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EFFECTIVENESS OF IN-SERVICE RELIABILITY IN AIRCRAFTS

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Effectiveness of In-Service Reliability in Aircrafts

Synopsis:

The in-service reliability measures the unforeseen service interruptions due to technical failures
and associated required maintenance. The types of interruptions can be described as below:

- Delay at takeoffs, departing later than scheduled time
- Mishandled baggage
- Flight cancellations
- Aircraft has to land at different airport than the scheduled ones (air diversions)
- Aircraft returns to departure airport (turn backs)

The improvements through in-service reliability in these aspects may not ensure 100% reliability, but they are still crucial steps to be taken for high-quality service.

Effectiveness of In-Service Reliability in Aircrafts

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Abstract

This paper deals with the application of Industrial Engineering (IE) tools that help to improve in-service reliability for aircrafts, and their effectiveness on general aviation business. In-service reliability affects the aircraft availability and punctuality at airline terminals. It is an important factor and crucial for airline business, in terms of delays or cancellations. The IE tools used in this paper include:

- Time study to generate time standards
- Total Productive Maintenance (TPM) of aircraft parts
- Process flow analysis using lean manufacturing techniques

The paper will also analyze the monetary effect of these methods to demonstrate financial effectiveness, as well as discusses the improved service quality, such as the improved customer satisfaction associated with overall improved in-service reliability.

1. Introduction

In the last few years, the airline industry initiated a focus on improving in-service reliability measures. Particular awareness was given to the statistical modeling aspect of reliability and reparability. An example of ineffectiveness with the current approach is the inaccurate estimations of process details. The ideal method should collect process details early, generate time standards and use these realistic data in computational models to ensure an accurate and realistic input analysis. The IE tools mentioned above can help to do more fundamental work. If the airline industry improves the maintenance by using strategies such as application of Total Productive

Maintenance (TPM) and lean manufacturing to reduce wasteful activities, aircraft availability and punctuality will increase subsequently.

Reliability for aircraft covers a wide range of topics. It needs a high-level reliability study in engines, cockpits, flight crew operations, and in-service reliability. In statistical terms, reliability is the consistency of a functional performance over a given period of time. This paper focuses on in-service reliability in airline business. The challenge in this subject is the number of involved elements in order to keep consistent maintenance and high service quality. The in-service reliability measures the unforeseen service interruptions due to technical failures and associated maintenance requirement. The types of interruptions can be described as below:

- Takeoff delay, or departing later than the scheduled time
- Mishandled baggage
- Flight cancellations
- Air diversion, or the aircraft lands at a different airport rather than the scheduled one
- Turn back, or the aircraft returns to departure airport

The Air Travel Consumer Report for Year 2009 [1] reveals some facts about the performance of airline industry. In North America, on average, 35% of flights arrived late, 40% of flights departed late, and 7% of flights mishandled baggage. The chart below shows the brief summary from the Air Travel Consumer Report and the areas for improvements by using Industrial Engineering tools. The chart in Figure 1 shows the breakdown of all delays in Year 2009. The recent data indicate that there is still room for improvement in flight delays. The different categories of delays can help focus on individual areas and sort out the controllable and uncontrollable types of delays.

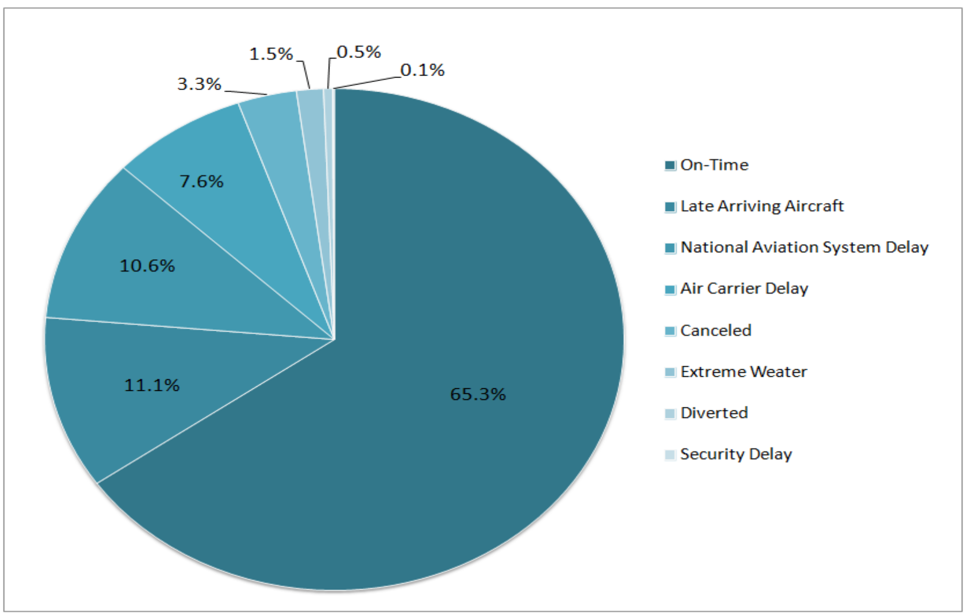

Figure 1: Flight Delay Chart (Air Travel Consumer Report) [1]

2. Further Discussion of Aircraft Service Quality

For airlines, unscheduled interruptions create a significant financial loss due to wasted fuel consumption, airport taxes, passenger and crew accommodations, and financial compensation to passengers. The indirect costs, such as airline's deprived image and customer dissatisfaction also make up a significant portion as well. Dissatisfied customers become less likely to fly the same airline. This leads to loss of business and, consequently, a hike in airfare to make up for the margin. As a consequence, in-service reliability has become huge designing criteria to airline managing team and aircraft designers.

	DEPARTURE AIRPORT *														
SCHEDULED DEPARTURE TIME	MDW	MIA	MSP	OAK	ORD	PDX	PHL	PHX	SAN	SEA	SFO	SLC	STL	TPA	TOTAL
600 - 659 AM	75.1	91.5	82.7	92.9	70.6	76.9	85.3	91.7	89.4	77.6	90.5	94.7	89.6	96.6	86.3
700 - 759 AM	72.9	83.9	83.7	88.2	66.6	73.0	81.3	93.6	82.9	73.2	86.1	90.1	86.7	93.3	84.1
800 - 859 AM	70.0	87.3	77.4	88.6	67.7	70.7	86.3	83.4	79.2	68.5	80.2	83.8	78.2	90.8	80.3
900 - 959 AM	72.4	80.1	75.3	81.0	60.7	63.6	75.2	79.7	74.8	67.5	77.1	79.7	78.2	90.7	76.5
1000 - 1059 AM	69.2	74.1	73.2	74.7	58.5	67.7	77.2	74.9	74.0	59.6	63.0	72.1	75.2	79.6	71.5
1100 - 1159 AM	61.2	71.8	66.9	63.5	55.7	63.9	68.4	71.0	64.8	58.8	54.3	71.8	73.3	78.0	69.1
1200 - 1259 PM	59.9	59.3	62.8	64.7	57.1	56.5	70.3	68.2	60.7	56.4	55.5	73.3	75.9	73.8	67.3
100 - 159 PM	57.7	74.0	69.1	63.5	59.0	60.9	72.5	68.7	67.4	59.0	52.6	66.2	62.3	74.6	65.8
200 - 259 PM	51.4	58.9	64.9	50.2	51.3	58.6	62.6	64.1	63.2	56.5	58.0	65.9	64.9	66.2	64.2
300 - 359 PM	51.7	63.2	62.5	52.6	49.9	62.4	64.9	57.6	59.7	56.8	56.5	63.2	64.8	73.5	61.8
400 - 459 PM	49.5	66.1	62.6	50.0	49.2	62.6	55.9	66.4	58.9	61.2	57.5	68.7	61.6	67.7	62.6
500 - 559 PM	48.9	64.2	62.6	58.8	49.7	58.7	49.1	65.8	57.9	55.4	59.9	68.2	60.8	67.0	60.9
600 - 659 PM	49.2	65.9	62.8	54.9	48.4	53.7	58.0	52.8	57.1	55.6	64.2	35.2	62.3	65.5	59.3
700 - 759 PM	41.3	61.1	60.7	60.9	45.0	54.7	45.6	71.8	63.9	48.6	63.3	65.2	51.4	58.9	59.9
800 - 859 PM	43.2	64.6	61.1	51.6	43.0	56.8	65.9	56.6	56.6	49.2	63.2	69.5	47.2	68.2	57.1
900 - 959 PM	42.0	58.4	59.7	51.4	51.1	57.9	56.3	64.8	56.0	46.8	67.6	64.4	39.2	68.3	60.7
1000 - 1059 PM	J/	70.3	60.4	35.5	47.9	30.6	75.0	82.9	82.8	64.6	69.1	J/	J/	J/	69.5
1100 - 559 AM	J/	J/	92.7	59.3	74.2	69.0	88.8	79.8	J/	64.0	77.7	80.8	81.6	92.3	76.7
TOTAL, ALL DEPARTURES, BY AIRPORT	57.9	69.6	67.9	67.3	55.3	64.7	68.0	70.8	68.9	61.6	66.2	71.7	70.0	76.4	68.3

Figure 2: Percentage of Departure on Time (Air Travel Consumer Report) [1]

The chart in Figure 2 shows the percentage of on-time departure during various time frames for several major airports, which gives an overall average 68%. The departure delay can cause the delay in arrival, but typical aircraft has some flexibility to cover the lost time to some extent. Thus the arrival and departure delay data is based on that the flights with lateness of no more than 15 minutes are considered as on-time.

The arrival data from Air Travel Consumer Report on Arrivals are depicted in Figure 3. As seen below, some airlines show lower rate of arrival delays. Arrival delays mostly depend on departure data and it is less likely that a flight will depart on time and still be delayed, considering all other aspects involved in the total flight time. The table in Figure 3 shows the arrival rates for 2009 from some major airports in the United States. On average, data shows that flights are late by around 29%. It's obvious that delayed departure time contributes to delayed arrival, but there can also be other factors that contribute to late arrival. The other factors, such as weather condition, airport traffic and number of terminals, can play a significant role in arrival rates as well.

ARRIVAL AIRPORT *																
	PHL		PHX		SAN		SEA		SFO		SLC		STL		TPA	
CARRIER*	# OF ARR.	% ON TIME	# OF ARR.	% ON TIME	# OF ARR.	% ON TIME	# OF ARR.	% ON TIME	# OF ARR.	% ON TIME	# OF ARR.	% ON TIME	# OF ARR.	% ON TIME	# OF ARR.	% ON TIME
9E	171	51.5	H/		H/		H/		H/		H/		190	59.5	H/	
AA	436	59.2	485	65.6	456	59.9	394	54.8	967	63.5	213	68.1	1293	74.8	546	74.9
AS	H/		246	62.6	301	62.8	3675	57.1	406	60.1	H/		H/		H/	
B6	H/		52	57.7	155	58.7	149	55.7	155	46.5	155	63.9	H/		329	63.8
CO	148	63.5	325	57.2	309	59.2	393	51.1	390	51.5	75	69.3	H/		402	70.1
DL	340	63.5	318	56.6	289	64.0	438	51.8	379	54.4	2132	66.2	96	61.5	721	73.0
EV	H/		H/		H/		H/		H/		H/		119	56.3	H/	
F9	31	64.5	176	51.1	152	46.1	119	37.8	121	40.5	168	50.0	89	66.3	31	45.2
FL	300	60.0	88	55.7	31	51.6	H/		35	28.6	H/		104	66.3	604	67.9
HA	H/		31	16.1	31	41.9	93	40.9	31	9.7	H/		H/		H/	
MQ	62	30.6	H/		606	78.9	H/		151	64.9	H/		63	38.1	H/	
NW	226	56.2	310	36.5	165	38.2	412	40.0	274	42.7	92	51.1	77	54.5	320	66.2
OH	286	49.3	H/		H/		H/		H/		H/		112	49.1	70	51.4
OO	106	35.8	215	70.7	517	80.5	428	62.4	3219	57.2	6278	69.4	75	65.3	H/	
UA	406	59.4	412	62.6	604	62.6	606	62.2	3352	64.6	91	70.3	30	90.0	291	69.1
US	3594	67.6	4838	70.4	379	65.4	330	61.2	558	54.3	124	70.2	91	81.3	632	71.8
WN	1893	64.5	5433	64.7	3058	61.7	1311	64.1	1172	51.4	1476	63.3	2170	70.6	2368	73.3
XE	44	59.1	56	66.1	H/		H/		H/		24	45.8	237	62.0	18	72.2
YV	60	58.3	2653	82.1	32	56.2	H/		H/		31	74.2	62	64.5	H/	
TOTAL	8103	63.3	15638	68.2	7085	63.6	8348	57.0	11210	58.2	10859	67.4	4808	69.1	6332	71.1

Figure 3: Arrival Data (Air Travel Consumer Report) [1]

The lack of quality or accuracy in processing data in computational methods will result in skewed output. On the other hands, there was little focus on practically understanding the operations where they actually occur. With the on-going research, improvements were done in the quality of instruments that are used in aircrafts but if we do not create a guideline on how to use these tools efficiently, then the problem will never be resolved.

This paper focuses on the ground work needed for quantitative and computational methods. The IE tools help efficient airline operations by developing proper flow and improving equipment availability. However, without efficiency built in operations, these sophisticated tools cannot help to improve in-service reliability.

3. Related Work

Many tools such as discreet event simulations, statistical modeling, and fault tree analysis built a good base to understand the root cause of the airline issues. Laurent, S et al in “Computing in-service reliability” [2] discuss the problem that is crucial for aircraft designers because it enables them to evaluate in-service interruption rates, in view of designing the system and of optimizing aircraft support. Leung et al [3] discuss in-service reliability using CH algorithm to examine failure pattern technique involving aircraft system knowledge and logistics factor. In this paper, we tried to implement IE tools to better advance in-service reliability modeling.

4. Implementation

So far we have discussed the incomplete quantitative approaches taken by researchers. These methods disregard the importance of valid and realistic data based on time standards for quantitative analysis by applying Total Productive Maintenance (TPM). It also shows how exactly they benefit from quantitative analysis, developing time standards for service crews to estimate completion time, and improving aircraft availability. TPM is used to improve the life span of each of the aircraft component and estimate any future failures, which effectively reduces unscheduled maintenances and process engineering analysis by applying lean manufacturing tools to reduce wasteful activities in overall airline operations. Those operations are ground operations, baggage handling, check in systems, and crew operations at the departure gates.

4.1 Time Standards

Accurate data is required to generate reliable and quantitative analysis which helps to improve on technical aspects that ultimately improve the reliability of aircraft operation. In service, an aircraft is subject to a sequence of steps, with each step consisting of flight phase and ground phase. In ground phase, aircraft goes under a series of operations and instructions from service crew members. This crew is a different group of people from cleaning the interior of the plane, fueling the aircraft, baggage handling, and security group, aircraft crew providing service in the plane, the crew managing the passengers, and the crew controlling the runway traffic. There is also some time associated with each of the groups for their part of the service. If the standards are created for each of the group's work content then it becomes easier for the managing crew to estimate the time for chain of events and to plan accordingly.

Also, these time standards can be key input data for quantitative analysis for more complex problems. Laurent [2] discussed different failure modes of an aircraft system during its successive flights and ground phase. From this operational context, his work discussed creating a mathematical framework which derived analytical probability equations for the basic mode events, and then, a way of developing an algorithm is also described to provide relevant bounds for aircraft reliability. In his paper, there are input parameters such as probability of failing of a component. As a key input for his model, the validity of input value is very important. Such probability can be estimated by analyzing historical data and taking an appropriate average to represent the realistic probability. The other method of estimation is to put a component in reliability test. In these tests, the component is run independently in a test room and a failure time is recorded. Such tests also indicate a realistic failure probability. Lastly, a component failure probability can be estimated from its subcomponent's failure probability. The other application, such as Monte Carlo Simulation, is very powerful in evaluating and optimizing flight schedules. Simulation is also useful to plan certain ground activities such as gate allocation. Loterella et al [4] explained in their paper, the formulation of Monte Carlo Simulation model and showed its application on scheduling. Some inputs in their model are boarding time, taxi time to runway and to gate, baggage removal time, and aircraft turnaround time for next flight. All these inputs are made up of ground crew operations. Loterella's model is designed to reduce gate schedule delays, therefore to improve punctuality. All the input parameters mentioned above will help to strengthen the results from the model and more confidence. His paper estimates an improved punctuality by 5% and our research only helps to have more confidence on his estimation. Time standards for above ground operations can be created by using observations and recording data in the form shown in Figure 4.

Task/Process Being Observed:					Observers:				Location/Dept:			Date & Time:
Step No.	Task Description	Observation Number								Assigned Task Time	Remarks
		1	2	3	4	5	6	7	8		
1											
2											

Figure 4: Data Collection Form

The form is designed such that all operation details will be collected. The time standards developed by this method can be used in further analysis. This research step assures the accurate data is used to improve in-service aircraft reliability. Once the standard operation steps are decided, the standard operating procedure can be rolled out to other airports for that airline.

4.2 Fleet Structure and Total Productive Maintenance (TPM)

This research paper also discusses improving aircraft availability by applying fleet structure and TPM. All airlines carry certain fleet size at any airport. It is not just a fleet size but also the variation within and across the aircraft types. Vulnerability to version and equipment change has a direct impact on the ability to quickly restore punctual operations after irregularities. If an airline carries more than the required fleet of each type of aircraft, then it is not an economical option for the airline. With these constraints, modification in aircraft design from the manufacturer can help reduce the turnaround time for each aircraft. Interchangeable parts are made to specifications, allowing them to fit into any aircraft of the same model. This interchangeability allows easy assembly of new devices, and easier repair of existing devices, while minimizing both the time and amount of skill required by the person doing the assembly or repair.

Table 1: List of Interchangeable Items

Doors	Seats
Windows	Seat Tracks
Elevators	Seat Belts
Altimeters	Vacuum Gages
Airspeed Indicators	Fuel Flow Indicators
Directional Gyros	Compass

Table 1 shows the partial list of items which can be interchangeable. Design modification can make some engine parts, wing or tail sections interchangeable. There are statistics indicating that aircraft delays or cancellations can be reduced by this technique. The improvement on interchangeable parts helps to improve in-service reliability.

Unscheduled maintenance or unpredictable breakdown is a major issue that affects aircraft availability. This is especially true for intensive hub and operations with tight rotation plans. TPM is a maintenance strategy, or conversely, a reversion to old ways but on a mass scale. In TPM, the equipment operator performs most routine maintenance tasks. This auto-maintenance ensures appropriate and effective efforts because the machine is the responsibility of one person or team. TPM is a critical adjunct to lean manufacturing. If machine uptime is not predictable and if process capability is not sustained, the process must keep extra stocks to buffer against this uncertainty, and flow through the process will be interrupted. One benefit of TPM is deterioration prevention and maintenance reduction. For this reason, many people also consider TPM as "total productive manufacturing" or "total process management". TPM is a proactive approach that essentially aims to prevent any kind of slack. Its motto is "zero error, zero work-related accident, and zero loss". The correctly implemented TPM program can help to identify technical issues with the aircraft early. If such indication is identified early, airlines can plan for repair and take actions accordingly.

The typical implementation of TPM requires rigor and motivation from engineering and operation crew. First, this cross functional team evaluates the maintenance history of an aircraft. Next, the team evaluates all types of indicating gages or and marks safe operating zones on them. A sample of inspection checklist is given in Figure 5.

Operators Daily TPM Checks Month:________________ Year:____________

Ensure PPE is worn at all times during maintenance inspection

Ensure Lockout-Tagout Procedure is followed when required

Checks to be completed prior to machine start-up

Ensure Tools are in good working condition

Initial box when PM completed

	Week 1						Week 2						Week 3						Week 4					
Task	M	T	W	Th	Fr	Sat	M	T	W	Th	Fr	Sat	M	T	W	Th	Fr	Sat	M	T	W	Th	Fr	Sat
1, 2 - Check all Switches, E-Stops, guard, & grinding wheel are functioning																								
3 - Check Hcordian covers for cracks or leaks																								
4, 5, 6 - Chk Hydraulic oil level, Chk hyd gage (10-16 psi). Check for hoses wear & leakages																								
7, 8 - Chk Way lube oil level. Chk hoses for wear & leakages																								
9, 10, 11 - Chk grinding wheel plumbing section. Chk drain for cleanliness. Chk settling tank for cleanliness																								
12, 13 - Chk main elect cabinet for external integrity. Chk motor filters, if dirty then replace																								
14 - Chk magnet for proper functioning																								

Figure 5: TPM Daily Checklist – Example

The above checklist is for a surface grinder from a manufacturing company. The TPM concept can be applied to any of the equipment used. This helps to improve proofing and control according to the information on the checklist. The minimum hydraulic fluid level required is also marked on the gage. The operator who conducts the check does not have to remember the required working limits on gages. This visual factor helps for quick and effective inspection. Other similar inspection modules can be designed for aircrafts. The checklist is designed such that all functional aspects of equipment get checked for its proper functionality on a daily or regular basis.

There is always some history such that some part of the equipment starts failing to operate and then the problem escalates to other areas, and eventually this makes the equipment non-operating. A research paper on TPM mentions that 95% of the breakdowns can be avoided by proper preventive maintenance. The inspection checklist can also be mentioned as a scheduled maintenance to be done on an aircraft. Systematic or scheduled maintenance is a policy in which specified components are replaced, usually at regular intervals, when they are becoming worn.

Figure 6: Picture of a TPM Check (Hydraulic Oil Measure)

In August of 2008, many flights at Manila, Philippines were cancelled or delayed [5]. An old and worn-out piece of equipment used to guide planes on takeoff and landing at the Ninoy Aquino International Airport broke down on early morning, causing cancelled and delayed flights. TPM is the best solution to avoid such incidents. The implementation of TPM is not very costly. It just takes engineering and operation crew to sit together and prepare a daily check list for all critical equipment. Once such checklist is prepared then the system works by itself as everybody supports it. Table 2 shows a typical list of equipment that is used to service an aircraft. All equipment can breakdown and some of them can be easily replaced if available.

Table 2: Typical Equipment List for Servicing Aircraft

Air Conditioners	Deicers
Aircraft Jacks	Fork Lifts
Airstart Units	Fuel Trucks
Baggage Carts	Ground Power Units
Baggage Tractors	Hydraulic Mules
Baggage Handling Conveyors	Lavatory Trucks/Carts
Beltloaders	Nitroboosters
Cargo Dollies	Passenger Stairs
Cargo Loaders	Pushbackback Tractors
Catering Truck	Towbars
Chocks	Water Carts
	Wheel Chair Lifts

An airline crew can decide on the critical equipment list based on its age and criticality to operations. TPM can be implemented for that critical equipment list. For example, forklifts are important aspect of operations which help to move baggage or heavy tools or elevate up or down. Forklift itself is an automobile and needs to have a rigorous checklist for maintenance. Few checklist items are shown in the Figure 7.

Engine Performance
1. Start the engine and listen for knocks or misses
2. Listen for any squealing caused by belts
3. Listen for any exhaust leaks
4. Drive Forward and backword to check for any slips or wheel issues
Safety Performance
5. Check for all gage performance
6. Check warning devices
7. Check cab lights, outside lights, back-up lights
Battey
8. Clean battery terminal, cables, and connectors
9. Open every cell cap and checkk cells for proper fill levels of water
10. Check protectant on connectors to avoid corrosion
Oil change
11. Take forklift to maintenance shop every 3 months for oil change
12. Grease all grease fittings
13. Check belts for any cracks
14. Check tires for any cracks or excessive wear
15. Checks for any leaks of hydraulic systems
16. Lubricate all fittings such as hoist mechanism and tie-rods
17. Check forks for any cracks or bends

Figure 7: Maintenance checklist for forklift

As it is clear from the above checklist, most of the inspection can be done in less than 10 minutes. Such reviews on daily basis can avoid big delays in long run. There is hardly any cost involved in preparing such checklist. When crew member conducts his/her check for their equipment, they can also mention for any irregularities on repair list which stays with the equipment. Maintenance crew checks repair list on daily basis to see if any items needs to be checked and if it may be replaced or repaired. This simple disciplined approach helps to identify most of the failures ahead of the time and avoids most of the urgent repairs and disruptions which affects aircraft availability and punctuality. In effect, TPM helps to improve in-service reliability of aircrafts. Similar checklist can be developed for all other critical equipment that effect aircraft's availability and punctuality. So TPM implementation all across the board can help to improve on in-service reliability.

The other aspect of TPM is managing the spare part inventory. Kanban systems can be effectively used to keep track of inventory management. Kanban is a signaling system to trigger action. Historically, Kanban was using cards to signal the need for an item. However, other devices such as plastic markers (Kanban squares), balls (often golf balls), an empty part transport trolley, or simply a floor location can also be used to trigger the movement, production, or supply of a unit in a factory. The conceptual idea of Kanban is easy to understand but equally rigorous to implement and follow the guidelines. Kanban works on a visual management basis. At aircraft maintenance workshops, all spare parts can be organized such that a visual glance can identify items with low stocks. The spare part bins can be marked with re-order points so that when parts go below re-order level, the spare parts need to be replenished. Such simple but effective technique can help to make sure that all spare parts are available all the time.

The Kanban picture in Figure 8 shows how a separate bin or queue is designed for different products. This helps quick access to the information about parts needed or available. This tool can help to minimize the line down situations. To some extent, Kanban system can help to maintain punctuality and availability of aircrafts.

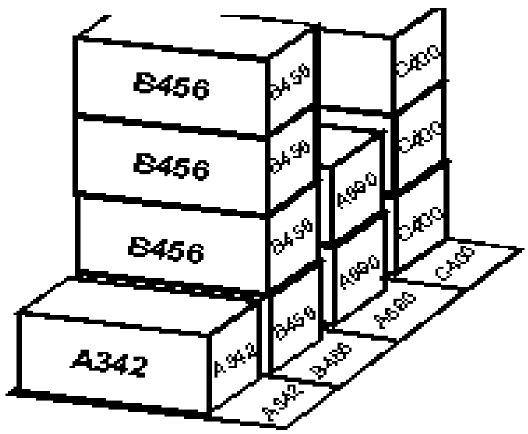

Figure 8: Kanban System – Example

4.3 Application of Lean Manufacturing

After discussing the importance of time standards and aircraft availability, this section discusses the process improvements in ground operations by applying lean manufacturing to reduce waste activities and effectively reduce operation time. This operation-diagnostic tool identifies the current process flow and brainstorms on non-value added activities. Ground operation is a big part of airline operation and at most of time, the operations are done at a critical stage where any delay directly impacts the passengers. If we have a delay here, then there is not much room to correct it later and this delay gets transferred to aircraft arrival, and future departure time. Industrial Engineering tools for process engineering can help minimize such delays.

This tool is widely known as lean manufacturing in product or service industry and is a proven method to reduce the turnaround time or lead time. The first step is to draw a process map of current operations. The map should show the whole ground operations in small meaningful steps. Then, information can be added such as cycle time, number of crew members being used, number of batch, and distance from previous operation. Once all operations are on the map, it is easy to see the whole operation and most importantly to identify bottleneck operations. A bottleneck in a process is a critical place in a chain of processes such that its limited capacity reduces the capacity of the whole chain. This is the operation that holds back the output of the entire department. Any improvement in bottleneck operation can help reduce the overall service time. Typically, a bottleneck operation is the one which takes longer cycle or processing time than other operations. The other method to identify a bottleneck is the operation where more crew members are used. Once such bottleneck is known, then all the improvements should be focused on that operation.

One standard check is the analysis of non-value added activities. Some examples of such activities are sorting, storing, waiting, or transporting back and forth.

The typical ground operations are shown below in Table 3. These are the major operations that are done on an aircraft to prepare it for a departure. In our case, front-line crew might be polite enough to deal with passengers but it is the ground operation that influences flight's departure time.

Table 3: Ground Operations

Refueling	Avionics
Cleaning inside and out	In-flight entertainment
Maintenance checks	Plumbing
Airframe repair	Electrical and electronics systems
Resupplying food, water	Inspections
Cabin pressurization	Correct loading of cargo and baggabe

All these ground operations are mostly conducted by separate crew groups and can be done in parallel. The first step, as a Lean Engineer, is the review whether all these are done in parallel or not. If not, analyze and understand how crew manpower can be divided so that these operations are being done at the same time. Just by changing this strategy, it can reduce the overall turnaround time of an aircraft.

Secondly, analyze the process steps for each of ground operation and record the one thar takes the longest time. For that specific operation, we focus on all improvements so that its processing time is reduced. Let's consider refueling aircraft as a process to review and improve. A typical refueling system is shown in figure 9.

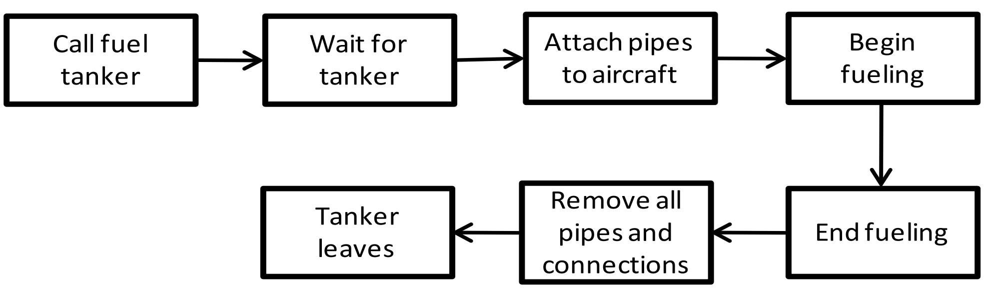

Figure 9: Aircraft refuel process flow

There are few things that can be modified in this process. The thought process behind this is the seven wastes of lean manufacturing. These seven wastes are commonly abbreviated as TIM WOOD; T–Transportation, I–Inventory, M–Motion (excessive), W–Waiting, O–Overproduction, O–Over processing, D–Defects.

The application of seven wastes to refueling process indicates that some operations can be modified. Firstly, the waiting time for tanker: when there is a schedule for aircraft departure, the tanker crew can be notified prior to the scheduled flight so that the waiting time could be eliminated or minimized. Secondly, by understanding the design of pipe and fuel pressure, the fill up time can be reduced. If pipe diameter is increased then more fuel can be pumped in less time. Similar types of analysis can be done for the rest of the ground operations and ideas can be implemented to reduce processing time for each ground operation. If all times are reduced then effectively aircraft turnaround time can be reduced. Such process improvements can also lead to better results from computation simulation methods.

5. Evaluation

The IE tools mentioned in implementation section are: developing time standards, TPM to improve aircraft availability, interchangeability, and process engineering for ground operations. As shown in Figure 1, data shows that on average 68% of flights are on time. From the remaining 32%, more than 20% of delays are controllable delays and can be controlled by application of the methods discussed in the implementation section. The breakdown of 20% controllable delays is shown below.

Cancelled – 3%   Carrier Delay – 7%   Late Arrival – 10%

The methods discussed may not help to reduce these delays to 0% but they will definitely make an impact. It will be difficult to estimate the exact results unless we know more details about the data. Our method of process improvement by applying IE tools can have different results at different airports or airlines. Based on the current performance of each airport or airline, the degree of improvement can vary. But all these IE tools are practical and focus on the root causes. The table below in Figure 10 summarizes the results in a logical way.

IE Method	Cancelled (3.3%)	Carrier Delay (7.7%)	Late Arrival (11.1%)
Development of Time Standards			
Interchangeability and modified fleet structure	×	×	×
TPM implementation	×	×	×
Lean manufacturing application for process improvement		×	×
Supplier relationship	×		

Figure 9: Summary Table

6. Conclusion

A lot of research has been done to improve in-service reliability using quantitative methods. However, there are not many papers discussing the improvement of in-service reliability applying IE process improvement tools. Firstly, we developed time standards for each airline operation, which can act as a backbone of quantitative analysis. These time standards will further give the confidence on results from quantitative analysis. Secondly, TPM will help to understand each aircraft by its maintenance history and help to create a custom maintenance checklist. This will help to keep the aircraft availability higher than before and consequently help to reduce delays and cancelations. Thirdly, this paper also discussed about the importance of having a Kanban system. This tool helps to keep optimum inventory of parts and services. Such tool can minimize stock-outs which affect the service level negatively during the actual departure or arrival times. At the end, process engineering tool will identify non-value added activities and will help to make the process more efficient. This tool can further help understand how a ground operation can be done differently while saving service time.

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