Using GIS to Allocate Elevated Aircraft Emissions Associated with Arrivals and Departures

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ABSTRACT

Aircraft emissions from commercial airports are often a major source of emissions in urban centers. To accurately allocate aircraft emissions in photochemical models, temporal and spatial factors must be applied. This necessitates assigning airport emissions to 3-dimensional modeling grid cell system. Aircraft emissions vary by mode of aircraft operation: idling, landing, take off, and climb out up to 1,000 meters. By obtaining the percentage of landings, take-offs for each end of a runway, it was possible to assign aircraft emissions generated by applying the Emission and Dispersion Modeling System (EDMS 4.2) to specific runways for arrival and departure flights. The aircraft emissions for take off, climb out, and approach flight modes were then allocated to a 3 dimensional photochemical modeling grid-cell system. The height, latitude, and longitude of multiple nodes, within the grid system, were calculated at incremental ground distances from the end of the runway using Geographic Information Systems (GIS) software. The final step in this process was to allocate the emissions from the end of each runway using GIS.

INTRODUCTION

San Antonio International Airport (SAIA) is located approximately seven miles north of the San Antonio central business district. Emissions occur from daily operations of a diverse range of sources such as aircraft emissions, vehicles, boilers, and lawn and garden equipment. The first example, aircraft emissions, is the focus of this paper. These emissions include commercial, general aviation, and military operations. The Federal Aviation Administration (FAA) established routines and procedures for recording airport activities and operations. The following are excerpts from the FAA report entitled "Order 7210.3T, Facility Operation and administration" explaining key terms in regard to data used for the modeling of airport emissions.

"A: Airport Operations Count
The airport operations count is the statistic maintained by the control tower. Basically, it is the number of arrivals and departures from the airport at which the airport traffic control tower is located. Specifically, one airport operation count is taken for each landing and takeoff (LTO), while two airport operations counts; i.e., one landing and one takeoff, are taken for each low approach below traffic pattern altitude, stop and go, or touch and go (TGO) operation.

B: Categories Of Operations
The airport authorities will maintain airport operations data by the following categories:

a. ITINERANT: Operations not classified as "local," including the following subcategories:
    1. *Air Carrier (Commercial).*
    2. *Air Taxi (Commercial).*
    3. *Military: All classes of military operations.*
    4. *General Aviation: Civil operations not classified as air carrier or air taxi.*

b. LOCAL: Operations remaining in the local traffic pattern, simulated instrument approaches at the airport and operations to or from the airport and a practice area within a 20-mile radius of the tower.
   1. *Military: All classes of military operations.*
   2. *Civil: All civilian operations, including local flights by air carrier and air taxi aircraft"* (General Aviation).[1]

METHODOLOGY

In the 2005 Emissions Inventory for the San Antonio area, aircraft emissions for the SAIA were calculated using the Emission & Dispersion Modeling System (EDMS) version 4.21.[2] All emission factors and estimation techniques used in EDMS are based on EPA-approved methodologies. Data on aircraft flight activities was collected from the "FAA/FPA Terminal Area Forecast" (TAF) software and "Airport IQ Data Center" Internet site, a web-based flight activity tracking and reporting software for all U.S. airports.

Based on the information indicated in the TAF database, the airport activity levels reached a total of 244,589 operations for "local" and "itinerant" categories in the year 2005 indicating a 2.6% decline in the aircraft operations from 1999 levels. Information on local and itinerant aircraft activities gathered from these sources was entered into the EDMS model to estimate the amount of pollutants attributed to aircraft activities.

Commercial Aircraft Operations

The data collected from the Internet site "Airport IQ Data Center" included operation data on commercial and civilian aircraft by landing/take off cycles and aircraft type for 2003 and part of 2004. To project to 2005, data from the TAF software was used. The 2005 forecast total for commercial operations was compared to the 2003 commercial operations to estimate a growth ratio, which was applied to the aircraft by type.

Table A in Appendix A contains a list of the type and activity level of commercial "air carrier" and "commuter" aircraft that were used in the analysis of commercial aircraft emissions for the year 2005. In cases where the exact aircraft type was not available in the EDMS software, a comparison of aircraft types was made with those of the EDMS 4.21 default aircraft categories to match the most compatible engine types. In two instances, a user-defined aircraft was created because the EDMS database contained no equivalent aircraft types.

General Aviation Operations

Based on information extracted from TAF software, a total of 107,903 general aviation aircraft operations were forecasted for SAIA (2005). The GA operations were divided into three types, Jet[3], Turbo-Prop[4], and Piston[5], based on the percentage of total GA operations in 2003. The results are shown in Table 1.

Table 1. 2003 Percentage of GA Operations at the SAIS with 2005 LTO Cycles and Operations

Aircraft Type	2003 Percentage of Total GA Operations	2005 Total LTO Cycles	2005 Operations by Engine type
Jet	47.8%	25,783	51,566
Turbo-Propeller	15.4%	8,323	16,646
Piston	36.8%	19,844	39,688
Total	100.0%	53,950	107,900*

*Due to rounding, the total for this column may appear slightly different from that of TAF software.

Tables B, C, and D in Appendix A list the type and activity level of GA aircraft that were used in the SAIA emissions analysis for the year 2005. When the exact aircraft type was not available in EDMS, an equivalent aircraft type, which had similar engine(s), was used. In five cases, a user-defined aircraft was created for this category because equivalent aircraft were not available in the EDMS database.

Military Aircraft Operations

The military utilizes the SAIA facilities for training purposes; TAF software maintains records on military activities at SAIA. Table 2 contains flight characteristics for military operations occurring at SAIA, which were used as input data to the EDMS model for the calculation of emissions from military aircraft activities.

Table 2. 2005 Military Aircraft Activity at the SAIA

Aircraft	LTO	TGO	Total
T-43	0	4,048	4,048
T-34/T-37	238	0	238
F-16	0	1,079	1,079
C-130	39	347	386
C-21	52	90	142
Total	329	5,564	5,893

Table 3 contains the estimated emissions from aircraft listed by aircraft category. Commercial aircraft was the largest emission source followed by military and GA-jet. These emissions estimations were used to geo-code the emissions spatially and temporally.

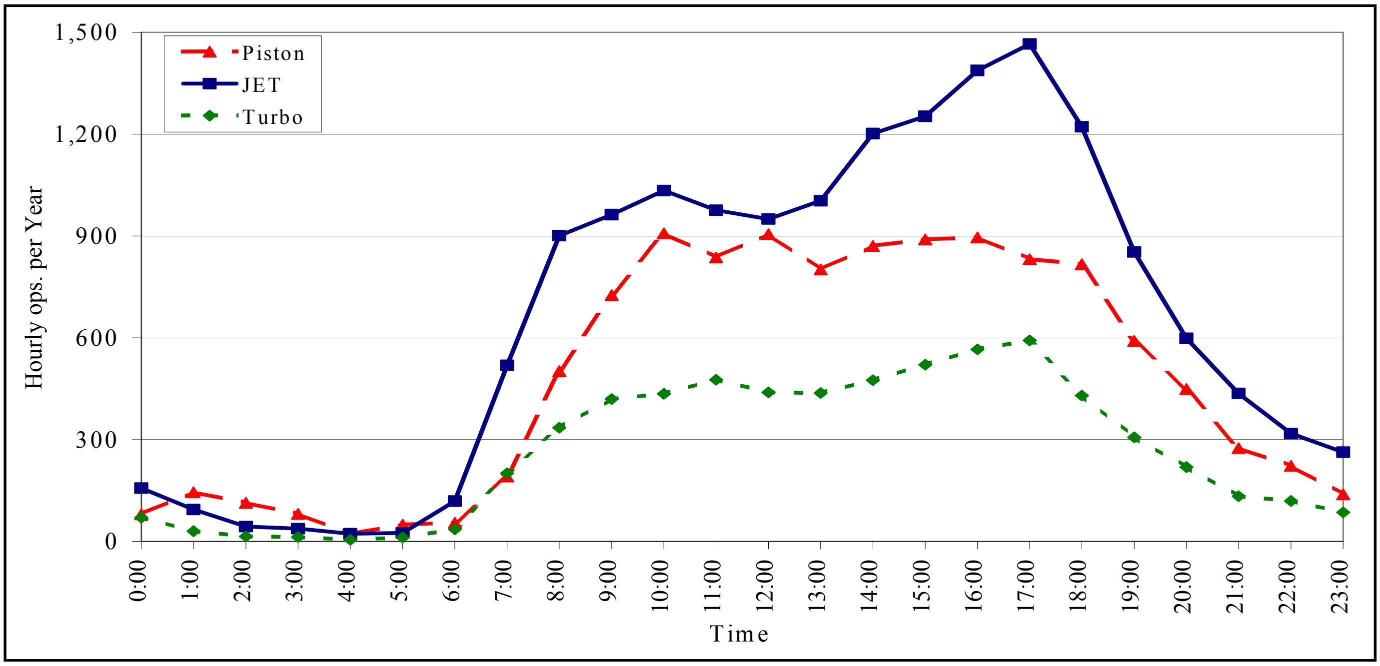
Table 3. 2005 Emissions by Aircraft Category and Mode

Aircraft Category	VOC (tons/day)			NOx (tons/day)		
	Take Off	Climb Out	Approach	Take Off	Climb Out	Approach
Commercial	0.003	0.004	0.015	0.438	0.290	0.206
Military	0.002	0.002	0.019	0.037	0.024	0.026
GA – Jet	0.001	0.001	0.014	0.035	0.022	0.021
GA – Turbo-Prop	0.000	0.000	0.004	0.002	0.001	0.004
GA – Piston	0.001	0.001	0.002	0.000	0.001	0.001
Total	0.007	0.008	0.054	0.512	0.338	0.259

Temporal Allocation

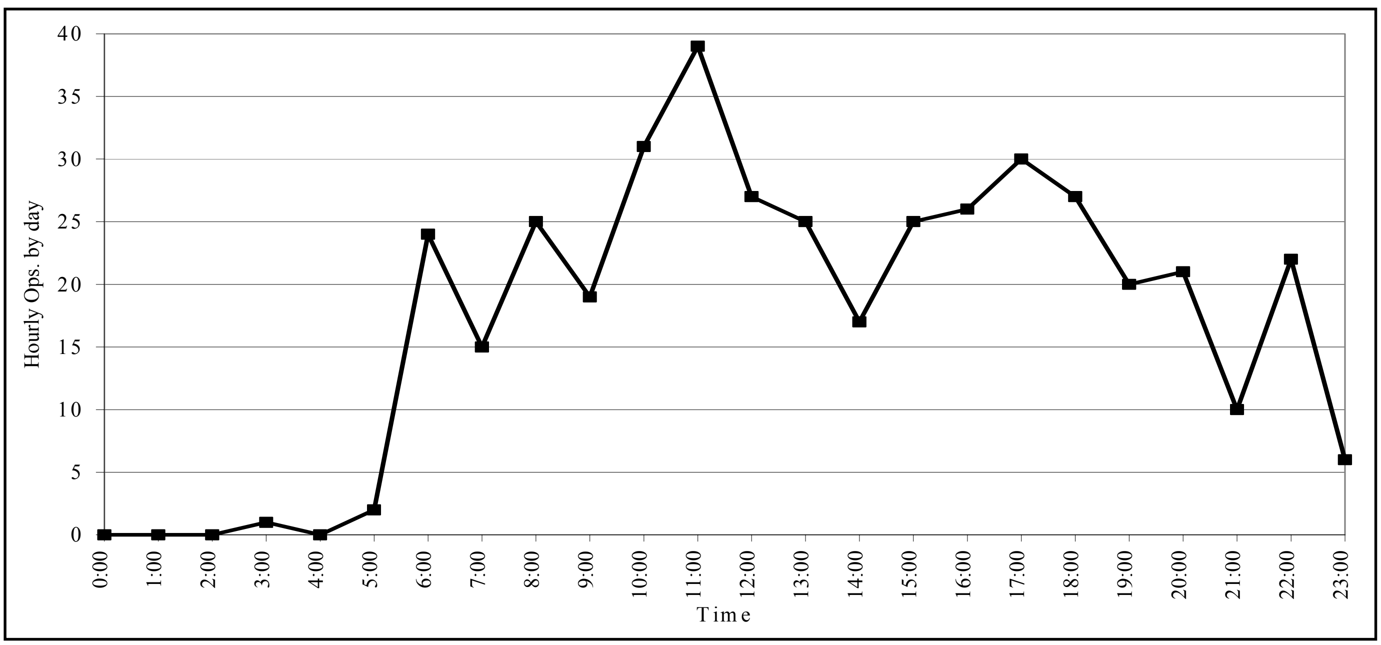
Processing emissions in a photochemical model includes such steps as chemical speciation, temporal allocation, and spatial allocation of emissions data. These steps require the conversion of aircraft emissions data to a grid-cell based modeling system and the conversion of daily emissions data to hourly data as required by the photochemical model. In Figure 1, the hourly temporal distribution of annual arrival and departure times for GA aircrafts are displayed graphically.

Figure 1. 2005 Hourly Distribution of General Aviation Operations by Aircraft Type at SAIA



Air career flight schedules for September 2005 were analyzed to determine the temporal distribution, as well as the peak hours of arrival and departure times for commercial flights. The results indicated that the commercial arrival and departure pattern varied from that of GA operations; while the peak hour for the GA flights is around 5:00 pm, the peak hour for the commercial flights is around 12:00 noon. The commercial hourly distribution is shown in the Figure 2.

Figure 2. Hourly Distribution of September 2005 Commercial Aircraft Operations at SAIA



Spatial Allocation

Information on runway patterns of specific aircraft traffic was obtained from the San Antonio Department of Aviation for use in the spatial allocation of aircraft emissions. The information provided the percentages of take off and landings that take place at each end of the runways, annually, and made it possible to assign EDMS generated aircraft emissions to each end of the runways for arrival and departure flights. Table 4 contains the breakdown by aircraft type for departure and arrival.

Table 4. Percentage of Aircraft Operations Allocated by Runway and Direction

Runway	Departure				Arrival			
	Commercial	Jet	Turbo	Piston	Commercial	Jet	Turbo	Piston
RW 12R	45%	61%	58%	51%	74%	70%	72%	58%
RW 12L	0%	3%	1%	4%	0%	2%	5%	13%
RW 21	2%	2%	2%	4%	3%	2%	2%	4%
RW 30R	0%	0%	2%	3%	0%	0%	1%	4%
RW 30L	14%	18%	14%	11%	13%	15%	11%	10%
RW 3	38%	16%	23%	27%	10%	11%	9%	11%
Total	99%	100%	100%	100%	100%	100%	100%	100%

To calculate hourly emissions by runway and aircraft classification, the following formula (Equation 1) was used:

Equation (1) Emissions in tons/hour (VOC and NOx) = PAO x EM x HR

where PAO = percentage of aircraft operations allocated by runway and aircraft category (Table 4)
EM = emission by mode for each aircraft type (Table 3)
HR = percentage of operations for each hour (Figure 2)
= (operations per desired hour ÷ total operations per day)

Example (1) Take off emissions calculation for commercial flights at 12:00 noon on runway 12R (NOx Emissions):

12R Take off Emissions (12 p.m.) = 45% x 0.438 tons/day x (27 ops/hr ÷ 409 ops/day)
= 45% x 0.438 tons/day x 0.066 days/hr
= 0.013 tons NOx/hour at 12:00 noon

In the next step, aircraft emissions for flight modes of take-off (0 – 1,000 feet ≅ 0 – 305 meters), climb out (1,000 – 3,000 feet ≅ 305 – 914 meters), and approach (3,000 – 0 feet ≅ 914 – 0 meters), were allocated to the Comprehensive Air Quality Model with Extensions (CAMx)[6] photochemical grid-cell system. Emissions from aircraft above 3,000 feet in elevation were not calculated. At those elevations, aircraft are usually above the mixing height for San Antonio and emissions would have a minor impact on ground-level ozone formation.

To allocate emissions to the CAMx grid cells, height, latitude, and longitude were calculated for 8 nodes at incremental ground distances from the ends of each runway. The GIS software TransCAD[8] was utilized for this purpose. Figure 3, which provides a diagram of the layout and dimensions of runways at SAIA, was used to calculate the latitude and longitude of each node.[7] The diagram also shows the location of each runway used in the calculations.

Figure 3. SAIA Runway Schematic

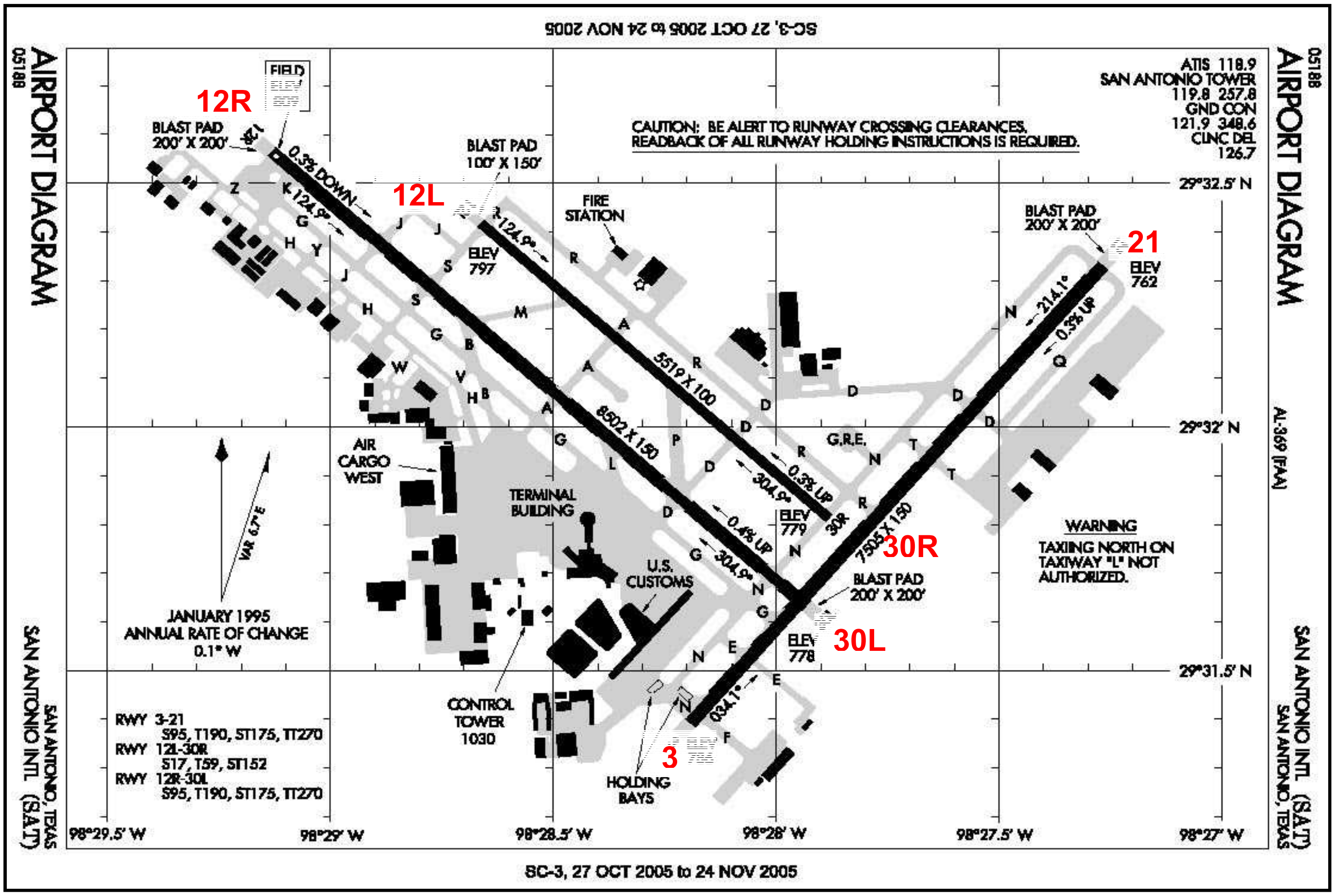


Figure 4. Aerial View of Calculated Nodes

Figure 4 was generated as part of the quality assurance process. The figure shows the nodes superimposed on an aerial photo of the airport, illustrating the horizontal location and distance of these nodes relative to both ends of each runway. In addition, grid cells are displayed in **light green**. As anticipated, the nodes form straight lines from the ends of the runways; planes usually do not bank (turn) until the plane is at least 5 km from the airport.

After consulting with staff of the Texas Commission on Environmental Quality (TCEQ) and applying EDMS defaults for landing, aircraft landing angles were set at 3º and departure angles were set at 9º. These angles are the same as those used previously in versions of the Dallas State Implementation Plan for the Dallas/Fort Worth International Airport.

This information, in addition to the formula below, was used in TransCAD to locate 8 nodes within the CAMx horizontal and vertical grid cells to replicate the 3-dimensonal paths of aircraft. The aircraft emissions per runway were then equally distributed and allocated to these nodes.

Equation (2) Node Height = D × TAN (9 × PI ÷ 180)

where
D = ground distance from the runway end point
TAN = tangent of 9° for take off and climb out; tangent of 3° for landing
PI = mathematical constant pi (≈3.14159)

Table 5 contains the height, latitude, and longitude of nodes for runway 3/21. Four nodes were used to allocate take off and climb out emissions. For landing emissions, six nodes were used. These were spaced in 1,000-meter increments from the end of the runway. The height of the landing nodes starts at 264 meters (which is the height of the plane at 5,000 meters ground distance from the airport) due to the uncertainty of aircraft direction before the aircraft gets within this distance of the airport.

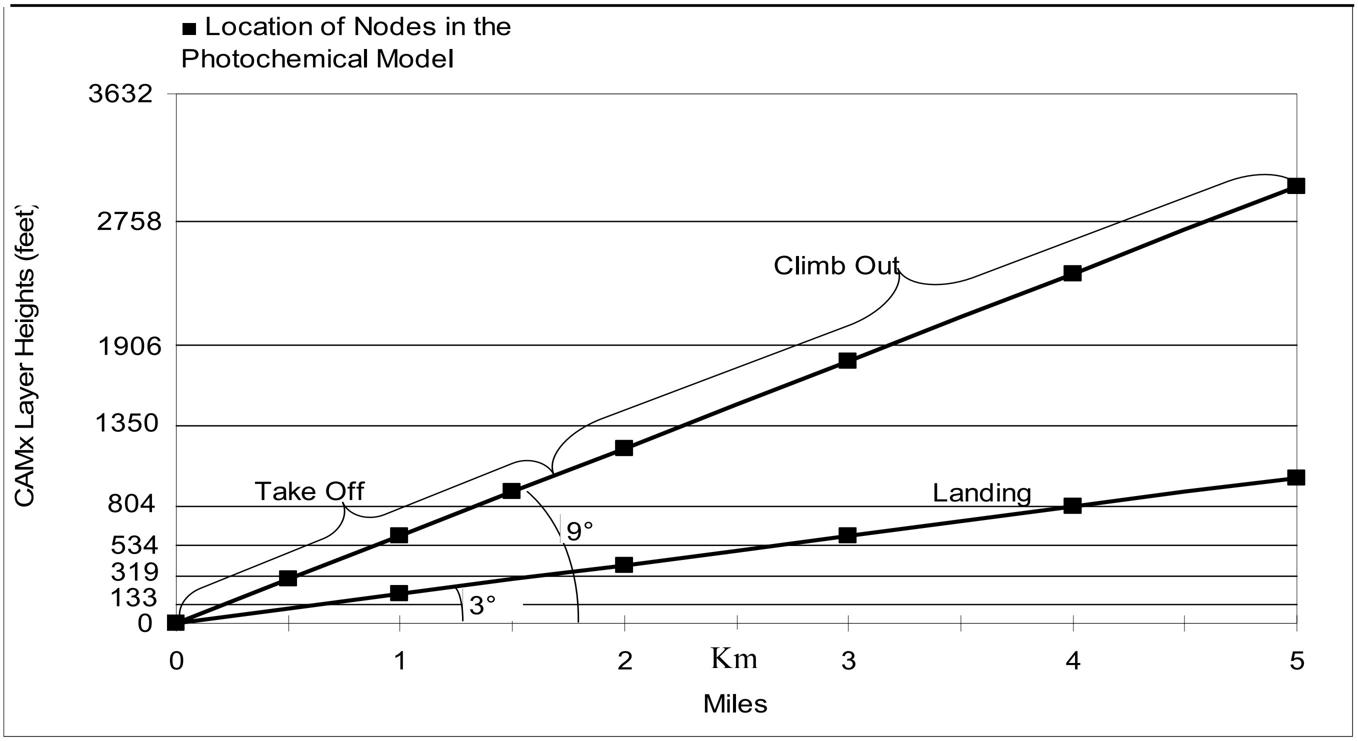
Table 5. Heights of Selected Nodes for Take off and Landing Operations at Runway 3/21

Runway Nodes (Direction)	Distance from End of Runway (m)	Latitude (Y coordinate)	Longitude (X Coordinate)	Node Height (m) for 9º - Take off	Node Height (m) for 9º - Climb out	Node Height (m) for 3º - Landing
Runway 3 Nodes (Northeast)	0	-1157.69	150.96	0	N/A	0
	500	-1157.31	151.27	79	N/A	N/A
	1,000	-1156.94	151.58	158	N/A	53
	1,500	-1156.56	151.89	238	N/A	N/A
	2,000	-1156.18	152.20	N/A	317	106
	3,000	-1155.43	152.83	N/A	475	158
	4,000	-1154.68	153.45	N/A	634	211
	5,000	-1153.92	154.08	N/A	792	264
Runway 21 Nodes (Southwest)	0	-1159.41	149.53	0	N/A	0
	500	-1159.79	149.22	79	N/A	N/A
	1,000	-1160.17	148.90	158	N/A	53
	1,500	-1160.54	148.59	238	N/A	N/A
	2,000	-1160.92	148.28	N/A	317	106
	3,000	-1161.67	147.66	N/A	475	158
	4,000	-1162.43	147.03	N/A	634	211
	5,000	-1163.18	146.41	N/A	792	264

N/A: these nodes were not used to allocate emissions

A graphic illustration of the vertical height by the three different aircraft modes and CAMx vertical grid layers is shown in Figure 5. Aircraft emissions were allocated to the first 8 vertical layers of the CAMx modeling grid system. Once the emissions were geocoded to correct location and height, the data was converted to a format suitable for photochemical modeling.

Figure 5. Calculated Heights of Nodes for LTO Operations at End of Runways*



*Note: Angles in diagram are for illustration purposes only and are not to scale.

CONCLUSION

Aircraft operations at the SAIA are a major source of emissions in the region. Aircraft emissions were found to vary by hour and location, depending on flight schedules and runways in use. By utilizing temporal and spatial factors obtained from TransCAD, the accuracy of aircraft emission allocations used in the photochemical modeling grid-system was improved. Allocating aircraft emissions to a 3-dimensional photochemical modeling grid system, through the use of GIS software, increases the accuracy of the model's predictive capabilities in terms of ozone formation and the effectiveness of control strategies.

The emission estimation methodology described in this paper is applicable to all airports, regardless of size. However, improvements to emission methodologies at larger airports, such as John F. Kennedy International Airport in New York and Hartsfield-Jackson Atlanta International Airport, are particularly crucial since the heavy traffic associated with these airports means larger aircraft emission inventories. Three-dimensional modeling improves the accuracy of aircraft emissions estimates at these airports, as well as smaller airports. Further research on this topic should include examining the impact of elevated aircraft emissions on photochemical modeling results.

APPENDIX A
Aircraft Types used in the Calculations

Table A. 2005 Commercial Aircraft Type and Arrival Activity at SAIA

Type	Number of LTO Cycles	Aircraft Name	Number of Engine	Engine Type	Equivalent Aircraft Used in Modeling
A306	550	AIRBUS - A-300B4 - 600	2J/H		
A30B	1	AIRBUS - A-300B4 - 600b	2J/H		A306
A310	107	AIRBUS - A-310 (CC-150 Polaris)	2J/H		
A319	2,640	AIRBUS - A-319, ACJ	2J/L		
A320	87	AIRBUS - A-320	2J/L		
A321	9	AIRBUS - A-321	2J/L		
A331	1	AIRBUS - A-331	2J/L		A-330
AC11	1	Rockwell - Commander	1P/S		
AC90	1	Gulfstream - 690 Jetprop Commander	2T/S	TPE 331	Swearingen Merlin
AC9L	1	Gulfstream Aerospace	2T/S	TPE 331	Swearingen Merlin
AT43	7	Aerospatiale - ATR-42-200/300/320	2T/L		ATR42
B190	276	Beech - 1900 (C-12J)	2T/S+	PT6A-65B	BH-1900
B350	14	Beech - B300 Super King Air 350	2T/S+		
B712	691	Boeing - 717-200	2J/L		
B721	8	Boeing - 727-100 (C-22)	3J/L		
B722	218	Boeing - 727-200	3J/L		
B727	6	Boeing – 727	3J/L		B721
B72Q	569	Boeing - 727 Stage 3 (-100 or -200)	3J/L		B721
B732	1,581	Boeing - 737-200 (Surveiller, CT-43)	2J/L		
B733	11,094	Boeing - 737-300	2J/L		
B734	12	Boeing - 737-400	2J/L		
B735	3,527	Boeing - 737-500	2J/L		
B737	2,971	Boeing - 737-700	2J/L		
B738	972	Boeing - 737-800, BBJ2	2J/L		
B739	94	Boeing - 737-900	2J/L		
B73Q	5,793	Boeing - B737 Stage 3	2J/L		B737
B741	5	Boeing - 747-100	4J/H		
B742	11	Boeing - 747-200 (E-4, VC-25)	4J/H		
B744	4	Boeing - 747-400 (International, winglets)	4J/H		
B752	1,566	Boeing - 757-200 (C-32)	2J/L		
B753	165	Boeing - 757-300	2J/H		
B757	1	Boeing – 757	2J/H		B752
B762	172	Boeing - 767-200	2J/H		
B763	9	Boeing - 767-300	2J/H		
B764	6	Boeing - 767-400	2J/H		
B772	2	Boeing - 777-200	2J/H		
BE10	1	Beech - 100 King Air	2T/S		
BE18	102	Beech - Twin Beech 18/Super H18	1P/S	O-200	Cessna 150
BE19	1	Beech - 19 Musketeer Sport, Sport	1P/S	IO-360-B	Cessna 172
BE20	63	Beech - 200 Super King Air	2T/S+		
BE30	2	Beech - Super King Air300	2T/S+		
BE33	2	Beech - 33 Debonair	1P/S	IO-360-B	Cessna 172
BE35	9	Beech - 35 Bonanza	1P/S	O-200	Cessna 150
BE36	20	Beech - 36 Bonanza	1P/S	IO-360-B	Cessna 172
BE3B	1	Beech - B300 Super King Air 350	2T/S+		
BE40	285	Beech - 400 Beechjet	2J/S+		
BE55	5	Beech - 55 Baron	2P/S	IO-360-B	Cessna T337
BE58	13	Beech - 58 Baron	2P/S	IO-360-B	Cessna T337
BE60	1	Beech - 60 Duke	2P/S	IO-360-B	Cessna T337

Type	Number of LTO Cycles	Aircraft Name	Number of Engine	Engine Type	Equivalent Aircraft Used in Modeling
BE90	1	Beech - King Air C-90	2P/S	IO-360-B	Cessna T337
BE9L	11	Beech - 90, A90 to E90 King Air (T-44)	2T/S		
C172	8	Cessna - 172	1P/S		
C177	1	Cessna - 177, Cardinal	1P/S	O-200	Cessna 150
C182	6	Cessna - 182	1P/S	O-200	Cessna 150
C206	14	Cessna - 206, Super Skywagon	1P/S	O-200	Cessna 150
C208	1,472	Cessna - 208 Caravan 1	1T/S		
C210	20	Cessna - 210, T210, Centurion	1P/S	O-200	Cessna 150
C310	6	Cessna - 310, T310 (U-3, L-27)	1P/S	IO-360-B	Cessna 172
C340	1	Cessna – 340	2P/S	IO-360-B	Cessna T337
C401	127	Cessna – 401	2P/S	IO-360-B	Cessna T337
C402	325	Cessna - 401, 402, Utililiner, Businessliner	2P/S	IO-360-B	Cessna T337
C404	4	Cessna - 404 Titan	2P/S	IO-360-B	Cessna T337
C414	2	Cessna - 414	2P/S	IO-360-B	Cessna T337
C421	2	Cessna - 421, Golden Eagle	2P/S	IO-360-B	Cessna T337
C425	1	Cessna - 425, Corsair, Conquest 1	2T/S	PT6A-112	User Defined Aircraft
C500	2	Cessna - 5000 Citation, Citation 1	2J/S		
C501	1	Cessna - 501 Citation 1SP	2J/S		C500
C525	62	Cessna - Citationjet 525	2J/S	FJ44-1A	C500
C550	127	Cessna – Citation 2	2J/S+		
C56	2	Lockheed - C-56 Loadstar	2T/S+	ARMY - Historical	Beech - B300 Super King Air 350
C560	354	Cessna - 560 Citation 5	2J/S+		
C56X	280	Cessna - 560 Citation 5	2J/S+		C560
C650	197	Cessna – Citation 3	2J/S+	CF34-3A	CL601-3A
C72R	1	Cessna - 172RG, Cutlass RG	1P/S		C172
C750	377	Cessna - 750 Citation 10	2J/S+		
CJR9	1	Unknown	0		Cessna 172
CL30	1	Bombardier – BD-100 Challenger 300	2J/S+	AS-907	400 Beechjet
CL60	111	Canadair - CL-600 Challenger	2J/L	CF34-3A	CL601-3A
CL64	1	Canadair - CL-600 Challenger	2J/L	CF34-3A	CL601-3A
CR2	1	Crossair	2J/S+		400 Beechjet
CRJ	1	Canadair - 850 Bombardier	2J/L		CL601-3A
CRJ1	299	Canadair - CL-600 Regional Jet CRJ-100	2J/L		
CRJ2	5,611	Canadair - Regional Jet 100/200	2J/L		CRJ1
CRJ7	584	Canadair - CL-600 Regional Jet CRJ-700	2J/L		
CRJ9	950	Canadair - CL-600 Regional Jet CRJ-900	2J/L		
CVLT	8	Convair - CV-580	2T/S+	NAVY - Historical	Beech - B300 Super King Air 350
D328	5	Dornier – 328	2T/S+		
DC10	270	McDonnell-Douglas - DC-10	3J/H		
DC3	1	McDonnell-Douglas - Skytrain	2P/S+	PT6A-65B	BH-1900
DC8	4	McDonnell-Douglas - DC-8	4J/H		
DC87	1	McDonnell-Douglas - DC-8-70	4J/H		
DC8Q	224	McDonnell-Douglas - DC-8 Stage 3	4J/H		DC8
DC9	12	McDonnell-Douglas - DC-9	2J/L		DC91
DC91	15	McDonnell-Douglas - DC-9-10	2J/L		
DC93	166	McDonnell-Douglas - DC-9-30 (C-9)	2J/L		
DC94	12	McDonnell-Douglas - DC-9-40	2J/L		
DC95	12	McDonnell-Douglas - DC-9-50	2J/L		

Type	Number of LTO Cycles	Aircraft Name	Number of Engine	Engine Type	Equivalent Aircraft Used in Modeling
DC9Q	358	McDonnell-Douglas - DC-9 Stage 3	2J/L		DC91
DR20	1	Unknown	0		Cessna 172
E110	503	Embraer - 110/111 Bandeirante (C-95)	2T/S+		
E120	4	Embraer - EMB-120 Brasilia (VC-97)	2T/S+		
E135	33	Embraer - EMB-135	2J/L		
E140	1	Embraer - EMB-140	2J/L		
E145	1,868	Embraer - EMB-145, ERJ-145	2J/L		
E45X	735	Embraer - EMB-145XR	2J/L		E145
F100	627	Fokker - 100	2J/L		
F2TH	87	Dassault - Breguet - Falcon 2000	2J/S+		
F900	2	Dassault – Falcon 900	3J/L	TFE731	Falcon 20 - 3
FA10	2	Dassault – Falcon (Mystere) 10	2J/S+		FA20
FA20	82	Dassault – Falcon (Mystere) 20	2J/S+		
FA50	38	Dassault – Falcon 50	3J/S+		
FJ2	1	Hawker Sea Fury	1T/S+	ARMY - Historical	Porter PC6/B2
GALX	40	Israel IAI-1126 Galaxy - 1126	2J/S+		
GL25	1	F 104 Starfighter	1J/S+	ARMY - Historical	A-7E Corsair
GLEX	1	Bombardier - BD-700-1A10	2J/S+		
GLF2	2	Gulfstream Aerospace - C-20J,/VC-111	2J/L		
GLF3	2	Gulfstream Aerospace	2J/L		
GLF4	25	Gulfstream Aerospace	2J/L		
GLF5	1	Gulfstream Aerospace G-V Gulfstream V	2J/L		
GLS4	1	Unknown	0		Cessna 172
H125	1	British Aerospace - Hawker Siddeley 125	2J/S+		
H25	2	British Aerospace	2J/S+		
H25A	8	British Aerospace - BAe HS 125 Series	2J/S+		
H25B	238	British Aerospace - BAe-125-700/800	2J/S+		
H25C	77	British Aero. - Hawker Siddel. HS 125	2J/S+		
HS25	1	British Aero. - Hawker Siddel. HS 125	2J/S+		
J328	4	Fairchild Dornier - 328JET, Envoy 3	2J/S+		
LJ23	1	Bombardier - Learjet 23	2J/S	TFE731-2-2B	Learjet 35/36
LJ24	28	Bombardier - Learjet 24	2J/S+		
LJ25	75	Bombardier - Learjet 25	2J/S+		
LJ31	28	Bombardier - Learjet 31	2J/S+		
LJ35	498	Bombardier - Learjet 35	2J/S+		
LJ36	1	Bombardier - Learjet 36	2J/S+		Learjet 35/36
LJ45	79	Bombardier - Learjet 45	2J/S+	TFE731-2-2B	Learjet 35/36
LJ55	39	Bombardier - Learjet 55	2J/S+	TFE731-2-2B	Learjet 35/36
LJ60	110	Bombardier - Learjet 60	2J/S+	TFE731-2-2B	Learjet 35/36
LR24	1	Bombardier - Learjet 24	2J/S		
LR25	1	Bombardier - Learjet 25	2J/S+		
LR31	2	Bombardier - Learjet 31	2J/S+		
LR35	6	Bombardier - Learjet 35	2J/S+		Learjet 35/36
LR36	1	Bombardier - Learjet 36	2J/S+		Learjet 35/36
LR45	1	Bombardier - Learjet 45	2J/S+	TFE731-2-2B	Learjet 35/36
LR60	2	Bombardier - Learjet 60	2J/S+	TFE731-2-2B	Learjet 35/36
M20	1	Mooney Aircraft - Mark 20	1P/S	IO-360-B	Cessna 172
M20J	1	Mooney Aircraft - Mark 20	1P/S	IO-360-B	Cessna 172

Type	Number of LTO Cycles	Aircraft Name	Number of Engine	Engine Type	Equivalent Aircraft Used in Modeling
M20K	1	Mooney Aircraft - Mark 20	1P/S	IO-360-B	Cessna 172
M20P	6	Mooney Aircraft - Mark 20	1P/S	IO-360-B	Cessna 172
MD10	141	McDonnell-Douglas - MD-10	3J/H		DC10
MD11	28	McDonnell-Douglas - MD-11	3J/H		
MD80	1,763	McDonnell-Douglas - MD-80	2J/L		
MD81	46	McDonnell-Douglas - MD-81	2J/L		
MD82	6,489	McDonnell-Douglas - MD-82	2J/L		
MD83	1,388	McDonnell-Douglas - MD-83	2J/L		
MD87	13	McDonnell-Douglas - MD-87	2J/L		
MD88	8	McDonnell-Douglas - MD-88	2J/L		
MD90	1	McDonnell-Douglas - MD-90	2J/L		
MO20	1	Mooney Aircraft - Mark 20	1P/S	IO-360-B	Cessna 172
MU2	504	Mitsubishi Aircraft - MU-2, Marquise	2T/S	PT6A-65B	BH-1900
MU2B	1	Mitsubishi Aircraft - MU-2, Marquise	2T/S	PT6A-65B	BH-1900
MU30	1	Mitsubishi Aircraft - MU-300 Diamond	2J/S+		
MX7	1	Mitsubishi Aircraft - Super Rocket, Star	1P/S	0-360-C1F	Cessna 172
P180	1	Piaggio - P-180 Avanti	2T/S	PT6A-66	BH-1900
P28A	8	Piper - Archer, Cadet, Cherokee	1P/S		
P28R	2	Piper - Archer, Cadet, Cherokee	1P/S		
P32T	1	Piper - Lance 2	1P/S	IO-360-B	Cessna 172
P46T	12	Piper - PA-46-500TP Malibu Meridian	1P/S	IO-360-B	Cessna 172
PA24	1	Piper - Comanche	1P/S	IO-360-B	Cessna 172
PA27	5	Piper - PA-23-235/250 Aztec	2P/S		
PA28	4	Piper - Archer, Cadet, Cherokee	1P/S		
PA30	8	Piper - PA-30/39 Twin Comanche	2P/S	IO-360-B	Cessna T337
PA31	11	Piper - Navajo, Navajo Chieftain, Chieftain	2P/S		
PA32	39	Piper - PA-32 Cherokee Six, Six, Saratoga	1P/S	IO-360-B	Cessna 172
PA44	1	Piper - Seminole, Turbo Seminole	2P/S	IO-360-B	Cessna T337
PA46	9	Piper - Malibu, Malibu Mirage	1P/S	IO-360-B	Cessna 172
PA60	1	Piper - Aerostar	2P/S	IO-360-B	Cessna T337
PAY2	1	Piper - PA-31T-620.T2-620	2T/S	PT6A-45	ATR42-400
PC12	40	Pilatus Flugzaugwerke PC-12, Eagle	1T/S	PT6A-67B	User Defined Aircraft
PRM1	18	Beech - Premier 1, 390	2J/S+	FJ442A	400 Beechjet
R722	2	Boeing - 727-200RE Super 27	3J/L		
SBR1	6	Rockwell - NA-265 Sabre 40/60/65	2J/S+	JT8D-7	400 Beechjet
SF34	428	Saab - SF-340	2T/S+		
SH36	6	Short Brothers - 360, SD3-60	2T/S+		
SR20	1	Cirrus - SR20	1P/S	IO-360-B	Cessna 172
SW2	4	Fairchild - Merlin 2	2T/S	TPE 331	Swearingen Merlin
SW3	92	Fairchild - Merlin 3, Fairchild 300	2T/S+	TPE 331-3	Swearingen Metro 2
SW4	344	Fairchild - SA-226AC, SA-227 Metro	2T/S+	TPE 331-3	Swearingen Metro 2
T38	2	Northrop - T-38, AT-38 Talon	2J/S+	TFE731-2-2B	Learjet 35/36
TB7	1	Grumman – Avenger	1T/S+	ARMY - Historical	Porter PC6/B2
WW24	2	IAI/Gulfstream - 1124 Westwind	2J/S+		
Total	62,452*				

*Due to rounding of aircraft operations, this total is slightly different than the total operations used in the EDS model.

Table B. 2005 GA Operations for Jet Engines at SAIA

Aircraft Name	Engine Type	Number of LTO Cycles
Bell 206 (Helicopter)	250B17B	170
Beechjet 400	JT15D-5 (A & B)	874
Premier 1390	JT15D-5 (A & B)	64
B747-200	JT9D-7Q	21
B737-700	CFM56-7B22	43
B757-200	PW2037	43
Bombardier CRJ700	CF34-8C1	362
Learjet 24D	CJ610-6	213
Learjet 25B	CJ610-6	852
Learjet 31	TFE731-2	916
Learjet 35/36	TFE 731-2-2B	3,346
BAE 125-700	TFE731-3	2,131
CL601-3A	CF34-3A	511
560 Citation V	JT15D-5 (A & B)	3,260
CITATION X	AE3007C	469
CL601-3A	CF34-3A	767
500 Citation	JT15D-1A & 1B	5,114
Falcon 2000EX	PW308C	170
Falcon 20	CF700-2D	1,214
Falcon 50	TFE731-3	490
Gulfstream V	BR700-710A1-10 Gulf V	256
Gulfstream IV	TAY Mk611-8	1,108
IAI 1124	TFE731-3	1,215
C-141	TF33-P-3/103	192
MU-300	JT15D-4 (B, C, D)	234
Rockwell 265 Sabre	JT15D-5 (A & B)	256
Galaxy (IAI) G200	PW306A	1,492
Total		25,783

Table C. 2005 GA Operations for Turbo-Prop Aircraft at SAIA

Aircraft Name	Engine Type	Number of LTO Cycles
TBM TB-700 Aerosp	User Defined Aircraft	602
Beech King Air 100	PT6A-28	498
Beech King Air 200	PT6A-41	1,432
Beech King Air 90	PT6A-28	2,926
Beech King Air 350	PT6A-60, -60A, -60AG	851
C425	User Defined Aircraft	228
Cessna 441 Conquest2	TPE331-8	602
Swearingen Metro 2	TPE331-3	436
Swearingen Merlin	TPE331-3	394
BH-1900	PT6A-65B	333
PC12	User Defined Aircraft	21
TBM TB-700 Aerosp	User Defined Aircraft	602
Total		8,323

Table D. 2005 GA Operations for Piston Aircraft at SAIA

Aircraft Name	Engine Type	Number of LTO Cycles
Aztec	TIO-540-J2B2	32
Cessna T337	IO-360-B	6,335
Cherokee six	TIO-540-J2B2	645
Twin Comanche	IO-320-D1AD	129
Twin Beech 18	User Defined Aircraft	97
Cessna 150	O-200	3,224
Cessna 172 Skyhawk	IO-360-B	7,625
Cessna 208 Caravan	PT6A-114	113
Piper PA-28	O-320	951
PA-31T Cheyenne	PT6A-28	580
Rockwell Commander	IO-360-B	113
Total		19,844

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KEY WORDS

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