FLIGHT LINE SUPPLY CHAIN SOLUTIONS: A COST BENEFIT ANALYSIS

GRADUATE RESEARCH PAPER

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Abstract

Air Force mission capable rates have remained at 65 percent over the last few years. One researcher identified a bottleneck constraining the increase of aircraft mission capable rates—the maintainer personnel shortage. The author argued that optimizing technology would allow more maintainer "'touch time' performing maintenance with fewer personnel, and provide a possible benefit of increasing aircraft availability." This author derived this conclusion using the assumption that there is a shortage of transportation vehicles compared to transportation requirements on the flight line.

Using the assumption that this flight line transportation bottleneck exists, the purpose of this research is to determine how the Air Force should relax this bottleneck. This research uses a cost benefit analysis (CBA) methodology to compare three alternatives that relax the flight line transportation bottleneck for maintainers.

This research shows replacing the existing transportation solution with cargo cycles would decrease lost maintainer touch time, decrease operating and acquisitions cost, and have a net benefit on the environment in terms of metric tons of CO2 emissions. Although cargo cycles may not be the trendiest solution, they are the simplest and most cost effective.

Acknowledgments

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FLIGHT LINE SUPPLY CHAIN SOLUTIONS: A COST BENEFIT ANALYSIS

I. Introduction

Background

Air Force mission capable rates have hovered around 65 percent across the entire fleet for the last several years (Ingram, 2020, p. 2). As such, the Air Force needs to seek new alternatives to enhance mission capable rates without spending a tremendous amount of funding or increasing complexity. One such area to investigate towards enhancing mission capable rates is maintainer touch time. Stanton (2020) identified a bottleneck that is constraining aircraft availability—the maintainer personnel shortage (p. 1). This research asserted that aircraft mission capable rates are decreasing due to the severe maintainer personnel shortage (Stanton, 2020, p. 1). The author argued that optimizing technology would allow more maintainer "'touch time' performing maintenance with fewer personnel, and provide a possible benefit of increasing aircraft availability" (p. 6). In other words, generating more maintainer touch time creates more capacity in terms of the bottleneck created by the maintainer personnel shortage.

In addition to the personnel shortage, Stanton (2020) identified an additional transportation bottleneck. She explained there exists a shortage of transportation vehicles to move maintainers and parts to and from the aircraft (Stanton, 2020, p. 4). Specifically, if a maintainer is already at an aircraft and requires a tool or part, he or she must call the expediter for pick up, go to the consolidated tool kit (CTK) or supply/Contractor Operated and Maintained Base Supply (COMBS), complete the process for tool or part issue, call the expeditor for pick up, and return to the aircraft (Stanton, 2020, p. 4). This cumbersome and time-consuming process motivated her research. Stanton (2020) proposed that if a maintainer could order the required tools or parts remotely via an app, an autonomous rover could be dispatched from the CTK or supply/COMBS to deliver the asset to the maintainer's location on the flight line (Stanton, 2020, p. 4). This proposal allows the processes of tool and part issue and delivery to be completed independent of the maintainer in order to reduce processing time and increase maintainer personnel "touch time" at the aircraft.

Stanton (2020) defined the transportation bottleneck by observing the 305 Aircraft Maintenance Squadron (AMXS) for C-17s and the 605 Aircraft Maintenance Squadron (AMXS) for KC-10s, both at Joint Base McGuire-Dix-Lakehurst (JB MDL) (p. 5). For both of these units, she assumed a requirement to transport 35 maintainers that queue at the same time when they come on shift (Stanton, 2020, p. 24). The bottleneck occurs because these maintainers rely on one expediter driving one panel van that is limited to six passengers per trip (Stanton, 2020, p. 27). This panel van shuttles maintainers to their work center at the aircraft, back to the CTK and supply/COMBS to pick up tools and parts, and back out to the aircraft (Stanton, 2020, p. 27). The author studied this bottleneck and created a simulation to model the data she collected (Stanton, 2020, p. 31); she incorporated the use of rovers into her simulation in order to determine if and how they would decrease the bottleneck on maintainer transportation (Stanton, 2020, p. 49).

This research will build off the Stanton (2020) assumption that there is a shortage of transportation vehicles compared to transportation requirements (2020, p. 4). This paper conducts a cost benefit analysis (CBA) across multiple transportation modes to determine the most cost efficient solution for the Air Force.

Problem Statement/Research Focus

By advancing Stanton (2020), this paper will focus on logistical capacities and innovations to prepare for the Flight Line of the Future (FLoF) in terms of using cargo cycles and/or autonomous vehicles to bridge a portion of a maintainer's logistical supply chain for tools and parts on the airfield.

Multiple studies compare the cost drivers of general-purpose vehicles with cargo cycles (Lenz & Riehle, 2013; Sheth et al., 2019; Choubassi et al., 2016; Tipagornwong & Figliozzi, 2014; Gevaers et al., 2009). A cargo cycle is a bicycle or tricycle with a compartment for carrying cargo. In terms of manpower costs, there is not a difference between these two modes of transportation because the cost per hour per employee does not change; however, there is a difference in terms of employee training costs (Lenz & Riehle, 2013, p. 40). Regarding purchase costs, cargo cycles are significantly cheaper than vehicles (Lenz & Riehle, 2013, p. 40). However, with maintenance costs, cargo cycles are significantly cheaper than vehicles. In terms of fuel, cargo cycles are significantly cheaper than vehicles. Depending on the distance required for delivery, cargo cycles are not as effective as vehicles. Depending on the payload that needs transported, cargo cycles may not be as effective as vehicles (Lenz & Riehle, 2013, p. 41). This research will explore the costs and benefits of using cargo cycle utilization for logistical support of tools and parts to aircraft maintainers.

This paper will also incorporate the cost drivers of autonomous vehicles. Autonomous vehicles, or self-driving cars, are expected to start entering the market in the near future at drastically lower operating costs than traditional cars. Specifically, Rocky Mountain Institute found that autonomous vehicles will achieve a per mile operating cost of less than one dollar (2016, p. 6). Personally owned vehicles currently cost approximately 82 cents per mile to operate while Transportation Network Companies (TNC) like Uber or Lyft cost about two dollars per mile to operate (Rocky Mountain Institute, 2016, p. 23). The significant difference between personally owned vehicles and TNC price comes from the man-hours required to out-source operating a vehicle when a customer decides to take an Uber or Lyft. However, an autonomous vehicle eliminates the man-hour cost of operating a vehicle.

If the aircraft fleet of the Air Force is truly around a 65% mission capable rate and there exist multiple bottlenecks, the AF needs to conduct a holistic analysis of what resources can relax those constraints. Building off Stanton (2020), this research chooses to investigate the transportation bottleneck which will enhance aircraft mission capable rates by increasing maintainer touch time.

Limitations/Assumptions/Methodology

This study is limited to the bottleneck Stanton (2020) observed at JB MDL. An assumption used in this research is that the single panel van used in this analysis is an Air Force owned asset. Stanton (2020) did not address this in her study, but the panel vans used at JB MDL are General Services Administration assets. A second assumption in the methodology section uses a C-17 cost factor to determine operating costs. This factor was used because C-17 costs factors were readily available; however, KC-10 cost factors were not. This cost factor is important because it allows this research to monetize the time lost at the transportation bottleneck.

This research was conducted through the lens of the Theory of Constraints in conjunction with the cost benefit analysis (CBA) methodology. Current transportation costs come from LIMS-EV Vehicle View Fleet Posture Report. The researcher calculated projected costs if maintainers replace the single panel van, which creates a transportation bottleneck, with a fleet of cargo cycles, autonomous vehicles, or additional panel vans.

Research Question

This research paper explores the following research question:

How should the Air Force most cost efficiently relax the maintainer transportation bottleneck identified in Stanton (2020)?

Implications/Summary

This research builds upon Stanton (2020) by exploring the use of cargo cycles, autonomous vehicles, or additional panel vans as additional transportation options to allow more maintainer “touch time” in an effort to enhance fleet mission capable rates. The results of this research will contribute to the Flight Line of the Future concept as well as the implementation of the Theory of Constraints as part of “develop[ing] an Air Force Sustainment Strategy Framework to improve the readiness of weapons systems and improve sustainment operations” (Secretary of the Air Force Public Affairs, 2020, para. 2).

II. Literature Review

Chapter Overview

This chapter will provide the contextual knowledge necessary to understand the feasibility of using cargo cycles and autonomous vehicles as flight line transport. This chapter will include explanations of the Theory of Constraints, cost benefit analysis, current Air Force vehicle supply chain policy, cargo cycle and autonomous vehicle capabilities, and how these concepts relate to the Flight Line of the Future.

Theory of Constraints

The theory of constraints is a supply chain management framework that asserts that a production manager must assess their production line for constraints, also known as bottlenecks. Once a bottleneck is found, all efforts must be made to increase the capacity of that constraint and subordinate all other activities to that bottleneck. This is because in a supply chain the constraint effectively becomes the limiting factor on the entire system or production line as it limits throughput.

The book *The Goal* explains the concepts of constraints, bottlenecks, and removing them from production lines (Goldratt, 1984). Goldratt (1984) asserts that if we know the goal of the system and that goal is to make money, then we can employ the following steps to increase flow at the bottleneck and work towards the goal:

1) Identify the system's constraint(s).
2) Decide how to exploit the system's constraint(s).
3) Subordinate everything else to the above decision(s).
4) Alleviate the system's constraint(s).
5) Warning! If in the previous steps a constraint has been broken, go back to step 1, but do not allow inertia to cause a system's constraint. (Goldratt, 1984, p. 307)

This research paper builds off the Stanton (2020) assumption that that there is a shortage of transportation vehicles compared to transportation requirements creating a bottleneck in production (2020, p. 4). This paper contributes to the discussion surrounding how to exploit the system's constraint following Goldratt's Theory of Constraints.

Cost benefit Analysis

Cost benefit analysis (CBA) is a tool that helps decision makers; it compares costs to benefits in a given situation. The textbook *Cost benefit Analysis: Concepts and Practice* explains and applies CBA (Boardman et al., 2018). This text explains CBA as a method of policy assessment that takes into account all the consequences of a policy for all members of society (Boardman et al., 2018, p. 2). The authors provide a list of steps to follow when conducting a CBA:

> The Major Steps in CBA
> 1. Explain the purpose of the CBA
> 2. Specify the set of alternative projects
> 3. Decide whose benefits and costs count (specify standing)
> 4. Identify the impact categories, catalogue them, and select metrics
> 5. Predict the impacts quantitatively over the life of the project
> 6. Monetize (attach dollar values to) all impacts
> 7. Discount benefits and costs to obtain present values
> 8. Compute the net present value of each alternative
> 9. Perform sensitivity analysis
> 10. Make a recommendation (Boardman et al., 2018, p. 5)

This research paper will employ the steps above to analyze the costs and benefits between the status quo—current maintainer supply transport process using a single panel van—and using cargo cycles, autonomous vehicles, or additional panel vans to deliver supplies to maintainers working on the flight line.

Current Air Force Vehicle Supply Chain Policy

Department of Defense Manual 4500.36 governs Air Force vehicle policy. This policy requires DoD Components to develop a vehicle allocation methodology (VAM) and use this VAM to optimize the non-tactical vehicle (NTV) fleet (Department of Defense [DOD], 2018, p. 12). This manual drives Air Force policy set forth in Air Force Policy Directive 24-3, *Management, Operation And Use Of Transportation Vehicles* which governs Air Force Instruction (AFI) 24-302, *Vehicle Management*. AFI 24-302 identifies the 441st Vehicle Support Chain Operations Squadron (VSCOS) as the organization responsible for Air Force vehicle funding, validation, and fleet management (Sanford, 2017, slide 8; AFI 24-302, 2020, p. 29). The 441 VSCOS validates vehicle requirements and fleet sizes (AFI 24-302, 2020, p. 32). The 441 VSCOS is responsible for managing the Air Force vehicle buy program (AFI 24-302, 2020, p. 101). This program is the Air Force mechanism to purchase vehicles in accordance with federal law, the Appropriations Act, and other price limitations set by Congress on certain vehicles (AFI 24-302, 2020, p. 101). Therefore, 441 VSCOS is the validation authority for new and existing vehicle authorizations (AFI 24-302, 2020, p. 101). Additionally, this organization is responsible for managing vehicle lifecycle costing program documentation for man-hour accounting, fuel consumption, and sustainment costs like vehicle parts (AFI 24-302, 2020, p. 30). This information is pertinent because this research obtained all general-purpose vehicle cost data from 441 VSCOS to provide validity to the analysis.

Current Cargo Cycle Capabilities

Using cycles to transport cargo is not a new concept. Dabbawalas in India have used bicycles to distribute more than 175,000 lunchboxes daily at a six-sigma level reliability rate since 1890 (Maes & Vanelslander, 2012, p. 411). Today, UPS, DHL, and FedEx are experimenting and utilizing cargo cycles in operations; these electric assist cargo cycles have two, three, or four wheels, a cargo compartment, and use either pedal power or energy from a battery pack (Sheth et al., 2019, p. 2). This review will provide an overview of the literature on cargo cycles including costs as well as other common research findings.

Figure 1. Larry vs. Harry Bullitt electric cargo bike (Sutton, 2016).

The literature on cargo cycle costs varies as shown in Table 1. As Table 1 illustrates, cargo cycles are significantly cheaper when compared with vehicles in every way. However, cargo cycles have significantly smaller range, battery or fuel capacity, and cargo payload than the vehicles included in the table.

Table 1. Transportation Mode Cost Comparison

	Electric Assist Cargo Cycle	Real World Truck Trike	Typical Tricycle Cycle Maximus	Pedelec Bike Larry vs. Harry Bullit Cargobike	Pedelec Trike Cycle Maximus Pedal Cargo Van Trike	USPS Long Life Vehicle (LLV)	Nissan e-NV200
Source	Sheth et al. (2019)	Sheth et al. (2019)	Tipagornwong & Figliozzi (2014)	Choubassi et al. (2016)	Choubassi et al. (2016)	Choubassi et al. (2016)	Choubassi et al. (2016)
Purchase Cost ($)	not available	not available	6200	1244	6491	21538	32301
Operating Cost ($/hour)	9.2	not available	not available	0.07 $/mi	0.07 $/mi	0.30 $/mi	0.1674 $/mi
CO2 Emissions (tons per day)	not available	not available	not available	0.00315	not available	0.22806	0.01746
Capacity (cu ft)	77	81	not available	5	49	121	148
Maximum Load (lbs)	600	not available	550	200	550	1000	1697
Speed mph	15	not available	10	10	10	55	75
Range (mi)	not available	not available	not available	75	90	not applicable	106
Wages ($)	25.17	not available	16.32	28	28	28	28
Maintenance Cost	included in OC	340 $/year	0.02 $/mi	0.02 $/mi	0.02 $/mi	0.15 $/mi	0.1174 $/mi
Battery Charge	unclear if included in OC	12-18 miles	864 watt-hours	not available	not available	not applicable	not available
Electricity or fuel economy	not available	not available	29 watt-h mi	0.05 $/mi	0.05 $/mi	0.15 $/mi	0.05 $/mi
Life Span (years)	not available	not available	not available	5	5	24	20

There are a few differences in terms of labor costs for cargo cycles versus vehicles. The hourly labor cost for a vehicle operator compared to a cargo cyclist is theoretically the same. Licenses or training required for vehicle operators may not be applicable to cargo cycle operators which could result in cost savings (Lenz & Riehle, 2013, p. 40). In contrast, Choubassi et al. (2014) argued that a cargo cyclist's age and physical fitness can impact his or her hourly labor rate; in other words, a fit person operating a cargo cycle may request additional pay (2016, p. 103). Tipagornwong and Figliozzi commented on this factor by saying that people still have to pedal a cargo cycle; an average fit man or woman can pedal a cargo cycle with the power output of 75 watts without suffering fatigue for 7 hours (2014, p. 76). Driver fatigue due to physical exertion is another factor to consider with cargo cycles (Lenz & Riehle, 2013, p. 41). There is significantly more physical exertion required to operate a cargo cycle than a vehicle. Driver fatigue also impacts battery size for cargo cycles; if the driver expects to be more fatigued during cargo cycle operations, he or she should use a cargo cycle with sufficient battery to complete the delivery. In a military setting, using a cycle on a regular basis for personal transportation could result in overall better health for individual service members. Maintainers are known to have little time during the duty day to exercise; incorporating cargo cycles into maintenance flight line operations could increase overall maintainer health. However, maintainer health is not the primary purpose of implementing cargo cycles as flight line transport; it is an indirect benefit.

Cargo cycle literature suggests that cargo cycles are most effective for short trips in urban areas because of known difficulties with the last mile of delivery. The last mile of delivery is the most expensive part of the supply chain, ranging from 13% to 75% of the total supply chain costs due to system inefficiency (Gevaers et al., 2009, p. 4). In 2009, transportation companies spent $33 billion due to congestion in the nation's largest urban areas with the largest factors being delay time and wasted fuel (Choubassi et al., 2016, p. 102). Parking tickets in urban areas are a factor that increases vehicle operations costs in urban areas. Cargo cycles are able to sidestep this cost because they can enter pedestrian neighborhoods and narrow alleyways more easily in comparison to vehicles (Choubassi et al., 2016, p. 103). Choubasssi et al. (2016) found that cargo trikes were more competitive in areas with high population density and with depots located within the delivery area boundaries (2016, p. 109).

It is important to touch on a few topics that are important to cargo cycle operations in urban areas but not on a flight line. A factor that came up in the literature is the impact of cargo cycles on unemployment. In some markets, cargo cycles contribute to major decreases in unemployment because a license is not required, thus increasing the hiring pool (Choubassi et al, 2016, p. 103). Security is another factor that appeared throughout the literature on cargo cycles. In urban areas, there are fears that cargo or cargo cycles will be stolen when delivering cargo; however, there were almost no reports of cargo cycle theft in reality (Lenz & Riehle, 2013, p. 41).

A final factor to consider with regard to cargo cycles is the negative perception of this transportation asset. This is a relevant factor because it was recurrent throughout the literature. Lenz and Riehle (2013) found that customers were resistant to cargo cycles and perceived cycle freight poorly: "The perception of customers is currently identified as the largest limiting factor: 'People don't know about a cargo bike and what it is.' People have certain ideas about the use of cargo cycles: '[t]he moment you talk about a bike, people automatically think of their bike they got in their shed'" (2013, p. 43). This factor was also found in another study that explained that although cargo cycles are proven to be an economical choice for last mile delivery in urban areas, businesses are still reluctant to add cargo cycles to their fleet (Gruber & Narayanan, 2019, p. 624). Stanton (2020) argued that <u>The Law of Disruption</u>—how innovation often outpaces acceptance in the social, business, and political realms—may impede the implementation of autonomous rovers on the flight line. This law seems to be applicable to cargo cycles as well (2020, p. 9).

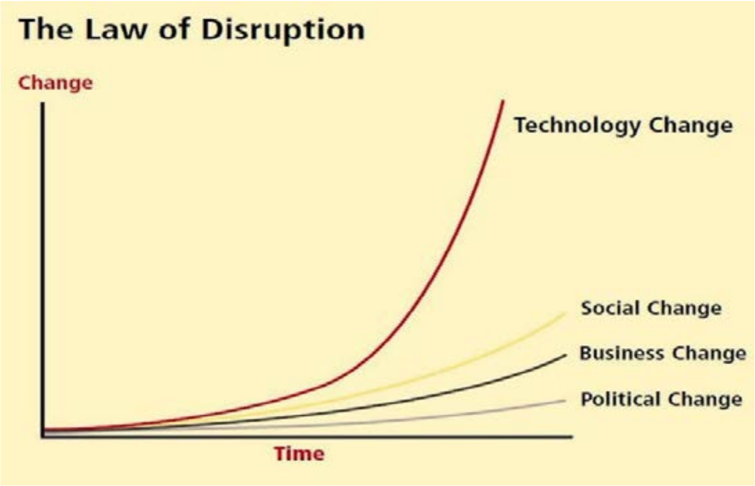

Figure 2. The Law of Disruption or Innovation's Progress outpacing societal, business, or political climates (McLelland, 2017).

Current Autonomous Vehicle Capabilities

Autonomous vehicles are an emerging technology poised to change the transportation landscape. These vehicles incorporate electric powertrains and autonomous driving systems that could result in significant cost savings (Rocky Mountain Institute, 2016, p. 5). Autonomous vehicles also reduce CO_2 emissions, which would "save tens of thousands of lives per year in the U.S. alone" (Rocky Mountain Institute, 2016, p. 5).

Rocky Mountain Institute analyzed incorporating autonomous vehicles into Transportation Network Companies and found that if autonomous vehicles were used in an Uber or Lyft business model, the cost would be less than one dollar per mile which is a significant economic tipping point for most Americans (2016, p. 6).

The assumption underpinning the paradigm shift to autonomous vehicles and communal transportation is the rise of the "service economy" (Rocky Mountain Institute, 2016, p. 5). This idea proposes that instead of owning a vehicle outright, mobility is moving towards a pay-per-use model. However, the fundamental challenge of this model using a shared autonomous fleet is finding a "balance between the amount of autonomous electric vehicles and the waiting time a customer has to expect until a requested shuttle arrives" (Fournier et a., 2017, p. 369).

Figure 3. Autonomous Electric Vehicle Nissan e-NV200 Evalia (2021)

Although the majority of literature discusses the economic benefits of autonomous cars from multiple perspectives (technical, logistics, environmental, etc.), there are more realist authors who suggest that autonomous vehicles are still far from being commonplace on roadways or used as transportation options. Litman (2017) argues that there is still too much incomplete engineering and basic science to widely implement autonomous vehicles (2017, p. 25). Moreover, he compares autonomous vehicles with electric cars, stating that these cars were developed as early as the 1800s, and even in 2020, 1% of total vehicle sales are electric (Litman, 2017, p. 27).

Environmental Impact

The Interim National Security Strategic Guidance published in March 2021 emphasizes the criticality of the climate crises; specifically, “climate” is used 27 times, usually in conjunction with “change” or “crises” (“Interim National Security Strategic Guidance,” 2021). It is clear that in the coming years, the Department of Defense must focus more on reducing its impact on the environment.

The DoD is the world’s largest user of petroleum and the largest producer of greenhouse gases in the world (Crawford, 2019, p. 2). Output of greenhouse gases is measured in CO_2 which will be the same unit of measure used in this paper (Crawford, 2019, p. 2). Because of the stated importance of improving military’s CO_2 impact on the environment, this will be one of the benefits used to measure the transportation solution to alleviate the bottleneck on the flight line.

Flight Line of the Future

In the Logistics Officer Association (LOA) “Exceptional Release Fall 2019,” Brigadier General Linda Hurry discussed Flight Line of the Future. She stated that the next war will be fought using advanced information technology, and in response the “Tesseract” team is

> . . . learning how to leverage and then scale Theory of Constraints methods to identify bottlenecks in our processes, lead process reengineering efforts and ultimately assist in constraint resolution. They will work with you to build LRS & Mx Next, the Flight Line of the Future with wireless internet access, mobile devices and software, and to learn about how to employ predictive algorithms in the weapon systems we launch or manage each day. (Hurry, 2019, p. 9)

Assistant Secretary of the Air Force for Acquisition, William Roper, echoed the same idea in a presentation to the House Armed Services Committee in 2018. He explained that acquisitions, artificial intelligence, and virtual reality are areas that could potentially reduce costs and contribute to the Flight Line of the Future which could be the "difference-maker in future conflicts" (2018, p. 8).

McDonald and Panebiano provide the most comprehensive and direct definition of Flight Line of the Future:

> The flight line of the future encompasses the entire communications ecosystem on a military base, including applications, databases, logistics, facilities and more. To meet future mission requirements, the DoD can upgrade and streamline communications with advanced technology that meets every military base's unique requirements so all airmen have access to the information they need, when they need it. Successful use cases can be used to replicate communication ecosystems globally across all military bases to realize the full mission value of electronic workflow. This will enable the DoD to save time and money, while becoming much more efficient in accomplishing its mission. (2020, para. 7)

Koser (2020) expanded on Flight Line of the Future from a technical standpoint. He explained that the flight line must be wifi, cellular, 5G, or Satcom enabled in order to keep up with and stay competitive and innovative (p. v). Flight Line of the Future moves us to a flight line where all the Airmen, aircraft, sensors, and maintenance equipment are connected via Wi-Fi and wireless technology (Koser, 2020, p. 1).

Stanton (2020) touched on the incorporation of Conditions Based Maintenance Plus (CBM+) into Flight Line of the Future (p. 10). CBM+ is an example of incorporating information technology into our processes that brings us closer to the Flight Line of the Future. The Air Force is using this predictive analytics tool to “track when parts on airplanes are likely to break, and schedule a convenient time to have a maintainer swap out that part ahead of time” (Losey, 2019, para. 2). Maintainers are using information technology like Koser (2020) mentioned to gather the data for this predictive analysis in order to execute appropriate and timely maintenance actions.

III. Methodology

Chapter Overview

The research question posed in this paper is most appropriately investigated through a cost benefit analysis (CBA). Several alternatives will be explored to include cargo cycles, autonomous vehicles, and additional panel vans. This chapter will identify the data source used to analyze this research question and complete steps one through four of the CBA methodology. Steps five through nine will be completed in the Analysis and Results section. Step ten will be completed in the Conclusions and Recommendations section.

Data Collection and Model Construction

The primary source of data used in this study to define the transportation bottleneck comes from Stanton's research (2020). Stanton observed that there are 35 maintainers that require transportation when they come on shift (2020, p. 24). This causes a bottleneck because all 35 maintainers arrive on shift simultaneously and rely on a single expediter for transportation (2020, p. 49). This situation invokes a 3 to 35 minute wait in order to ride with the expediter from the main squadron building to the CTK, then to the flight line, and then possibly to other locations depending on mission requirements (Stanton, 2020, p. 46). The transportation bottleneck is caused by the single expediter vehicle with a six-person capacity. The factors Stanton (2020) found in her primary data were used to calculate the man-hours lost at this bottleneck. Calculations used a group of 35 maintainers waiting up to 35 minutes to be transported to the flight line (p. 46). These factors indicate that the expediter was able to pick-up an additional six maintainers approximately every seven minutes. Stanton's data indicates that the total number of man-hours lost waiting on the expeditor in a single day is 9.9 hours. There are 20 aircraft maintenance man-hours required per flying hour (“C-17 Globemaster III,” 2018, para. 3). A C-17 costs $23,811 per flight hour (Ritsick, 2020, para. 10). According to Goldratt, “an hour lost at a bottleneck is an hour lost for the entire system” (1984, p. 158). Therefore, each man-hour lost at this bottleneck equates to $1,190.55. Due to the complicated nature of attributing cost to government operations, this factor will be used to monetize the CBA results.

Table 2. Maintainer Touch Time Lost at Bottleneck Due to Transportation

Maintainers Transported	Time Waiting	Maintainers Waiting	Time until next shuttle	Mins Lost
6	0	29	7	203
12	7	23	7	161
18	14	17	7	119
24	21	11	7	77
30	28	5	7	35
35	35	0	7	0
Total min lost		595		
Total man-hours lost		9.92		
C-17 Cost per Flying Hour		$ 23,811.00		
Man-Hours per Flying Hour		20		
Value of 1 Man-Hour		$ 1,190.55		
Value of time lost per day		$ 11,806.29		

The second data source for this study is Logistics Installation and Mission Support Enterprise View Vehicle View (LIMS-EV VV) Fleet Posture Report. LIMS-EV VV is an information technology data service that provides an enterprise reporting and analysis capability to the Air Force transportation community (AFI 24-302, 2020, p. 210). The researcher obtained the data for the status quo by contacting the 441 VSCOS who pulled the vehicle purchase and sustainment costs for the 305 AMXS and 605 AMXS. However, panel vans used by both units included in Stanton (2020) are leased through General Services Administration (GSA). 441 SCOS does not track the operations and maintenance costs of these vehicles because these costs are incorporated into the lease cost unless GSA deems it as not normal wear and tear. This study compares the costs and benefits of used a panel van that is an Air Force owned asset. Table 4 lists the cost factors of an Air Force owned panel van. These values are averages from 2019 for a KC-135 Aircraft Maintenance Unit. Operations cost includes direct labor cost and parts costs.

Table 3. Air Force Owned Panel Van Cost Factors

Nomenclature	Management Code	Acquisition Cost	Operations Cost ($/day)	Energy Cost ($/day)
Maint Utility Del Van (Panel Van)	B180	$40,405.00	$1.44	$1.96

Cost benefit Analysis Application

The first step of CBA is to explain its purpose. The purpose of applying CBA in the case of this research is to determine the costs and benefits of replacing the bottleneck Stanton (2020) observed with additional transportation assets. Creating additional capacity at this bottleneck will deliver more maintainer touch time at the aircraft which should result in higher aircraft availability rates.

The second step of CBA is to specify the set of alternative projects. This research will consider three alternatives. The first alternative is to replace the status quo—a single panel van—with a fleet of 35 cargo cycles in order to alleviate the bottleneck. The second alternative is to replace the existing panel van with six autonomous vehicles in order to alleviate the bottleneck. The third alternative is to add five additional panel vanes in order to alleviate the bottleneck.

For the first alternative, the cargo cycle that will replace the existing vehicle fleet is a pedelec Larry vs. Harry Bullit Cargobike pictured in Figure 1 because it is the cheapest option available and still has a sufficient maximum load of 200 pounds to transport any necessary tools and parts (Choubassi et al, 2016, p. 104). A pedelec bike is an electric bicycle that will produce power when the cyclist is pedaling (Choubassi et al, 2016, p.104). The cargo cycle maintenance cost factor was $0.02 per mile and the fuel/electricity cost factor was $0.05 per mile resulting in an operating cost of $0.07 per mile (Choubassi et al., 2016, p. 104). Stanton (2020) was used to determine the number of miles each cargo cycle would travel from the squadron to the CTK to the aircraft location. For C-17 maintainers at JB MDL, the main squadron where the maintainers queue is co-located with the CTK. The author stated that the C-17 expeditor drove 37.5 miles in a 10-hour shift or 90 miles in a 24-hour period (Stanton, 2020, p. 45). Using a factor of 90 miles per day, a fleet of 35 cargo cycles would incur an operating cost of $6.30 per day and would result in 0.00315 metric tons of CO_2 emissions per day. Additionally, a fleet of 35 cargo cycles purchased at $1244 a piece would cost $43,540.00.

Table 4. Cargo Cycle Cost Factors

Cargo Cycle Operating Cost ($/mi)	$0.07
Miles per day	90
Operating Cost per day ($)	$6.30
# of Cargo Cycles	35
$ per Cargo Cycle	$1,244.00
Acquisition Cost of Fleet	$43,540.00

For second alternative, the autonomous vehicle considered is a Nissan e-NV200 Evalia (Fournier et al., 2016, p. 373). This autonomous electric vehicle (AEV) can seat seven people (an expediter and six passengers) and is used for transporting groups and goods ("Nissan e-NV200 Evalia", 2021). According to Fournier et al. (2016), when used in an autonomous vehicle fleet, the Nissan e-NV200 Evalia incurs annual operations costs of €1656 per year and energy cost of €6.47 per 100 km (Fournier et al., 2016, p. 373). Again, using a factor of 90 miles per day and converting these values to dollars using a rate of $1.13 per euro in 2017, using 1 autonomous vehicle would incur an operating cost of $5.13 per day and an energy cost of $10.59 per day totaling $15.71 per day. Additionally, a single autonomous vehicle would cost €37,602.00 or $42,490.26 (Fournier et al., 2016, p. 373). A fleet of six AEVs will reduce the flight line transportation bottleneck. An AEV produces 0.01746 metric tons of CO_2 emissions per day. These factors are used in the Analysis and Results section to monetize the impact categories.

Table 5. Autonomous Elective Vehicle (AEV) Cost Factors

AEV Operating Cost per day ($)	$15.71
# of AEVs	6
€ per AEV	€ 37,602.00
$/€ (in 2017)	$1.13
Acquisition Cost	$254,941.56

For the third alternative, an additional five panel vans are added. Using the same factors cited in Table 3, an additional panel van would incur an operating cost of $1.44 per day and an energy cost of $1.96 per day resulting in a total operating cost of $3.40.

An additional panel van has an acquisition cost of $40,405.00; an additional 5 panel vans has a total acquisition cost of $202,025.00 if the status quo panel van is not included. CO_2 emissions per day for a USPS Long Life Vehicle was substituted for a panel van; this factor accounts for 0.11403 metric tons of CO_2 emissions per day for one panel van.

The third step of CBA is determining whose benefits and costs count. The primary stakeholders in this case are the maintainers that use panel vans for flight line transport because it is their time and value that is being lost at the bottleneck. The secondary stakeholders are all Air Force entities interested in increasing maintainer touch time as well as aircraft availability. The tertiary stakeholders are the taxpayers who fund this process expecting aircraft availability to result in increased national defense for the United States.

The fourth step of CBA is to identify the impact categories, catalogue them, and select metrics. The impact categories considered in this CBA are time cost, operating cost, and environmental benefit.

Summary

This methodology consisted of a description of the data source, CBA analysis of the alternative projects for this research, stakeholder identification, and determination of the impact categories used to evaluate the costs and benefits of the options to increase maintainer touch time at the aircraft. The analysis and results section will discuss the additional CBA steps including predicting the impacts quantitatively over the life of the project, monetizing all impacts, discounting benefits and costs to obtain present values, computing the net present value of each alternative, and performing a sensitivity analysis.

IV. Analysis and Results

Chapter Overview

The analysis and results section will complete the additional CBA steps including predicting the impacts quantitatively over the life of the project, monetizing all impacts, discounting benefits and costs to obtain present values, computing the net present value of each alternative, and performing a sensitivity analysis. Step ten will be completed in the Conclusions and Recommendations section.

Analysis and Results

The fifth step of CBA is to predict the impacts quantitatively over the life of the project. The below table details the impact in terms of man-hours lost at the bottleneck as well as the amount of CO_2 emissions saved per day for each of the alternatives identified in the methodology.

Table 6. Impact Predictions

Alternatives	Man-Hours Lost	Available Seats	CO_2 Emissions (metric ton) Per Day Saved
Status Quo	9.92	6	0
Alt 1: 36 Cargo Cycles	0	35	0.11088
Alt 2: 6 AEVs	0	36	0.07911
Alt 3: 5 Panel Vans	0	36	0

These results are monetized in the next step in CBA. A factor of $62 per day was used to monetize the value of the CO_2 emissions (Interagency Working Group, 2016, p. 4).

Table 7. CBA Results with Monetization

Alternatives	Time Cost Per Day	Operating Cost Per Day	Acquisition Cost	CO_2 Emissions Benefit Per Day
Status Quo	$11,810.26	$3.40	$40,405.00	$0
Alt 1: 36 Cargo Cycles	$0	$6.30	$43,540.00	$6.87
Alt 2: 6 AEVs	$0	$15.71	$254,941.56	$0.57
Alt 3: 5 Panel Vans	$0	$17.00	$202,025.00	$0

Step seven of CBA is to discount benefits and costs to obtain present values. This step is not relevant in this analysis because these values are considered in the same present year.

Step eight of CBA is to compute net values of each alternative.

Table 8. Net Values of Each Alternative

Alternatives	Costs Per Year	Benefits Per Year	Net Value
Status Quo	$4,352,389.44	$0	$(4,352,389.44)
Alt 1: 36 Cargo Cycles	$45,839.50	$2,509.21	$(43,330.29)
Alt 2: 6 AEVs	$260,675.71	$209.78	$(260,465.93)
Alt 3: 6 Panel Vans	$208,230.00	$0	$(208,230.00)

CBA advises that if no value is positive, then no alternative is better than the current policy, and the current policy should remain in place (Boardman et al., 2018, p. 14). In this case, all alternatives are negative including the status quo. This study deviates from the general CBA guidance and implements the least negative alternative because it is clear that this option is the most cost efficient way to reduce the transportation bottleneck. The bottleneck is the factor that is driving up the net value of the status quo. It is imperative that the bottleneck caused by requiring the maintainers to queue is reduced because of the high value of lost maintainer time.

Step nine of CBA is to perform a sensitivity analysis. Sensitivity analysis is a technique which allows the analysis of changes of assumptions used in forecasts (Riley, 2018). Key questions to ask when performing sensitivity analysis are how reliable are the assumptions that were made; what happens if assumptions turn out to be significantly different in reality; and which assumptions are the most significant to the forecast (Riley, 2018). In this analysis, the key assumption made was that the value lost at the bottleneck per day was $11,806.29. This assumption is reliable based on the Theory of Constraints assertion that “an hour lost at a bottleneck is an hour lost for the entire system” (Goldratt, 1984, p. 158). However, if this value was significantly different in reality, that would impact the net values calculated and subsequently the recommendation produced from this CBA. The value lost at the bottleneck is also the value most significant to the forecast. Therefore, value lost at the bottleneck will be the cost input variable accounted for in the sensitivity analysis. A second assumption was that the value of a metric ton of CO_2 is $62; this factor comes from a 2016 technical paper and specifies that this is the 2.5% average of the value per metric ton of CO_2 emissions in 2007 dollars for the year 2020 (Interagency Working Group, 2016, p. 4). This source also provides the 5%, and 3% averages for the value per metric ton of CO_2 emissions as well as the 95% value for the range of years from 2010 to 2050 at five-year increments (Interagency Working Group, 2016, p. 4). This paper is transparent that there is uncertainty in the model that predicts the value per metric ton of CO_2 emissions; it states that that the distribution of the estimates reflects uncertainty in two key model parameters—the sensitivity of the climate to increases in carbon dioxide concentrations and the uncertainty in default parameters set by the model developers (Interagency Working Group, 2016, p. 4).

Although the value used in this study—\$62 per ton of CO_2—did not have a significant effect on the forecasted net values, the valuations of the impact of a ton of CO_2 on the environment vary widely. The monetized value of the impact of a ton of CO_2 on the environment could be much different in reality, which could significantly influence the forecast. Therefore, the value of CO_2 emissions will be the benefit input variable accounted for in the sensitivity analysis.

To perform this sensitivity analysis, we determined how the net value is affected as these two variables change. This sensitivity analysis set the row input as the cost per hour of maintainer time lost at the bottleneck ranging from \$500 to \$2000. This sensitivity analysis set the column input as the benefit per metric ton of CO_2 emissions saved ranging from \$30 to \$2000. The What-If function in Excel was used to populate the sensitivity analysis data table, Table 9. From this table, it is clear that as the value of the maintainer time lost at the bottleneck ranges from \$500 to \$2000 there is a large impact on the net value. However, as the value of metric tons of CO_2 emissions ranges from \$30 to \$2000, there is far less effect on net value. Therefore, the value of maintainer time lost at the bottleneck is a much more sensitive factor in relation to the net value than metric tons of CO_2 emissions are.

This sensitivity analysis does not change the conclusion that the least negative alternative should be implemented to reduce the net value lost overall. Alternative 1, the least negative alternative, remains the desired COA because it completely reduces the bottleneck at the point where the maintainers queue, has the least expensive operating and acquisitions cost, and has the greatest net benefit on the environment in terms of metric tons of CO_2 emissions. Alternative 1 is still sensitive to variance in terms of the cost of maintainer time at the bottleneck and the benefit of metric tons of CO_2 emissions saved.

Table 9. What-If Analysis Data Table

		Value of Time Lost at Bottleneck				
	$(4,352,389.44)	500	750	1000	1500	2000
Value of metric tons of CO_2 emissions	30	$1,769,968.14	$2,675,168.14	$3,580,368.14	$5,390,768.14	$7,201,168.14
	60	$1,771,182.27	$2,676,382.27	$3,581,582.27	$5,391,982.27	$7,202,382.27
	90	$1,772,396.41	$2,677,596.41	$3,582,796.41	$5,393,196.41	$7,203,596.41
	120	$1,773,610.54	$2,678,810.54	$3,584,010.54	$5,394,410.54	$7,204,810.54
	150	$1,774,824.68	$2,680,024.68	$3,585,224.68	$5,395,624.68	$7,206,024.68
	180	$1,776,038.82	$2,681,238.82	$3,586,438.82	$5,396,838.82	$7,207,238.82
	500	$1,788,989.60	$2,694,189.60	$3,599,389.60	$5,409,789.60	$7,220,189.60
	1000	$1,809,225.20	$2,714,425.20	$3,619,625.20	$5,430,025.20	$7,240,425.20
	1500	$1,829,460.80	$2,734,660.80	$3,639,860.80	$5,450,260.80	$7,260,660.80
	2000	$1,849,696.40	$2,754,896.40	$3,660,096.40	$5,470,496.40	$7,280,896.40

V. Conclusions and Recommendations

Conclusions of Research

This research highlighted several transportation solutions to mitigate the bottleneck that occurs when maintainers need to be transported to the flight line at JB MDL. To appropriately conduct this analysis, the costs and benefits of these solutions were determined. CBA advises that if no value is positive, then no alternative is better than the current policy, and the current policy should remain in place (Boardman et al., 2018, p. 14). In this case, all alternatives are negative including the status quo due to the tremendous value lost at the transportation bottleneck. This study deviates from the general CBA guidance and implements the least negative alternative because it is clear that this option is the most cost efficient way to reduce the transportation bottleneck. It is imperative that the bottleneck caused by requiring the maintainers to queue is reduced because of the high value of lost maintainer time. Regardless of whether decision makers would decide to implement a course of action to purchase additional transportation assets to reduce the discussed bottleneck, this research shows that there are alternative methods of transport besides a single panel van or the purchase of additional panel vans.

The bottleneck Stanton (2020) identified can be alleviated in many ways in addition to those that were considered in this research. If maintainer touch time really is a constraint on aircraft availability, serious consideration should be given to all modes of transport to alleviate the bottleneck at the flight line. However, this analysis could not include the additional beneficial value associated with the time gained once the constraint is relaxed. Such benefits that were not monetized for this analysis include: maintainers fixing aircraft, completing other mandatory military requirements (i.e. training, planning, professional development, etc.), additional time with family, or the infinite number of other things that the maintainer could be doing other than waiting for transportation.

Recommendations for Action

The tenth step of CBA is to provide a recommendation. The results of the CBA indicate that cargo cycles should replace the panel van that is used to transport maintainers to and from the flight line based on the value of lost maintainer touch time, minimal operating and acquisitions cost, and by comparison the greatest net benefit on the environment in terms of metric tons of CO2 emissions. Consequently, this study highlights a simple and relatively low technological solution, which may not brief as well to senior leaders when compared to the futuristic appeal of assets like autonomous vehicles.

Future Research

Cargo cycles are a simple, common sense solution to relax this transportation bottleneck. Cargo cycles have a low purchase cost, low maintenance cost, and low impact on the environment. There are a few other low cost solutions to this bottleneck including walking, scooters, or Segway’s to transport personnel and cargo around the flight line that could also be employed for consideration; however, transportation time and carrying capacity may undermine these alternatives. Future research should investigate these potential alternatives and survey maintainer personnel for subject matter expert input to gauge cultural acceptance of any given solution.

Autonomous vehicles should continue to be studied because the concept will not go away with advances in material science and computing power. All reports indicate that full implementation of autonomous vehicle technology is just over the horizon.

Autonomous vehicle utilization is expected to decrease vehicle operator man-power requirements (in this case, the expeditor). Consequently, this study should be repeated periodically to assess how much progress has been made with autonomous vehicles and incorporating them into the Flight Line of the Future more cost efficiently.

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14. ABSTRACT

Air Force mission capable rates have remained at 65 percent over the last few years. One researcher identified a bottleneck constraining the increase of aircraft mission capable rates—the maintainer personnel shortage. The author argued that optimizing technology would allow more maintainer “‘touch time’ performing maintenance with fewer personnel, and provide a possible benefit of increasing aircraft availability.” This author derived this conclusion using the assumption that there is a shortage of transportation vehicles compared to transportation requirements on the flight line. Using the assumption that this flight line transportation bottleneck exists, the purpose of this research is to determine how the Air Force should relax this bottleneck. This research uses a cost benefit analysis (CBA) methodology to compare three alternatives that relax the flight line transportation bottleneck for maintainers. This research shows replacing the existing transportation solution with cargo cycles would decrease lost maintainer touch time, decrease operating and acquisitions cost, and have a net benefit on the environment in terms of metric tons of CO2 emissions. Although cargo cycles may not be the trendiest solution, they are the simplest and most cost effective.

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