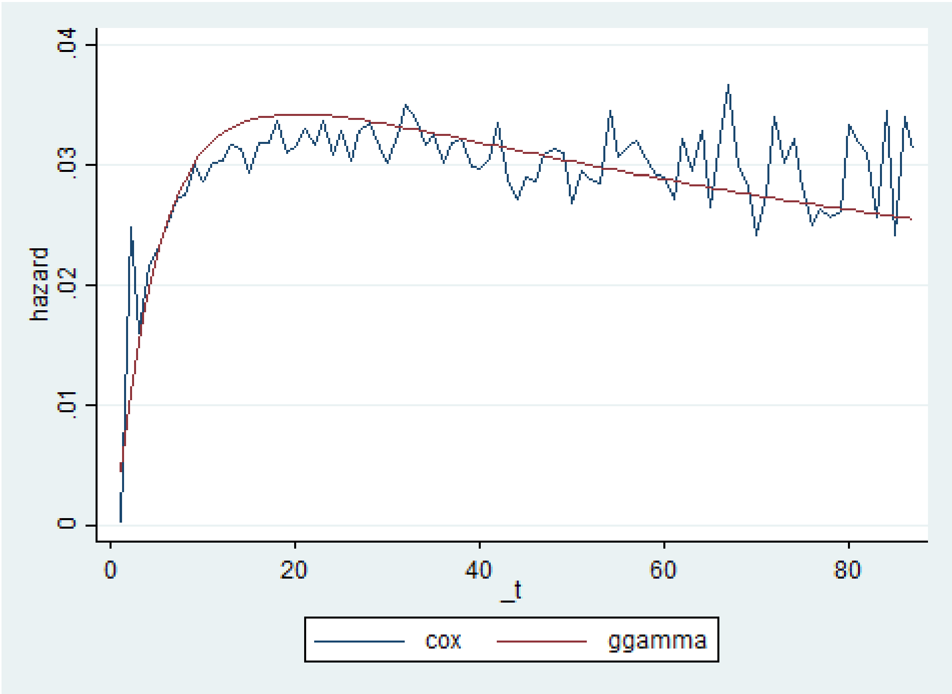

Figure D-3. Hazard Functions for CSMS/MATES Vehicles Final Specification

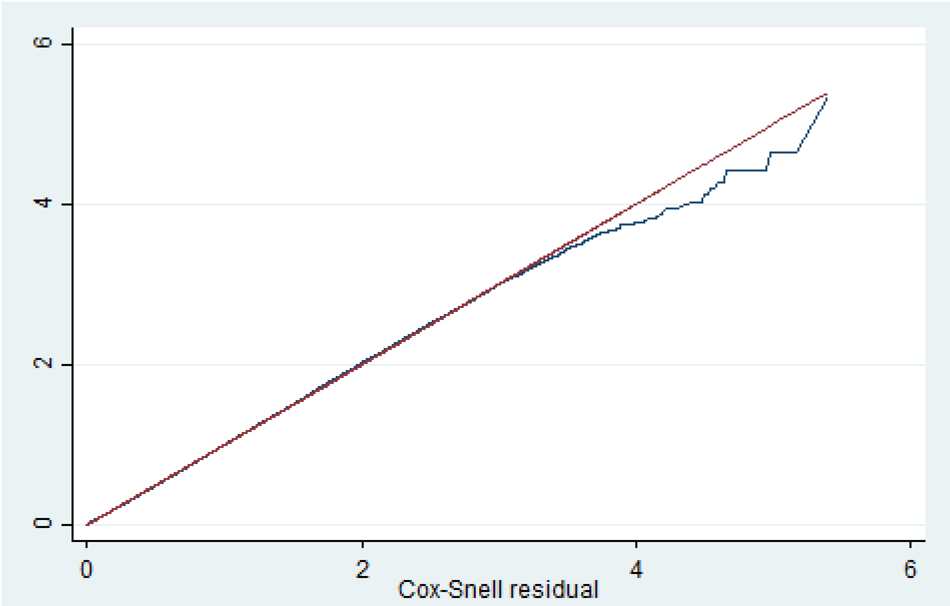

Figure D-4. Cox-Snell Residuals for CSMS/MATES Vehicles Final Specification

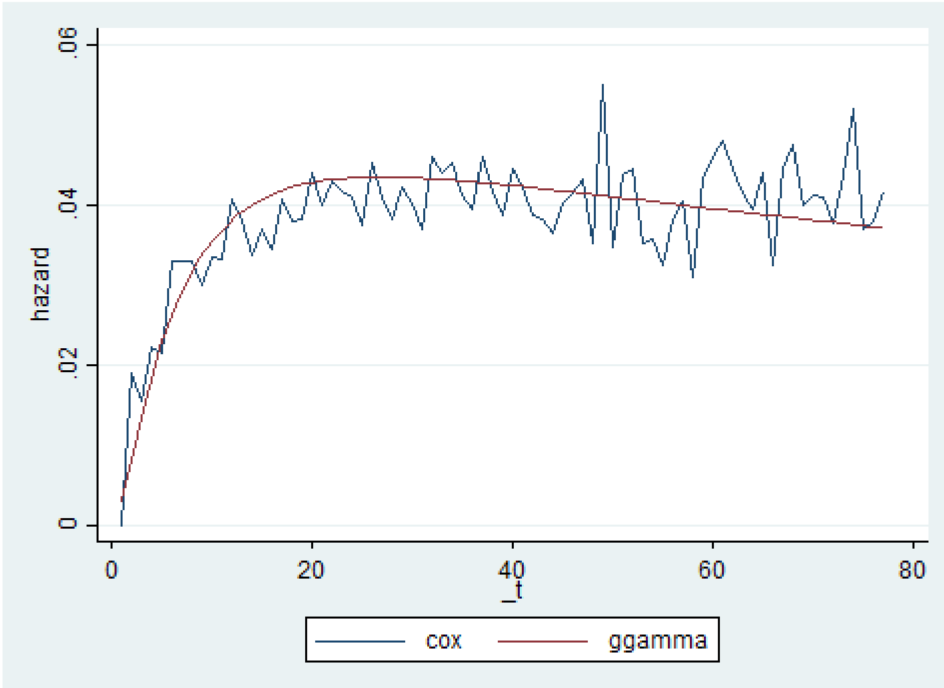

Figure D-5. Hazard Functions for CSMS/MATES Electronics Final Specification

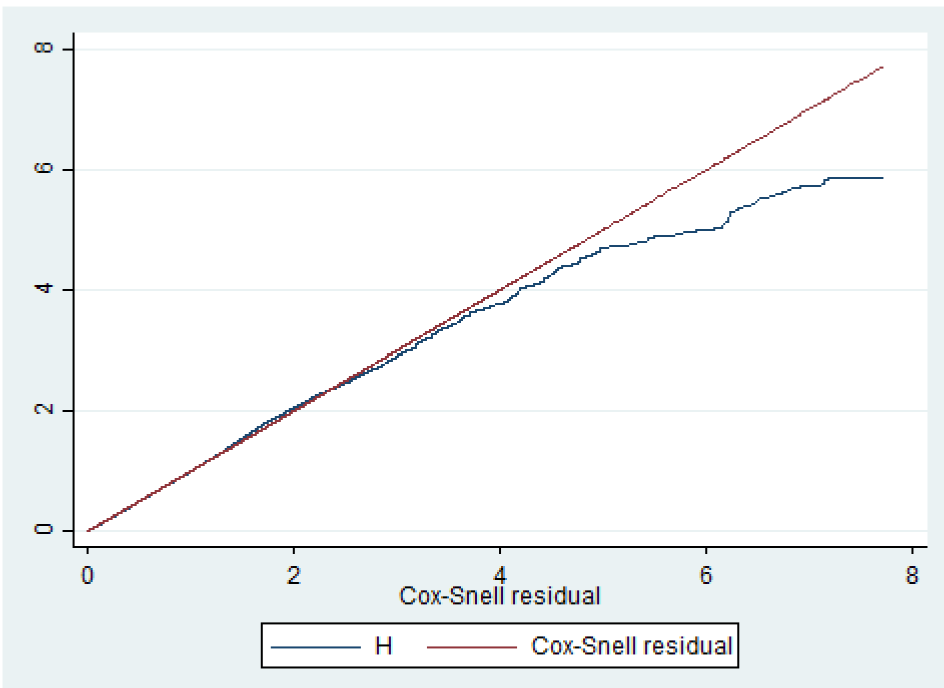

Figure D-6. Cox-Snell Residuals for CSMS/MATES Vehicles Final Specification

Appendix E. Technical Addendum

Density for Generalized Gamma

We start with the density from Stata streg documentation (for $\kappa \neq 0$):

$$f(t;\sigma,\gamma,u) = \frac{\gamma^{\gamma}}{\sigma t\sqrt{\gamma}\Gamma(\gamma)} e^{z\sqrt{\gamma}-u}.$$

Following the Stata documentation, we make the following substitutions of $\gamma = |\kappa|^{-2} = \kappa^{-2}$, $z = \frac{sign(\kappa)(log(t)-\mu)}{\sigma}$, and $u = \gamma e^{|\kappa|z}$ to arrive at a density parametrized in terms of $\{\mu,\sigma,\kappa\}$, which corresponds to the model that Stata estimates in streg:

$$\begin{aligned}
f(t;\mu,\sigma,\kappa) &= \frac{(\kappa^{-2})^{\kappa^{-2}}}{\sigma t\sqrt{|\kappa|^{-2}}\Gamma(\kappa^{-2})} e^{\frac{sign(\kappa)(log(t)-\mu)}{\sigma}\sqrt{|\kappa|^{-2}}-\kappa^{-2}e^{|\kappa|\frac{sign(\kappa)(log(t)-\mu)}{\sigma}}} \\
&= \frac{|\kappa|}{\sigma t\Gamma(\kappa^{-2})} (\kappa^{-2})^{\kappa^{-2}} e^{\frac{sign(\kappa)(log(t)-\mu)}{\sigma}|\kappa|\kappa^{-2}} e^{-\kappa^{-2}e^{|\kappa|\frac{sign(\kappa)(log(t)-\mu)}{\sigma}}} \\
&= \frac{|\kappa|}{\sigma t\Gamma(\kappa^{-2})} \left(\kappa^{-2} e^{\frac{sign(\kappa)(log(t)-\mu)}{\sigma}|\kappa|}\right)^{\kappa^{-2}} e^{-\kappa^{-2}e^{|\kappa|\frac{sign(\kappa)(log(t)-\mu)}{\sigma}}} \\
&= \frac{|\kappa|}{\sigma t\Gamma(\kappa^{-2})} \left(\kappa^{-2}(te^{-\mu})^{sign(\kappa)\frac{|\kappa|}{\sigma}}\right)^{\kappa^{-2}} e^{-\kappa^{-2}(te^{-\mu})^{sign(\kappa)\frac{|\kappa|}{\sigma}}} \\
&= \frac{|\kappa|}{\sigma t\Gamma(\kappa^{-2})} \left(\kappa^{-2}(te^{-\mu})^{\frac{\kappa}{\sigma}}\right)^{\kappa^{-2}} e^{-\kappa^{-2}(te^{-\mu})^{\frac{\kappa}{\sigma}}}
\end{aligned}$$

This result matches the parametrization given in Cox and Matheson (2014).

Change of Variables to Obtain Accelerated Failure Time (AFT) Model

Rearrange terms in anticipation of the change of variables operation:

$$\begin{aligned}
f(t;\mu,\sigma,\kappa) &= \frac{|\kappa|}{\sigma t\Gamma(\kappa^{-2})} \left\{\left((\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}t\right)^{\frac{\kappa}{\sigma}}\right\}^{\kappa^{-2}} e^{-\left((\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}t\right)^{\frac{\kappa}{\sigma}}} \\
&= \frac{|\kappa|}{\sigma t\Gamma(\kappa^{-2})} \left((\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}t\right)^{\frac{\kappa}{\sigma}\kappa^{-2}} e^{-\left((\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}t\right)^{\frac{\kappa}{\sigma}}} \\
&= \frac{|\kappa|(\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}}{\sigma\Gamma(\kappa^{-2})} \left((\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}t\right)^{\frac{\kappa}{\sigma}\kappa^{-2}-1} e^{-\left((\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}t\right)^{\frac{\kappa}{\sigma}}}.
\end{aligned}$$

For ease of exposition, assume that $\kappa > 0$. Let a new R.V. W be defined as

$$T \quad = \frac{e^{W\frac{\sigma}{\kappa}}}{e^{-\mu}(\kappa^{-2})^{\frac{\sigma}{\kappa}}}.$$

Taking the natural log of T gives

$$ln(T) = \mu + 2\frac{\sigma}{\kappa}ln(\kappa) + \frac{\sigma}{\kappa}W.$$

The distribution of W can be found through a change of variables integration:

$$\begin{aligned}
F(t) \quad &= \int_0^t f\,(u)du \\
F(w) \quad &= \int_{-\infty}^{w} f\left(\frac{e^{v\frac{\sigma}{\kappa}}}{e^{-\mu}(\kappa^{-2})^{\frac{\sigma}{\kappa}}}\right)\frac{du}{dv}dv \\
&= \int_{-\infty}^{w}\left(\frac{\kappa(\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}}{\sigma\Gamma(\kappa^{-2})}\left((\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}\left(\frac{e^{v\frac{\sigma}{\kappa}}}{e^{-\mu}(\kappa^{-2})^{\frac{\sigma}{\kappa}}}\right)\right)^{\frac{\kappa}{\sigma}\kappa^{-2}-1} e^{-\left((\kappa^{-2})^{\frac{\sigma}{\kappa}}e^{-\mu}\left(\frac{e^{v\frac{\sigma}{\kappa}}}{e^{-\mu}(\kappa^{-2})^{\frac{\sigma}{\kappa}}}\right)\right)^{\frac{\kappa}{\sigma}}}\right)\left(\frac{\sigma}{\kappa}\frac{e^{v\frac{\sigma}{\kappa}}}{e^{-\mu}(\kappa^{-2})^{\frac{\sigma}{\kappa}}}\right)dv \\
&= \int_{-\infty}^{w}\frac{1}{\Gamma(\kappa^{-2})}\left(e^{v\frac{\sigma}{\kappa}}\right)^{\frac{\kappa}{\sigma}\kappa^{-2}-1} e^{-e^{v}}e^{v\frac{\sigma}{\kappa}}dv \\
&= \int_{-\infty}^{w}\frac{1}{\Gamma(\kappa^{-2})}\left(e^{v\kappa^{-2}-v\frac{\sigma}{\kappa}}\right)e^{v\frac{\sigma}{\kappa}-e^{v}}\,dv \\
&= \int_{-\infty}^{w}\frac{e^{\kappa^{-2}v-e^{v}}}{\Gamma(\kappa^{-2})}dv.
\end{aligned}$$

This result matches the density described in Kalbfleisch and Prentice (2002) Chapter 2, pp. 35-36, with the substitution of $\kappa^{-2} = k$ to match their notation. In particular, they state that W has a negatively skewed distribution.

Finally, setting $\mu \equiv X\beta$ gives $ln(T)$ as a function of $X\beta$:

$$ln(T) = 2\frac{\sigma}{\kappa}ln(\kappa) + X\beta + \frac{\sigma}{\kappa}W.$$

Predicted Difference in Mean Duration at Different Manpower Levels

Translating the Expectation of the Generalized Gamma into the Stata Parameterization

The expression for the rth moment about 0, from Stacy and Mihram (1965) but adapted to the parameterization of Stacy (1962), is given by

$$E[T^r] = a^r \frac{\Gamma\left(\frac{d+r}{p}\right)}{\Gamma\left(\frac{d}{p}\right)}.$$

Therefore, the mean is

$$E[T] = a \frac{\Gamma\left(\frac{d+1}{p}\right)}{\Gamma\left(\frac{d}{p}\right)}.$$

Compare the density as parameterized originally by Stacy (1962) to the Stata density:

$$\begin{aligned} f(t; a, d, p) &= \frac{\left(\frac{p}{a^d}\right) t^{d-1} e^{-\left(\frac{t}{a}\right)^p}}{\Gamma\left(\frac{d}{p}\right)} \\ f(t; \mu, \sigma, \kappa) &= \frac{|\kappa|}{\sigma t \Gamma(\kappa^{-2})} \left(\kappa^{-2} (t e^{-\mu})^{\frac{\kappa}{\sigma}}\right)^{\kappa^{-2}} e^{-\kappa^{-2} (t e^{-\mu})^{\frac{\kappa}{\sigma}}}. \end{aligned}$$

Translating the expression for the mean into the Stata density:

$$\begin{aligned} p &= \frac{\kappa}{\sigma} \\ d &= \frac{1}{\sigma\kappa}. \end{aligned}$$

Perform the algebra to get a:

$$\begin{aligned} \left(\left(\frac{1}{\kappa^2}\right)^{\frac{\sigma}{\kappa}} e^{-\mu}\right)^{\frac{\kappa}{\sigma}} &= \left(\frac{1}{a}\right)^{\frac{\kappa}{\sigma}} \\ \left(\frac{1}{\kappa^2}\right)^{\frac{\sigma}{\kappa}} e^{-\mu} &= \frac{1}{a} \\ a &= \kappa^{2\frac{\sigma}{\kappa}} e^{\mu}. \end{aligned}$$

Plug the Stata parameterization into the expression for the mean:

$$
\begin{aligned}
E[T] &= a \frac{\Gamma\left(\frac{d+1}{p}\right)}{\Gamma\left(\frac{d}{p}\right)} \\
&= \kappa^{2\frac{\sigma}{\kappa}} e^{\mu} \frac{\Gamma\left(\frac{\frac{1}{\sigma\kappa}+1}{\frac{\kappa}{\sigma}}\right)}{\Gamma(\kappa^{-2})} \\
&= \kappa^{2\frac{\sigma}{\kappa}} e^{X\beta} \frac{\Gamma\left(\kappa^{-2}+\frac{\sigma}{\kappa}\right)}{\Gamma(\kappa^{-2})}.
\end{aligned}
$$

Applying the Delta Method to a Prediction of the Difference in Mean Duration

Let the vector X_1 denote a covariate vector that includes manpower level M_1 and possibly polynomial or interacted manpower terms as well. Let X_2 denote a second covariate vector evaluated at a second manpower level M_2.

Let the parameters $\{\beta, \kappa, \sigma\}$ be represented by the $1 \times k$ vector θ. We are interested in predicting the difference g in mean duration of T that arises from X_1 versus X_2:

$$g(\theta, X_1, X_2) = E[T]|_{X=X_1} - E[T]|_{X=X_2}.$$

Using the expression for $E[T]$ given above, $g(\theta, X_1, X_2)$ can be rewritten in factored form as

$$g(\theta, X_1, X_2) = E[T]|_{X=X_1}\left(1 - e^{\beta(X_2 - X_1)}\right).$$

This factored version allows for abbreviated code to be written for Stata's predictnl command, which we use to calculate both an estimate of g with $g(\hat{\theta}, X_1, X_2)$, as well as a confidence interval using the delta method. The delta method is reviewed below, using Stata's notation from the predictnl documentation.

Stata Predictnl Delta Method Equations

The estimated standard error $\widehat{se}\{g(\hat{\theta}, X_1, X_2)\}$ is given by

$$\widehat{se}\{g(\hat{\theta}, X_1, X_2)\} = \sqrt{GVG'}$$

where V is the estimated variance-covariance matrix for $\hat{\theta}$ and G is the gradient of g evaluated at $\hat{\theta}$:

$$G = \left\{ \left. \frac{\partial g(\theta, X_1, X_2)}{\partial \theta} \right|_{\theta=\hat{\theta}} \right\}_{(1\times k)}.$$

A $(1-\alpha)\cdot 100\%$ confidence interval is given by

$$g(\hat{\theta},X_1,X_2) \pm z_{\frac{\alpha}{2}}\,\widehat{se}\left\{g(\hat{\theta},X_1,X_2)\right\}.$$

Standard Error of Predicted Difference in Mean Annual Throughput at a Facility

For a maintenance facility with a given number W of work orders accepted in a year, the expected total number of days saved by increasing manpower, as represented by moving from covariate level X_1 to X_2, is given by the following:

$$h(\hat{\theta},X_1,X_2,W) = W\cdot g(\theta,X_1,X_2) = W\cdot E[T]|_{X=X_1}\left(1-e^{\beta(X_2-X_1)}\right)$$

Using the delta method equations above, the standard error $\widehat{se}\left\{h(\hat{\theta},X_1,X_2,W)\right\}$ of the predicted number of days saved in a year has the following relationship to the standard error of the predicted number of days saved for one work order $\widehat{se}\left\{g(\hat{\theta},X_1,X_2)\right\}$:

$$\widehat{se}\left\{h(\hat{\theta},X_1,X_2,W)\right\} = \sqrt{W^2GVG'} = W\cdot\widehat{se}\left\{g(\hat{\theta},X_1,X_2)\right\}$$

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Appendix F. Site Visit

The research team conducted a field visit at Havre de Grace Combined Support Maintenance Shop (CSMS), collocated with a Field Maintenance Shop (FMS) in Maryland, in September 2016 to contextualize the quantitative analyses and understand the maintenance facility workflow. During our visit, we met with the Lieutenant Colonel serving as the Maryland Surface Maintenance Manager, the Chief Warrant Officer serving as the manager of the CSMS, and several of the military technicians (MilTechs) supporting maintenance operations. This site accommodates Maryland's only CSMS, supports the nine FMS facilities in Maryland, and is the country's oldest CSMS facility.

Maintenance activities at this site take place in two buildings. The main building has bays to accommodate simultaneous work on five or six vehicles, one heavy crane, and one paint booth. Another room on the first floor of the main building houses allied trades[39] equipment dating back to the 1970s, including woodworking, upholstery, and machine tools. The level above the ground floor stores part inventory and serves as a production control space. The second building contains administrative offices and three maintenance areas—one dedicated to small arms, one to missiles, and one to electronics and calibration.

Constraints imposed by the facility's physical characteristics impact the efficient flow of work. During the winter months, the limited floor space for vehicles constricts throughput. The building has insufficient vertical clearance to use the overhead crane for removing engines from large trucks. At the time of our visit, a parking lot adjacent to the main building held more than 50 vehicles—mostly High Mobility Multipurpose Wheeled Vehicles (HMMWVs)—waiting for service.

The staff at the Havre de Grace facility consists of 25 direct personnel and 6 supervisors. Staffing categories include vehicle maintainers, allied trades, electronics, armaments, and supply, which had a vacant position at the time of our visit. Each category has its own supervisor and staff. Leaders and supervisors have approximately ten years of experience. Supervisors do not usually contribute directly to maintenance activities, but do get involved during busy seasons.

Leadership at the Havre de Grace location report that staffing between the collocated FMS and the CSMS may blur in high workload periods—especially in overlapping skill sets, such as vehicle maintenance. Staffing for specialized skill sets remains distinct between the FMS and the CSMS.

[39] The "allied trades" classification includes specialties such as welding, machining, upholstery, paint, etc.

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Appendix G. Illustrations

Figures

Tables

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Appendix H.
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Appendix I.
Abbreviations

ADOS-RC	Active Duty for Operational Support, Reserve Component
AFQT	Armed Forces Qualification Test
AFT	Accelerated Failure Time
AGR	Active Guard and Reserve
AK	Alaska
AL	Alabama
AR	Arkansas
ARNG	Army National Guard
ARNG-HRM	ARNG Personnel Programs, Resources and Manpower Division
AZ	Arizona
CA	California
CMIS	Corporate Management Information System
CO	Colorado
CSMS	Combined Support Maintenance Shop
CT	Connecticut
DC	District of Columbia
DE	Delaware
DOD	Department of Defense
ECC	Equipment Category Code
FL	Florida
FMS	Field Maintenance Shop
FMSWeb	Force Management System Website
FSC	Federal Stock Code
GA	Georgia
GCSS-Army	Global Combat Support System-Army
HI	Hawaii
HMMWV	High Mobility Multipurpose Wheeled Vehicles
IA	Iowa
ID	Idaho
IL	Illinois
IN	Indiana
JFHQ	Joint Force Headquarters
KS	Kansas
KY	Kentucky
LA	Louisiana

LIN	Line Identification Number
LOGSA	Logistics Support Activity
MA	Massachusetts
MATES	Maneuver Area Training and Equipment Site
MD	Maryland
ME	Maine
MI	Michigan
MN	Minnesota
MO	Missouri
MOS	Military Occupational Specialty
MS	Mississippi
MT	Montana
MTOE	Modification Table of Organization and Equipment
NC	North Carolina
ND	North Dakota
NDAA	National Defense Authorization Act
NE	Nebraska
NGB	National Guard Bureau
NH	New Hampshire
NIIN	National Item Identification Number
NJ	New Jersey
NM	New Mexico
NV	Nevada
NY	New York
OCONUS	Outside the Continental United States
OH	Ohio
OK	Oklahoma
OPM	U.S. Office of Personnel Management
OR	Oregon
PA	Pennsylvania
PH	Proportional Hazards
RI	Rhode Island
SAMS-E	Standard Army Maintenance System-Enhanced
SC	South Carolina
SD	South Dakota
TAMMS	The Army Maintenance Management System
TDA	Table of Distribution and Allowances
TDC	Type of Duty Code
TN	Tennessee
TX	Texas
UIC	Unit Identification Code

UP	Uniformed Personnel
UT	Utah
UTES	Unit Training Equipment Site
VA	Virginia
VT	Vermont
WA	Washington
WI	Wisconsin
WON	Work Order Number
WV	West Virginia
WY	Wyoming

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14. ABSTRACT

Equipment readiness underpins the training and deployment of Army National Guard (ARNG) units. Using survival analysis regressions to quantify the causal effect of ARNG maintenance personnel on ground equipment readiness as proxied by the time required to complete maintenance work, we find that investments in maintainers result in economically meaningful and statistically significant reductions in the length of time ground equipment remains in a mission-incapable state. We find that adding one vehicle maintainer to each of the 472 Field Maintenance Shops studied would produce approximately 79,000 additional ready equipment days each year across the ARNG, holding constant all other staffing and features. Adding one vehicle and one electronics maintainer to each of the 81 Combined Support Maintenance Shops and Maneuver Area Training and Equipment Sites studied would produce approximately 25,000 additional ready equipment days each year across the ARNG, all else equal. Our results suggest that personnel constraints currently hamper the timely completion of equipment maintenance and impact overall equipment readiness levels in the ARNG.

15. SUBJECT TERMS

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