

# LCA Case Study for O'Hare International Airport Taxiway A & B Rehabilitation

John Kulikowski

*U.S. Air Force, Tyndall AFB, FL, United States*

**ABSTRACT:** The ability to measure and quantify the environmental impacts of such projects is in higher demand. Life cycle assessment (LCA) studies/tools are developed for highway infrastructure and pavements but a limited number of studies/tools have been developed for airports and few for their pavement facilities. This paper utilizes an airfield pavement LCA tool called LCA-AIR 1.0 to quantify the sustainability strategy for O'Hare International Airport's rehabilitation of Taxiway A and B. LCA-AIR was used to evaluate three rehabilitation options consisting of rubblization of existing Portland cement concrete (PCC) with mill/asphalt concrete (AC) inlay, precast concrete panel (PCP) replacement and full-depth reconstruction. The results showed the strategy with the least impact for global warming potential (GWP) was as follows: PCP replacement, rubblization with a mill/AC inlay, and full-depth reconstruction. The ranking of least impact for energy for the three strategies was rubblization with a mill/AC inlay, PCP replacement, and finally, full-depth reconstruction. The GWP potential for rubblization was 2,395 kg CO<sub>2</sub>/yd<sup>2</sup> (4.310x10<sup>-10</sup> kg CO<sub>2</sub>/lb-mile), for reconstruction was 2,409 kg CO<sub>2</sub>/yd<sup>2</sup> (4.729x10<sup>-10</sup> kg CO<sub>2</sub>/lb-mile), and for PCP was 2,413 kg CO<sub>2</sub>/yd<sup>2</sup> (4.736x10<sup>-10</sup> kg CO<sub>2</sub>/lb-mile). The energy consumed for rubblization was 0.1861 TJ/ yd<sup>2</sup> (3.576x10<sup>-8</sup> TJ/lb-mile), for PCP was 0.1863 TJ/ yd<sup>2</sup> (3.657x10<sup>-8</sup> TJ/lb-mile) and for reconstruction was 0.1864 TJ/ yd<sup>2</sup> (3.658x10<sup>-8</sup> TJ/lb-mile).

## 1 INTRODUCTION TO LCA

In the United States the transportation sector generates 27% of total US greenhouse gas emissions (GHG) of which, aircraft account for 8.2% of the total (Federal Highway Administration 2015b). The US has an estimated 13,112 airports (Federal Aviation Administration 2015a). Airports world-wide (U.S.) process 3.3 billion passengers (838 million), 3.6 trillion passenger-miles (963 billion) and 55 million short-tons of freight annually, driving approximately 3.0% of the world's GDP (International Civil Aviation Organization 2014; Senguttuvan 2011). Significant quantities of environmental impacts are produced from the transportation sector. Quantifying these impacts requires a transparent method, more specific than rating systems. Many rating systems currently exist for facilities with a limited number for infrastructure. These rating systems help agencies and other organizations find sustainable and innovative solutions to minimize their impacts on the environment. Currently, airport pavements do not have such rating systems or methods to quantify environmental impacts. A life cycle assessment (LCA) is a method to quantify these environmental impacts from processes and projects throughout its life (Santero N. J. 2009). LCA studies/tools have been completed and developed for highway pavements, such as PaLate (Horvath 2004), PE-2 (Mukherjee & Cass 2011), Athena Pavements LCA (Athena Sustainable Materials Institute 2013), and recently the Illinois Tollway tool, ICT-LCA (Al-Qadi et al. 2015) but airport pavement LCA studies and tools are needed. LCA-AIR opens the field for improvements and expansion. Using a LCA methodology, LCA-AIR analyzed three different rehabilitation strategies for Chicago's O'Hare International Airport (ORD) taxiways. LCA results

can be used in conjunction with other tools available to airport owners, operators, engineers and contractors to make educated decisions regarding infrastructure investment and their influence on environmental impacts.

## 2 INTRODUCTION TO ORD TAXIWAYS

The pavement structure of ORD Taxiways A & B, surrounding the main terminal, is reaching the end of its performance life and is in need of rehabilitation. There are various distress types and severity levels in the pavement structure. In addition to loading and environmental factors, inadequate site, surface, and subsurface drainage may be contributing to the pavement structural condition and impact future rehabilitation choices. Based on as-built data provided by ORD engineers, the taxiways (TWs) were constructed between 1986 and 1988 over cohesive soils with varying amounts of sand. The approximate length of each taxiway is 11,088 feet. Per as-built drawings, typical pavement section consists of 21 inches of PCC over six inches of a bituminous aggregate mixture, over six inches of an aggregate base over the subgrade. Coring data from 2007 and 2013 showed PCC surface ranges from 19-1/2 inches to 25.5 inches with an average of 21.96 inches. The asphalt base ranges from 0 inches to 9 inches thick with an average of 5.31 inches. The aggregate base layer ranges from 0 inches – 20 inches with an average of 5.51 inches thick (MACTEC, 2007; Chicago Airports Resources Enterprise, 2014).

After evaluating a wide suite of rehabilitation strategies (mill PCC and in-lay AC, mill PCC and in-lay bonded/unbonded PCC with macrofibers, reconstruction, selective slab replacement, mill PCC and provide geo-fabric or stress absorbing interlayer membrane interlayer with AC surface, partial/full depth repair) for ORD's Taxiways A&B, three strategies were selected as cases for further investigation: precast concrete panel (PCP) replacement, rubblization of existing PCC with mill/AC inlay and full-depth reconstruction. PCP consists of removing the slabs and placing a precast slab in the void after preparing the base from damage done during removal to ensure compacted, uniform support. Rubblization consists of using a guillotine and multi-head breakers to rubblize the existing PCC layer. This also facilitates more rapid milling prior to AC inlay. Milling will go to a depth of five inches to void entanglement in the welded-wire mesh. Reconstruction consists of demolition of all pavement and base layers down to the subgrade prior to reconstruction. These methods were selected as feasible alternatives based on impact to airlines, long term performance and elevation constraints from adjacent features. The material quantities and construction methods differ for each alternative and will have different associated environmental impacts. These rehabilitations occur at the 30-year point and will extend the taxiway's life to 50 years. The rubblization with mill/AC inlay has a potential to last 10 to 15 years, depending on the traffic level and thickness of the AC inlay, after which a milling of the old asphalt/new inlay will occur. For the assessment, this milling of the inlay occurs at year 40 to ensure the pavement reaches 50 years. The PCP or full-depth reconstruction will last between 20 to 40 years. For this assessment a 20-year extension was used. Current data on the remaining slabs that were rehabilitated especially in low traffic path zones still have good remaining life and are performing well. It is probable the remaining slabs will require significant work after this 50 year period. Therefore, extending the PCC repair analysis in conjunction with long term plans to 30 or 40 years was not performed. Doing so, would reduce the impacts per functional units compared to the impacts of one to two more mill and inlays to reach another 10 to 20 years. An extensive cost analysis was not part of this study. This paper focuses on the LCA for each case in the rehabilitation for 200, keel section slabs (125,000 ft<sup>2</sup>) on the southern side of each TW. Each strategy rehabilitates the same area per TW but the depth and materials are dependent on the method. Figure 1 shows the pavement cross-sections for original construction and each rehabilitation strategy with the legend to the right. The red dashed line indicates the depth limit of each strategy.

Information on the development of LCA-AIR can be found in the 11<sup>th</sup> International Conference on Concrete Pavements (ICCP) from the paper titled, Development of LCA-AIR – An Airport Pavement Life Cycle Assessment Tool (Kulikowski, et al., 2015). The inputs for each phase are discussed. The results for Tool for the Reduction and Assessment of Chemical and other Environmental Impacts 2.1 (TRACI) indicators were calculated and presented with a focus on energy and GWP with respect to functional units of square yard and pound-mile due to the unique aspects

of airfield pavements. Square yard was used for the material production (MP) and construction, maintenance and rehabilitation (CMR) phases. The second unit, pound-mile, was used as the functional unit for the use (U) phase accounting for aircraft weight and travel distance as it is not a direct result of pavement conditions as in roadway LCAs. The total impacts were divided by the area of the TWs and the total impacts for the use (U) phase were divided by the total pound-mile traveled. The MP impacts for initial construction and U phases are assumed to be the same for each case because initial construction is not different and the maintenance does not change the U phase components. Therefore, the case study will focus on the impact results from the CMR phase that includes the impact from all machinery used in initial construction, the maintenance and rehabilitation in addition to the new materials used in the repairs and rehabilitation.

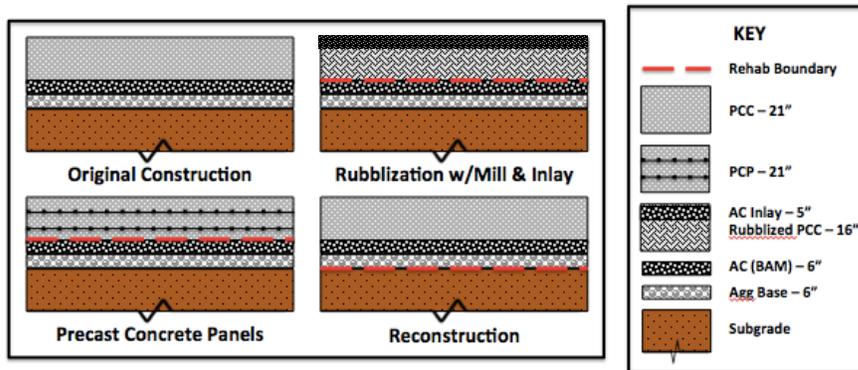


Figure 1. Rehabilitation Strategy Cross-Sections

### 2.1 Geometry, Pavement Structure and Mix Design Inputs for Initial Construction

The geometry and pavement structure used for initial construction was based on the as-built drawings with the width and length of each TW being 75 feet and 11,088 feet. The concrete, asphalt and aggregate base densities were assumed to be 150, 145 and 140 pounds/ft<sup>3</sup>, respectively. These slabs had doweled transverse joints and for the most part include welded wire mesh 6.5 inches from the surface. Individual slab weight is 165,000 pounds with 942 pounds from steel contribution (0.0571%). The original mix designs were not available, so the following mix designs in Table 15 were used for the analysis in the construction and maintenance materials. A prime coat was used on the crushed aggregate base and a tack coat was used between asphalt layers. It was assumed the six – seven inch asphalt layers were placed in two lifts. The distance from the concrete and asphalt plant to the construction site was five miles.

Table 1. Mix Designs for LCA Case Studies

AC	% Weight of Surface Mix	% Weight of Base Mix
Virgin coarse crushed aggregate	71.325	74.178
Virgin fine crushed aggregate	20.922	20.922
Virgin natural sand	0	0
Coarse RAP (3.6% binder)	0	0
Fine RAP (6.4% binder)	0	0
Mineral Filler	2.853	0.571
Total binder	4.9	5
Distance from plant to site (miles)	5	5
PCC	JPCP (lbs/yd <sup>3</sup> )	
Virgin coarse crushed aggregate	2,075	
Virgin fine crushed aggregate	1,056	
Portland cement	401	
Fly Ash	134	
Water	240	
Slag cement	0	
Distance from Plant to Site	5	

As discussed in the ICCP, the impacts for the CMR phase is a function of the equipment used, their productivity/fuel efficiency and the impacts associated with the repair materials. The productivity and fuel consumption is impacted by the operator's competency level, the material type and cycle times performing each activity. Based on experience, industry averages, interviews and literature the productivity and fuel consumption were calculated (Muench, et al., 2011; Ross, 2011; Pullen, Edwards, Rutland, & Tingle, 2014; CATERPILLAR, 2015; Craftco, 2015; Bockes, 2015; Shinnars, 2015; Shinnars, 2015; Wirtgen Group, 2015). When fuel consumption was not available, EPA NONROADS database was used based on the engine horsepower (Environmental Protection Agency, 2008).

The initial construction impacts of the TWs are the same for each case. The AC portions consisted of: the AC base under the PCC surface and the AC shoulders on each side of the TWs. The PCC portion was only used for the three, paving lane slabs on each TW. Equipment was selected for each task and then based on the geometry (volume and tonnage) and productivity/fuel efficiency the diesel combustion for each activity was calculated. The total fuel consumed during construction for the AC base (1,663,200 ft<sup>2</sup>) and AC shoulders (1,108,800 ft<sup>2</sup>) 11,899 gallons. The total fuel consumed during construction for the PCC 15,794 gallons. (A basis of square feet should not be used to compare the asphalt work vs. concrete work, as the volume is significantly different.)

Maintenance and repair at airports occurs around the clock and very few activities are consistently scheduled to reoccur. A recurring maintenance/rehabilitation schedule was not available so schedules and quantities were established. For this study, the maintenance activities were aggregated over time and assumed to occur at specific years. Below is a list of the general activity intervals used for each case. The AC activities are on the shoulders with the exception of the reconstruction (base layer) and the rubblization with mill/inlay.

#### PCC

- Restriping airfield markings – every ten years
- Joint and crack sealing – every eight years
- Full and partial depth repairs – every fifteen years
- Brooming – every other day

#### AC & AC Shoulders

- Restriping airfield markings – every ten years
- Crack sealing – every ten years
- Asphalt patching – every fifteen years
- Mill/inlay – every fifteen years
- Mill/inlay – 10 years after the initial rubblization with mill/inlay section

## 2.2 Use Phase Components

As discussed in the ICCP paper, the U phase is broken into the following three categories: aircraft fuel consumption, snow removal operation (fuel consumption), and lighting (electricity usage for edge and centerline lights). Similarly, the U phase dominates the other phases because of the fuel consumed over thousands of flights per year for 50 years. This is especially case when including half of the time in flight to each airport. Fuel consumed in aircraft was modeled based on kerosene (heavy fuel, closest to jet fuel) combusted in industrial equipment because combustion of Jet A/Jet B or Jet Proppellant-8 was not defined in LCA data bases. However, the U phase has a small contribution when only the additional fuel consumed because of a change in roughness is calculated. Roadway LCAs attribute fuel consumption to the pavement facility for each vehicle because of constant pavement-vehicle interaction. However, this pavement-vehicle interaction is negligible for airport pavement facilities with the aircraft traversing the pavement surface approximately 20 minutes before taking off. Kulikowski, et al. discussed international roughness index (IRI) as applied in LCA-AIR (Kulikowski, et al., 2016). For each of the three cases the change in roughness of the pavement surface was assumed to be similar based on material deterioration.

Greater resistance and increased fuel consumption for airplanes is experienced from aerodynamic drag (Goldhammer & Plendl 2014).

The aircraft selected for use and their associated weights/operations are seen Table 2. Based on the International Civil Aviation Organization (ICAO) the actual weight of 75% of the maximum take-off weight (MTOW) was used. MTOWs were based on manufacture specifications. Four aircraft were selected to represent the eight aircraft categories (MTOW) trafficking TW A and B. The B737 represents groups one through four, the A330 represents groups five and six, the B777 represents group seven and the B747 represents group eight. The number of operations was based on the 2018-projected traffic. Due to the small quantity of operations in groups five through 8 the average operations were divided by three and attributed to each aircraft.

Table 2. Use Phase Aircraft Information

Aircraft Type	Operation Weight (75% MTOW) (lbs)	Yearly Number of Operations	Air Flight Duration (hrs)	Max Weight (lbs)
B747-200B	624,750	1738	2	833,000
B777-200 ER	570,000	1738	2	760,000
A330-300 opt	390,525	1738	2	520,700
B737-700	115,875	62500	2	154,500

The other factors considered in the U phase were lighting and snow removal. There were 440 centerline lights and 887 edge lights used in the calculation of the electricity impact. The lights are used for night operations and during daytime inclement weather. Therefore, an average time of 12 hours per day was assumed for each case. Twenty snow occurrences were assumed for each case utilizing brooms and blows to clear every square foot of pavement as standard operating procedure. The efficiencies of equipment were considered and diesel combusted in industrial equipment was used for impact determination. Lighting and snow removal operation factors contributed minimally to the U phase impacts.

### 3 LIFE CYCLE ASSESSMENT FOR RUBBLIZATION WITH MILL/AC INLAY

This strategy consists of rubblizing the existing PCC pavement and providing an AC inlay. Due to the TWs connection to other features, changes in elevation can be detrimental to operations or require significant investment to remedy. The method for this rehabilitation consists of using a two-step breaking process which has proven successful at other airfields along with highways (Kulikowski, Development of A Pavement Life Cycle Assessment Tool for Airfield Rehabilitation Strategies, 2015). First, a guillotine style breaker will be dropped breaking the slab in the larger pieces (similar to the break and seat methods of highways). Immediately following this, a multi-head breaker will reduce the sizes varying from a few inches down to 12-15 inches at the bottom of the slab. Finally, milling machine removes the specified amount of rubblized PCC for paving operations (Figure 2).



Figure 2. Milling of Rubblized PCC with an AC Overlay (Hanson Engineering, 2015)

The standard maintenance used was discussed previously. At 30 years, a large rehabilitation is performed on the TWs A&B. The following LCA analyzes the rubblization of 250,000 ft<sup>2</sup> (200 slabs per TW) and five inches of milling with a five-inch AC inlay. For ORD, milling deeper than five inches is not feasible because of the wire mesh at approximately six inches from the surface.

Appropriate equipment was selected for the CMR activities for PCC and AC, respectively. Figure 3 shows the fuel consumed for each activity. For many activities, it is a summation of the fuel consumption from multiple pieces of equipment. For example, the rubblization activity uses the fuel consumed from a guillotine breaker, multi-head breaker, z-grid roller and a steel drum roller. The highest fuel consumption activities during the CMR phase were brooming (112,721 gal), crack sealing (31,771 gal), restriping (16,746 gal) and land clearing (12,328 gal).

Converting the brooming machine to an electric source will eliminate the fuel consumed for brooming operations. There will be an adjusted impact for electrical consumption with use if it is powered from a power plant. If it is by solar energy, the impacts will be reduced significantly. Frangible equipment could be utilized for solar generation as well as reducing green space maintenance and bird-air strike hazards. Adjusting the brooming schedule will also save fuel. Reducing the cleaning to once every five days will provide a 10% reduction in total fuel consumed. This must be balanced with increased risk of foreign object debris on the TWs. Crack sealing is a time and energy intensive activity. The tank must remain at a high temperature to ensure the sealant is still flowable. The sealant is placed by an individual with a wand walking every crack. The use of alternative, lower temperature sealant will reduce some of the impact.

Using asset optimization principles contracts can be structured to only include cracks of a certain size, which will reduce the impact as well. Similar asset management principles can be used to reduce the frequency or quantity of markings restriped. For land clearing, it was assumed the clearing for the entire depth of the pavement structure, in this case 33 inches. Stabilizing the subgrade may result in additional saving because of a reduction of aggregate subbase and total pavement thickness. The main rehabilitation activity of rubblization consumed 954 gallons of fuel and the additional AC inlays (apart from the shoulder inlays) consumed 553 gallons to place. The total fuel combusted was one component used to determine the environmental impacts for the CMR phase. The total fuel consumed for the CMR phase was 204,568 gallons.

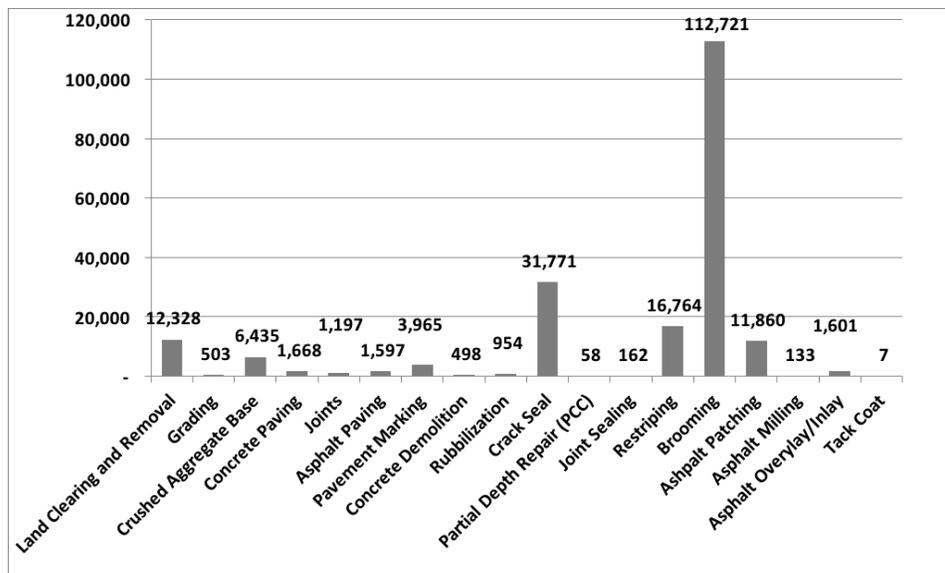


Figure 3. CMR Fuel from Rubblization

The second component used to determine the total CMR impacts was the materials used in the maintenance and the rehabilitation. As expected, the rubblization with mill/inlay used the least amount of material because the 16 of the 21 inches of PCC remain in place. The only new material

added for the rehabilitation is the prime/tack coats and the new five inches of inlayed asphalt. Rubblization showed 24% and 30% less energy consumption compared to precast panels and reconstruction respectively. For GWP there was 43% lower production than precast panels and 37% lower production than reconstruction.

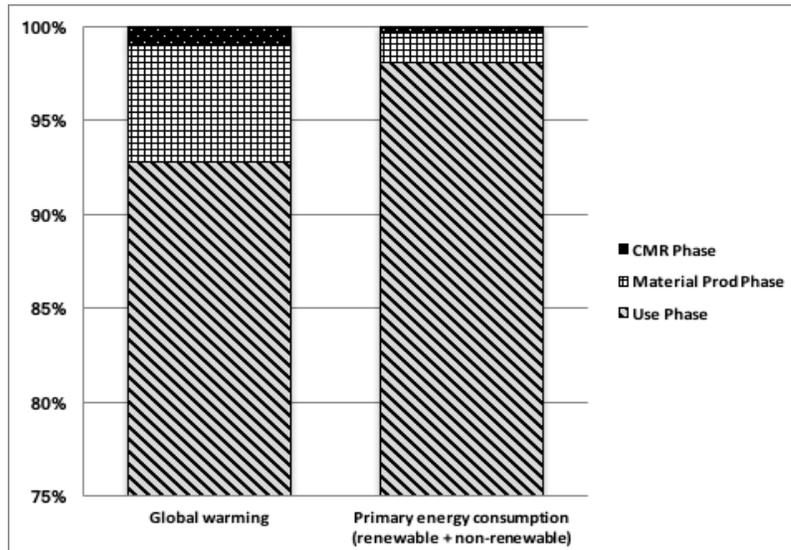
### 3.1 Rubblization with Mill/AC Inlay Impacts per Phase and Functional Units

The total impact from each phase was summed and then divided by the functional units for the airport.

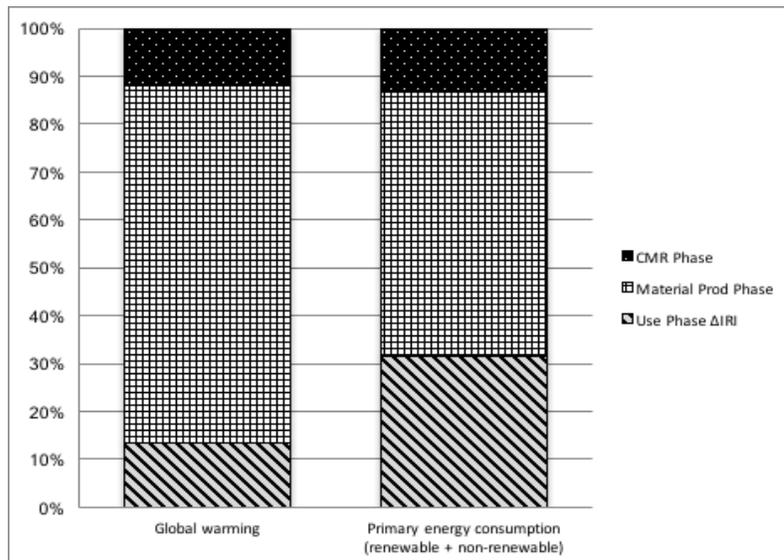
Table 3 shows the total values for the impacts using both aircraft fuel consumed for one-half the time in flight as well as for only the aircraft fuel consumed because of an increase in international roughness index (IRI). Figure 4a and 4b show the percent contribution from each phase. As discussed previously, the fuel consumed by the aircraft over 40 years dominates the LCA. Although not in contact with the pavement there is still an environmental impact that doesn't disappear when the plane leaves the airport. When only using the fuel consumed by change in IRI (no aircraft fuel consumption while in air), MP phase accounts for about 56% of primary energy consumption, CMR phase accounts for 13% and the use phase is approximately 31%. This demonstrates a significant difference between highway and airfield pavement LCAs as noted previously by Kulikowski (Kulikowski, 2015).

Table 3. Total Impacts per Functional Units – Rubblization with Mill/Inlay Case

Impact category	Unit	TW A&B		TW A&B	
		Total Impact Per yd <sup>2</sup>	Total Impact Per lb-mile	Total Impact Per yd <sup>2</sup> (ΔIRI Only)	Total Impact Per lb-mile (ΔIRI Only)
Global warming	kg CO2 eq	2.40E+03	4.31E-10	2.00E+02	3.93E-11
Primary energy consumption (renewable + non-renewable)	TJ	0.18612	3.58E-08	0.00518	1.02E-09



a) percent contribution including time-in-flight fuel consumption  
Figure 4. Phase Impact Contributions – Rubblization and Mill/Inlay Case



b) percent contribution including only aircraft fuel consumed from change in IRI  
Figure 4 (cont.)

#### 4 LIFE CYCLE ASSESSMENT FOR PRECAST CONCRETE PANELS

Figure 1 shows the depth of repair (21 inches of PCC). The slab lift-out method was assumed for removal. Appropriate equipment was selected for the CMR activities for PCC and AC. Figure 5 shows the fuel consumed for each activity. The highest fuel consumption activities were brooming (112,721 gal), crack sealing (31,072 gal), restriping (16,222 gal) and land clearing (12,328 gal).

Brooming impacts are similar to the rubblization case study. Crack sealing is slightly less than the rubblization case because the PCP repair section will not require the same crack sealing as the AC inlay. The main rehabilitation activities were concrete pavement demolition, PCP placement, and diamond grinding. The concrete demolition consumed an additional 523 gallons of fuel. The PCP placement consumed 2,937 gallons and diamond grinding added 761 gallons of fuel. It was assumed the entire repair area was diamond ground to remove irregularities. Close coordination with the fabricator and installer can ensure tight tolerances are achieved and only spot grinding is necessary. The amount of patching is reduced on the rehabilitated section compared to rubblization because of the increased durability of concrete. The total fuel combusted was one component used to determine the environmental impacts for the CMR phase. The total fuel consumed for the CMR phase was 206,078 gallons, which is 2,052 gallons more than rubblization. The rubblization method is an efficient operation for demolition (leaves material in place) and paving is also fast providing for key reductions.

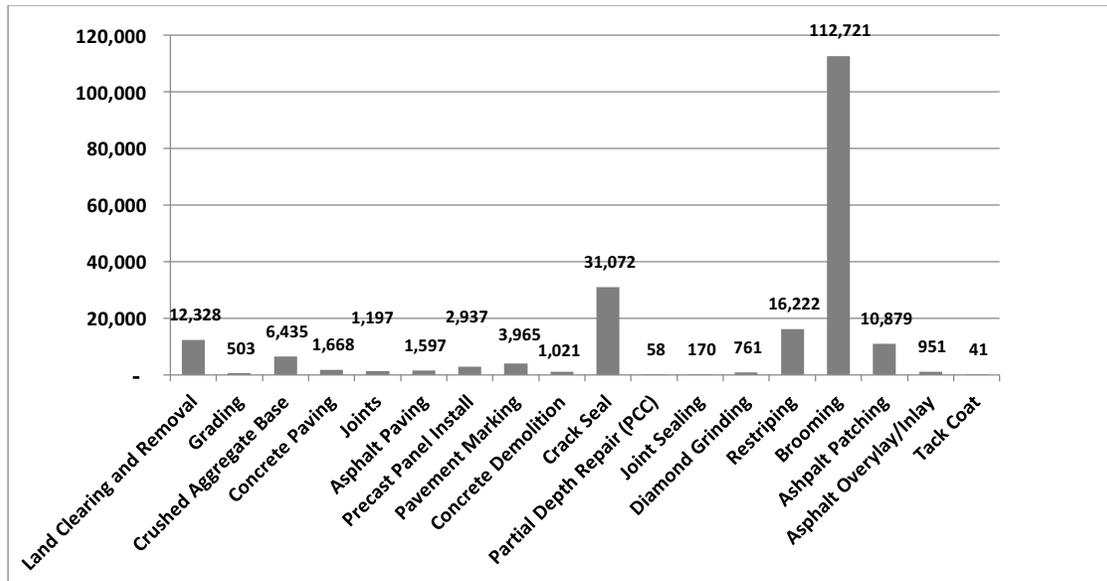


Figure 5. CMR Fuel Consumption per Activity – Precast Panels

The second component used to determine the total CMR impacts was the materials used in the maintenance and the rehabilitation process. The precast strategy replaced the second most amount of material following reconstruction and subsequently will have higher impacts than rubblization as well as a longer service life. The new material includes some base leveling fine aggregate and new reinforcement in the PCC slabs. An 8% lower value in energy consumption and a 9% increase in GWP production was seen in the PCP method compared to reconstruction. The lower energy value is attributed to a lower intensity installation process than reconstruction. This increase in GWP is attributed to the two mats of steel in the PCP panels.

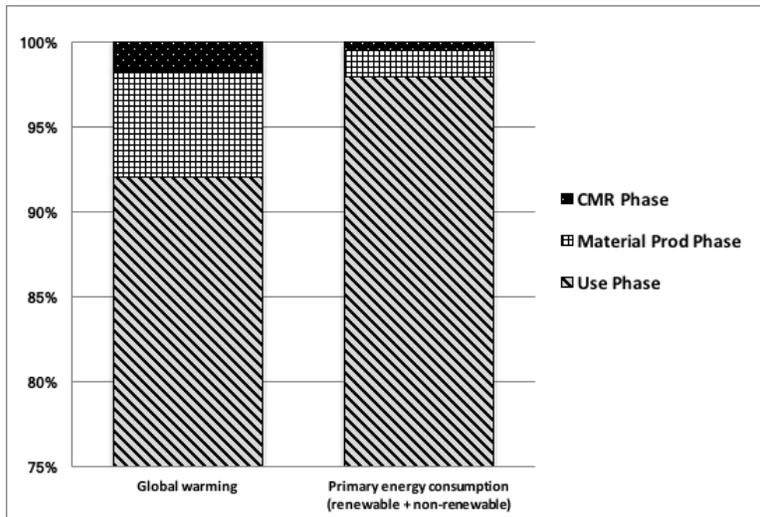
#### 4.1 Precast Impacts per Phase and Functional Units

The total impact from each phase was summed and then divided by the functional units for the airport.

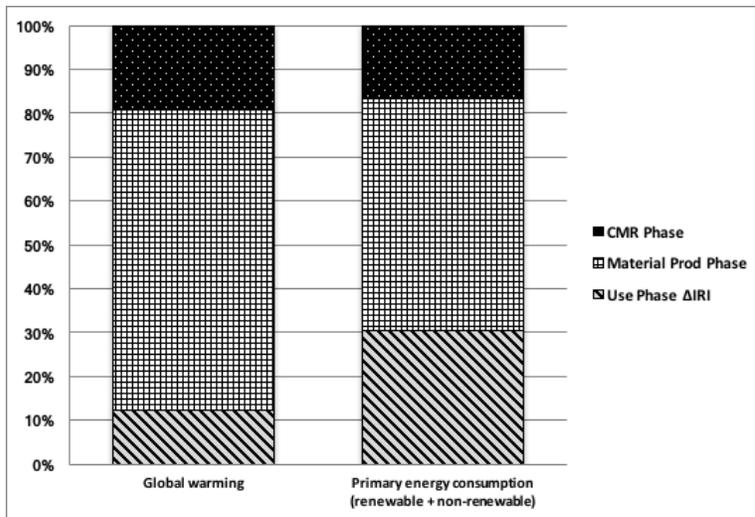
Table 4 shows the total values for the impacts using both aircraft fuel consumed for one-half the time in flight as well as for only the aircraft fuel consumed due to an increase in IRI. Figure 6a and 71b show the percent contribution from each phase. When only using the fuel consumed by change in IRI, MP phase accounts for about 53% of primary energy consumption, CMR phase accounts for approximately 17% and the U phase is approximately 30%.

Table 4. Total Impacts per Functional Units – Precast Panel Case

Impact category	Unit	TW A&B		TW A&B	
		Total Impact Per yd <sup>2</sup>	Total Impact Per lb-mile	Total Impact Per yd <sup>2</sup> (ΔIRI Only)	Total Impact Per lb-mile (ΔIRI Only)
Global warming	kg CO2 eq	2.41E+03	4.74E-10	2.18E+02	4.29E-11
Primary energy consumption (renewable + non-renewable)	TJ	0.1863	3.66E-08	0.0054	1.06E-09



a) percent contribution per phase including time-in-flight fuel consumption



b) percent contribution per phase including only aircraft fuel consumed from change in IRI  
 Figure 6. Phase Impact Contributions – Precast Panel Case

## 5 LIFE CYCLE ASSESSMENT FOR RECONSTRUCTION

The reconstruction method assumes the PCC, AC base and base course layers are removed and rebuilt. The method for breaking the slabs was a hydraulic hammer on the end of an excavator. It is efficient, rapid and provides enough breakage to allow equipment to remove the debris. Appropriate equipment was selected for the CMR activities for PCC and AC, respectively. Figure 7 shows the fuel consumed for each activity. The highest fuel consumption activities were brooming (112,721 gal), crack sealing (31,072 gal), restriping (16,222 gal) and land clearing (12,328 gal).

Brooming impacts are similar to the rubblization case study. Crack sealing is slightly less than the rubblization case because the reconstruction (PCC) repair section (like PCP case) will not require the same crack sealing as the rubblization AC inlay. The most impactful rehabilitation activities were concrete/asphalt demolition, grading after demolition, and concrete/asphalt paving. These activities consumed 1,458, 1,135 and 1,848, respectively. The amount of patching is reduced compared to rubblization (same as PCP) because of the increased durability of concrete.

The total fuel combusted was one component used to determine the environmental impacts for the CMR phase. The total fuel consumed for the CMR phase was 205,201 gallons, which is 1,175 gallons more than rubblization and 877 gallons less than precast. The difference between precast and reconstruction is attributed to the speed of demolition and construction. Demolition and the placement of concrete requires less time than the placing of PCPs.

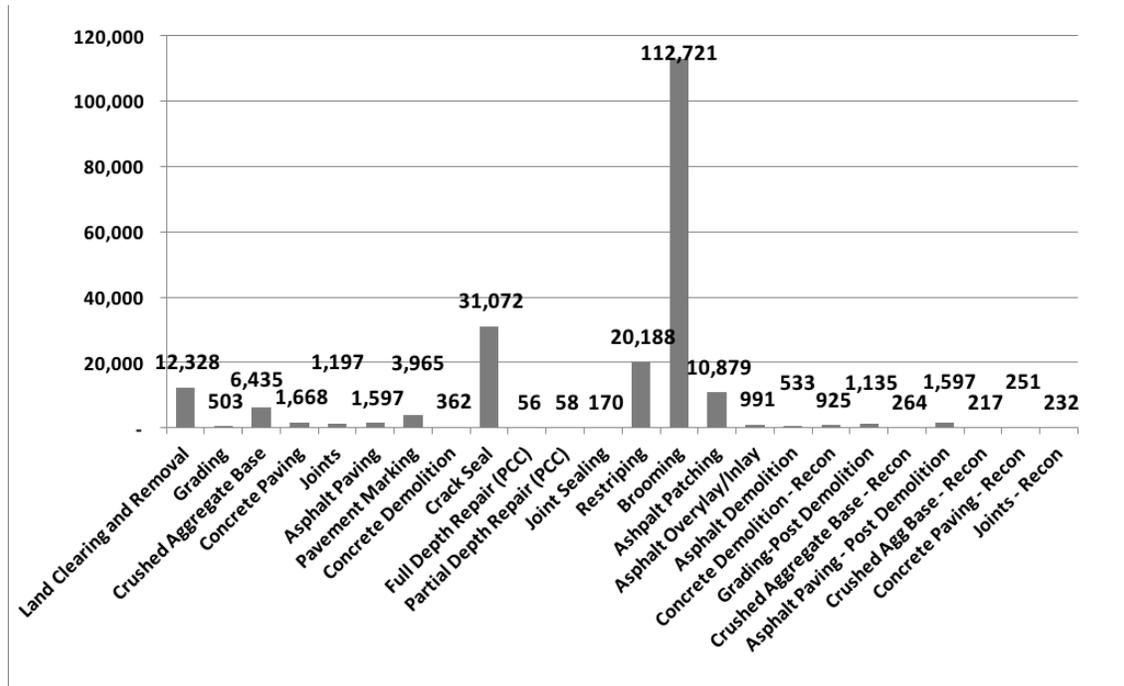


Figure 7. CMR Fuel Consumption per Activity - Reconstruction

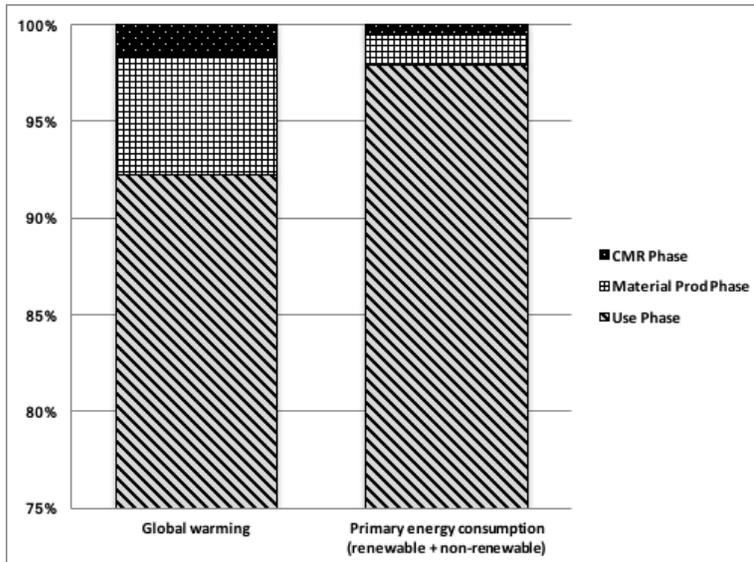
The second component used to determine the total CMR impacts was the materials used in the maintenance and the rehabilitation. As expected, reconstruction had the highest material impacts of all three cases, replacing the full pavement structure to the subgrade. A 30% higher value in energy consumption and a 37% higher value in GWP production were seen in the reconstruction method compared to rubblization. These increases are 6% higher than the PCP method.

#### 5.1.1 Reconstruction Impacts per Phase and Functional Units

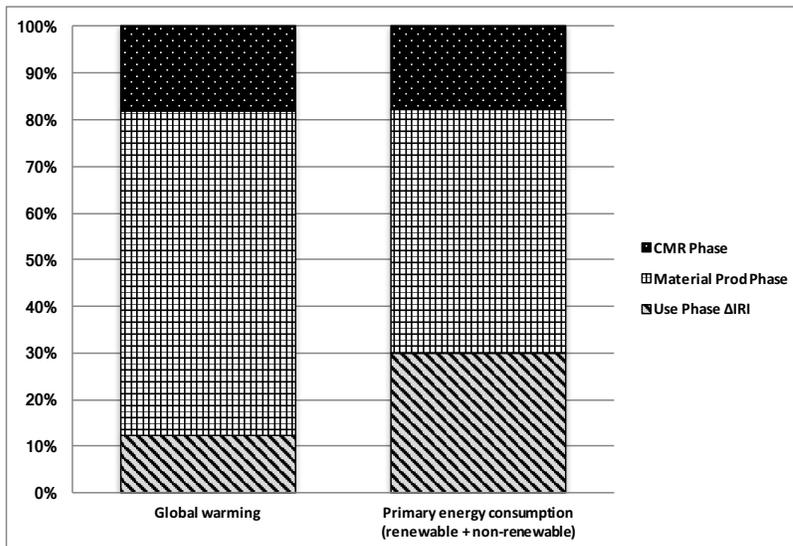
The total impact from each phase was summed and then divided by the functional units for the airport. Table 5 shows the total values for the impacts using both aircraft fuel consumed for one-half the time in flight as well as for only the aircraft fuel consumed due to an increase in IRI. Figure 8a and 8b show the percent contribution from each phase. When only using the fuel consumed by change in IRI, MP phase accounts for about 42% of primary energy consumption, CMR phase accounts for 28% and the use phase is approximately 30%.

Table 5. Total Impacts per Functional Units – Reconstruction Case

Impact category	Unit	TW A&B		TW A&B	
		Total Impact Per yd <sup>2</sup>	Total Impact Per lb-mile	Total Impact Per yd <sup>2</sup> (ΔIRI Only)	Total Impact Per lb-mile (ΔIRI Only)
Global warming	kg CO2 eq	2.41E+03	4.73E-10	2.15E+02	4.22E-11
Primary energy consumption (renewable + non-renewable)	TJ	0.1864	3.66E-08	0.0055	1.07E-09



a) Percent contribution including time-in-flight fuel consumption



b) Percent contribution including only aircraft fuel consumed from change in IRI

Figure 8. Phase Impact Contributions - Reconstruction Case

## 6 CONCLUSION

LCA is one of many tools available to airport owners, operators, engineers and contractors to make educated decisions regarding infrastructure investment and their influence on environmental impacts. LCA-AIR was used to evaluate three rehabilitation options consisting of rubblization with mill/AC inlay, precast panel replacement and full-depth reconstruction for O'Hare International Airport TW A & B. The impacts were normalized to two functional units (square yard and pounds-mile traveled). Each case had the same values for the material production phase (initial construction) and use phase. The construction, maintenance and rehabilitation phase showed differences stemming from the quantity of materials, the construction methods and equipment used in the proposed rehabilitation methods. The rehabilitations at year 30 extended the pavement life to 50 years. The rubblization with mill/AC inlay required a second AC mill/inlay at year 40 to reach 50 years. The precast panels and reconstruction performance life was an additional 20 years from the time of rehabilitation. The results showed the rehabilitation with the least impact for GWP was as follows: precast concrete panel replacement, rubblization with a mill/AC inlay, and

full-depth reconstruction. The ranking of least impact for energy for the three rehabilitation strategies were rubblization with a mill/AC inlay, precast concrete panel replacement, and finally, full-depth reconstruction. The GWP potential for rubblization was 2,395 kg CO<sub>2</sub>/yd<sup>2</sup> (4.310x10<sup>-10</sup> kg CO<sub>2</sub>/lb-mile), for reconstruction was 2,409 kg CO<sub>2</sub>/yd<sup>2</sup> (4.729x10<sup>-10</sup> kg CO<sub>2</sub>/lb-mile), and for PCP was 2,413 kg CO<sub>2</sub>/yd<sup>2</sup> (4.736x10<sup>-10</sup> kg CO<sub>2</sub>/lb-mile). The energy consumed for rubblization was 0.1861 TJ/ yd<sup>2</sup> (3.576x10<sup>-8</sup> TJ/lb-mile), for PCP was 0.1863 TJ/ yd<sup>2</sup> (3.657x10<sup>-8</sup> TJ/lb-mile) and for reconstruction was 0.1864 TJ/ yd<sup>2</sup> (3.658x10<sup>-8</sup> TJ/lb-mile).

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