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Development Of Key Performance Indicators And Strategic Plan For Crew Scheduling Department At A Saudi Airline Company

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***Abstract*— This study presents a structured approach to improving cockpit crew scheduling efficiency in a leading Saudi airline through the application of the Lean Six Sigma (LSS) DMAIC methodology. One key tool was applied in each phase to ensure focus and clarity in problem solving. SIPOC mapping was used in the Define phase to outline process boundaries and stakeholder relationships. Control charts in the Measure phase established performance baselines and identified variability. The Analyze phase employed a Fishbone diagram to determine root causes of inefficiencies. Value Stream Mapping (VSM) in the Improve phase was used to redesign the scheduling workflow and eliminate non-value-added steps. Finally, a Key Performance Indicator (KPI) dashboard in the Control phase ensured ongoing performance tracking and sustainability. The results demonstrated measurable improvements in crew productivity, absenteeism rate, and planning accuracy, providing a data-driven foundation for long-term operational excellence in aviation resource management.**

Keywords*— Strategic Plan; Lean Six Sigma; DMAIC; crew scheduling; aviation operations; process improvement; Key Performance Indicators

I. INTRODUCTION

The aviation industry functions as a global network of interdependent systems that require precision, safety, and synchronization. It not only connects nations and drives tourism but also serves as a critical pillar for economic development and international trade. Within this dynamic sector, the efficiency of flight crew scheduling plays a pivotal role in ensuring that airlines achieve optimal utilization of their most valuable resource — their human capital [1]. Crew scheduling is a multifaceted process that involves assigning qualified pilots and crew members to flights while adhering to strict regulatory requirements, safety constraints, and labor agreements. The process must balance operational efficiency with fatigue risk management, cost control, and customer satisfaction.

In the Saudi Arabian aviation sector, this challenge is amplified by the Kingdom's national transformation strategy — Vision 2030 — which emphasizes digital transformation, service excellence, and global competitiveness [2],[3]. Saudi Arabia's flagship carriers, along with emerging airlines such as Riyadh Air and Flynas companies, are expanding rapidly, contributing to a surge in air traffic and route networks [4]-[7]. Consequently, the demand for more accurate, agile, and data-driven crew scheduling systems has never been greater. The General Authority of Civil Aviation (GACA) has reinforced this need by mandating operational efficiency standards and fatigue risk management systems to ensure sustainable growth and safety compliance. The increasing complexity of fleet diversity Airbus A320, A330 and Boeing B777, B787, base expansion, and variable crew qualifications require advanced methodologies that combine data analytics, process improvement, and performance measurement. Traditional scheduling practices — often rely on manual oversight or non-integrated tools — are insufficient to meet modern operational challenges. Therefore, adopting structured improvement frameworks such as Lean Six Sigma (LSS) offers an opportunity to address inefficiencies through statistical analysis, process mapping, and continuous improvement cycles [8],[9].

Despite technological advancements in crew management systems, many airlines continue to experience inefficiencies in scheduling that result in operational disruptions, resource underutilization, and increased costs. In the case of the studied a Saudi airline company, three recurrent issues have been identified:

- Inconsistent Crew Utilization: A gap exists in productivity levels, indicating inefficiencies in crew deployment and workload balancing.
- Limited Performance Monitoring: The absence of clearly defined Key Performance Indicators (KPIs) limits the ability to evaluate performance trends or identify root causes of inefficiency.
- Weak Process Standardization: Lack of standardized Standard Operating Procedures (SOPs) and an integrated control mechanism prevents the organization from achieving sustained operational excellence.

These challenges are compounded by fragmented data systems and insufficient integration between operational departments (e.g., scheduling, training, and flight operations). As a result, the scheduling process remains reactive rather than proactive, leading to recurring deviations between planned and actual flight crew utilization.

In a competitive aviation environment, such inefficiencies not only increase operational costs but also undermine reliability, which is a critical success factor in airline performance. Hence, there is a clear need to introduce a systematic, data-driven improvement model that can identify performance gaps, quantify their impact, and establish mechanisms for sustainable control.

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A. Research Aim and Objectives

To address these challenges, this study aims to develop a performance improvement and strategic control framework for the cockpit crew scheduling process at a leading Saudi airline, based on the Lean Six Sigma (LSS) DMAIC methodology. The DMAIC model—Define, Measure, Analyze, Improve, and Control—has proven to be a reliable structure for diagnosing inefficiencies, eliminating waste, and sustaining performance improvements in both manufacturing and service industries [8]-[11].

The objectives of this research are as follows:

- Identify and analyze inefficiencies within the cockpit crew scheduling process through data-driven investigation.
- Apply the Lean Six Sigma DMAIC framework for systematic process improvement, using appropriate tools under each phase.
- Analyze the root causes of productivity disruptions.
- Design and implement measurable Key Performance Indicators (KPIs) for productivity, absenteeism, and planning accuracy.

The framework not only seeks to improve short-term efficiency but also to establish a strategic performance management system that aligns with the airline's long-term objectives of operational excellence and compliance with national aviation standards.

B. The impetus for the study

This research holds considerable significance for both academia and the aviation industry.
From an academic perspective, it contributes to the growing body of knowledge on the application of Lean Six Sigma methodologies in service operations, particularly in high-risk, human-centered environments like aviation. This study demonstrates how tools such as SIPOC mapping, Fishbone analysis, and Value Stream Mapping (VSM) can be adapted to complex scheduling processes that rely heavily on human expertise and regulatory constraints.

From an industrial perspective, the study introduces a data-driven performance model that enables airlines to make informed decisions, anticipate scheduling disruptions, and implement proactive corrective measures. By establishing a KPI-based control system, the framework enhances organizational visibility, accountability, and strategic alignment. The results of this study are directly applicable to the airline's operational management, supporting the Saudi Vision 2030's focus on operational excellence and digital transformation within Saudi Arabia's transport sector [2].

Moreover, the developed framework can serve as a benchmark for other airlines in the region seeking to optimize resource allocation, strengthen governance mechanisms, and embed continuous improvement into daily operations. The integration of Lean Six Sigma with performance measurement ensures that the improvements achieved are both quantified and sustainable, providing a long-term strategic advantage in a highly competitive industry.

C. The structure of the study

The remainder of this paper is organized as follows, section 2 represents recent studies in literature that highlight important factors influencing Crew scheduling and Leas six sigma (LSS). Section 3 describes Material and methodological framework, section 4 presents the Data Collection and Application, and section 5 provides Results and Discussion of this study.

II. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Performance management in aviation has become increasingly critical in recent decades as airlines seek to balance safety, efficiency, and sustainability under complex regulatory and operational environments. The continuous improvement of internal processes—such as flight operations, maintenance, and crew scheduling—has been recognized as essential for maintaining competitiveness and achieving strategic alignment with national transformation programs such as Saudi Arabia's Vision 2030.

Ertuğrul [12] and Kiracı et al. [13] emphasize that effective performance management systems integrate both quantitative and qualitative measures through Key Performance Indicators (KPIs), providing a structured mechanism for monitoring operational effectiveness and ensuring continuous enhancement of productivity and service quality.

Recent studies by Al-Sari et al. [14] highlight that performance in aviation must extend beyond traditional cost, safety, and on-time performance metrics to include environmental stewardship, digital innovation, and human resource optimization. Within the Saudi context—where the aviation industry is undergoing rapid expansion through initiatives such as the Riyadh Air launch and major modernization programs—Alothaim et al. [15] noted that performance evaluation frameworks are essential to ensure operational decisions align with broader economic and strategic objectives. The integration of data-driven tools and dashboard systems has thus become central to supporting transparency, accountability, and evidence-based decision-making in departments such as crew scheduling and manpower planning.

Among the methodologies supporting systematic performance improvement, Al-Qatawneh et al. [16] and Akbulut-Bailey et al. [17] found that Lean Six Sigma (LSS) has gained significant traction for its ability to integrate waste elimination with variation reduction. The DMAIC framework—Define, Measure, Analyze, Improve, and Control—provides a structured, iterative cycle for diagnosing inefficiencies, implementing corrective measures, and institutionalizing process control. The strength of DMAIC lies in its data-centric approach, which combines statistical analysis with process mapping to uncover and correct root causes of underperformance.

In aviation, Ahmed et al. [18] demonstrated how the approach can enhance safety performance through systematic data analysis, while Arango et al. [19] successfully implemented LSS to optimize reporting processes for flight operations. More recent advancements—described as DMAIC 4.0—extend the model through integration with Industry 4.0 technologies such as IoT, data analytics, and automation, making it particularly relevant for modern airline process optimization Pongboonchai-Empl et al. [20].

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Parallel to the evolution of Six Sigma methodologies, the Balanced Scorecard (BSC) remains one of the most influential frameworks for linking operational activities with strategic goals. Introduced by Kaplan and Norton [21], the BSC enables organizations to view performance through four perspectives—financial, customer, internal process, and learning & growth—ensuring that short-term initiatives align with long-term strategies. In the airline industry, this approach has been applied to evaluate safety, service quality, sustainability, and operational resilience Raval et al. [22], Al-Suwaidi et al. [23]. The BSC framework allows departments such as crew scheduling to connect daily operational decisions with organizational priorities by integrating performance indicators that reflect both efficiency and human capital management.

The synergy between Lean Six Sigma and the Balanced Scorecard has been recognized as a powerful approach for achieving continuous improvement and strategic alignment. While LSS provides the analytical foundation, BSC ensures that improved processes translate into strategic outcomes. Bazrkar et al. [24] and Kiracı et al. [25] highlighted how this integration transforms the Balanced Scorecard from a passive monitoring tool into an active system for continuous performance management. The combination of these methodologies enables airlines to develop sustainable KPI frameworks that quantify operational results while linking them to long-term objectives such as productivity growth, safety compliance, and workforce well-being.

In the context of cockpit-crew scheduling, the integration of LSS, BSC, and KPI frameworks provides a practical pathway for addressing long-standing challenges in manpower utilization, absenteeism, and planning accuracy. Mishra and Sharma [26] confirm that data-driven KPI dashboards enhance visibility into scheduling performance and improve communication between operational and strategic levels. Salwin [27] showed that Value Stream Mapping (VSM) can be used to track efficiency and identify bottlenecks, while Singh and Khanduja [28] noted that control charts help sustain improvements by reducing manual interventions and ensuring alignment with key performance objectives. By embedding these principles within a Control Plan with Reaction Strategy (CPRS), organizations can achieve sustainable performance control, improve scheduling predictability, and minimize operational risk.

The theoretical framework developed in this study synthesizes these insights into an integrated model connecting the Lean Six Sigma DMAIC methodology with the Balanced Scorecard approach to form a KPI-based control system for cockpit-crew scheduling. Here, DMAIC functions as the operational engine driving data analysis, root-cause identification, and improvement actions, while the BSC ensures that all performance dimensions align with both the airline's strategic vision and Saudi Arabia's national transformation agenda. The Control phase institutionalizes KPI monitoring through automated dashboards and reaction strategies to maintain improvements and foster a culture of continuous excellence.

Ultimately, this integrated framework supports the study's objective—to enhance cockpit-crew scheduling efficiency through measurable, sustainable, and strategically aligned performance management. The fusion of LSS and KPI ensures that improvements are not only statistically validated but also organizationally embedded, providing a comprehensive mechanism for driving continuous improvement in Saudi Arabia's rapidly evolving aviation sector.

III. Material and Methodological Framework

This study adopts the Lean Six Sigma (LSS) Define-Measure-Analyze-Improve-Control (DMAIC) framework to improve the efficiency of cockpit-crew scheduling in a leading Saudi airline. The methodological structure combines data-driven analysis, process-mapping tools, and performance monitoring techniques to achieve measurable and sustainable improvement in manpower utilization, absenteeism reduction, and planning accuracy. The DMAIC approach was selected due to its proven capability to integrate statistical rigor with practical process improvement, aligning operational initiatives with the airline's broader strategic goals under Saudi Vision 2030 [29].

The DMAIC model structured the study as an iterative improvement cycle that began with defining the process scope, measuring baseline performance, analyzing root causes, redesigning workflows, and establishing a long-term control system. Each phase utilizes one primary Lean Six Sigma tool to maintain methodological clarity and reproducibility.

The study's workflow and tool-selection rationale are summarized in Figure 1 and Table 1.

This structured design ensured that each tool contributed to the overall improvement cycle, while findings from one phase informed the next, forming a closed-loop system of continuous performance enhancement [30], [31].

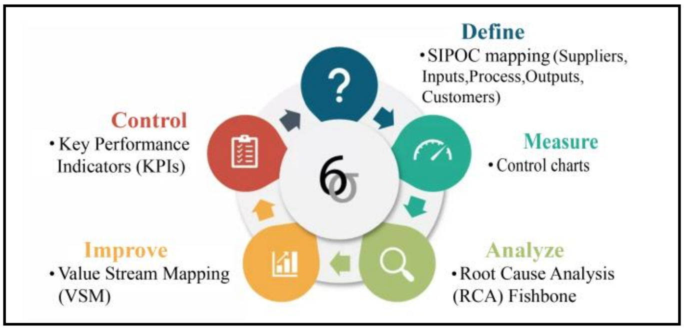

FIGURE 1. LEAN SIX SIGMA DMAIC CYCLE AND TOOLS USED

TABLE 1. OVERVIEW OF DMAIC PHASES, APPLIED TOOLS, AND THEIR PURPOSES IN THE LEAN SIX SIGMA MODEL

DMAIC Phase	Primary Tool Used	Purpose
Define	SIPOC Mapping	To identify process boundaries, inputs, outputs, and stakeholders
Measure	Control Charts	To establish baselines and detect performance variation
Analyze	Fishbone (Ishikawa) Diagram	To determine root causes of inefficiencies
Improve	Value Stream Mapping (VSM)	To eliminate non-value-added activities and redesign process flow
Control	KPI Dashboard	To institutionalize continuous monitoring and maintain improvements

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A. *Define Phase – SIPOC mapping*

The Define phase aimed to map the current cockpit-crew scheduling process and clarify its operational boundaries. The Supplier-Input-Process-Output-Customer (SIPOC) diagram identified the main stakeholders (Scheduling Department, Training, Flight Operations, and IT Support), process inputs (crew data, qualification records, flight schedules), and final outputs (published monthly rosters and compliance reports).

According to Ahmed and Hussain [29], SIPOC mapping provides a structured overview that prevents scope drift and ensures cross-functional alignment before quantitative analysis begins. In this study, SIPOC revealed interdepartmental dependencies and highlighted the lack of integration between CARDEX and SABRE systems. These insights guided the formulation of performance indicators later assessed in the Measure phase.

By aligning process ownership with stakeholder accountability, the SIPOC output directly supported Vision 2030's emphasis on operational transparency and data governance [30].

B. *Measure Phase – Control charts*

The Measure phase established baseline performance metrics using Control Charts, one of the core tools in Statistical Process Control (SPC). Monthly data for Utilized Crew Productivity, Pay-audit Crew Productivity, Absenteeism Rate, and Planning Accuracy were analyzed to detect both common- and special-cause variations. Pay-Audit crew includes all members of the cockpit flown by the company to get paid as a pilot, while Utilized-Crew includes all cockpit crew members who are working full-time in positions specifically related to flying aircraft or have any flying hours counted. The utilized crew productivity is calculated using equation (1):

$$Utilized\ crew\ productivity = \frac{Crew\ block\ hours}{Number\ of\ utilized\ crew} \qquad (1)$$

Where Crew block hours represent the total number of hours flown (gate-to-gate) by all active cockpit crew during the reporting period.

Similarly, to the pay-audit crew productivity is determined as shown in equation (2):

$$Pay\_Audit\ crew\ productivity = \frac{Crew\ block\ hours}{Number\ of\ Pay\_audit\ crew} \qquad (2)$$

The Absenteeism rate, another critical performance metric, measures crew availability consistency and its potential impact on scheduling efficiency. It is defined using equation (3) and equation (4):

$$Absenteeism\ per\ day = \frac{Total\ absenteeism}{30} \qquad (3)$$

$$Absenteeism\ \%\ per\ day = \frac{Absenteeism\ per\ day}{Number\ of\ utilized\ crew}\ x\ 100 \qquad (4)$$

Where Total absenteeism refers to the total number of recorded crew absence events in each month.

The constant "30" standardized the monthly duration to normalize results across months with different day counts.

Finally, Planning Accuracy is a key performance indicator (KPI) that evaluates the precision of the crew scheduling process by comparing planned block hours with actual block hours achieved during operations. It reflects how closely the scheduling department's forecasts align with real-world execution and serve as a direct measure of the planning system's reliability. Planning accuracy percentage is calculated as shown in equation (5):

$$Planning\ Accuracy\ \% = \frac{Actual\ crew\ Block\ hours}{Planned\ crew\ Block\ hours}\ x\ 100 \qquad (5)$$

Where:

Planned Block Hours denote the total number of hours originally scheduled for the same period in the monthly crew plan.

Following the guidance of Singh et al. [31] and Bollapragada [32], the control-chart method enabled the identification of unstable performance patterns. This phase produced control limits that defined the statistical foundation for subsequent root-cause analysis, providing quantitative evidence of where process variability occurred [33].

C. *Analyze phase – Root Cause Analysis (RCA), Fishbone*

In the Analyze phase, the Fishbone (Ishikawa) diagram was applied to categorize potential causes of process inefficiencies. Data from control-chart deviations were grouped into four domains: People, Process, Technology, Environment and Management. As Oliveira and da Silva [34] noted, combining Fishbone analysis with empirical data enhances the reliability of causal identification and prioritization. The results of this phase directly informed the VSM redesign, ensuring that improvement actions targeted the most critical process bottlenecks rather than surface symptoms.

D. *Improve Phase – Value Stream Mapping (VSM)*

The Improve phase involved process re-engineering through Value Stream Mapping (VSM). The VSM diagram visualized the complete flow of crew-scheduling information from data input to final roster publication. Non-value-added activities were identified and eliminated.

According to Stadnicka and Litwin [33], VSM enables both time-reduction and error-minimization by streamlining workflows. In this study, the redesigned map reduced the average cycle-time for monthly roster finalization, while improving synchronization with training availability. Gomaa [35] similarly found that Lean-based mapping in aerospace operations enhances service-quality consistency and decreases rework cycles.

The improved workflow was validated by subject-matter experts in crew management and then piloted for three scheduling cycles to confirm its stability and reproducibility.

E. *Control Phase – Key Performance Indicator (KPI) Dashboard Monitoring*

The Control phase institutionalized the improvements achieved through the previous stages. A Key Performance Indicator (KPI) Dashboard was developed using data integration between CARDEX and SABRE systems to automate the monitoring of Utilized Productivity, Absenteeism Rate, and Planning Accuracy.

The dashboard enabled near-real-time performance visualization and automatic variance alerts, aligning with

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recommendations by Raval and Kant [22]. Daniyan et al. [36] emphasized that digitized dashboards under Lean Six Sigma frameworks strengthen feedback loops and reduce managerial response times. By embedding the KPI Dashboard into routine decision-making, the Control phase ensured that improvements were maintained beyond the project life cycle. The system also reinforced organizational accountability, linking KPI thresholds with department-level performance evaluations and aligning results with Vision 2030's broader digital-transformation objectives.

IV. Data Collection

The data analyzed in this study were obtained from the operational databases of a leading Saudi airline, covering cockpit-crew activities from 2017, 2018, 2019, 2022, 2023, and up to mid-2024. Data from 2020 and 2021 were intentionally excluded due to the severe disruption in airline operations during the COVID-19 pandemic, which caused irregular flight schedules and atypical crew utilization patterns. All records were sourced from the airline's CARDEX and SABRE systems—recognized as the authoritative repositories for flight scheduling, manpower planning, and performance reporting.

The dataset included multiple aircraft fleets (Airbus A320, A330; Boeing B777, B787) and two primary ranks Captain (CA) and First Officer (FO). Each observation represented monthly data points encompassing total aircraft hours, crew block hours, number of utilized crew, number of pay-audit crew, total absenteeism events, and planned versus actual block hours. These variables formed the quantitative foundation for the study's Key Performance Indicators (KPIs): Utilized Crew Productivity, Pay-Audit Crew Productivity, Absenteeism Rate, and Planning Accuracy—as defined in the Measure Phase of the DMAIC methodology.

The data collected were processed and organized into three analytical tables representing different operational dimensions, Table 2 shows the Annual Crew Activity Summary: consolidates overall yearly averages for aircraft hours, crew block hours, number of utilized and pay-audit crew, productivity for utilized and pay-audit crew, and absenteeism rates. While Table 3 represents the crew Productivity Baselines by the company's operation Expertise, presents comparative productivity averages by aircraft type and crew rank, establishing baseline metrics for efficiency evaluation. Finally, Table 4 displays the Planning Accuracy Summary represent the relationship between planned and actual crew block hours, measuring the precision and consistency of scheduling forecasts.

To minimize seasonal fluctuations and enhance year-to-year comparability, monthly data were aggregated into annual averages for Tables 2 and 4. This data-squeezing technique ensured consistency across variable flight schedules and workload patterns while preserving the statistical reliability of the original dataset. The process followed Six Sigma best practices for data normalization to prevent bias from seasonal or operational irregularities. All datasets underwent data-cleaning, normalization, and verification procedures. Outliers, missing values, and inconsistencies were cross-checked against operational reports and adjusted only when verified discrepancies were identified. Absenteeism figures were standardized to a 30-day monthly basis, allowing proportional comparison across months of varying length.

Data integrity was validated through triangulation across multiple operational sources and cross-verification with the airline's manpower-planning department. Only verified data points from CARDEX and SABRE were included in the analysis. Periods with incomplete, atypical, or irregular flight activity were excluded to maintain consistency. This consolidated and validated dataset provided the empirical foundation for all subsequent phases of the DMAIC framework—supporting baseline establishment in the Measure Phase, causal diagnosis in the Analyze Phase, and performance verification in the Control Phase. The resulting metrics and analytical outcomes are presented in Section V – Results and Discussion.

TABLE 2. ANNUAL CREW ACTIVITY SUMMARY

Year	Aircraft Type	Rank	Average aircraft hours	Average crew block hours	Average Number of utilized crew	Average Utilized Productivity	Average Number of Pay-audit crew	Average Pay-audit Productivity	Average Absenteeism	Average Absenteeism /Day	Average % Absenteeism /Day
2017	A320	CA	17,583	19,502	323	60.4	386	50.5	642	21	6.63%
2017	A320	FO	17,583	17,391	331	52.6	432	40.2	343	11	3.45%
2017	A330	CA	8,287	9,170	157	58.4	184	49.7	313	10	6.63%
2017	A330	FO	8,287	8,111	136	59.6	153	53.0	381	13	9.33%
2017	B777	CA	15,627	25,078	348	72.0	396	63.4	664	22	6.35%
2017	B777	FO	15,627	23,079	338	68.4	377	61.2	592	20	5.84%
2017	B787	CA	2,475	4,125	68	60.5	80	51.4	210	7	10.27%
2017	B787	FO	2,475	2,716	46	58.8	52	51.9	123	4	8.88%
2018	A320	CA	19,314	20,373	308	66.2	368	55.4	598	20	6.46%
2018	A320	FO	19,314	19,058	334	57.1	438	43.5	479	16	4.80%
2018	A330	CA	9,905	10,358	175	59.4	206	50.3	337	11	6.42%
2018	A330	FO	9,905	10,159	192	52.8	217	46.9	421	14	7.28%
2018	B777	CA	14,316	23,402	325	72.1	369	63.4	499	17	5.12%
2018	B777	FO	14,316	18,824	279	67.5	312	60.3	537	18	6.42%
2018	B787	CA	4,126	6,211	91	67.9	108	57.8	129	4	4.70%
2018	B787	FO	4,126	4,264	71	60.0	80	53.1	168	6	7.88%
2019	A320	CA	19,161	20,229	310	65.2	359	56.3	589	20	6.32%
2019	A320	FO	19,161	18,763	353	53.2	392	47.9	439	15	4.14%
2019	A330	CA	9,602	10,025	161	62.3	184	54.6	310	10	6.40%

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Year	Aircraft Type	Rank	Average aircraft hours	Average crew block hours	Average Number of utilized crew	Average Utilized Productivity	Average Number of Pay-audit crew	Average Pay-audit Productivity	Average Absenteeism	Average Absenteeism /Day	Average % Absenteeism /Day
2019	A330	FO	9,602	10,035	201	49.9	224	44.9	407	14	6.76%
2019	B777	CA	14,087	22,946	310	74.1	353	65.0	494	17	5.33%
2019	B777	FO	14,087	17,972	250	72.0	289	62.2	641	21	8.57%
2019	B787	CA	4,536	7,029	103	68.2	119	58.9	170	6	5.53%
2019	B787	FO	4,536	4,409	79	56.2	89	49.8	189	6	8.03%
2022	A320	CA	16,866	18,291	280	65.3	324	56.4	656	22	7.82%
2022	A320	FO	16,866	15,584	306	50.9	333	46.8	382	13	4.15%
2022	A330	CA	7,392	8,312	134	62.3	153	54.2	346	12	8.61%
2022	A330	FO	7,392	7,960	146	54.7	164	48.7	289	10	6.60%
2022	B777	CA	11,869	18,785	239	78.5	270	69.5	382	13	5.31%
2022	B777	FO	11,869	14,383	198	72.7	245	58.7	450	15	7.59%
2022	B787	CA	5,225	7,841	118	66.2	145	53.9	191	6	5.40%
2022	B787	FO	5,225	5,348	86	62.4	107	49.9	115	4	4.44%
2023	A320	CA	16,792	18,665	288	64.7	351	53.2	446	15	5.17%
2023	A320	FO	16,792	15,835	256	61.9	276	57.5	367	12	4.77%
2023	A330	CA	8,533	9,576	142	67.4	163	58.9	301	10	7.04%
2023	A330	FO	8,533	9,117	137	66.6	151	60.3	269	9	6.58%
2023	B777	CA	13,017	20,991	267	78.7	301	69.7	409	14	5.10%
2023	B777	FO	13,017	15,130	213	71.1	256	59.2	476	16	7.47%
2023	B787	CA	6,886	10,765	154	69.8	181	59.4	344	12	7.46%
2023	B787	FO	6,886	7,421	114	65.3	140	53.1	164	6	4.84%
2024	A320	CA	18,294	20,080	313	64.2	356	56.4	669	22	7.13%
2024	A320	FO	18,294	17,515	287	61.0	304	57.6	396	13	4.60%
2024	A330	CA	8,717	9,843	147	66.9	164	60.1	324	11	7.34%
2024	A330	FO	8,717	9,139	140	65.2	155	58.8	286	10	6.78%
2024	B777	CA	13,106	20,445	269	75.9	293	69.7	395	13	4.90%
2024	B777	FO	13,106	15,306	224	68.4	256	59.7	356	12	5.32%
2024	B787	CA	8,209	13,316	184	72.4	204	65.4	307	10	5.54%
2024	B787	FO	8,209	8,782	128	68.8	143	61.4	141	5	3.68%

TABLE 3. CREW PRODUCTIVITY BASELINES BY THE COMPANY'S OPERATION EXPERTISE

Fleet	Average Utilized Crew Productivity baseline	Average Pay-Audit Crew Productivity baseline
All Aircrafts	72	65
A320	67	58
A330	67	59
B777	74	70
B787	72	65

TABLE 4. PLANNING VERSUS ACTUAL HOURS ACCURACY

Fleet	Rank	Average of Planned Crew block hours	Average of Actual Crew block hours	Average Planning Accuracy (%)
A320	CA	17,930	19,473	108.6%
A320	FO	17,960	17,343	96.6%
A330	CA	9,485	9,521	100.4%
A330	FO	9,395	9,082	96.7%
B777	CA	21,269	22,077	103.8%
B777	FO	17,977	17,644	98.1%
B787	CA	6,967	7,751	111.3%
B787	FO	5,212	5,191	99.6%

V. RESULTS AND DISCUSSION

This section presents the outcomes of the Lean Six Sigma (LSS) DMAIC application aimed at improving cockpit-crew scheduling efficiency in a leading Saudi airline. Each DMAIC phase—Define, Measure, Analyze, Improve, and Control—yielded specific findings that collectively enhanced process standardization and performance. Quantitative results were derived from the operational datasets summarized in Tables 2–4, while analytical tools such as SIPOC, Control Charts, Fishbone Diagram, Value Stream Mapping (VSM), and KPI Dashboard provided a data-driven basis for improvement and decision-making.

A. Define phase – SIPCO mapping

In the Define phase, the Supplier–Input–Process–Output–Customer (SIPOC) framework was applied to clarify the scope and boundaries of the cockpit-crew scheduling process. The analysis distinguished between the Pay-Audit Crew and the Utilized Crew, representing active flight-duty personnel. This differentiation revealed a structural imbalance in crew deployment, where some pilots were reassigned to non-flying duties, leading to inefficiencies and lower utilization rates.

The SIPOC diagram in Figure 2 identified primary suppliers such as the Scheduling, Flight Operations, and Training departments, alongside inputs including crew qualifications, flight schedules, and aircraft types. The process mapped key activities in developing monthly rosters, with outputs comprising finalized schedules and compliance performance reports. This phase has two major gaps: (1) resource misallocation across operational and administrative roles, and (2) limited system integration between CARDEX

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Suppliers	Inputs	Processes	Outputs	Customers
- Cockpit crew members.	- Current Crew Scheduling Data.		- **Poor Crew Deployment:** Misbalance of crew assignments causing uneven distribution of work.	- **Cockpit Crew:** Required equal workload and clear rostering.
- Scheduling Software Providers.	- Available Crew and Preferences.		- **Insufficient cockpit Productivity:** not efficiently scheduling and underutilizing crews, leading to a decrease in productivity.	- **Flight operations team:** Depend on effective crew management for smooth operations.
- Aviation Regulatory Authorities.	- Operational Needs and Conformance Criteria.		- **Loss of Resources:** Poor planning equals lost pilot hours and inflated operations expenses.	- **Airline Management:** Applied to maximize resource exploitation and to meet compliance regulations.
- Training Providers for cockpit.	- Crew Feedback on Scheduling Experience.		- **Decrease Crew Moral:** Dissatisfaction with unfair workload and lack of strategic planning.	- **Operational Teams:** Responsible for managing crew logistics and inquiries.
- Human Resources Specialists.	- Historical Scheduling Data.		- **Crew Not Properly Supported:** Poor resource leading to confusion among crew.	- **Regulatory Agencies:** Ensuring compliance with aviation standards.
- Data Analysts.	- Performance Metrics Over Time.		- **Costing more to Operate:** The more it costs to run inefficiently & wasted resources costing more to run.	- **Stakeholders:** Concerned about optimizing operations and crew satisfaction.

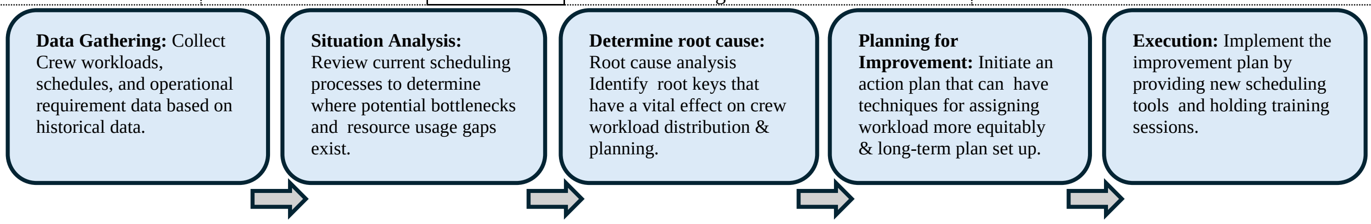

FIGURE 2. SIPOC MAPPING FOR COCKPIT CREW SCHEDULING PROCESS

and SABRE platforms. These issues contributed to delays, inconsistent workload distribution, and reduced pilot productivity. By applying SIPOC, the status of crew utilization was visualized, providing a foundation for developing long-term plans aligned with operational requirements and Vision 2030's focus on efficiency and human-capital optimization [29], [30].

B. *Measure phase – Control chart*

Following the Define phase, which established process boundaries through SIPOC mapping, the Measure phase quantified cockpit-crew performance using Control charts. X̄–R charts were developed for all aircraft fleets (A320, A330, B777, and B787) to assess productivity stability and detect performance variation in both Utilized Crew and Pay-Audit Crew categories. Figures 3 and Figure 4 present the control-chart outcomes. Each X̄ chart illustrates the monthly mean productivity over time, enabling detection of trends or shifts, while the accompanying R chart highlights the range of subgroup variability—an indicator of consistency within the crew performance data.

For Utilized Crew Productivity (Figure 3), several data points exceeded the upper control limits points more than 3.0 standard deviations from the centerline, specifically at subgroups 1, 3, 4, 8, 16, 18, 24, 67, 69, 73, 75, 76, 77, 86, and 88. These deviations reveal operational instability or shifts in crew deployment efficiency, likely resulting from training schedules, manpower redistribution, or seasonal workload imbalances. The R chart similarly showed out-of-control points at 2, 6, and 8, indicating temporary inconsistencies among subgroup productivity levels.

For Pay-Audit Crew Productivity (Figure 4), the X̄ chart displayed out-of-control points at 3, 4, 8, 16, 18, 24, 62, 64, 75, 76, and 130, signifying significant fluctuations in monthly averages. The R chart again indicated violations at 2, 6, and 8, suggesting intermittent irregularities in workload balance and performance stability.

Overall, the X̄–R analysis confirmed that while productivity performance remained largely within control limits, several periods exhibited special-cause variations that warranted deeper diagnostic evaluation. These insights formed the statistical foundation for the Analyze Phase, where root causes were further explored through the Fishbone diagram [31]–[33].

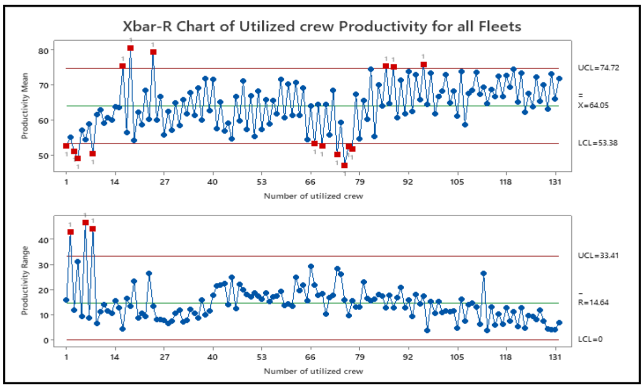

FIGURE 3. CONTROL CHART FOR UTILIZED CREW PRODUCTIVITY OF ALL FLEETS

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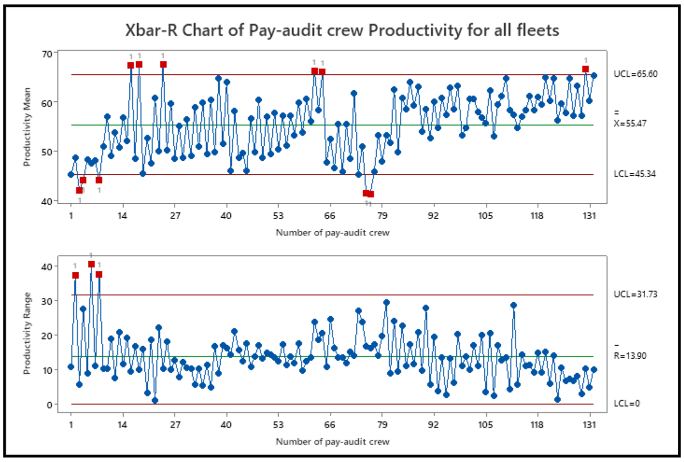

FIGURE 4. CONTROL CHART FOR PAY-AUDIT CREW PRODUCTIVITY OF ALL FLEETS

Planning Accuracy was analyzed to assess how effectively the scheduling department's planned crew block hours matched the actual block hours flown across all fleets and ranks. This metric reflects the precision and reliability of the planning process, serving as a critical performance indicator for operational alignment and forecast efficiency.

As summarized in Table 4, the results show that overall planning accuracy across all fleets exceeded 95%, indicating strong synchronization between planned and executed schedules. The A320 fleet achieved 108.6% accuracy for Captains (CA) and 96.6% for First Officers (FO), suggesting occasional overestimation in captain deployment. The A330 fleet demonstrated balanced planning, with Captains at 100.4% and First Officers at 96.7%, reflecting stable forecast alignment. For wide-body fleets, the B777 achieved 103.8% and 98.1% for Captains and First Officers, respectively, while the B787 exhibited the highest deviation, with Captains recording 111.3% accuracy compared to 99.6% for First Officers.

These findings indicate that while the planning system performs efficiently overall, recurrent overestimation in captain block-hour planning—particularly in the A320 and B787 fleet

signals potential areas for optimization. Such discrepancies emphasize the need for closer coordination between manpower planning and operational execution teams, forming the basis for the root-cause exploration in the Analyze Phase.

C. Analysis phase – Root Cause analysis (Fishbone)

The Analysis phase aimed to determine the underlying causes of variability and inefficiency identified in the Measure phase through a structured Root Cause Analysis (RCA) using the Fishbone (Ishikawa) Diagram. This tool provided a systematic framework for categorizing potential causes of poor crew utilization into five domains—People, Process, Technology, Environment, and Management—as illustrated in Figure 5.

The analysis revealed that the core problem was the misallocation of cockpit crew resources, driven by inadequate workload distribution and insufficient long-term planning. Under the People category, communication gaps, irregular operational updates, and insufficient training capacity were identified as major contributors to reduced productivity. Within the Process domain, rigid scheduling methodologies and non-standardized assignment practices led to uneven workload distribution and inefficiencies in roster generation.

Technological limitations were another key factor: outdated or non-integrated scheduling systems (e.g., CARDEX and SABRE) restricted data sharing and hindered accurate forecasting. Environmental influences, such as regulatory constraints further amplified workload imbalance.

Finally, at the Management level, short-term decision-making and resistance to change in adopting modern planning tools prevented sustainable improvement.

Collectively, these findings highlighted that inefficiencies in

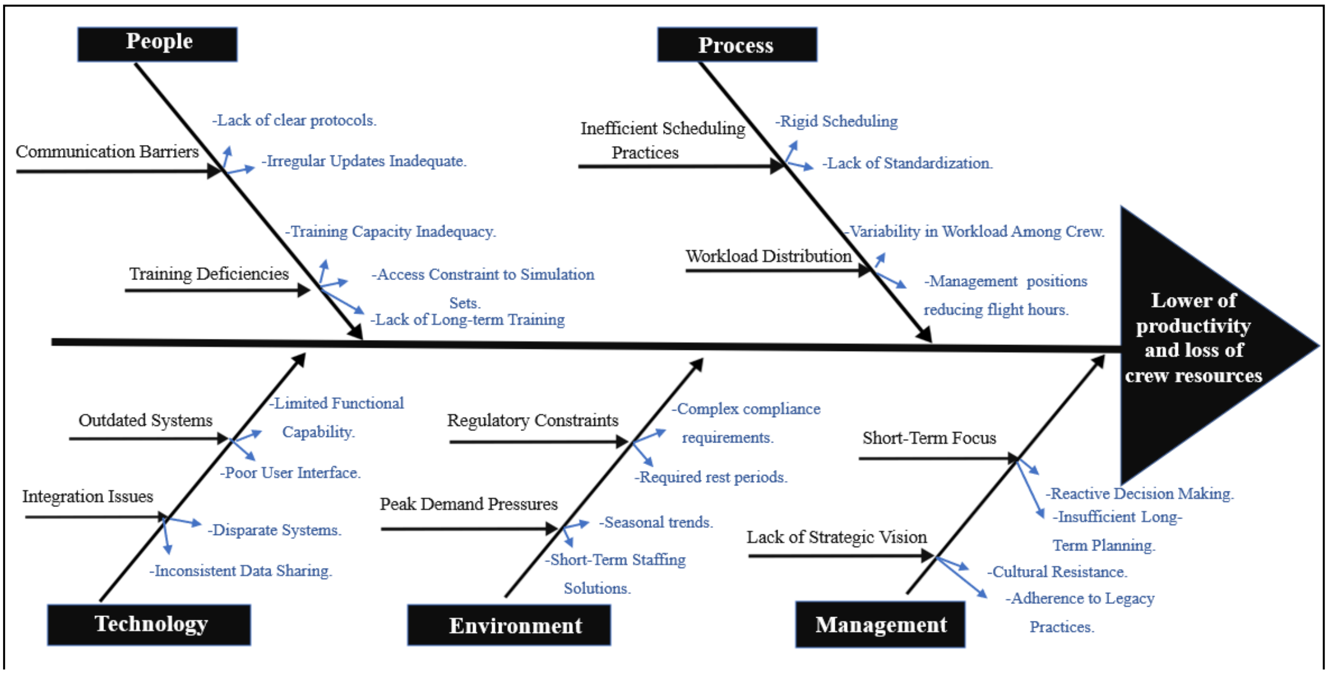

FIGURE 5. FISHBONE (ISHIKAWA) DIAGRAM FOR ROOT CAUSE ANALYSIS OF CREW UTILIZATION INEFFICIENCIES

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cockpit crew utilization stemmed from a multifactorial interplay between human, procedural, and systemic elements. Addressing these interconnected causes required a holistic redesign of scheduling workflows—initiated in the Improve Phase—to ensure better workload balance, streamlined communication, and enhanced data integration across operational departments.

D. Improve phase – Value Stream Mapping

The Improve phase focused on redesigning the cockpit-crew scheduling workflow through Value Stream Mapping (VSM), a Lean Six Sigma technique that visualizes end-to-end processes to eliminate waste and streamline flow. Analysis of the current-state VSM revealed that the scheduling system relied heavily on manual inputs, fragmented communication across departments, and delayed approvals that hindered responsiveness and transparency. Repetitive data entry in tools such as Excel, email exchanges, and non-integrated systems (CARDEX, SABRE) led to duplicated effort, limited visibility, and reactive decision-making.

The Future State VSM showing in Figure 6 depicts a digitally integrated and standardized process characterized by automation, cross-functional coordination, and data-driven forecasting. Real-time aircraft availability is synchronized through API-based integration, enabling the scheduling team to access live operational inputs within hours instead of days. Forecasting tools and dashboards consolidate crew availability and training data, producing dynamic roster plans supported by AI-based decision algorithms. This redesign significantly shortened process-cycle times—from over a week to approximately three to four working days—and minimized human-error risk by automating data transfer and approvals through a shared dashboard environment. Departmental coordination between Scheduling, Training, and Flight Operations became centralized, enhancing visibility and accountability. Monthly feedback loops and KPI-based dashboards were added to track performance, fatigue trends, and workload balance, ensuring continuous improvement and long-term sustainability.

Overall, the future-state VSM established a lean, transparent, and proactive scheduling ecosystem that aligns with the airline's strategic goals under Saudi Vision 2030. The transition from manual to automated processes not only improved planning accuracy but also strengthened integration between operational and strategic levels of decision-making. Similar Lean-based redesign approaches have been shown to significantly reduce cycle times and enhance process reliability in aviation and aerospace operations [33], [35], [36].

E. Control phase – Key Performance Indecators (KPIs)

The Control Phase aimed to sustain the performance gains achieved in earlier DMAIC stages by implementing a Key Performance Indicator (KPI) Dashboard designed to monitor cockpit crew scheduling efficiency in real time. This phase integrated data from both the CARDEX and SABRE systems, allowing for automated data flow, continuous visibility, and proactive management of performance deviations.

The dashboard focused on four main KPIs: Utilized Crew Productivity, Pay-Audit Crew Productivity, Absenteeism Rate, and Planning Accuracy. Each KPI was selected for its relevance to operational efficiency, manpower optimization, and long-term planning reliability. Following the approach of Arango et al. [19] and Pongboonchai-Empl et al. [20], the Control Phase emphasized the importance of digital integration and data-driven supervision within Lean Six Sigma frameworks.

Baseline values and control thresholds for each KPI were established through a combination of historical data (2017–mid 2024) and expert judgment from the airline's Manpower and

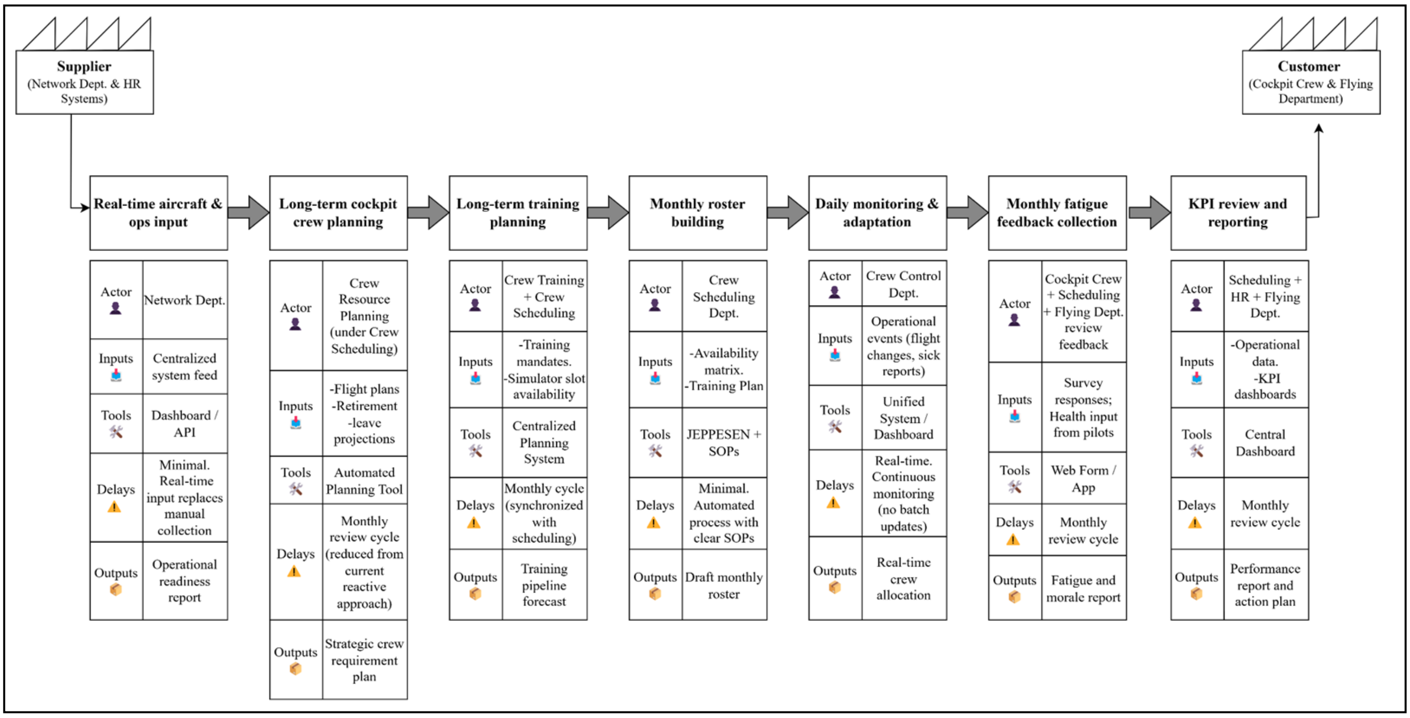

FIGURE 6. IMPROVED VALUE STREAM MAPPING OF THE COCKPIT-CREW SCHEDULING PROCESS

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Crew Scheduling Department as shown in table 3. These experts defined the acceptable ranges of variation based on actual operational behavior and managerial experience. Notably, the absenteeism baseline was fixed at 2.5%, representing the average daily absence rate that maintains stable operational performance under normal scheduling conditions.

A color-coded alert system—Green, Amber, and Red—was incorporated to visualize performance conditions and provide managers with an intuitive signal-response framework. Each KPI alert was linked to a specific corrective action, ensuring that deviations triggered a standardized organizational response. This structure aligns with the recommendations of Daniyan et al. [36], who emphasize that visual management tools strengthen feedback loops and improve the responsiveness of aviation operations to performance anomalies. The summary of all monitored KPIs, performance thresholds, and corresponding actions is presented in Table 5.

VI. CONCLUSION

This study addressed the long-standing inefficiencies in cockpit crew scheduling by applying the Lean Six Sigma (LSS) DMAIC methodology to a leading Saudi airline. The research provided a structured, data-driven framework to enhance crew utilization, minimize absenteeism, and improve planning accuracy—three critical dimensions of operational performance.

Through the Define phase, the study established the process boundaries and identified the underlying issues of resource misallocation using SIPOC mapping, which clarified stakeholder roles and cross-functional dependencies.

In the Measure phase, control chart analysis provided statistical evidence of instability in productivity and absenteeism patterns, validating the need for process standardization. The Analyze phase, using the Fishbone diagram, revealed that inefficiencies stemmed primarily from training capacity limitations, outdated scheduling systems, poor workload distribution, and reactive management practices. Building on these insights, the Improve phase utilized Value Stream Mapping (VSM) to redesign the scheduling process, removing non-value-added activities and introducing a more synchronized workflow. The improved process emphasized efficiency, transparency, and interdepartmental coordination. Finally, the Control phase institutionalized these gains through a KPI Dashboard, enabling real-time performance tracking across four indicators—Utilized Productivity, Pay-Audit Productivity, Absenteeism Rate, and Planning Accuracy—supported by baseline thresholds established through expert judgment.

The implementation of the LSS-DMAIC approach yielded measurable outcomes: increased stability in crew productivity

TABLE 5 KEY PERFORMANCE INDICATORS (KPIS) WITH CONTROL THRESHOLDS FOR COCKPIT CREW SCHEDULING PERFORMANCE

KPI	Definition	Purpose / Interpretation	Control Thresholds (Performance Alert)	Recommended Action
1. Utilized Crew Productivity	Measures productivity of all cockpit crew personnel who are performing in full-time duty status in positions directly associated with flight duties	Indicates operational efficiency and workload balance of active pilots.	🟢 **Green:** Within ±5% of baseline 🟠 **Amber:** ±6% to ±10% deviation 🔴 **Red:** >±10% deviation	🟢 Maintain current scheduling practices. 🟠 Review monthly crew distribution and Investigate root cause. 🔴 Conduct manpower reallocation and investigate underutilization causes (e.g., training gaps, leave imbalance).
2. Pay-Audit Crew Productivity	Measures productivity level of all cockpit crew members recognized by the company for remuneration as pilots, includes airmen flying, and airmen holding non-flying positions.	Reflects how effectively compensated crew time translates into operational productivity.	🟢 **Green:** Within ±5% of baseline 🟠 **Amber**±6% to ±10% deviation 🔴 **Red:** >10% deviation	🟢 Continue monitoring. 🟠 Reassess duty assignments for non-flying cockpit crew. 🔴 Immediate corrective scheduling action. Initiate corrective review to ensure flight hours correspond with payroll and duty records.
3. Absenteeism Rate (Daily)	Percentage of cockpit crew absent per day relative to total utilized crew.	Emphasizes workforce reliability and potential fatigue or morale concerns.	🟢 **Green:** ≤2% 🟠 **Amber:** 3–5% 🔴 **Red:** >5%	🟢 Maintain crew engagement and communication. 🟠 Review roster fairness and analyze fatigue reports. 🔴 Conduct root-cause analysis (medical, fatigue, or morale) and apply mitigation strategy.
4. Planning Accuracy (%)	Comparison between planned and actual block hours achieved.	Evaluates forecasting reliability and scheduling precision.	🟢 **Green:** within 95% - 105% 🟠 **Amber:** 90%–94.9% 🔴 **Red:** < 90% or > 105%	🟢 Continue current forecasting models. 🟠 Validate plan-to-actual deviations, review scheduling logic, and validate pairing accuracy. 🔴 Recalibrate planning inputs, Investigate the sever underutilization or overload risk, rebalance duties, audit fatigue exposure

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metrics, improved alignment between planned and actual block hours, and a structured mechanism for absenteeism control. These results demonstrate that integrating Lean Six Sigma principles within aviation manpower planning not only improves operational efficiency but also aligns organizational practices with Saudi Vision 2030's objectives of digital transformation and sustainable excellence. Future research could extend this framework by incorporating machine learning models for predictive scheduling, automated fatigue risk detection, and cross-functional resource optimization across cockpit and cabin crew domains. Additionally, integrating data analytics with real-time operational dashboards can further enhance forecasting accuracy and decision responsiveness in dynamic aviation environments.

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