Leadership in Sustainable Infrastructure
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Vancouver, Canada
May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

THE IMPACT OF SITE LAYOUT PLANNING: A CASE STUDY OF AN OPERATIONAL AIRPORT

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Abstract: Studies suggest that site layout planning can improve cost overruns in construction projects by saving the travel and material handling time. There is a large body of literature on site layout modeling and processes. These studies commonly use small examples, as a proof of concept, to demonstrate the capabilities of the proposed process or model. However, a case study that can be used to measure the impact of site layout on an actual construction project is rare. The objective of this study is twofold. First, a formal case study of a construction project is created that can be used to demonstrate and compare the capabilities of different models on the same basis; and second, possible cost savings through site layout planning is demonstrated using the developed case study. The study is built based on the expansion project of the Calgary Airport. The close proximity between passengers and airport operations to construction work in an operational airport imposes a number of extra constraints on site layout planning including safety and security of the aviation operations and passengers. The case study was developed through direct observations on the site over the course of four months. In order to accurately monitor site logistics, a CAD model was created to reflect worker between site objects over the period of four months. It was demonstrated that with simple changes cost savings could be achieved. The site layout and associated cost savings is of interest to all project stakeholders including the owner and construction management team.

1. Introduction

Consideration of construction site logistics is a crucial aspect of site planning that impacts cost, schedule and safety. Effective site layout aims to optimize worker travel routes over the course of a construction project in order to reduce travel times and improve manpower efficiencies on site. It is important to consider the progression of work over time and the location of the site objects including temporary facilities and material storage required by the workers. Specifically in fixed fee contracts, optimizing worker travel routes and layout of the site is advantageous since the workers are compensated hourly and such costs are directly borne by the construction manager and owner. Site layout planning is executed by the construction manager, who is responsible for coordinating all on site facilities, access points, material deliveries and site security. Site logistics should be actively managed by the site superintendent and project manager making necessary adjustments to account for the progression of the construction over time.

In this research paper the construction site layout of the domestic terminal of the Calgary International Airport ("YYC") will be examined as a case study for construction site logistics. The close proximity of passengers, airport operations and user groups amplify the importance of proper site planning and result in a challenging multi-phased renovation. Construction operations interface with tenant spaces, passengers, primary security lines, airlines and mechanical & electrical building management system. In order to optimize the construction schedule, project budget, YYC operations and passenger experience, a holistic view of all impacts of construction must be taken into consideration and collectivity assessed.

The budget for the domestic terminal upgrades project is approximately $240 million. The scope of work includes the installation of new structure and building envelope around the existing building structure, demolition of the existing structure, new architectural finishes, installation of moving walkways and a Compact Transit System ("CTS") bus route from Concourse A to the International Terminal. The work requires building temporary construction hoardings including overhead work platforms, structural infills, complete building envelope and a multi-phased construction of the CTS bus route. The project started April 2014 and expected completion of the work is August 2018.

2. Objective

The objective of the study was to understand the influence of construction site layout on the efficiency of the construction operations taking into consideration external impacts to airport operations and passenger experience. This paper aims to present the relevant data of the construction site layout over a 4 month period examining worker travel routes, costs of travel and discuss potential cost savings initiatives. Analyzing the layout of the site over time can be utilized to track travel costs by extrapolating specific workers hourly wages, frequency and travel times. Improvements made to the construction site layout have a direct impact on both the construction schedule and project costs. Specifically at the Calgary Airport, detailed project planning is necessary to mitigate adverse impacts to airport operations, user groups and the overall passenger experience. An understanding of line of balance may be implemented in order to maintain continuity of subtrades work over various phases of the project to reduce mobilization costs. In summary, this research aims to reduce costs and optimize the construction schedule by improving on site productivity.

3. Project Constraints

Calgary International Airport is an operational facility; as a result there are many constraints that impose unique challenges to the construction site layout. Highly involved coordination between security, operations and passenger experience are required to ensure that impacts to the day to day activities are mitigated. Firstly, national transportation regulations require all construction areas to be properly delineated by construction hoarding to minimize the interaction between construction personnel and general passengers. Secondly, all tools, materials and equipment must be stored within a construction hoarding to eliminate threats against aviation security. Thirdly, any construction work ongoing past the Primary Security Line (PSL), which separates airside from groundside, requires that workers be screened at non-passenger screening areas. Fourthly, close coordination with airports operations is required in order to minimize the influence of construction on the airlines and baggage services including delays. These highly specific airport protocols impose stringent restrictions on the laydown of construction areas, differing significantly from a new construction build. A comprehensive review of the overall airport operations must be conducted in order to plan the construction phasing accordingly. Calgary airport operations has some flexibility with gate and vehicle services route closures however alternate arrangements need to be made in order to accommodate such closures. Seasonal effects of passenger travel including increased holiday influxes must be considered when planning construction work and gate closures. Upgrading of mechanical and electrical systems involving service shutdowns require significant lead time and 4-6 hour overnight shutdown periods prolong install durations. Lastly, in order to ensure business positive future cash flows, the passenger experience must be managed including passenger safety, noise and visual aesthetics. As a result noisy and intrusive work such as structural steel install, grinding, coring and hammer drilling must be completed during the night to mitigate adverse effects on the overall passenger experience. Running multiple shift work crews demands involved planning and communication to ensure all material, equipment and necessary shutdowns are in place for the off-hours crews. Collectively, all of these project constraints play a large role in amplifying the importance of proper planning in an operational airport facility.

4. Site Layout Modeling

In order to track the configuration of the site layout, AutoCAD was used to model the construction site between January and April 2016. Utilizing direct on site observation and laser measurements a model was developed to accurately depict the use of space over time. Layers were created to represent space usage including areas of demolition, ongoing construction, finished construction and passenger travel. Site objects including site trailers, offices, washroom facilities, smoke shacks and fabrication shops were input to the model in order to determine distances from given work areas to site facilities. Utilizing the architectural floor plans, the site laydown was accurately monitored using laser measurement off existing gridlines and columns. In the January – April 2016 time period, four significant site layout changes occurred that were tracked in AutoCad. Each work area that existed between January and April was numbered from No. 1-15 to obtain travel times and evaluate on-site efficiency.

Figures 1 to 4 below represent the use of space over time from January – April 2016.

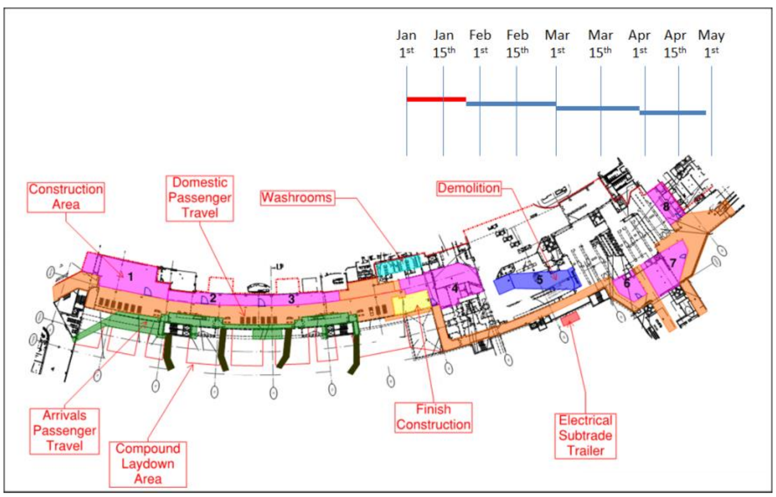

Figure 1: January 1st – January 21st Site Layout

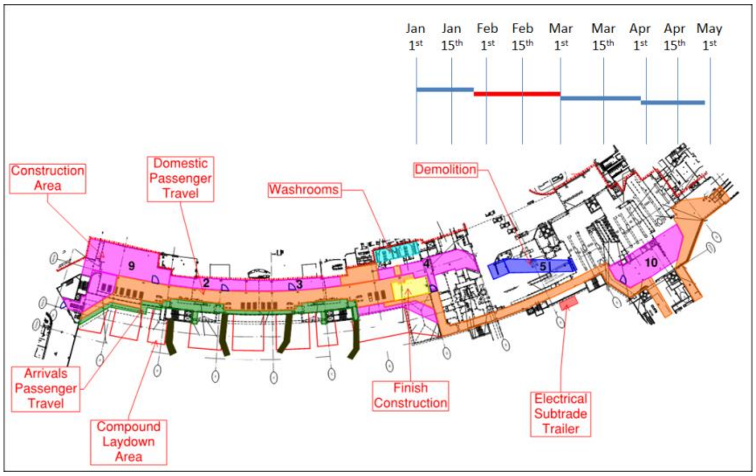

Figure 2: January 22nd- February 29th Site Layout

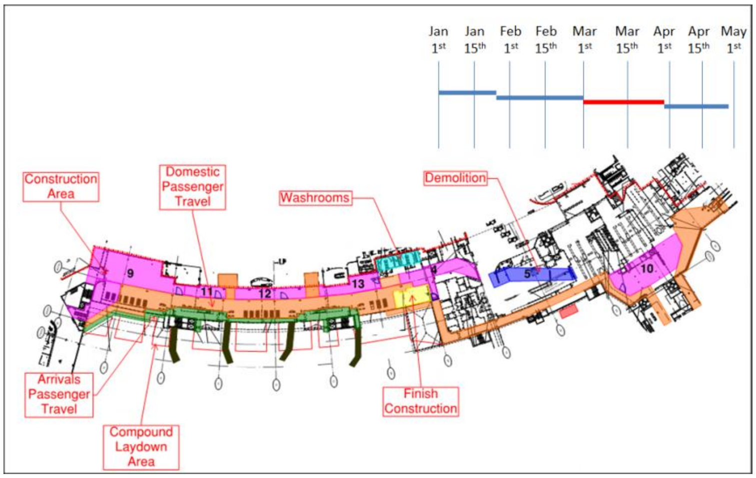

Figure 3: March 1st – March 27th Site Layout

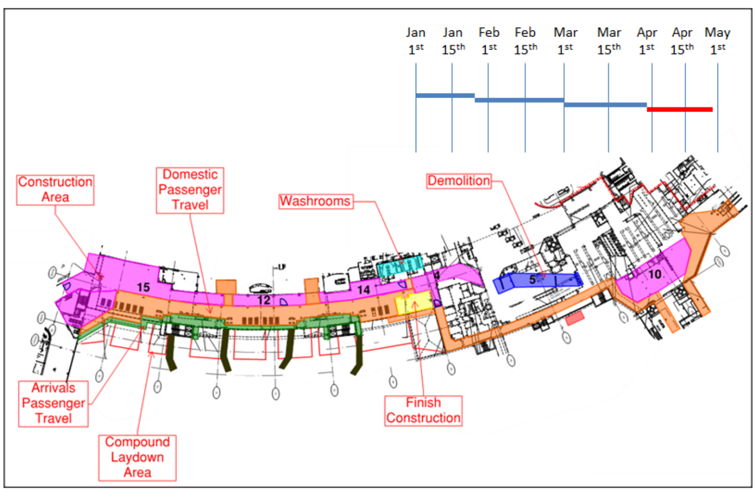

Figure 4: March 28th- May 1st Site Layout

The site objects monitored are displayed in Table 1 below.

Table 1: Site Objects

1	Work Area #1	13	Shared Trade Trailer
2	Work Area #2	14	Electrical Site Office
3	Work Area #3	15	EllisDon Site Office Trailer
4	Work Area #4	16	ED PM Office
5	Work Area #5	17	Fabrication Shop
6	Work Area #6	18	Smoking Area #2 South
7	Work Area #7	19	Work Area #11
8	Work Area #8	20	Work Area #12
9	Work Area #9	21	Work Area #13
10	Work Area #10	22	Washrooms
11	Mechanical Site Office	23	Work Area #14
12	Smoking Area #1 North	24	Work Area #15

5. Analysis

A total of 24 site objects consisting of nine fixed objects and 15 work areas were input to a spreadsheet and the typical travel time between each site object was cross referenced. Since the layout of the site progressed over time not all site objects were present simultaneously and if this was the case “N/A” was assigned to the obsolete cell. To develop the travel times between site objects the travel route was walked three times and the average of the three trips was recorded. In order to quantify these travel times to travel costs Equation 1 was utilized.

[1] $$Weekly\ Cost\ of\ Travel = \sum(\frac{Travel\ Time}{60} * Freq * P * n_w)$$

Travel Time= Travel time between objects (mins)

Freq= Typical work week frequency of travel between two site objects

P= Hourly pay ($/hr)

n_w= number of workers on site

The frequency of worker travel was populated based on site observations and conversations with the site superintendents. In order to mitigate error, the average frequency of travel between two site objects was recorded over a week timeline. The number of workers on site was based on an average of the daily man counts that were captured by the site safety team. Hourly pay was separated into four categories (1) Labourer (2) Tradesmen (3) Superintendent (4) Project Manager. Average hourly rates are displayed below in table 2.

Table 2: Hourly pay rates

Worker Type	No. Workers	Hourly Pay
Labourer	25	$30.00
Tradesmen	60	$45.00
Superintendent	12	$60.00
Project Manager	6	$75.00

Equation 2: Sample calculation of one tradesmen travel from Work Area #1 to the Construction Manager's (EllisDon) Site Office

[2] $One\ tradesmen\ from\ Area\ \#1\ to\ ED\ Site\ Office = \left(\frac{5\ minutes}{60\ min}\ x\ 1\ hr\right) x \frac{2}{week} x\ \frac{\$45}{hr}\ x\ 1\ worker$

$One\ tradesmen\ from\ Area\ \#1\ to\ ED\ Site\ Office = \frac{\$3.75}{week}$

Utilizing the equation for the total weekly costs of travel based on 103 personnel on site yields an average weekly travel cost of $62,476.25 weekly or $3,248,765 yearly. It is evident that small improvements to the site layout could have a significant cost savings effects over time.

In order to reduce travel times one solution would be to install a temporary washroom facility within the construction hoarding at a central high density location. Based on 103 personnel on site, travel times to the washroom alone cost roughly $6,600 per week. One source of error that is difficult to account for is if the workers use the washroom facility while travelling between work areas. Regardless, shortening travel times, especially in a high density work areas such as Area #2 would reduce wasted travel time. One unique benefit of installing a portable washroom facility at Area #2 is that it would eliminate the need for workers to cross the trans-border doors between work Area #2 and work Area #3. Crossing the trans-border doors between work Area #2 and work Area #3 requires a security clearance that has the potential to delay workers. Figure 5 below displays a suggested install location for a temporary washroom facility.

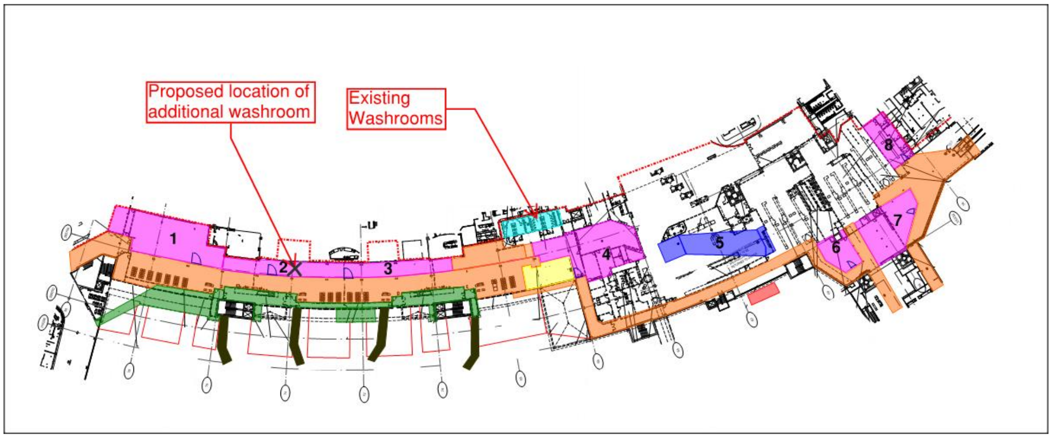

Figure 5: Proposed temporary washroom facility

Utilizing the model with the obtained worker travel frequency, travel times, number of workers in the area and hourly pay it is projected that $450 weekly could be saved in travel times by installing a temporary washroom facility at work Area #2. Factoring in $47.50 weekly costs obtained from the temporary washroom facility provider on the airport site the delta cost savings would be roughly $400 weekly.

6. Optimizing the Construction Site

6.1. Optimizing the schedule

One of the unique properties of the airport is that the cost of accelerating the project schedule to open airline gates, tenant spaces including restaurants and necessary security spaces is often a feasible process due to the offsetting influx of spending from passengers. As a cost exercise, it will be assumed that one gate is closed for a week due to construction and an airline must divert a flight to an alternate airport. One Boeing-777 carries at capacity approximately 350 passengers each of who pay a $30 airport improvement fee. Assuming 15 flights per day based on the 2014 average this translates to 105 flights per week and $1,102,500 if the flights are at full capacity. It is evident that all efforts to expedite the construction are highly favorable financially. Crashing the project schedule may require expediting material deliveries, running multiple crews or outsourcing highly-efficient equipment.

To optimize the construction schedule it is most important for the construction site layout to be configured in such a manner than travel times and inefficiencies are minimized. It is vital to pay attention to all critical path activities affecting airport operations especially those which impact sustaining passenger travel. A highly organized construction management team is required to coordinate all subcontracts and their own forces work to ensure there are no schedule delays. For each critical activity there are many variables that must be monitored including predecessors, material procurement and manpower availability. Careful selection of reliable experienced subcontractors with strong vendor connections is highly desirable and may outweigh up-front tender costs.

6.2 Line of Balance

Line of balance is a scheduling technique that aims to maintain continuity of the construction work on site, preventing delays, stagnant work crews and optimize resources. Properly applied line of balance scheduling allows the construction manager to effectivity schedule the allocation of resources to repeated tasks and gain better control of subcontractors. Line of balance is most effectively applied to schedules with repeated activities however with creativity and advanced planning the line of balance technique may be applied to a more complex phased construction site such as the Airport. One of the major project milestones is the construction of the Compact Transit System (CTS) bus system throughout the terminal. The CTS route is a prime example of an application of the line of balance technique since it involves highly repetitive tasks broken into phases that repeat sequentially and progress throughout the CTS bus route. Figure 6 to 8 below outlines the activities necessary to complete a section of the CTS route.

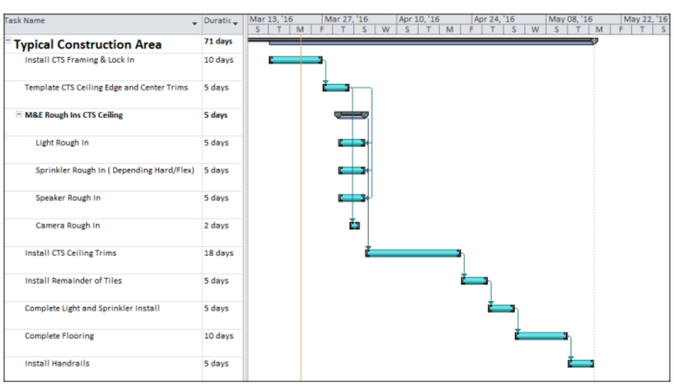

Figure 6: CTS Route Schedule

Figure 7: Pre Construction CTS Route

Figure 8: Finished CTS Route

6.3 Mitigating impact to airport

Selective placement of construction site layout has a significant influence on eliminating adverse effects on airport operations. On the exterior, compound laydown areas must be strategically configured such that airline tug routes and baggage services operations are not hindered while still providing consideration to worker travel routes and material deliveries. Maintaining access to baggage carousels, vehicle services routes and emergency fuel shutoff valves must all be taken into account when configuring exterior compounds. Figure # 9 below depicts the coordination of exterior construction with airline tug operations.

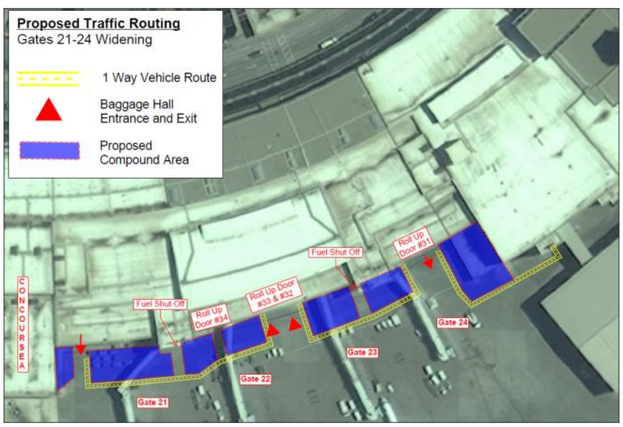

Figure 9: Exterior Site Layout

Interior construction site layout impacts multiple airport user groups including passengers, airline staff, tenants and security. It is therefore very important that these operational impacts be monitored, communicated and mitigated as best as possible. The configuration of the interior site layout needs to ensure sufficient passenger travel routes from designated passenger screening to the departing gate, while meeting airport security requirements and maintaining the passenger experience. To maintain the passenger experience the construction management team has made the following provisions on the Calgary Airport. Firstly, temporary passenger holdrooms have been constructed while the demolition of existing hold rooms and construction of the permanent holdrooms is ongoing. The holdrooms are complete with trans-border flexibility to maintain the security structure of the airport and maintain the ability to isolate holdrooms. Secondly, any loud and intrusive work will be executed at night to mitigate the sensory impacts of construction. Lastly, construction hoarding complete with comprehensive signage are installed to delineate ongoing construction from public space. This method creates a buffer zone between the public and construction work that increases the safety, security and the overall passenger experience.

6.4 Optimizing costs

Analyzing the optimization of site layout on construction costs requires a comprehensive understanding of the influence of construction on the operational facility. This process requires in-depth planning by both the construction manager and airport owner to ensure an ideal financial trade-off between construction costs and external effects on airport operations. An assessment of operational impacts should be completed to understand the trade-off between impacting airport operations and simplifying construction activities.

Minor modifications to the site layout that do not adversely affect operations but have significant cost savings potential are achievable. For example, a 5% reduction in travel time translates to a $162,000 cost savings per year based on the $3,200,000 yearly travel costs. It is crucial for the construction manager to pay close attention and monitor the site logistics throughout the course of the project. It is important to focus on optimizing travel routes from high worker density areas to material laydown spaces and washrooms. In particular, focus should be given to those areas with skilled tradesmen who are compensated at a higher hourly rate than labourers. One way to reduce travel costs would be conducting a review of the upcoming construction phasing and strategically placing required material throughout the construction hoardings accordingly. Another way of simply reducing travel time loss would to install portable washrooms close to high density work areas. Additionally the construction site should be designed to minimize airside to groundside travel paths that require security screening. It is advantageous to sequence the construction work to occur mainly on airside and then mobilize the necessary crew all to groundside. Phasing work in this manner eliminates unnecessary security delays and reduces congestion for other airport employees at non-passenger screening lanes. Furthermore, travel routes that could be compromised are the routes from (1) project management offices to low density construction spaces and (2) low density construction spaces to construction sea-can trailers as they are less frequently travelled.

7 Site Layout and Compensation Structures

Construction within an operational airport facility differs significantly from new build construction. The complicated multi-phased renovation could impose a serious risk of both budget overruns and airport delays to an inexperienced contractor. Within the airport there are often many unforeseen conditions that impose unique challenges when tendering scopes of work. Security delays, existing site conditions and coordination with tenants all impose a risk on lump sum contracts that are difficult to account for at the time of tender. As a result, a fixed fee contract type is highly recommended for both the general contractor and subtrades with large scopes of work to mitigate these risks. A fixed fee contract results in increased collaboration between the owner and contractor working together to achieve the desired design while lessening operational impacts. In fixed fee contracts, the contractor works to actively manage the project budget serving the owner’s best intentions. In particular at an operational airport this contract type is favorable since it reduces schedule delays, costs incurred from delayed openings and external impacts from construction.

8 Conclusion

The close proximity of passengers and airport operations, interfacing with construction renovations result in a challenging multi-phased project requiring methodical site layout. The magnitude of cash flow from the airport the improvement fee favours accelerating the project schedule to expedite the opening of public spaces and increasing airport capacity. A capable construction manager is necessary to effectivity monitor critical path activities and associated submittals, procurement and predecessor activities that could impact operations. Strategic site laydown that shortens high density worker travel routes is necessary to achieve cost savings. The costs of installation of temporary facilities such as portable washrooms and material sea-cans that reduce travel times often outweigh the costs of lengthy travel routes. It is important for the construction manager to monitor the construction site layout over time and provide consideration to future phasing when configuring the site. Future research should be conducted to assess other construction projects of operational airports as well as increase consultation with key airport stakeholders.

9 Future Research

In the future it would be relevant to investigate and model other airport construction sites to gain a further understanding of effective site layout and provide a benchmark to evaluate the site logistics of Calgary Airport project. Gaining a further understanding of the efficiencies on other similar sites would aid in developing a more effective site layout structure. Lengthening the timeline for which data was collected would be beneficial in analyzing the overall effectiveness of the site layout and assist in generating further cost savings initiatives. Incorporating input from airport stakeholders including operations managers and airline duty managers would help to further mitigate adverse effects on operations and passenger experience.

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