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REGULAR PAPER

Estimating the required number of Harbour Pilots to support airline operations of a single pilot commercial aircraft at a UK regional airport

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Abstract

Single pilot passenger aircraft concepts are being developed by several manufacturers. Various technological approaches are being explored: One concept is to use a Harbour Pilot dedicated to providing support for departures and arrivals. The Harbour Pilot has comprehensive knowledge of the terminal area airspace, procedures and operations. If a single pilot aircraft is to be viable, however, the number of supporting personnel needs to be significantly smaller than the number of First Officers normally employed for a two-crew aeroplane, but the number such staff has yet to be determined. This study models operations by a UK low-cost operator at a regional airport to determine the optimum number of Harbour Pilots required to support operations throughout the day. The model uses a simplified timeline analysis with task data incorporated into a dynamic discrete event modelling system allowing for multiple replications using various configurations. Results suggest that for this operation six Harbour Pilots per shift used flexibly to support both departures and arrivals would be required.

Nomenclature

ATC	Air Traffic Control
EGGW	London Luton Airport (ICAO code)
FAA	Federal Aviation Administration
FL	Flight Level
IAS	Indicated Air Speed
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
KPI	Key Performance Indicator
NASA	National Aeronautics and Space Administration
OESD	Operational Event Sequence Diagram
STAR	Standard Terminal Arrival Route
UAS	Uninhabited Aviation System

1.0 Introduction

At the present time, both by regulation and by law, the reduction in the number of pilots on the flight deck is not possible: Two pilots are the current minimum flight crew complement for a large commercial aircraft. Nevertheless, there are indications that this may change. In 2018 the as part of the FAA Reauthorization Act 2018 put in front of the US Congress, it was proposed that the '*Administrator shall transmit a report to the Committee on Science, Space, and Technology of the House of Representatives* *and the Committee on Commerce, Science, and Transportation of the Senate that describes... a review of FAA research and development activities in support of single-piloted cargo aircraft assisted with remote piloting and computer piloting'* [1]. Such a change in legislation would clear the way for the introduction of a single pilot passenger aircraft. In January 2021, FlightGlobal reported that EASA (European Aviation Safety Agency) was also considering the potential for the relaxation of the rules currently restricting single pilot operations in commercial aviation [2].

The original impetus for single pilot operations was financial; however, this is now not the only reason for developing such an aircraft. Other factors have accelerated the need for this technology, including constant downward demands on pricing and unpredictable, fluctuating fuel costs coupled with a low operating margin. Between 2000 and 2010, it was estimated that on a global basis, the aviation industry cumulatively lost $47 billion [3]. As a result of the COVID-19 pandemic, the International Air Transport Association (IATA) estimates that the global airline industry recorded a net loss of $126 billion in 2020, to be followed by a $48 billion loss in 2021 [4].

For a major European low-cost operator, each aircraft requires 9 or 10 pilots. Airline personnel costs vary between about 13.5% to 18% of operating costs, depending upon aircraft type, sector length and how much activity is outsourced [5–7]. Crew personnel can represent almost 15.3% of operating costs [6] and this percentage can increase as the size of the aircraft decreases. Airbus [8] estimated that over 39,000 new aircraft would be required by 2038, more than doubling the fleet size within the next 20 years. The corresponding Boeing estimate was considerably higher, suggesting a demand for over 43,000 aircraft by 2039, with recovery from the pandemic occurring before the end of the decade [9]. However, commensurate with the expected in increase in the demand for air travel and the global fleet size, there is an accelerating, global shortage of airline pilots.

Estimates of the size of the pilot shortfall vary. It was estimated that in the US alone between 2013 and 2031, there will be a shortage of over 35,000 pilots [10]. The majority of this will be borne by the regional carriers operating smaller aircraft, as pilots migrate to job opportunities in the major national and intercontinental operators. It has been estimated that there will be a cumulative shortage of approaching 40,000 FAA certificated airmen by 2035 [11]. Numbers from the UK Civil Aviation Authority also exhibited a decline of 31% in total Commercial Pilot Licenses issued in the four years between 2011 and 2015; 1,555 licenses were issued in 2011 compared to 1,072 in 2015. Boeing projected that between the years 2021 and 2040 the world's airlines will need about 612,000 new pilots. Of these, 130,000 new commercial pilots will be required in North America alone: 115,000 will be required in Europe and approaching a quarter of a million will be needed in the China/Asia-Pacific region [12]. Over 60% of these new pilots will be required to service the expansion in the industry. This shortfall will also push up the cost of trained, experienced airline pilots.

Addressing such shortages has traditionally seen as a pilot recruitment and training issue. However, being able to reduce the number of flight crew may provide a further option for reducing costs and helping to avert a potential pilot shortage.

More recently a third compelling reason of the introduction of single pilot operations has emerged. Short-range, electric commercial aircraft are currently being developed in an attempt to reduce the carbon footprint of aviation (e.g. the 19-seater Heart Aerospace ES-19, scheduled for service entry in 2026). The operating economics of such an aircraft would benefit greatly from a reduction in flight deck crew, where pilot costs have to be amortised over just 19 seats. Significant weight reductions are also possible, especially if the flight deck is re-designed to accommodate just a single pilot, relieving the aircraft of not only the weight of the pilot but also their seat, displays, controls and so on.

Various technological approaches are currently being explored for the development of a single-pilot airliner. Some focus upon the development of sophisticated automation, for example, intelligent knowledge-based systems, autonomous systems and adaptive automation [13, 14]. Others adopt a more technologically cautious approach to that of using a large amount of on-aircraft computing. These use a distributed systems-based design philosophy, utilising extant technologies and operating concepts derived from military fast-jet and UASs (Uninhabited Aviation Systems) [15–17]. It would be incorrect to characterise these approaches as either/or options, though: There is a great deal of commonality in the technologies to be developed and the operational challenges that airlines face operating a single pilot airliner.

In NASA's Single-Pilot Operations Technical Interchange Meeting [18] five basic configurations were identified. One of these was a configuration where the single pilot was aided by a ground-based team member who replaced the second pilot: a *distributed crewing approach*. Neis, Klingauf & Schiefele described two further sub-categories of this configuration, one of which was where a remote pilot had the capability of exerting control from the ground, replacing the on-board pilot (if required) during any phase of flight. The second category (originally developed by NASA) involved a *Harbour Pilot*, a role similar in concept to its marine counterpart [19].

In the Harbour Pilot concept, there is a dedicated ground-pilot providing support to the single onboard flight deck crew member at each airport. They have comprehensive knowledge of the terminal area airspace, procedures and operations. This approach was developed by NASA [20, 21]. The Harbour Pilot can also offload the workload of the aircraft pilot and provide assistance in the event of an emergency in terminal airspace. Simulated flight trials using this concept found that while pilots had some concerns regarding communication and coordination between the Harbour Pilot and the flight deck, workload was low and situation awareness was high. Performance was maintained during a variety of approach and weather scenarios. Despite reservations, participants saw the benefits of a crew member who was dedicated to one airport and was knowledgeable about current terminal conditions, weather, air traffic control procedures, etc.

However, the main benefits of this approach are also its major drawbacks. The Harbour Pilot concept requires ground support operators for each airport, hence potentially limiting the range of destination airports that can be served by a single pilot aircraft (although the Harbour Pilot need not be physically located at that airport). One Harbour Pilot may be able to service several airports (flight scheduling permitting) but for the sake of system redundancy, should more than one ground operator always be available (c.f. a single air traffic controller providing remote tower ATC operations to a number of airports [22])? Furthermore, if the goal is to open up thinner routes, which may only be served by one or two flights every day, the economic viability of a dedicated Harbour Pilot for each destination is questionable.

There is the business potential for Harbour Pilot services to be provided by the airport itself rather than the airline; however, there may be issues associated with variations in procedures between airlines and different single crew aircraft types. Furthermore, the function of the Harbour Pilot is restricted to taxi-out, take-off, approach and landing, and taxi-in. Non-normal and emergency situations are largely outwith their remit. All these issues will need to be addressed and any en-route cover will still need to be provided by the airline.

All current concepts being envisaged for single pilot commercial operations involve both an air-based component (the aircraft) and a ground-based component. However, the functions of the ground-based support system will very much depend upon the technological approach implemented. Furthermore, if the single pilot aircraft is to enable significant cost savings to an airline, the ratio of personnel involved in the ground support of such an aircraft needs to be considerably more favourable than the current 1:1 ratio of flight deck crew (one First Officer for every Captain) but while maintaining or bettering current standards of safety and efficiency. The number of ground-based personnel in relation to aircraft in the air is a key factor that has yet to be determined. The goal of the NASA studies was for the ground-based element to provide support for up to 12 aircraft in flight [23]. The French Air and Space Academy (Académie de l'Air et de l'Espace) proposed a more modest target of 5:1 ground operators to pilots, potentially rising to 7:1, once experience in the operational concept has been accrued [24]. NASA studies suggested a Harbour Pilot could handle between 4 and 6 consecutive approaches, assuming no off-normal situations [21].

Using a modelling approach, this study estimates the number of ground-based support operators required using the Harbour Pilot concept in a scenario based around the typical movements of a low-cost operator (easyJet) using a single crew airliner, at a UK regional airport (London Luton airport: ICAO code EGGW).

2.0 Modelling Approach

The method used was based around a simplified Operational Event Sequence Diagram (OESD) time-line model, with task data incorporated into a dynamic modelling system allowing for multiple replications. Harris, Stanton & Starr and Huddlestone, Sears & Harris [16, 17] both used OESDs to aid in specifying crewing configurations for a single pilot commercial aircraft.

OESDs were originally developed to represent information decision sequences and subsequently complex, multi-person tasks [25–28]. OESDs can be used to illustrate and describe interactions between operators and artefacts within a system and how the tasks performed and their interactions between operators and artefacts may change. They can be developed from formal analyses of task flows during the early design stages. OESDs can facilitate the comparison between system configurations, which make them ideal for the early assessment of alternative single pilot aircraft system configurations, including estimating the amount of ground-based support required.

In the following study OESDs were supplemented using discrete-event simulation models, where entities such as ground operators, aircraft automated systems and ATC were characterised as limited availability resources. Transaction times, variability and critical queue sizes were estimated, and system throughput value estimates derived using Monte Carlo simulations. Using this approach different configurations, can be modelled simply and the effects of throughput be assessed at an early stage of the development process.

The utility of the modelling approach employed was also be assessed for its applicability to other flight scenarios and aircraft/system configurations.

3.0 Modelling Scenario

Two scenarios were considered for single pilot operations supplemented by assistance from a Harbour Pilot. The simplest scenario assumed that there were separate Harbour Pilots for departures (taxi-out, take-off and initial climb) and for landing (intermediate and final approach; landing and taxi-in). One Harbour Pilot was allocated to each aircraft for the duration of either the take-off phase or approach and landing phase. Alternatively, it was assumed that there would be a pool of Harbour Pilots used flexibly for departures and arrivals, as required.

A period between handling each flight of two minutes was allowed (to update paperwork, for the Harbour Pilot to appraise themselves of flight status and any special requirements, etc.).

For the purposes of this model, it was assumed that Harbour Pilots were contracted to an individual airline and had the equivalent of an aircraft type-rating. The scenarios modelled did not cover the enroute portion of the flight, the approach, landing and take-off from remote airports nor any non-normal situations. As a consequence, results can be considered to be best estimates of throughput and capacity.

Modelling scenarios are based upon the operation of easyJet at London, Luton airport on Wednesday 6 April, 2022, once flight schedules were anticipated to return to normality following the COVID-19 disruption to services. It was selected as a representative flight schedule for the early summer period. The model encompassed all projected easyJet arrivals and departures on that day. easyJet operate Airbus A320 family aircraft (A319/A320/A321) which share a common type rating. Departure and arrival rates (per hour) are depicted in Figs. 1 and 2.

3.1 Task stages for modelling

For departing aircraft, it was assumed that pre-flight planning and briefing for the single crew aircraft was completed prior to the pilot boarding. Initial flight deck configuration was undertaken by the pilot. Assistance from ground-based support commenced with pre-flight checks (but not all pre-departure procedures; it was presumed that many of these will be undertaken by the single pilot alone and subject to verification by the aircraft systems) followed by push back/engine start and taxi-out. Support to the flight deck continued until the aircraft is handed off by the tower.

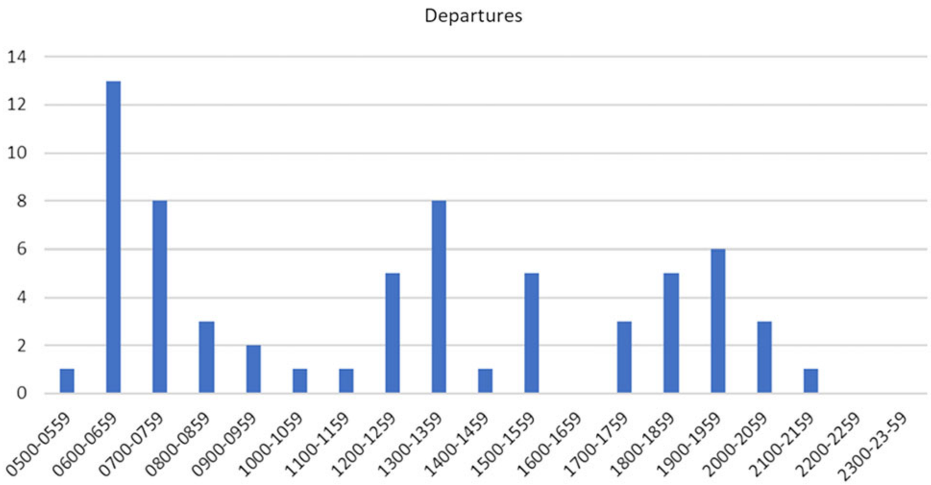

Figure 1. *Hourly frequency of easyJet departures from London Luton Airport (Wednesday 6 April, 2022).*

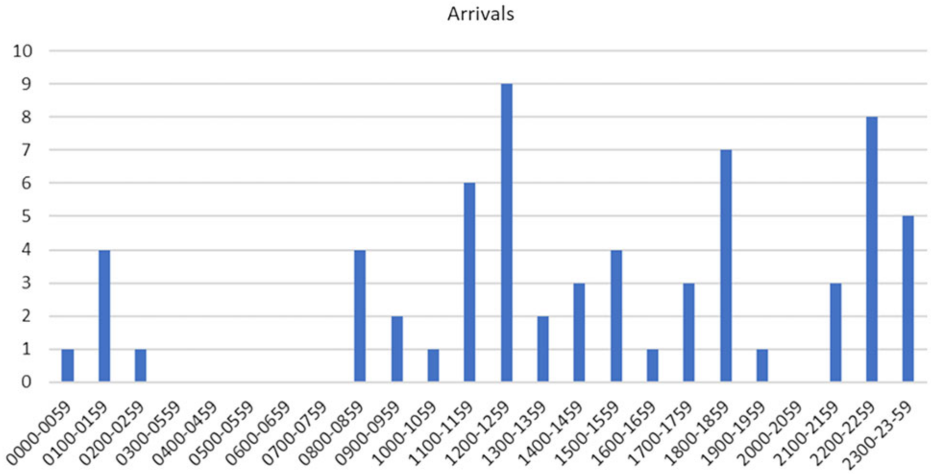

Figure 2. *Hourly frequency of easyJet arrivals to London Luton Airport (Wednesday 6 April, 2022).*

The model assumed departures from runway 25 at Luton Airport. A high-level schematic of the departure task stages (including potential delays between task phases) can be found in Fig. 3. Taxi out from the terminal was via taxiways Echo, Delta and Foxtrot to holding point Alpha 1. Aircraft could experience a short hold at Delta 3 and potentially a longer hold at either Alpha 2 or Alpha 1 prior to entering the runway. There was also a further hold once lined up prior to departure. All these holds were incorporated into the departure scenario. Modelling of the process ceased when ATC changes from Luton Tower to area control.

NASA studies of the Harbour Pilot concept did not specify the extent of their responsibility [21] but simply specified they assumed the responsibilities of the Pilot Monitoring during a Standard Terminal Arrival Route (STAR). In the current scenario it is assumed that a LOREL 1R or LOREL 4Q STAR will be performed with an approach into EGGW from the East, leading to an instrument approach to runway 25.

In the model employed, the Harbour Pilot provided support for the initial approach briefing prior to top of descent (assumed to be around FL320). No further ground support was be provided until the

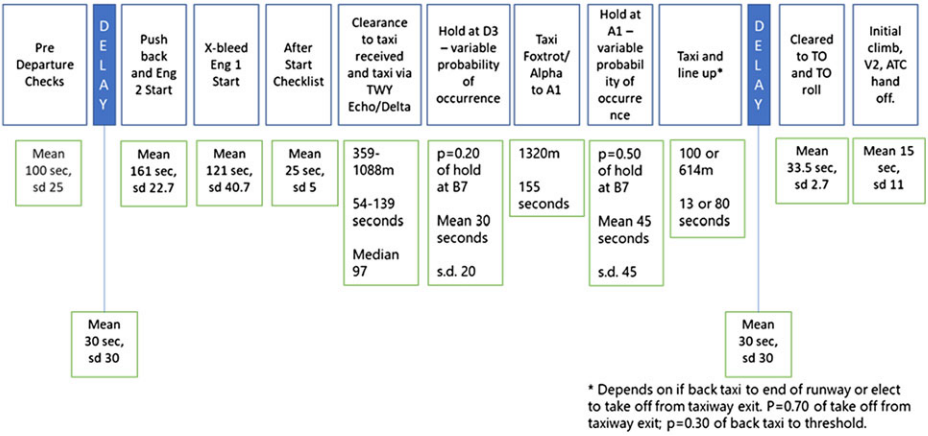

Figure 3. *High-level schematic of the departure task stages at London Luton Airport (EGGW).*

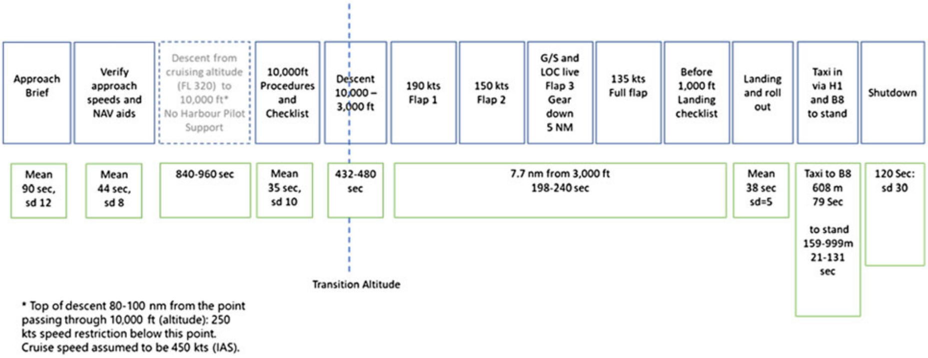

Figure 4. *High-level schematic of the approach and landing modelling task stages at London Luton Airport (EGGW).*

aircraft descended through approximately 10,000 ft. It was estimated that the top of descent point was 80–100 nm from the point the aircraft passed through 10,000 ft (altitude) and assumed a 250 kts speed restriction below this point. Cruise speed was assumed to be 450 kts (IAS). Continuous support was provided during all stages of the intermediate and final approach (flap extension; gear deployments and checklists) and during landing, rollout, taxi in and shutdown. A high-level schematic of the arrival task stages can be found in Fig. 4.

It was expected that all arrivals would also be to runway 25 and exited the runway via taxiway Hotel and then then taxi via Hotel 1 and Bravo 8. Occasional holds were expected during the taxi in at Bravo 6 (an aerodrome map of London, Luton Airport is available at https://www.aurora.nats.co.uk/) htmlAIP/Publications/2021-10-07-AIRAC/graphics/177463.pdf).

Data to populate the task models described in Figs. 3 and 4 were derived from various sources. Start up and push back task-time data were derived from real-time videos of Airbus A320 operations available from various internet resources. The same sources were used to estimate these parameters for the take-off run. Taxi times were estimated assuming an average continuous taxi speed of 15 kts (excluding holds) for both taxi out and taxi in (once the runway was vacated). To allow for Harbour Pilots' familiarisation, briefings, etc., it was initially estimated that two minutes will be allowed between handling flights.

Data for hold times, initial climb and approach and landing segments were derived from surveillance data from radio and FlightRadar$^{\mathrm{TM}}$. Similar internet sources were utilised to obtain task-time data (and variances) for final approach and taxi-in phases of arrivals.

Table 1. *Simulation trial results for Harbour Pilots dedicated only to departures. All times are expressed in seconds. Numbers in parentheses indicate numbers of Harbour Pilots assigned to the early, midday and late shifts*

	Two Harbour Pilots all day	Four Harbour Pilots all day	Shift System (4:2:2)	Shift System (4:2:4)
Overall mean time	930.82	888.15	905.82	896.03
Standard deviation	179.52	143.02	151.06	146.22
Mean number of non-zero waits	13.38	12.93	12.94	12.93
Mean maximum number waiting	2.85	2.72	2.72	2.72
Mean non-zero waiting time	137.84	118.38	118.34	118.37
Harbour Pilot utilisation	8%	4%	6%	5%

3.2 Shift systems

For the scenarios where Harbour Pilots were dedicated to either only arrivals or departures, several different shift systems were trialled. For departures simulated trials were run using either two or four Harbour Pilots for the whole working day or were conducted using a shift system (early shift 00:00–08:00; midday shift 08:00–16:00; late shift 16:00–00:00). Two different staffing levels were modelled: Four Harbour Pilots on the early shift, followed by either two on the midday shift and two on the late shift (designated the 4:2:2 shift pattern) or two on the midday shift and four on the late shift (4:2:4 shift pattern). These coincided with peaks in departure demand (see Fig. 1).

To support aircraft on approach, simulated trials were again run using either two or four Harbour Pilots for the duration or were conducted using a shift system with varying numbers of staff to support peaks in arrival demand (see Fig. 2). As a result of the different pattern of arrivals compared to departures, the shift pattern was slightly different, with two Harbour Pilots in the morning and either two or four on the midday shift, and four on the evening (2:2:4 or 2:4:4 shift patterns).

When Harbour Pilots were expected to deal with both departures and arrivals, scenarios were modelled containing four, six or eight Harbour Pilots available at all times throughout the day. In these scenarios priority was always given to arriving flights.

3.3 Key performance indicators (KPIs)

For departures, the following KPIs were selected. All KPIs were taken over 1,000 of the simulation (see Tables 1 and 3).

- Mean overall time in seconds (and standard deviation), from initiating pre-departure checks to the end of initial climb flight phase. This was the total time that the Harbour Pilot was engaged with the departing aircraft. The Harbour Pilot was dedicated to this aircraft during this time.
- Mean number of non-zero waits (each day) for a Harbour Pilot to be available for pre-departure check. A non-zero wait indicates that the pilot was not aided immediately by a Harbour Pilot. Basically, a delay caused by a Harbour Pilot not being available to service a departing aircraft.
- Mean non-zero waiting time. The mean length of delays (in seconds) resulting from non-availability of a Harbour Pilot.
- Mean maximum number of aircraft waiting pre-departure. The maximum number waiting each day represents the largest queue during that period.
- Percentage Harbour Pilot utilisation reflects the percentage of time that Harbour Pilots were actively involved in supporting a single crew aircraft as a function of all the time that they were available on shift.

Table 2. *Simulation trial results for Harbour Pilots dedicated only to arrivals. All times are expressed in seconds. Numbers in parentheses indicate numbers of Harbour Pilots assigned to the early, midday and late shifts*

	Two Harbour Pilots all day	Four Harbour Pilots all day	Shift System (2:2:4)	Shift System (2:4:4)
Overall mean time	2, 562.17	1, 997.44	2437.98	2005.16
Standard deviation	1, 005.16	393.31	1000.39	391.07
Mean number of non-zero waits (FL320)	32.63	13.95	25.96	13.95
Mean maximum number waiting (FL320)	2.39	1.50	2.01	1.50
Mean non-zero waiting time (FL320)	178.23	36.56	156.13	36.57
Mean number of non-zero waits (FL100)	32.89	0.01	20.28	2.95
Mean maximum number waiting (FL100)	1.27	1.00	1.27	1.00
Mean non-zero waiting time (FL100)	132.03	0.31	172.22	46.76
Harbour Pilot utilisation	42%	21%	32%	26%

Queue size and Harbour Pilot utilisation throughout the day were also logged.

For arrivals the following KPIs were logged. As before, all KPIs were taken over 1,000 of the simulation (see Tables 2 and 3).

- Mean overall time (and standard deviation) in seconds, from top of descent briefing to shut down. This was the total time that the Harbour Pilot was assigned to an arriving aircraft but note that the Harbour Pilot was only *solely* dedicated to the flight from FL100. Note that no Harbour Pilot support was provided between FL320 (post top of descent briefing) to FL100 (see Fig. 4).
- Mean number of non-zero waits at top of descent (FL320) each day, for a Harbour Pilot to be available for top of descent briefing. As before, a non-zero wait indicates that the pilot was not aided immediately by a Harbour Pilot so represents the mean number of delays (per day) caused by a Harbour Pilot not being available to service an arriving aircraft.
- Mean non-zero waiting time at FL320. The mean length of delays (in seconds) resulting from non-availability of a Harbour Pilot prior to commencing briefing at top of descent.
- Mean maximum number waiting at top of descent (FL320). The maximum number waiting each day represents the largest queue waiting for a top of descent briefing during that period.
- Mean number of non-zero waits at 10,000 ft (FL100) each day. From this point during all stages of the intermediate and final approach Harbour Pilot support is continuous until shutdown.
- Mean non-zero waiting time at 10,000 ft (FL100). The mean length of delays (in seconds) resulting from non-availability of a Harbour Pilot prior to commencing procedures and checklist sub-task before intermediate and final approach.
- Mean maximum number waiting at 10,000 ft (FL100). The maximum number waiting each day represents the largest queue waiting for support at 10,000 ft (procedures and checklist sub-task) prior to commencing intermediate and final approach.
- Percentage Harbour Pilot utilisation reflects the percentage of time that Harbour Pilots were actively involved in supporting a single crew aircraft during arrivals as a function of all the time that they were available on shift.

Table 3. *Simulation trial results for Harbour Pilots used flexibly for departures and arrivals. All times are expressed in seconds. Numbers in parentheses indicate numbers of Harbour Pilots assigned to the early, midday and late shifts*

		Four Harbour Pilots all day	Six Harbour Pilots all day	Eight Harbour Pilots all day
Departures	Overall mean time (sec)	990.62	894.05	893.85
	Standard deviation	251.33	145.63	145.47
	Mean number of non-zero waits each day	23.71	14.12	13.98
	Mean maximum number waiting each day	3	3	3
	Mean non-zero waiting time	102.58	124.29	125.42
Arrivals	Overall mean time (sec)	2078.84	2046.41	2046.40
	Standard deviation	476.64	439.55	439.53
	Mean number of non-zero waits (FL320) each day	18.26	16.05	16.05
	Mean maximum number waiting (FL320) each day	3	3	3
	Mean non-zero waiting time (FL320)	100.22	110.15	110.15
	Mean number of non-zero waits (FL100) each day	7.33	0.01	0.01
	Mean maximum number waiting (FL100) each day	1	1	1
	Mean non-zero waiting time (FL100)	38.72	0.12	0.13
	Harbour Pilot utilization	38%	25%	19%

4.0 Results

4.1 Harbour Pilots dedicated to departures

Apart from the scenario of just two Harbour Pilots being employed all day, there was no difference in the mean number of aircraft waiting to enter the system (mean maximum number waiting – see Table 1). For aircraft that had to wait to commence departure checks, the wait time was considerably longer when just two Harbour Pilots were on duty all day.

The lowest mean duration for which a Harbour Pilot was required to provide support (from pre-departure checks to hand-off during initial climb) was when four operatives were employed all day. However, this configuration provided only marginal benefits over both the 4:2:2 and the 4:2:4 shift systems. These 4:2:2 shift system increased the overall time in the system by an average of *circa* 18 seconds; but the 4:2:4 shift system increased the overall average time by just *circa* 8 seconds.

In all shift systems the major queueing peak coincided with the early morning departure peak. As short queues on departures are acceptable (from an operational standpoint), when considering the operational impact on departures alone, either of the two shift systems (4:2:2 or 4:2:4) would appear to be acceptable.

From the Harbour Pilot perspective, it is not surprising that two Harbour Pilots all day had the highest overall percentage employment (Table 1) with four Harbour Pilots all day having the lowest percentage utilisation. However, even though the percentage utilisation is relatively low, for two Harbour Pilots there was little spare capacity available at certain times, especially in the peak departure periods. Both the proposed shift systems suggested similar overall levels of utilisation for the Harbour Pilots, however there was some additional spare capacity available with the 4:2:4 system during the evening peak departure period, providing a greater operating margin which would potentially be useful if there was a requirement to accommodate delays or diversions.

4.2 Harbour Pilots dedicated to arrivals

Four Harbour Pilots available all day for arrivals clearly gives the best performance of all shift systems (Table 2), and in particular avoids any delays at the critical 10,000 ft point from which point continuous support is required. However, the 2:4:4 shift system produces almost comparable performance, overall but with a delay at the 10,000 ft point (particularly during the morning shift) with a mean, non-zero waiting time of 46.76 seconds. This would be just marginally operationally acceptable. The overall mean time for the 2:4:4 shift pattern is only *circa* 8 seconds longer than that for four Harbour Pilots employed all day. Both shift systems using two Harbour Pilots in the midday slot produced an unacceptable number of delays for pilot support at FL100 during this period, and also in the case of just two Harbour Pilots being available all day, during the late shift. They also produced significantly larger queues and longer waits at the FL 320 point, particularly around the midday peak, where incoming pilots would be expecting an approach briefing.

From the Harbour Pilot's point of view, again two staff all day had the highest overall percentage employment (Table 2) with four having the lowest percentage utilisation. The high utilisation of the Harbour Pilots in the 2:4:4 system around the midday peak helped to reduce the overall average time in the system (see Table 2) and provides a degree of spare capacity in the system. Four Harbour pilots in this respect had few benefits over the 2:4:4 shift system. Utilisation of Harbour Pilots overall was higher during arrivals than departures simply as a result of the longer period for which they were required to provide support.

4.3 Harbour Pilots used flexible for departures and arrivals

Four Harbour Pilots used flexibly to support both departures and arrivals clearly provides the worst performance of the options (see Table 3). However, while eight staff produce marginally the best performance, there is very little advantage over six Harbour Pilots. Critically, both six and eight Harbour Pilots avoid any queues of incoming aircraft at the critical FL100 point and wait parameters are almost identical at FL 320.

With regard to utilisation throughout the day, just four Harbour Pilots leaves very little spare capacity in the system, especially around the departure and arrival peaks. Both six or eight staff used flexibly gives good performance, and while eight Harbour Pilots provides for additional resource to be deployed in the system during peak periods, using six personnel also provides some spare capacity and exhibits more efficient utilisation of this resource.

5.0 Discussion

In this exemplar the operational scenario modelled was for a large low-cost operator at a moderately large regional airport (London-Luton airport, with 142,00 movements per year in 2019, with easyJet accounting for approximately 49,000 of these [29]). The scenarios modelled did not include non-normal nor emergency operations, or even more common occurrences such as a go-around. Furthermore, the effects of flight delays (on departure or arrival) are not considered. Modelling was restricted to operations around the airport (just a single STAR) and did not consider enroute support that the single pilot may require, and how and by whom it would be provided. Task times were estimated for an Airbus A320 aircraft. While some task times for an aircraft specifically designed for single crew operations may differ from the estimates in the model (e.g. in the areas of checklists and procedures) other transaction times will not be affected by the number of pilots on board (e.g. those derived from taxi times, approach speeds, take-off and landing roll, etc.). It was also assumed that the Harbour Pilots were employed by the airline and were aircraft type specific.

The results of the scenarios modelled suggest that the optimum number of Harbour Pilots is six, used in a flexible manner (for both departures and arrivals). The overall arrivals performance of six Harbour Pilots used flexibly produces slightly longer overall transaction times than four dedicated to this task (mean of 2,046.41 seconds Vs 1,997.44: Tables 2 and 3) but and would not result in any delays in arriving aircraft being offered assistance from the ground during the approach briefing at top of descent, and through the later stages of approach and landing. Overall departure transaction times for six Harbour Pilots used in a flexible manner are also slightly longer than for four personnel dedicated to departures (mean of 894.05 seconds Vs 888.15: Tables 1 and 3). The mean number of non-zero waits prior to a Harbour Pilot becoming available to assist a departing aircraft is slightly greater when six Harbour pilots are used flexibly (four dedicated to departures: mean non-zero waits – 12.93: six Harbour Pilots used flexibly: mean = 14.12 - see Tables 1 and 3) and the mean waiting time is also approximately six seconds longer (118.38 Vs 124.29 seconds). However, while the six Harbour Pilot solution does produce slightly inferior performance it still allows for relatively efficient traffic flow with few delays, and these are probably acceptable compared to the cost of the engagement of two more personnel.

From a workload perspective, six Harbour Pilots used throughout the day in a flexible manner also ensures that these resources are not over-stretched during periods of peak demand and there is also spare capacity available in the system if needed. Harbour Pilots were actively handling flights for 25% of their allocated time.

The flexible utilisation of Harbour Pilots for both departures and arrivals is preferable given the disparity in their utilisation between the two phases (see Tables 1–3). A great deal more of this resource is used during arrivals than departures. When comparing engagement with departing and arriving aircraft, it can be seen that the Harbour Pilots are engaged with arriving flights for over double the amount of time of departing flights (see Table 3). This reflects the relative balance of time and work in these flight phases. The studies undertaken by NASA did not consider the role of the Harbour Pilot for departing traffic or combining these two functions [20, 21]. While departures and arrivals take place all day, the majority of departures take place earlier in the day whereas the bulk of arriving flights occur later in the day (see Figs. 1 and 2). The flexible use of Harbour Pilots can accommodate these schedules more easily and efficiently (fewer personnel required) than having teams dedicated to departures and arrivals, even if these teams are varied in size throughout the day to accommodate the anticipated traffic flows.

This arrangement proposed from this modelling process would only seem to be viable for large operators at either larger airports where they have a significant presence, or their home operating bases. One of the potential benefits of single pilot operations is to reduce the operating costs of smaller aircraft, making thinner routes into regional airports financially sustainable. In the modelling scenario described there were 66 arrivals and 66 departures per day. It is estimated that this would normally require 132 First Officers to crew these aircraft throughout the day (two per aircraft); 18 Harbour Pilots would be needed for support at London, Luton Airport over the course of the day, plus further support enroute and at the destination airports. A larger international airport (e.g. Amsterdam Schiphol, Dallas Fort Worth or Denver International) with much longer taxi times may require more Harbour Pilots for the same number of flights. Harbour Pilot resources for approach could be further freed up if an enroute support pilot did the brief at top of descent. This does, however, negate one of the benefits of the Harbour Pilot concept, that of exploiting their local knowledge of the airport and surrounding air traffic environment.

A further option to reduce the potential number of Harbour Pilots required would be to re-schedule departures and arrivals using single pilot airliners to avoid the peaks and troughs in operations (see Figs. 1 and 2). This would also give benefits in freeing up spare capacity in the system (from the Harbour Pilot perspective) during peak periods, providing some flexibility to deal with potential delays. However, this would have other operational consequences for the airline's schedule.

To make single pilot operations a feasible option (particularly for thinner routes) would require any Harbour Pilots to be engaged by the airport down route and also potentially be non-aircraft type specific. The role of a potential Harbour Pilot needs to be carefully considered when designing the flight deck and operational procedures of a single pilot airliner, especially if their role is non-aircraft type specific and non-airline specific. Integration of a Harbour Pilot concept into Air Traffic procedures also needs to be considered.

In contrast to using a great deal of on-board automation and autonomy [e.g. [13, 14]], the distributed systems-based design philosophy [15–17] for a single pilot aircraft has been regarded as the more conservative, safer approach to development of such an aircraft; a solution more likely to gain early acceptance from the certification authorities [30]. However, if a Harbour Pilot approach is adopted this may seriously restrict the number of potential destinations for such an aircraft, especially on thinner routes where the introduction of this type of operation may have the greatest cost saving potential. Ultimately, the more autonomous approach may provide a more flexible solution for the operation of a single pilot airliner and one also be less reliant on ground-based support, giving greater scope for an overall reduction personnel and in operating costs. Nevertheless, a distributed system approach such as that employed in the Harbour Pilot configuration may provide an essential steppingstone to the introduction of a single pilot aircraft that uses autonomous systems.

This modelling technique provides a flexible approach for estimating the level of support required. It is flexible, scalable and the level of task granularity required can be varied as necessary. However, the approach used is only as good as the data underlying the model; increasing the detail in the model will require considerably more resource intensive data collection methods (e.g. in-flight observational data collection). Ideally, any model developed should also be validated against operational data, if possible. Nevertheless, this approach to modelling still allows for the early, cost-effective evaluation of design options. The approach can be extended to other phases of flight and non-normal operations. It provides a basis for estimating the operational and economic impact of various single pilot system configurations.

6.0 Conclusions

- To support 66 departures and arrivals involving a single crew airliner at London, Luton airport, six ground-based Harbour Pilots would be required (per shift), assuming normal operations.
- Re-scheduling departures and arrivals using single pilot airliners to avoid the peaks and troughs in operations would allow further potential reductions in the number of Harbour Pilots required.
- This modelling technique developed provides a flexible, scalable approach for estimating the level of support required.

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