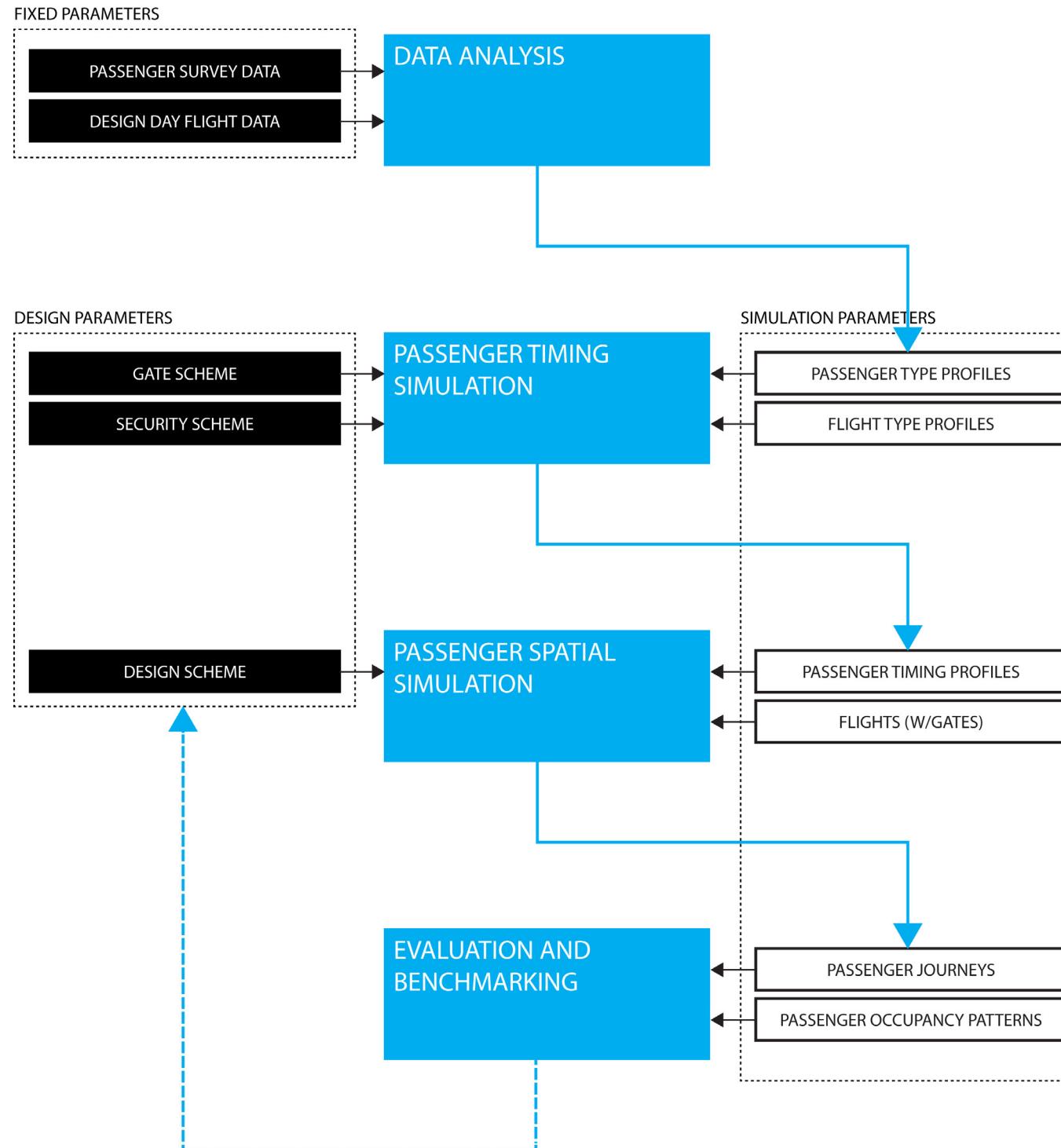


SUPERSPACE

Aviation simulation

A system for air-side passenger behavior simulation

Index



01 - Data Analysis:

- Passenger type distribution and profile generation
- Aircraft type and flight profile generation

02 - Passenger Timing Simulation:

- Gate packing optimisation and spatial configuration
- Curbside - departure passenger timing event generation

03 - Passenger Spatial Simulation:

- Passenger behavior
- Passenger Movement
- Passenger Density

04 - Evaluation and Benchmarking

- Output analysis
- Optimization metrics
- Performance comparison

01

Data Analysis

PASSENGER
Type : leisure.domestic.departing
Gender : F
bags : false
isPreCheck : true
isTransfer : false
Flight Name : AA to Los Angeles, Boeing 737-800
Timing Profile :
brshop / shop : 52 / 22
brfood / food : 73 / 51

Preliminary data collection and analysis of key metrics for building airport specific passenger and flight profiles.

Specifications for passenger types:

- Propensities towards air-side behavioral patterns (buying from duty-free, F+b, etc...)
- Propensities towards land-side behavioral patterns (bag-check, global entry, pre-check, etc...)
- Arrival patterns

Specifications for flight types:

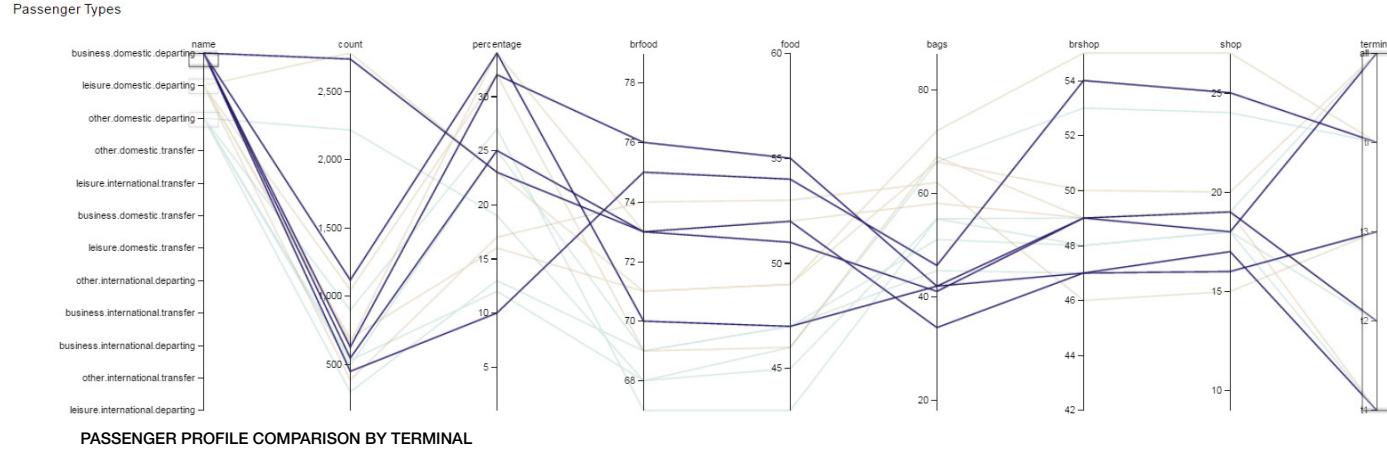
- Propensities towards passenger type distributions
- Current/expected turnaround times by airline/aircraft
- Design day flight schedule/gate scheme
- Load factor

DATA ANALYSIS

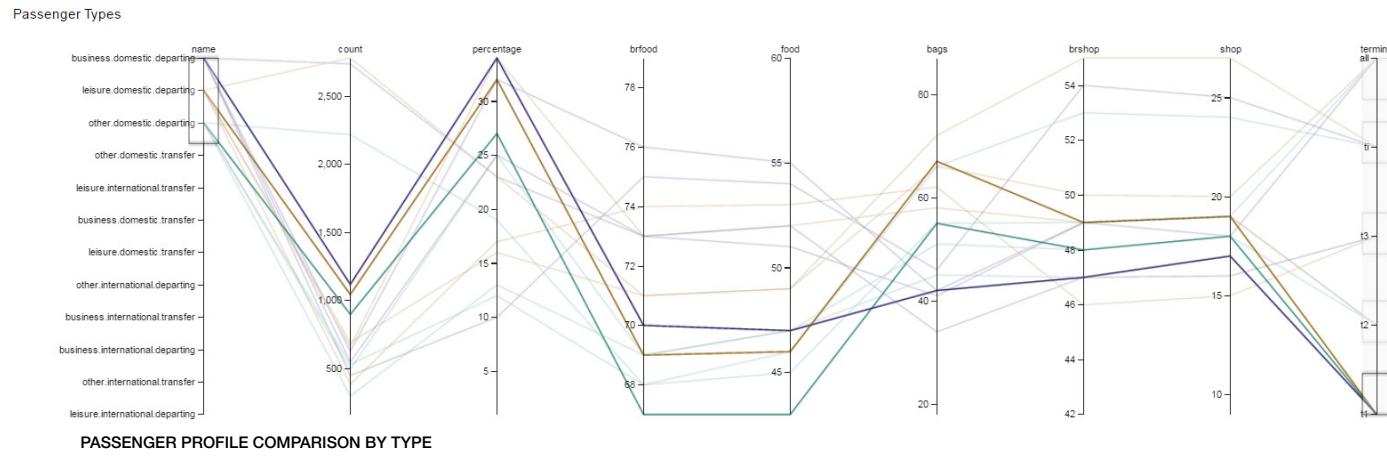
PASSENGER TYPE DISTRIBUTION AND PROFILE GENERATION

In order to accurately simulate the behavioral patterns of passengers in the airport, preliminary work was done to distill passenger data into distinct types. An analysis of ~15000 responses to passenger satisfaction surveys conducted by SFO over the last 4 years (weighted by SFO to reflect actual customer traffic disbursement), in addition to prior research done by the ARCP, led to 12 distinct types (and underlying sub-types) which were used to build a holistic picture of passenger behavioral patterns in the airport:

BUSINESS | LEISURE | OTHER / DOMESTIC | INTERNATIONAL / DEPARTING | TRANSFER



Output data from the analysis is an interactive graphic allowing for relative comparisons between occupancy patterns filtered by type, by terminal, or by propensity. The image above is a snapshot showing the purchasing propensities and total percentages of business.domestic.departing passengers (purple) for all 4 terminals of the San Francisco International Airport, as well as average propensities across all terminals. In addition, the cyan and orange represent equivalent propensities for leisure.domestic.departing and other.domestic.departing respectively for comparison.



The image above shows the relative comparisons of all three types of domestic passenger, filtered to display for terminal 1 only.

Passenger propensities towards un-measured variables were complemented by existing data sets for similar airports. In this case, the propensity of a passenger to browse a shop was not accounted for in the survey data. However, the Denver International Airport reported a set of data that showed a clear correlation between passenger browsing propensities and passenger buying propensities. Statistical linear regression was used to apply this correlation to the browsing propensity of SFO passengers.

In addition, some assumptions were needed regarding the frequency of passenger bathroom breaks, walking speeds and the propensity to revisit certain concessions. This information could easily be inbedded within the simulation if it were available.

TOTAL PASSENGER PROFILES

Name	Count	% Total Count	% Bags	% br Food	% Food	% br Shop	% Shop	Weighted
all	11759	100	53	72	50	48	17	false
all.business	3643	31	42	73	52	48	17	false
all.business.domestic	3065	26	39	73	52	49	18	false
Name	2719	23	41	73	51	49	18	false
Name	347	3	73	71	49	42	9	false
all.business.international	577	5	58	73	49	42	9	false
Name	410	3	73	71	49	42	9	false
Name	167	1	23	79	60	43	11	false
all.business.departing	3129	27	45	72	51	48	17	false
all.business.transfer	514	4	24	78	55	48	17	false
all.leisure	4849	40	62	72	51	48	17	false
all.leisure.domestic	3348	28	59	72	50	50	20	false
all.leisure.international	1301	11	70	73	52	42	10	false
Name	954	8	87	72	51	42	10	false
Name	337	3	22	77	55	42	9	false
all.leisure.departing	3730	32	71	71	49	45	15	false
all.leisure.transfer	919	8	25	77	55	45	13	false
all.other	3467	29	54	69	49	48	17	false
all.other.domestic	2672	23	50	69	49	48	20	false
Name	2198	19	65	69	45	45	19	false
Name	474	4	25	72	51	52	23	false
all.other.international	795	7	67	69	47	42	9	false
all.other.departing	2729	23	61	68	45	45	17	false
all.other.transfer	738	6	27	73	51	48	18	false
all.domestic	9366	77	50	72	50	49	19	false
all.international	2873	23	67	72	51	42	10	false
all.departing	9588	82	60	71	49	48	17	false
all.transfer	2171	18	25	76	55	47	15	false

UNIQUE PASSENGER PROFILES

Name	Count	% Total Count	% Bags	% br Food	% Food	% br Shop	% Shop	Weighted
all.business.domestic.departing	2719	23	41	73	51	49	18	false
all.business.international.departing	347	3	25	77	58	50	20	false
all.business.international.transfer	410	3	73	71	49	42	9	false
all.business.transfer	167	1	23	79	60	43	11	false
all.leisure.domestic.departing	2766	24	66	71	49	50	20	false
all.leisure.international.departing	582	5	26	77	57	47	16	false
all.leisure.international.transfer	964	8	87	72	51	42	10	false
all.leisure.transfer	337	3	22	77	58	42	9	false
all.other.domestic.departing	2198	19	55	68	45	49	19	false
all.other.domestic.transfer	474	4	29	72	51	52	23	false
all.other.international.departing	531	5	85	57	44	42	9	false
all.other.international.transfer	284	2	30	74	53	43	10	false

AIRCRAFT PROFILES

Name	Count	% Total Count	% Bags	% br Food	% Food	% br Shop	% Shop	Weighted
all	11759	100	53	72	50	48	17	false
all.business	3643	31	42	73	52	48	17	false
all.business.domestic	3065	26	39	73	52	49	18	false
Name	2719	23	41	73	51	49	18	false
Name	347	3	73	71	49	42	9	false
all.business.international	577	5	58	73	49	42	9	false
Name	410	3	73	71	49	42	9	false
all.business.departing	3129	27	45	72	51	48	17	false
all.business.transfer	514	4	24	78	55	48	17	false
all.leisure	4849	40	62	72	51	48	17	false
all.leisure.domestic	3348	28	59	72	50	50	20	false
Name	954	8	87	72	51	42	10	false
Name	337	3	22	77	55	42	9	false
all.leisure.international	1301	11	70	73	52	42	10	false
Name	964	8	87	72	51	42	10	false
Name	337	3	22	77	58	42	9	false
all.leisure.departing	3730	32	71	71	49	45	15	false
all.leisure.transfer	919	8	25	77	55	45	13	false
all.other	3467	29	54	69	49	48	17	false
all.other.domestic	2672	23	50	69	49	48	20	false
Name	2198	19	65	69	45	45	19	false
Name	474	4	25	72	51	52	23	false
all.other.international	795	7	67	69	47	42	9	false
all.other.departing	2729	23	61	68	45	45	17	false
all.other.transfer	738	6	27	73	51	48	18	false
all.domestic	9366	77	50	72	50	49	19	false
all.international	2873	23	67	72	51	42	10	false
all.departing	9588	82	60	71	49	48	17	false
all.transfer	2171	18	25	76	55	47	15	false

PASSENGER PROFILE TREE AND UNIQUE PASSENGER TYPES (WITH PROPENSITIES)

profiles.csv profiles.json

Hide Results Save

Show Results Hide Results

>> PASSENGER TIMING SIMULATION

0.9 Load Factor

0 to 24 Time Frame

American Airlines Filter Flights

leisure.departing Filter Passengers

Run Show Results

Show Results Hide Results

All	Terminal
Run	Show Results
Hide Results	
Save	aircraft.json
<input type="checkbox"/> aircraft.csv	<input checked="" type="checkbox"/> aircraft.json

DATA ANALYSIS

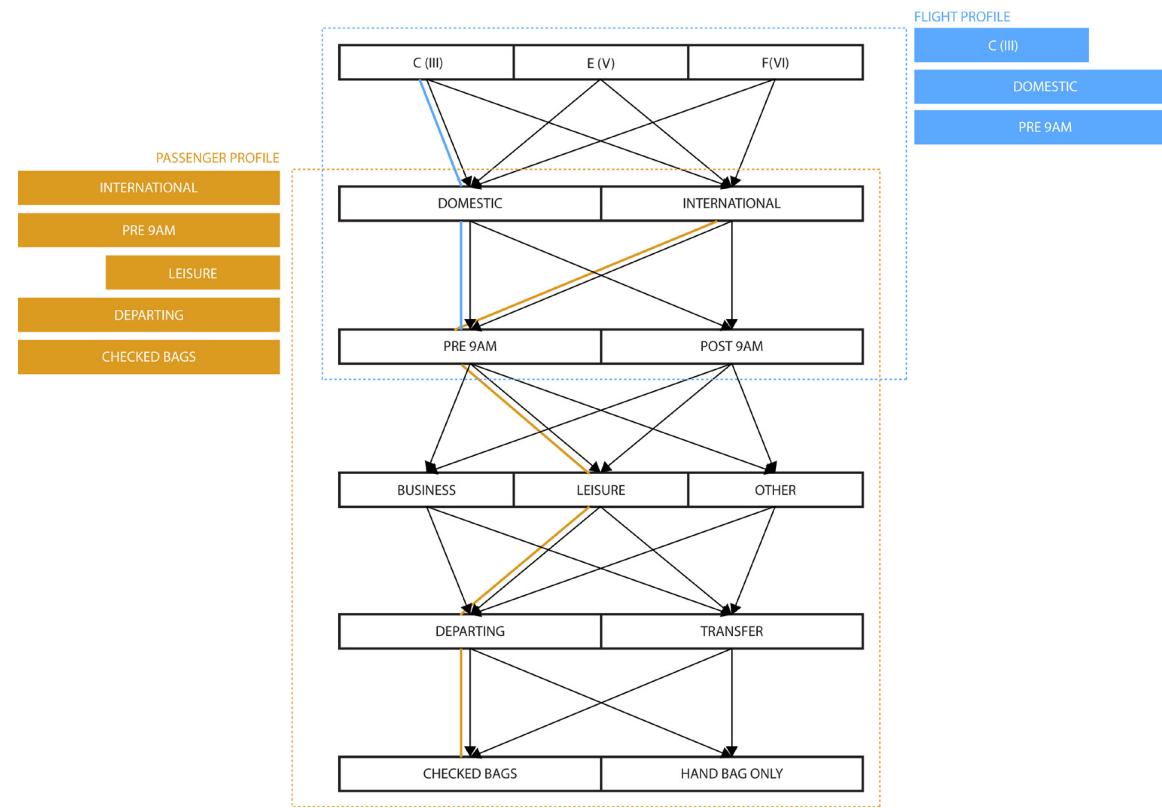
AIRCRAFT TYPE AND FLIGHT PROFILE GENERATION

Cross referencing passenger survey data with a database of existing and past departing flights, and information about carrier, aircraft and turnaround times results in a set of flight profiles that store replicatable simulation information regarding passenger type disbursement, arrival rates and other key information needed to generate a set of passengers for each flight, specific to that flight's profile.



As a methodology to distill and categorize the data, flight and passenger profiles belong to a tree of possible attribute permutations. Each attribute's distinct nature eliminates passenger/flight crossover between types (e.g. passengers cannot be domestic and international), and provides a framework by which to label passenger profiles for simulation and propensity assignment.

In addition, passenger types that resulted in little to no respondents were culled from the flight profiles - either due to incompatible types (e.g. F.international : domestic.leisure.transfer), or minimal percentages (e.g. C.international : international.business.transfer).



ARRIVAL DISTRIBUTIONS BY FLIGHT AND PASSENGER TYPE

TOTAL PASSENGER PROFILES

UNIQUE PASSENGER PROFILES

AIRCRAFT PROFILES

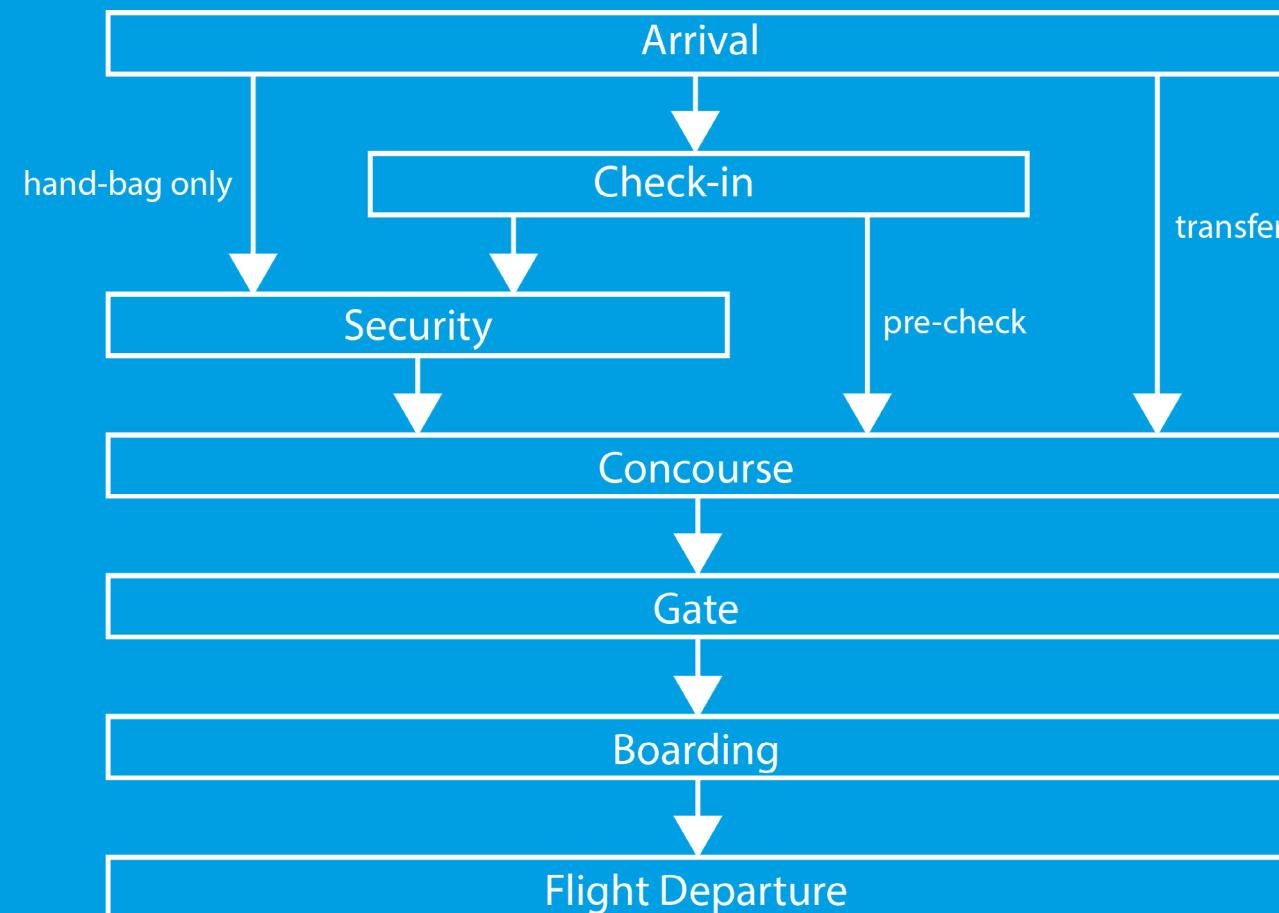
C		Name	Count	% Passengers	Weighted	Arrival Distribution
		C.domestic		2363		--
		C.business.domestic.departing		789	33	0.000
		C.business.domestic.transfer		272	11	0.000
		C.leisure.domestic.departing		673	29	0.000
		C.leisure.domestic.transfer		147	6	0.000
		C.other.domestic.departing		548	23	0.000
		C.other.domestic.transfer		113	5	0.000
E		Name	Count	% Passengers	Weighted	Arrival Distribution
		E.domestic		444		--
		E.business.domestic.departing		75	9	0.000
		E.business.domestic.transfer		21	2	0.000
		E.leisure.domestic.departing		160	36	0.000
		E.leisure.domestic.transfer		53	12	0.000
		E.other.domestic.departing		101	23	0.000
		E.other.domestic.transfer		34	8	0.000
F		Name	Count	% Passengers	Weighted	Arrival Distribution
		F.domestic		43		--
		F.leisure.domestic.departing		30	70	0.000
		F.leisure.domestic.transfer		1	2	0.000
		F.other.domestic.departing		10	23	0.000
		F.other.domestic.transfer		2	5	0.000
F		Name	Count	% Passengers	Weighted	Arrival Distribution
		F.international		144		--
		F.business.international.departing		23	16	0.000
		F.business.international.transfer		7	5	0.000
		F.leisure.international.departing		58	40	0.000
		F.leisure.international.transfer		9	6	0.000
		F.other.international.departing		35	24	0.000
		F.other.international.transfer		12	8	0.000

>> PASSENGER TIMING SIMULATION	
0.9	Load Factor
0 to 24	Time Frame
American Airlines	Filter Flights
leisure.departing	Filter Passengers
Run	Show Results
Show Results	

AIRCRAFT PROFILE TREE AND PASSENGER TYPE DISTRIBUTIONS

02

Passenger Timing Simulation



The passenger timing model generates timing profiles for all passengers from curbside to departure using passenger profiles, arrival rates and flight type distributions. These journeys are split into a series of timing events that feed into the passenger spatial simulation.

The system outputs a series of passengers with corresponding timings, as well as :

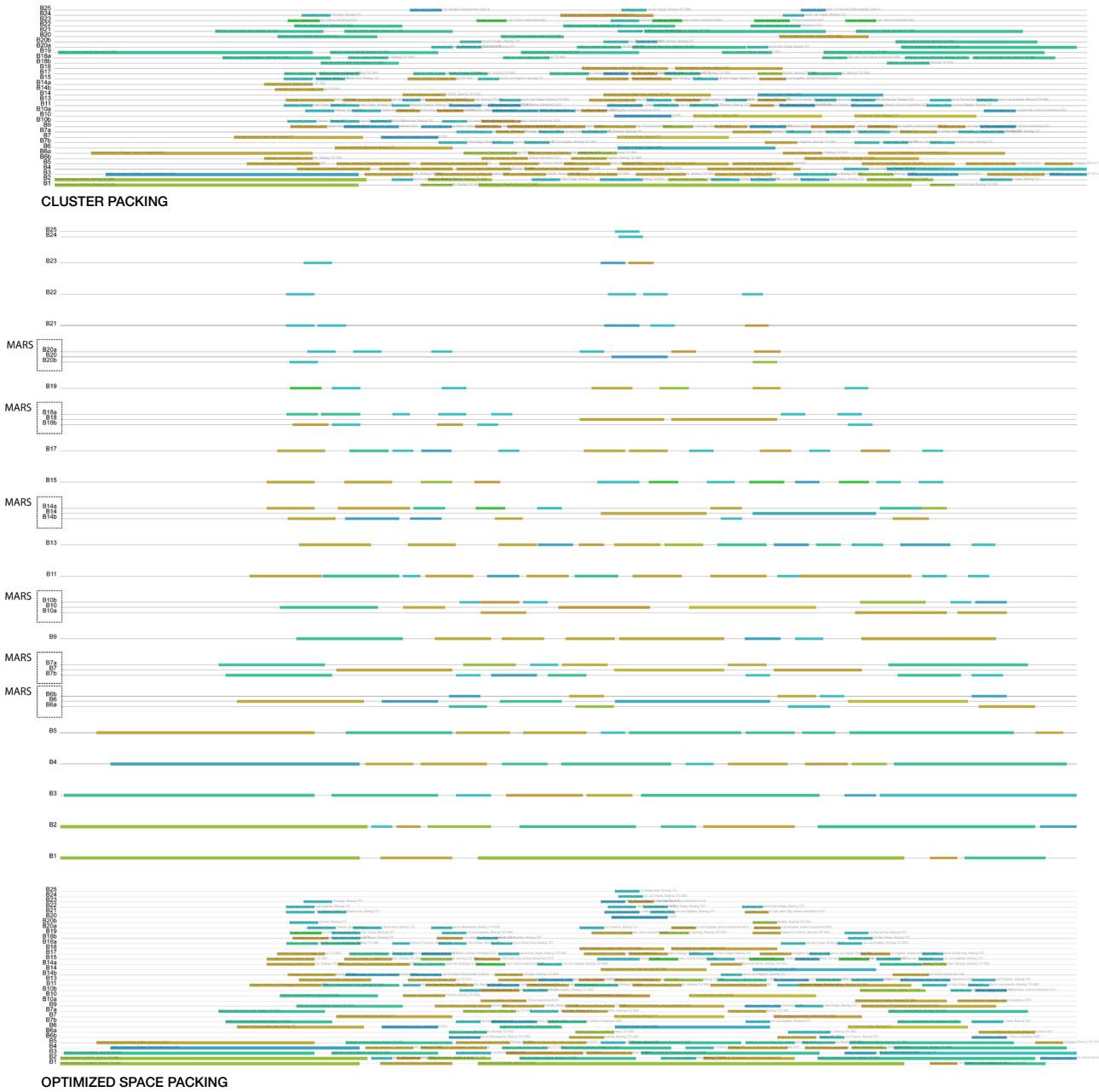
- Information about arrival rates and queuing times based on the current design scheme and flight schedule
- Optimized gate allocation (if none present) based on the airport specific flight profiles, allowing the spatial simulation to be linked to a CAD plan for the simulation of concession usage on the given design day.

All	Terminal
Run	Show Results
Show Results	Show Results
Show Results	Show Results
Show Results	Show Results

PASSENGER TIMING SIMULATION

GATE PACKING OPTIMIZATION AND SPATIAL CONFIGURATION

For the output from the passenger timing simulation to be linked to an existing design scheme, peak design day flight schedule input is required as a measure of passenger flow. In this case, the schedule included all desired flights out of SFO on a maximum capacity day in 2023. This data was then filtered by terminal to include flights strictly for Terminal 1.



Given that flights from the design day have not been assigned a gate, and in order to tie the simulation to the plan of a test fit during the design phase, two kinds of gate packing are implemented to simulate passenger flow through the concourse. Both account for Multi Aircraft Ramping System (MARS) gates, gate capacity and design group restrictions during flight allocation. A database of turnaround times by aircraft, and by airline were used along with aviation industry standards for time padding on interval extents in order to allocate the necessary amount of time for each flight.

- Optimized space packing assigns flights to gates as closely as possible, potentially eliminating unnecessary gates. Airlines are distributed without location preferences on the concourse and there is no attempt to keep flights from a single airline together.

- Cluster packing is slightly less optimal, but maintains groups of airlines together as well as specific gate allocations to airlines.

TOTAL PASSENGER PROFILES

UNIQUE PASSENGER PROFILES

AIRCRAFT PROFILES

FLIGHTS

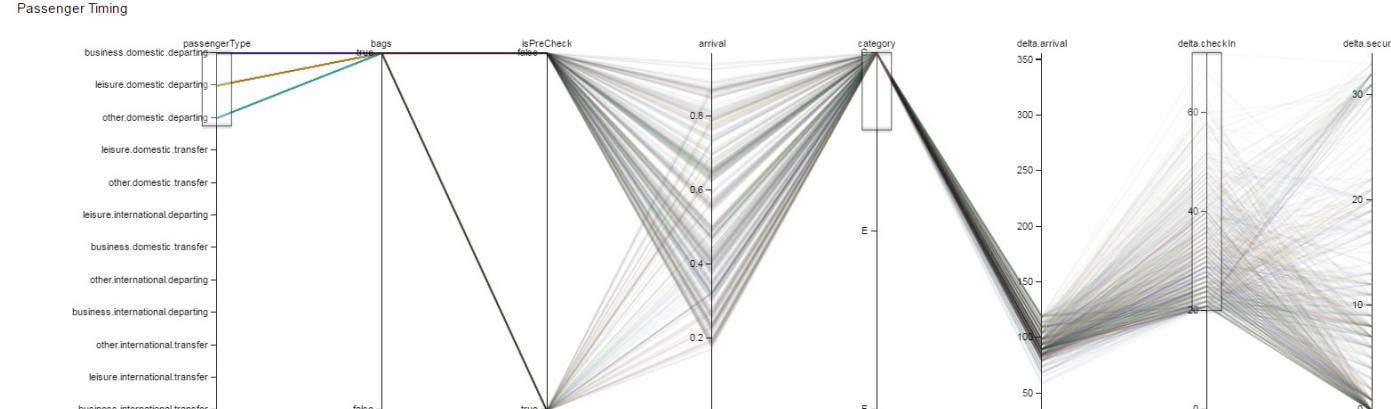
Name	Code	Flight ID	Load Factor	Seats	Passenger Count	Gate	Departure Time
American Airlines to Phoenix, Airbus Industries A321	AA	f1f4993-4005-4966-9ae1-1a2228948a33	1	183	155	B6a	06:00:00
American Airlines to Charlotte, Airbus Industries A321	AA	8090023c-3aa7-4b05-a9d0-63379047a4d0	1	183	155	B3	10:59:59
American Airlines to Philadelphia, Airbus Industries A321	AA	0852039e-370c-4391-0914-502065f9080a	1	183	167	B6b	10:59:59
American Airlines to Charlotte, Airbus Industries A321	AA	202075a7-f518-4223-a284-35900793610	1	183	155	B5	11:13:00
American Airlines to Atlanta, Airbus Industries A321	AA	1024038a-4005-4966-9ae1-1a2228948a33	1	183	151	B1	11:13:00
American Airlines to Phoenix, Airbus Industries A321	AA	89593a99-c0de-40e5-9e65-7e63359a2c3a	1	183	168	B6a	12:00:00
American Airlines to Charlotte, Airbus Industries A321	AA	6011c37-4922-453a-89d5-7e63359a2c3a	1	183	170	B15	12:30:00
American Airlines to Philadelphia, Airbus Industries A321	AA	123239a8-7655-4890-9100-355007303075	1	183	166	B5	13:30:00
American Airlines to Phoenix, Airbus Industries A321	AA	d0c7774d-55c0-4879-e0a8-e104ee455d83	1	183	160	B5	15:42:00
American Airlines to Philadelphia, Airbus Industries A321	AA	695f0056-4747-e29t-0014-16e305c03099	1	183	173	B4	17:19:59
American Airlines to Phoenix, Airbus Industries A321	AA	a1690d40-305c-4945-9855-52d09f8cc0fa	1	183	178	B5	17:10:00
American Airlines to Philadelphia, Airbus Industries A321	AA	0f12a2b8-a735-480e-8510-9af2e20a0ad1	1	183	175	B6a	20:00:00
American Airlines to Phoenix, Airbus Industries A321	AA	35e6004c-305a-4945-9855-52d09f8cc0fa	1	183	179	B7a	20:30:00
American Airlines to Atlanta, Airbus Industries A321	AA	00a07f20-4005-4966-9ae1-1a2228948a33	1	183	151	B1	20:30:00
American Airlines to New York, Airbus Industries A321	AA	5a5fd22c-8a17-4244-8a73-5a97178a47	1	183	101	B3	20:59:59
American Airlines to Phoenix, Airbus Industries A321	AA	c020b17a-0745-4442-341f-1629a691eeef	1	183	163	B4	09:15:00
American Airlines to Philadelphia, Airbus Industries A321	AA	d1a391a4-d353-4f1c-a050-e12138299c08	1	183	162	B5	09:09:59
American Airlines to Philadelphia, Airbus Industries A321	AA	e7a1a7e-420b-456b-87b1-75079f6af3	1	183	179	B5	08:18:00
American Airlines to Charlotte, Airbus Industries A321	AA	f2c230d-4165-4334-a785-700aae050e04	1	183	164	B4	07:20:00
American Airlines to Los Angeles, Boeing 737-800	AA	3d02a2f-41ff-47c3-8a81-e433a776090	1	149	151	B5	10:04:00
American Airlines to Chicago, Boeing 737-800	AA	0e6a037-4209-40fe-8e03-96761233	1	149	146	B7a	10:35:59
American Airlines to Chicago, Boeing 737-800	AA	701195a2-4105-4940-9777-3885502841	1	149	142	B7a	10:35:59
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	020303-4005-4945-9855-52d09f8cc0fa	1	149	145	B5	11:35:59
American Airlines to Miami, Boeing 737-800	AA	05166529-3112-4523-8a73-5a97178a47	1	149	144	B5	12:54:59
American Airlines to Miami, Boeing 737-800	AA	336fb23e-12d4-438c-a309-8264a14a3798	1	149	144	B3	13:02:00
American Airlines to Los Angeles, Boeing 737-800	AA	ac1f1a3-8950-4071-8522-0615059d7e	1	149	135	B6b	12:49:59
American Airlines to Chicago, Boeing 737-800	AA	d13333a7-37d3-4504-bee9-104571607a5	1	149	141	B13	13:30:00
American Airlines to Chicago, Boeing 737-800	AA	5eaa560-4324-a6a9-0013-0e9f10341518	1	149	141	B4	14:10:00
American Airlines to Los Angeles, Boeing 737-800	AA	b55250d0-4007-4209-8058a27103	1	149	142	B15	14:19:59
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	020303-4005-4945-9855-52d09f8cc0fa	1	149	145	B5	15:35:59
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	51d4a381-4385-4252-8683-23176573	1	149	145	B5	16:35:59
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	33d03673-3823-4252-8683-23176573	1	149	145	B5	16:35:00
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	c70e023-0773-4105-bc23-720005551	1	149	133	B7a	16:35:59
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	1643994-3a5b-4879-8160-40675d3d9026	1	149	136	B13	16:59:59
American Airlines to Los Angeles, Boeing 737-800	AA	40b1618-0431-4450-8655-7f5f19301215	1	149	140	B7b	17:18:00
American Airlines to Chicago, Boeing 737-800	AA	1ea75807-0005-4879-8438-6560540f616	1	149	147	B6a	17:50:00
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	80ba082-5504-4025-ba50-296036761126	1	149	147	B6b	20:05:00
American Airlines to Miami, Boeing 737-800	AA	46596430-4007-4209-8058a27103	1	149	142	B5	20:35:00
American Airlines to Chicago, Boeing 737-800	AA	020303-4005-4945-9855-52d09f8cc0fa	1	149	145	B5	20:35:00
American Airlines to Chicago, Boeing 737-800	AA	5ea241f-411f-4485-8307-2050511c9f	1	149	144	B14	06:15:00
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	ad7f3859-0304-4871-8a6e-0497a2d5cf	1	149	142	B15	09:20:00
American Airlines to Miami, Boeing 737-800	AA	42c139f-1937-4865-8160-1300077215	1	149	135	B14	09:20:00
American Airlines to Los Angeles, Boeing 737-800	AA	010297-37a1-4723-0a39-53a01405300	1	149	135	B13	09:25:59
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	4096975-5572-4049-8265-65605634613	1	149	141	B6b	09:00:00
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	7ea1062-3340-4536-0169-40d030303031	1	149	142	B13	07:50:00
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	8a1f029a-0349-4520-0250-11e45104749	1	149	142	B13	08:10:59
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	0349540-4115-4538-0169-40d030303031	1	149	142	B13	08:30:00
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	5a0241f-411f-4485-8307-2050511c9f	1	149	144	B14	06:15:00
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	ad7f3859-0304-4871-8a6e-0497a2d5cf	1	149	142	B15	09:20:00
American Airlines to Los Angeles, Boeing 737-800	AA	42c139f-1937-4865-8160-1300077215	1	149	135	B14	09:20:00
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	010297-37a1-4723-0a39-53a01405300	1	149	135	B13	09:25:59
American Airlines to Dallas-Fort Worth, Boeing 737-800	AA	4096975-5572-4049-8265-65605634613	1	149	141	B6b	09:00:00
Air France to Paris, Airbus A380	AF	45a0b39-5262-40a8-8900-56391559862	1	516	510	B10	17:50:00
Air France to Paris, Boeing 777	AF	16739340-d340-4a85-8265-5302071a	1	310	297	B7	15:42:00
Air France to Paris, Boeing 777	AF	1740027-0271-4105-0e69-52633030648	1	310	298	B10	21:24:59
Air France to Seattle, Boeing 777-300	AF	1813099-2710-4204-8769-967273959a	1	157	147	B5	10:09:59
Air France to Seattle, Boeing 777-300	AF	020303-4005-4945-9855-52d09f8cc0fa	1	157	153	B2	11:53:59
Air France to Seattle, Boeing 777-300	AF	0570a95-4202-4049-8346-4023a0d0164	1	172	170	B1	08:15:00
Air France to Puerto Vallarta, Boeing 737-800	AF	4					

PASSENGER TIMING SIMULATION

CURBSIDE - DEPARTURE PASSENGER TIMING EVENT GENERATION

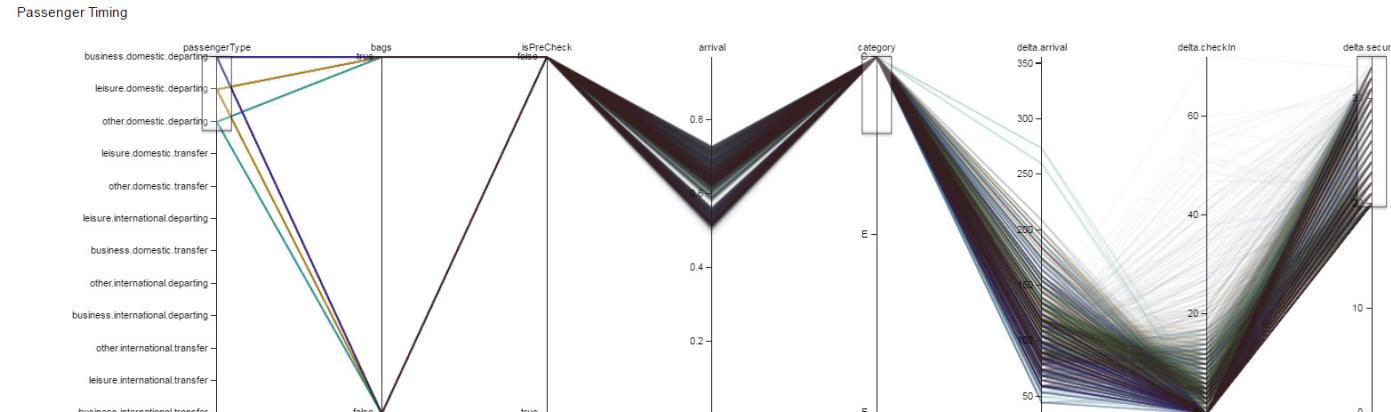
Using the pre-computed passenger types and aircraft types specific to the airport, and coupled with the design day flight schedule and design scheme variables, the preliminary passenger timing simulation produces a set of passengers with journey events for every flight out of the airport over the course of the design day:

ARRIVAL | CHECK-IN | SECURITY | CONCOURSE | GATE | BOARDING | DEPARTURE



DOMESTIC TYPE C PASSENGER TIMING FILTERED BY CHECK-IN TIME

Passenger check-in times are algorithmically computed using bespoke in-house Superspace methods, and are a function of the ARCP's LoS standards for acceptable queuing times and processing rates at check-in kiosks. This could be used to test various combinations of check-in kiosks and the corresponding effect on queuing times. Passenger arrival distribution rates and the percentage of passengers checking in bags versus carry-on only are derived from the pre-computed profiles specific to the flight type (i.e. domestic type C / international type F), load factor, and time of day (pre 9AM vs post 9AM).



DOMESTIC TYPE C PASSENGER TIMING FILTERED BY SECURITY TIME

Similarly, passenger security times are driven by passenger flow from check-in to security for all enplaning flights at a given time slice delta, as well as the current design scheme's security unit capacity. Flow rates are assumed to be around 140 passengers per hour per security unit (ARCP), or 1 passenger every $140/(60 \cdot n)$ units * delta. Variable security unit counts are implemented, as the current SFO design scheme provides a base of 10 security units for all passengers, with an additional 6 available to passengers without checked bags.

delta.change rates are not reflective of actual times from check-in to security. They are representative of the cumulative delay to passengers assuming a regular flow rate and walk times between events, so how much longer from 0 minutes the passenger will wait. For example, a passenger with an average security processing time of 30 sec, 5 min walk to security, and a **delta.security of 4 min** would have an actual time of 9.5 min from check-in to concourse.

TOTAL PASSENGER PROFILES

UNIQUE PASSENGER PROFILES

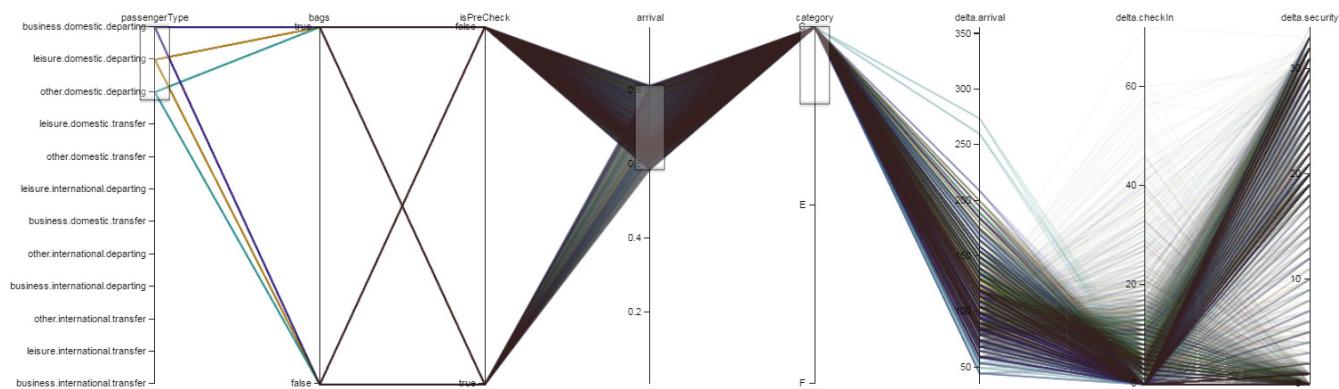
AIRCRAFT PROFILES

FLIGHTS

PASSENGERS

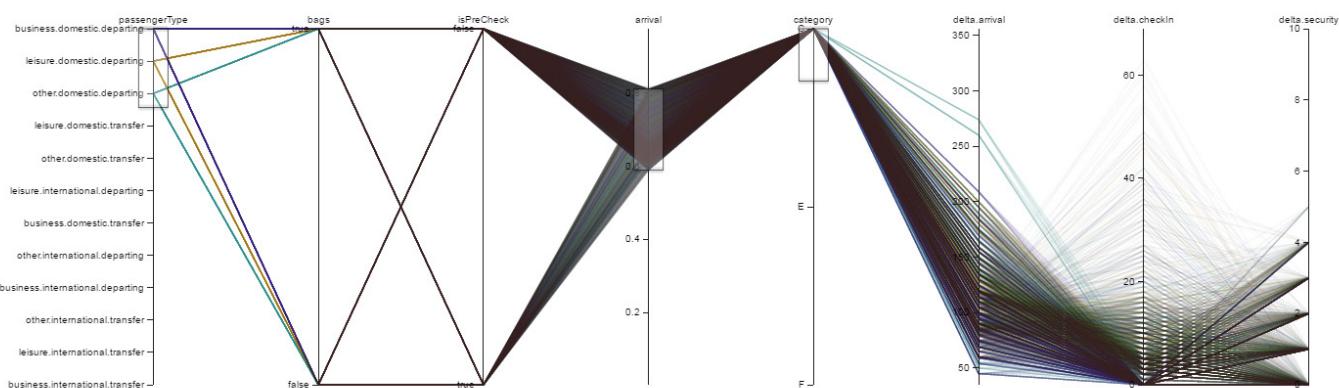
Name	Gender	Bags	Pre Check	Flight ID	Arrival	Security	Concourse	Gate	Boarding	Departure
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	05:06:00	05:06:00	05:14:00	05:39:00	05:38:00	05:00:00
all.business.domestic.departing	M	true	false	f1149973-4005-4966-99e1-1a222994ae33	05:06:00	05:06:00	05:14:00	05:39:00	05:38:00	05:00:00
all.business.domestic.departing	M	false	false	f1149973-4005-4966-99e1-1a222994ae33	05:06:00	05:06:00	05:14:00	05:39:00	05:38:00	05:00:00
all.business.domestic.departing	F	true	true	f1149973-4005-4966-99e1-1a222994ae33	05:00:00	05:04:00	05:14:00	05:40:00	05:40:00	05:00:00
all.business.domestic.departing	M	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:54:00	04:54:00	05:27:00	05:45:00	05:42:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:51:00	04:55:00	05:27:00	05:40:00	05:40:00	05:00:00
all.business.domestic.departing	M	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:51:00	04:51:00	05:27:00	05:42:00	05:42:00	05:00:00
all.business.domestic.departing	F	false	true	f1149973-4005-4966-99e1-1a222994ae33	04:46:00	04:46:00	05:39:00	05:48:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:41:00	04:41:00	05:37:00	05:47:00	05:45:00	05:00:00
all.business.domestic.departing	M	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:41:00	04:41:00	05:37:00	05:47:00	05:45:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:37:00	04:50:00	05:41:00	05:43:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:38:00	04:38:00	05:45:00	05:46:00	05:45:00	05:00:00
all.business.domestic.departing	M	false	true	f1149973-4005-4966-99e1-1a222994ae33	04:35:00	04:35:00	05:26:00	05:47:00	05:40:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:30:00	04:30:00	04:33:00	04:33:00	05:39:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:30:00	04:38:00	04:41:00	05:29:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:30:00	04:30:00	04:40:00	04:40:00	05:40:00	05:00:00
all.business.domestic.departing	M	false	true	f1149973-4005-4966-99e1-1a222994ae33	04:28:00	04:28:00	05:21:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:28:00	04:28:00	05:42:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:27:00	04:27:00	05:41:00	05:43:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:26:00	04:26:00	05:44:00	05:49:00	05:49:00	05:00:00
all.business.domestic.departing	M	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:21:00	04:26:00	05:38:00	05:44:00	05:44:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:20:00	04:24:00	05:38:00	05:40:00	05:40:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:19:00	04:19:00	05:40:00	05:40:00	05:40:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:18:00	04:18:00	05:43:00	05:48:00	05:48:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:17:00	05:39:00	05:43:00	05:43:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:44:00	05:44:00	05:44:00	05:00:00
all.business.domestic.departing	M	false	true	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:44:00	05:44:00	05:44:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	M	false	true	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	M	false	true	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	M	false	true	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	true	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	M	false	true	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00
all.business.domestic.departing	F	false	false	f1149973-4005-4966-99e1-1a222994ae33	04:09:00	04:09:00	05:45:00	05:45:00	05:45:00	05:00:00

Passenger Timing



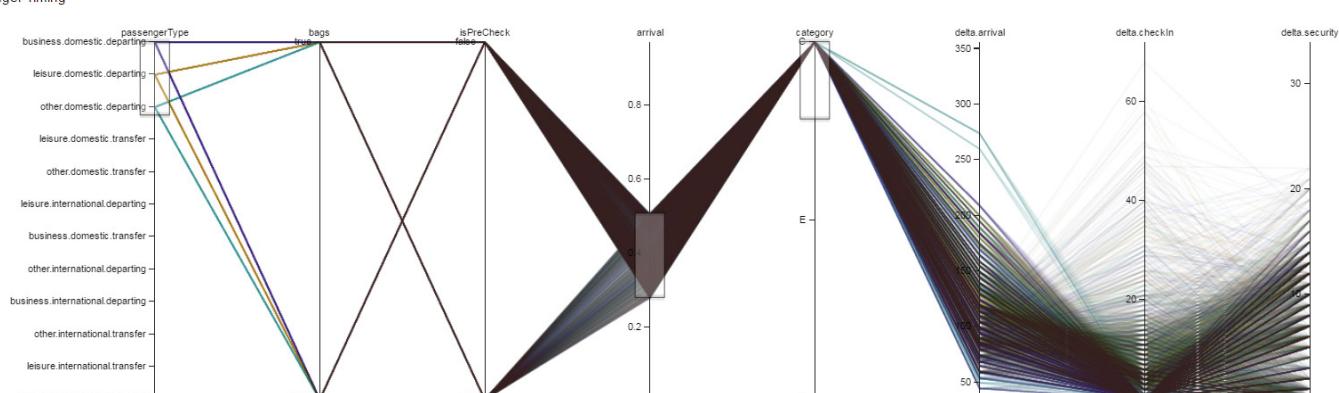
DOMESTIC PASSENGER SECURITY TIMES | AFTERNOON PEAK - SCHEME I (10/12 SECURITY LINES)

Passenger Timing



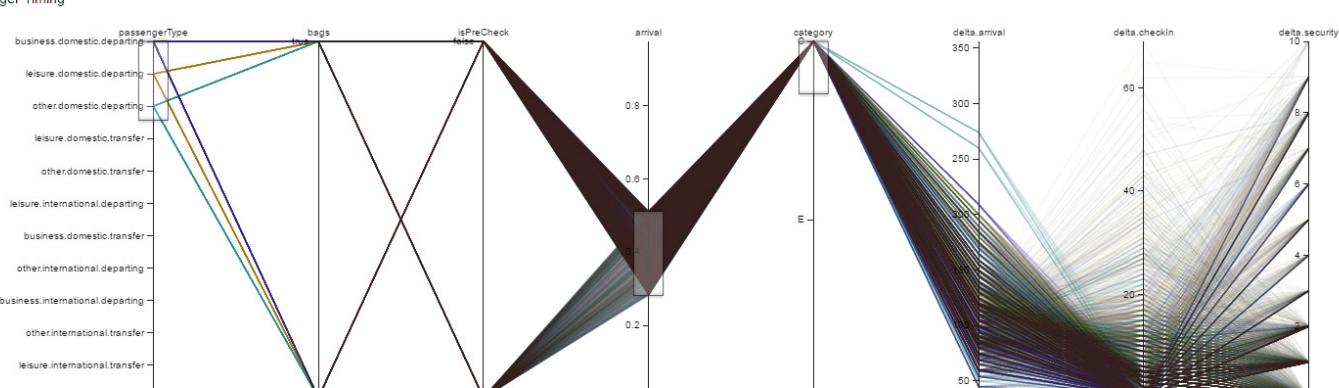
DOMESTIC PASSENGER SECURITY TIMES | AFTERNOON PEAK - SCHEME II (10/16 SECURITY LINES)

Passenger Timing



DOMESTIC PASSENGER SECURITY TIMES | MORNING PEAK - SCHEME I (10/12 SECURITY LINES)

Passenger Timing

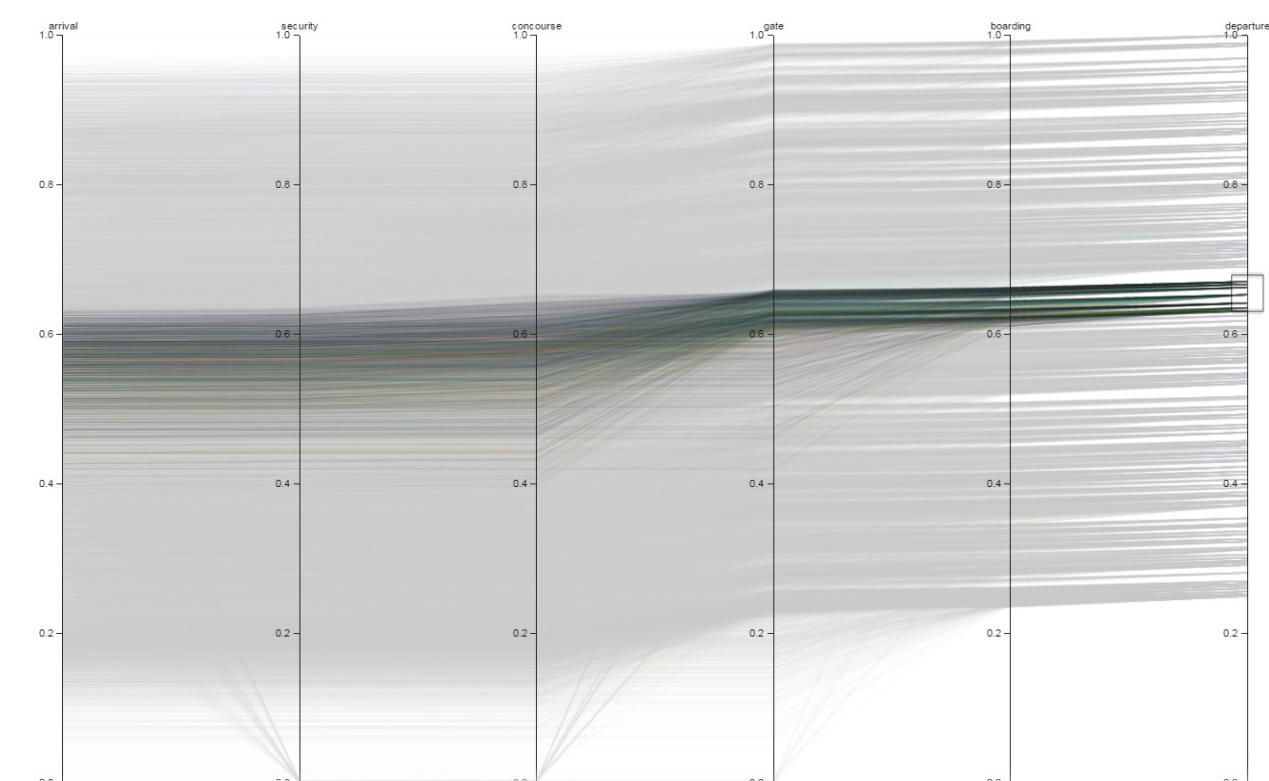


DOMESTIC PASSENGER SECURITY TIMES | MORNING PEAK - SCHEME II (10/16 SECURITY LINES)

Passenger Timing

TOTAL SIMULATED DESIGN DAY 2023 FLIGHT PASSENGERS - FLOW FROM CURBSIDE TO DEPARTURE

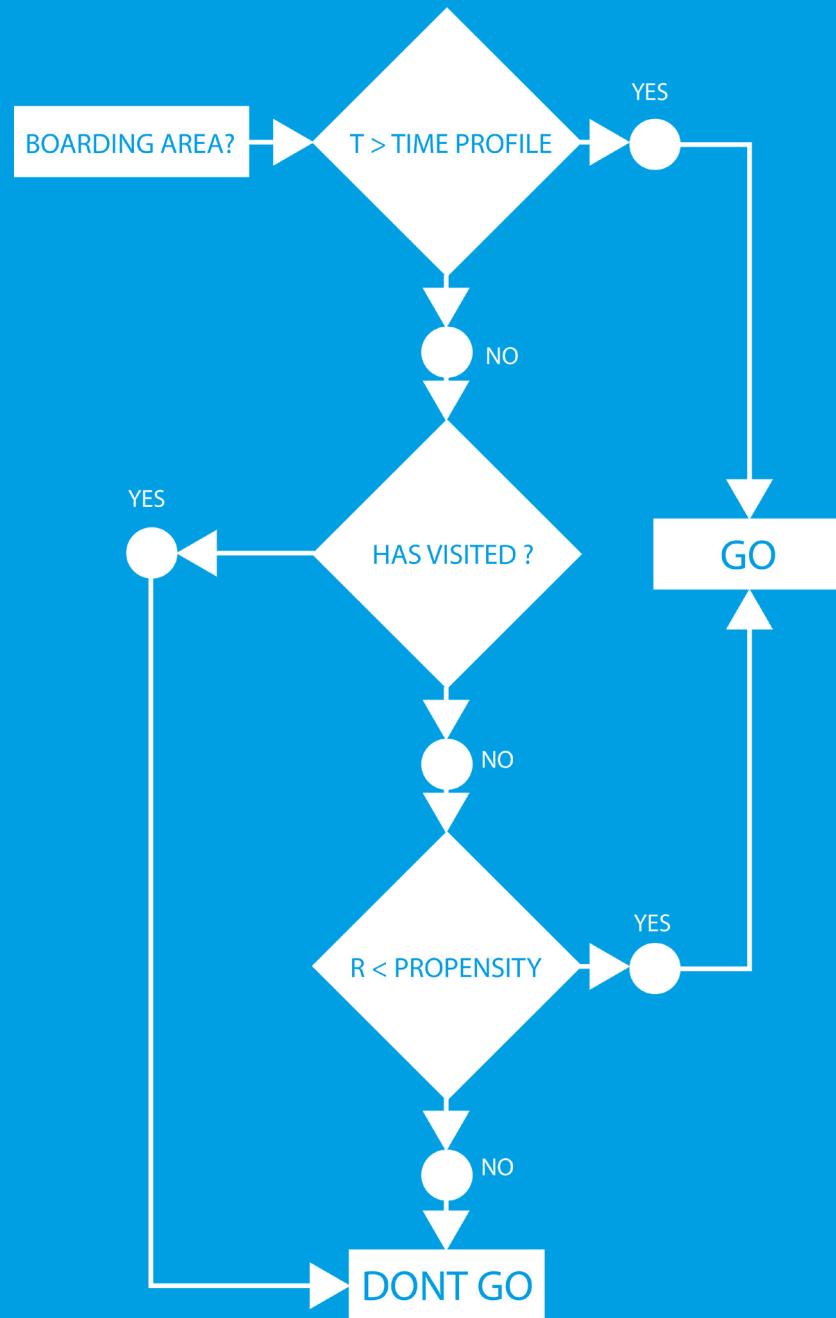
The images on the left show the changes in security times between two different schemes - one with a base 10 + 2 units, and the other with a base 10 + 6 units (current scheme). The top two images are filtered to afternoon peak hours, and the bottom are filtered to morning peak hours. The images above and below are total passenger flow through the airport for the current design scheme and design day flights.



PASSENGERS FILTERED BY DEPARTURE TIME - FLOW FROM CURBSIDE TO DEPARTURE

03

Passenger Spatial Simulation



The passenger spatial model simulates occupational patterns and behaviors on the air-side of a given airport design scheme configuration.

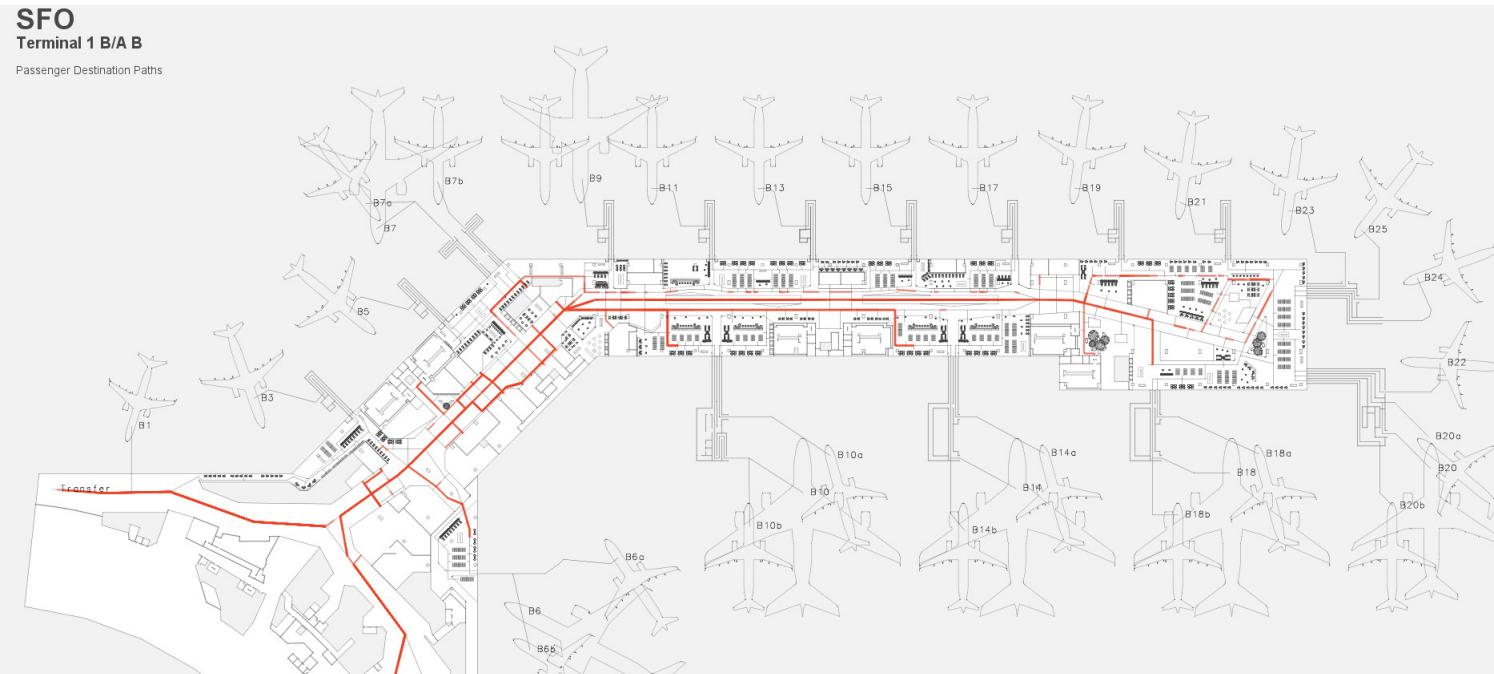
Using the timing profiles for each passenger's overall airport journey events, and the specifications for each unique passenger type, the system outputs a spatial representation of the total occupation and usage of the design layout for:

- Seating configurations
- Retail/concessions/F&B
- Bathrooms
- Access/pathways
- Hold room occupancy/arrival rates
- Visibility/distances

PASSENGER SPATIAL SIMULATION

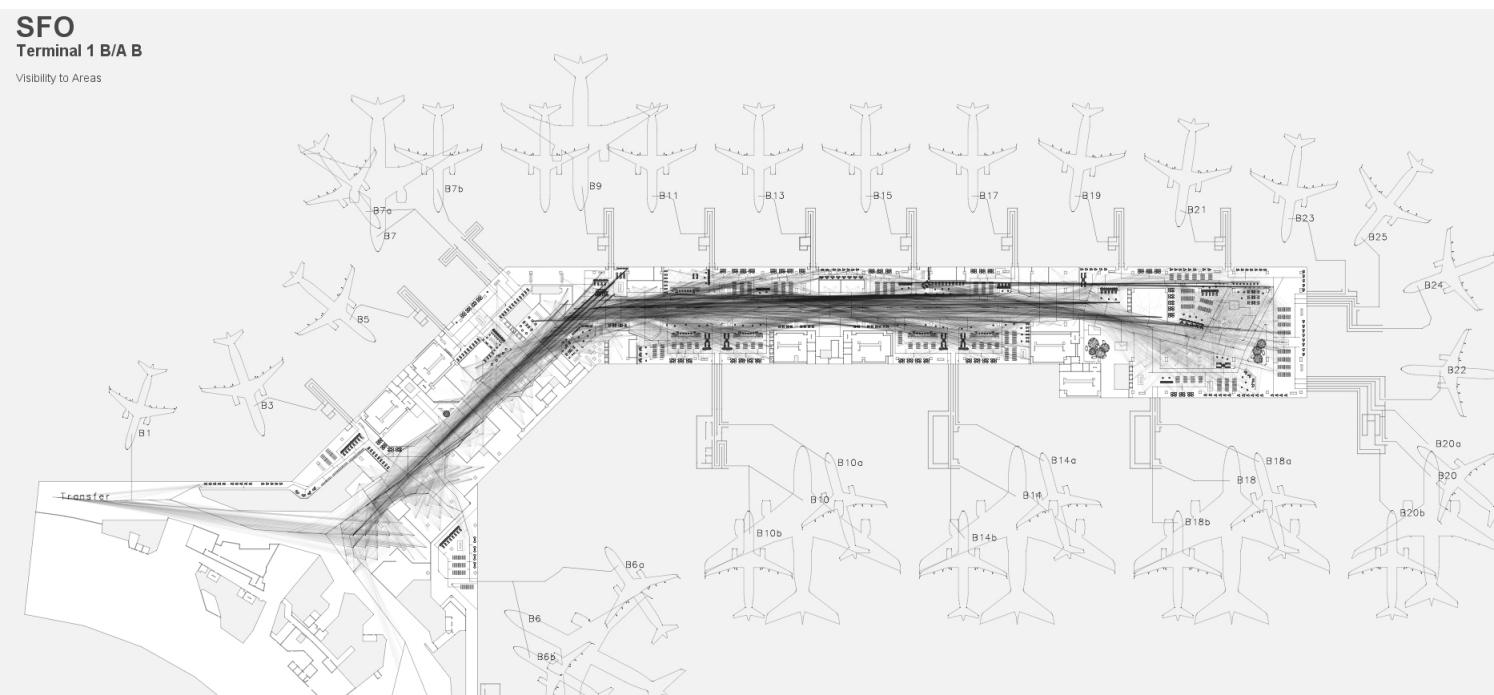
PASSENGER BEHAVIOR

With a spatial graph representation of the scheme, and using the generated timing profiles, more detailed behaviors for each passenger can be simulated moving through the departure lounge. The combination of passenger type definitions with inherent spatial properties such as visibility, distance to destination and shortest path are used to improve the agent decision making process.

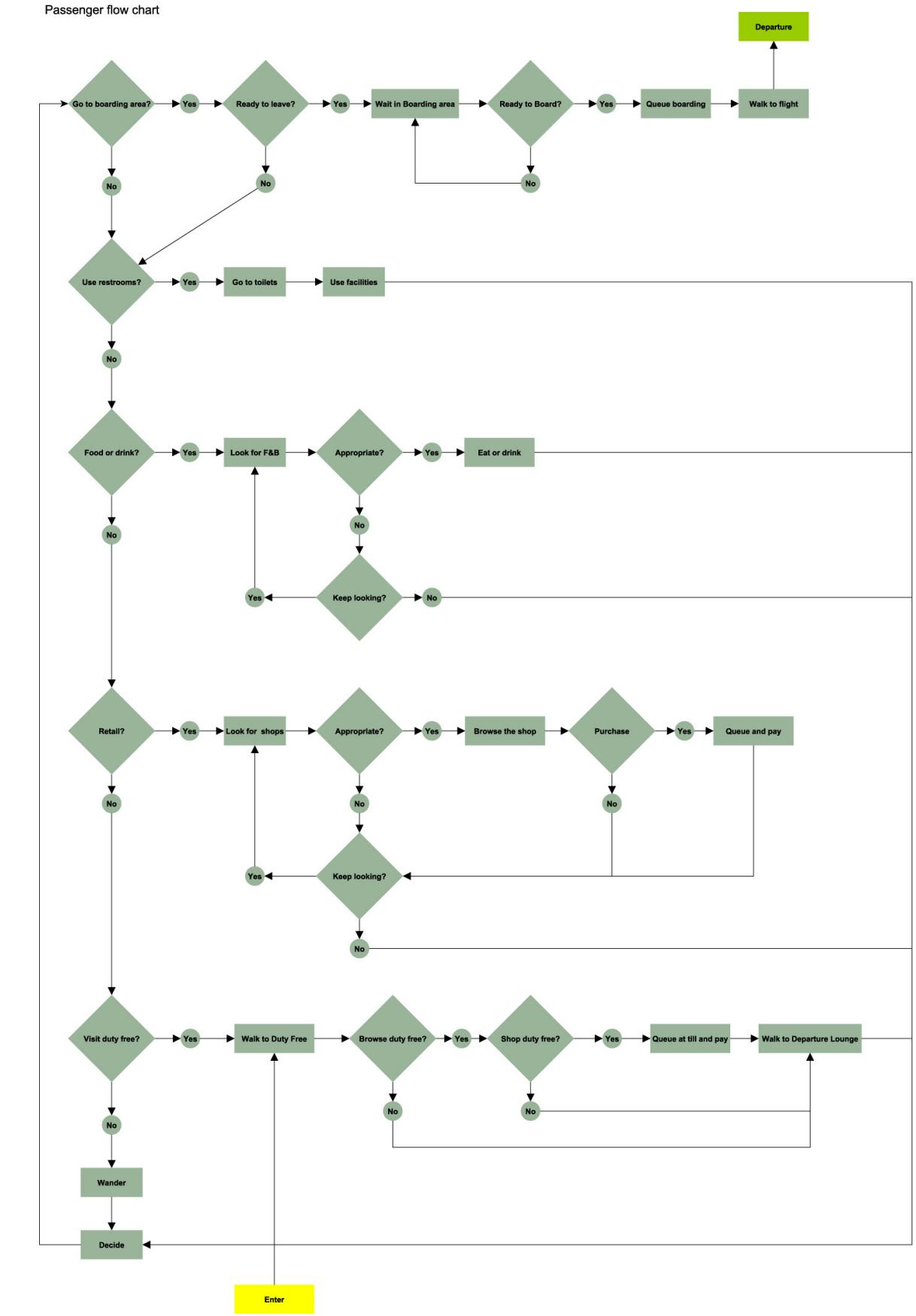


DESIGN SCHEME SPATIAL GRAPH AND PASSENGER DECISION PATHS

The image to the right is an example of a passenger journey flow chart. The individual journey is determined according to passenger type, generic behaviour, and spatial conditions. Diamond nodes represent individual decisions that the passenger can make. Round nodes represent potential outcomes of that decision (boolean yes | no), and rectangles represent action resulting from that decision. For each decision, an evaluation of the passenger profile and propensities is used to weight the best outcome.



DESIGN SCHEME VISIBILITY FROM GRAPH NODE LOCATIONS



PASSENGER SPATIAL SIMULATION

PASSENGER MOVEMENT

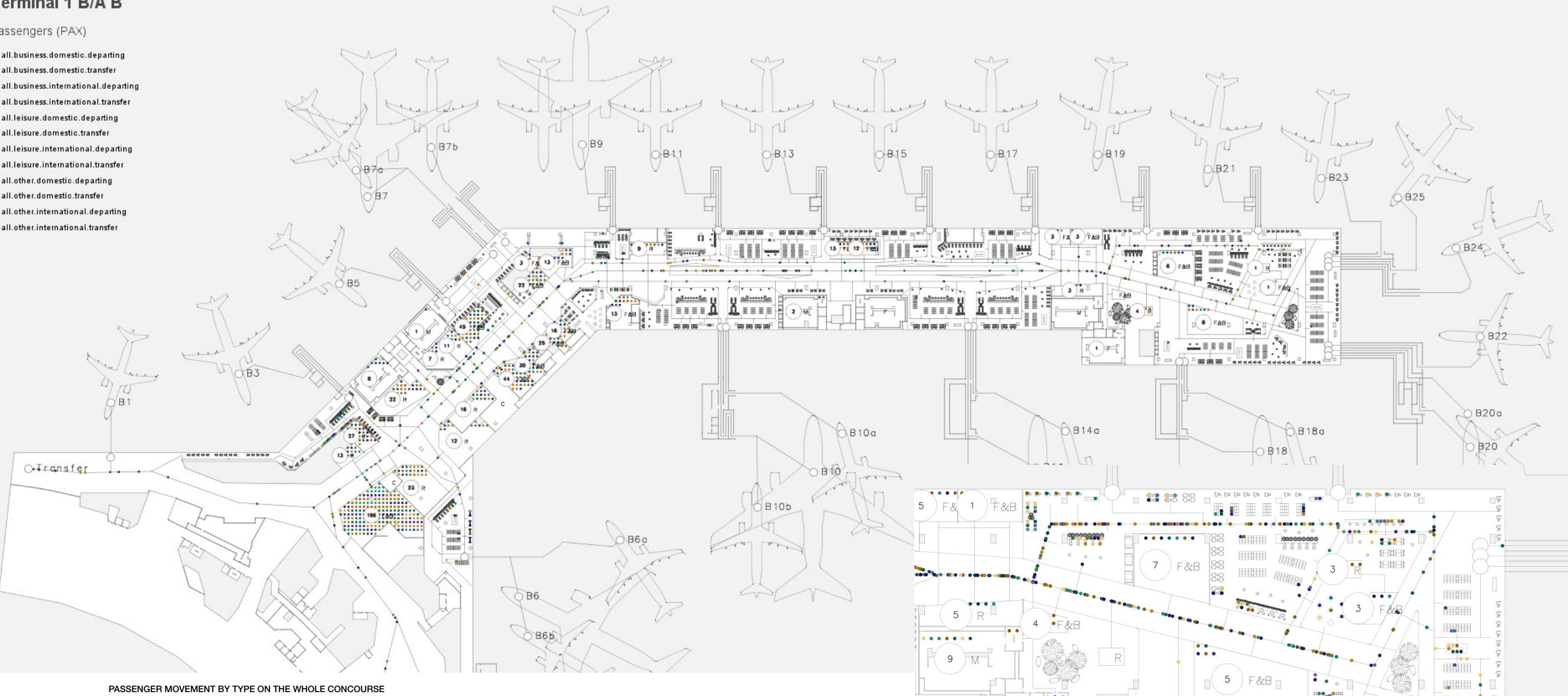
Passenger movement and spatial usage on the air-side of the design scheme can be visualized by passenger type and retail type. Propensities of different passengers towards different retail/FnB/concessions allows for a visualization of possible occupation patterns for a given gate scheme/design day flight schedule.

SFO

Terminal 1 B/A B

Passengers (PAX)

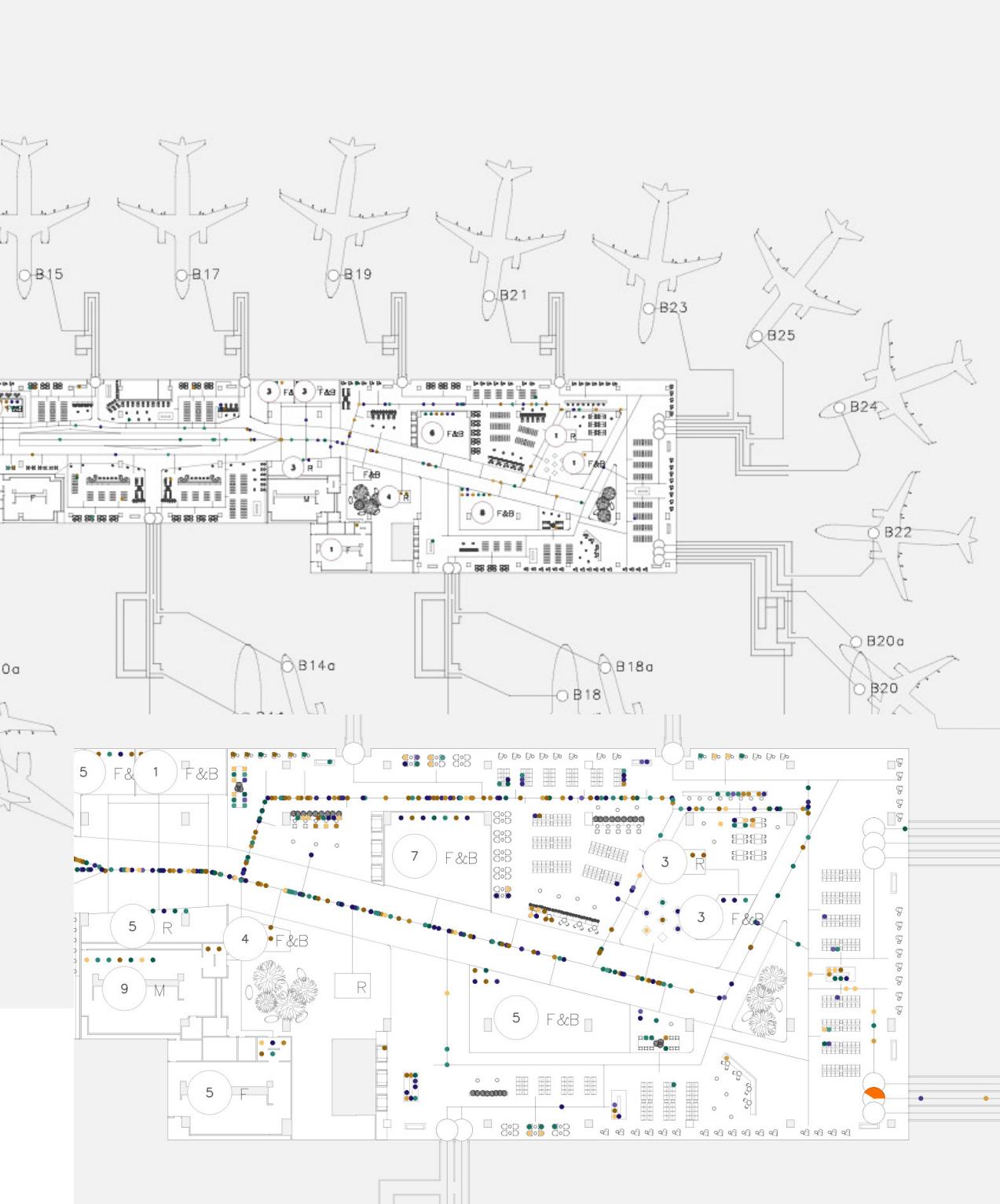
- all.business.domestic.departing
- all.business.domestic.transfer
- all.business.international.departing
- all.business.international.transfer
- all.leisure.domestic.departing
- all.leisure.domestic.transfer
- all.leisure.international.departing
- all.leisure.international.transfer
- all.other.domestic.departing
- all.other.domestic.transfer
- all.other.international.departing
- all.other.international.transfer



Hold rooms and seating area occupation have been integrated within the simulation in line with the design scheme, maximum allowable densities by LoS, and number of seats. Over the simulation run, passengers occupy the boarding lounge, gate hold-rooms and boarding areas according to existing statistics on airport patterns, but could be catered and refined to specific airport patterns with relevant data sources. The current scheme is the following :

- 17% of passengers move directly from security to their gate
- 29-50% of passengers are at their gate 5 min prior to the first call for boarding

Residual passenger gate and boarding arrival rates are computed using a Weibull distribution. Passenger concession/bathroom and amenity usage are profile driven and based on type, propensity, location and remaining time until departure.



PASSENGER SPATIAL SIMULATION

PASSENGER DENSITY

Concession usage output statistics include total average and instantaneous values on passenger occupancy densities. By standard LoS measures of acceptable square footage per person, this is capped at a 0.4 persons per m² during simulation. Average density per amenity can reflect adequate program sizing (seating, holdrooms, bathrooms), and inform retail and F&B placement optimization strategies.

SFO

Terminal 1 B/A B

Passenger Density (PAX/M2)

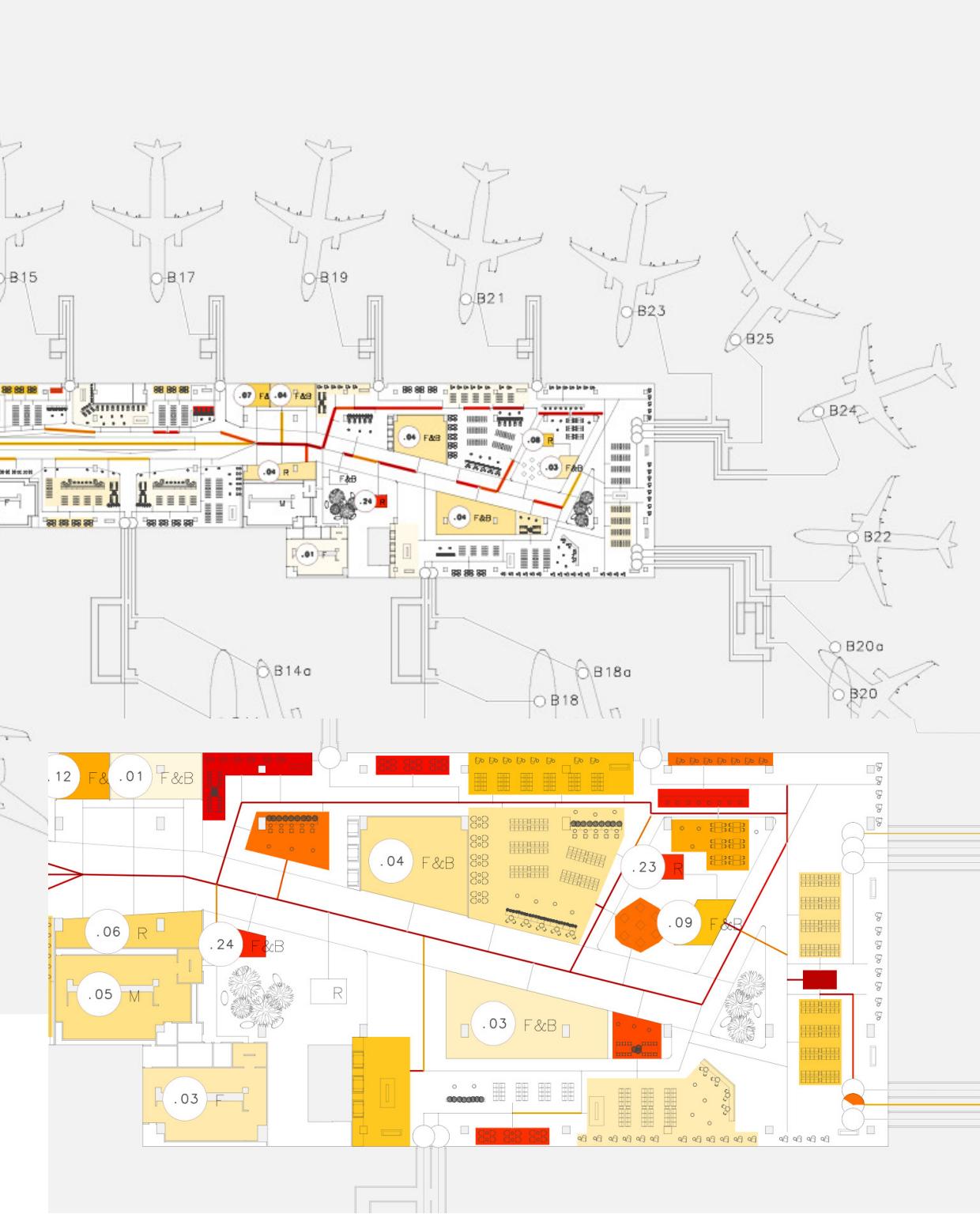


PASSENGER DENSITY BY PROGRAM ON THE WHOLE CONCOURS

Instantaneous densities on the spatial graph over time can help predict zones of high passenger concentration at specific paths on the concourse, highlighting possible pinch points, bottle necks and queues.

Individual passenger paths and timing scenarios inform spatial experiences, helping to map unpredictable outcomes in passenger behaviors as a direct result of design decisions. Aggregated, these paths help visualize and understand occupational patterns which can then be fed back into the design as a part of the iterative process:

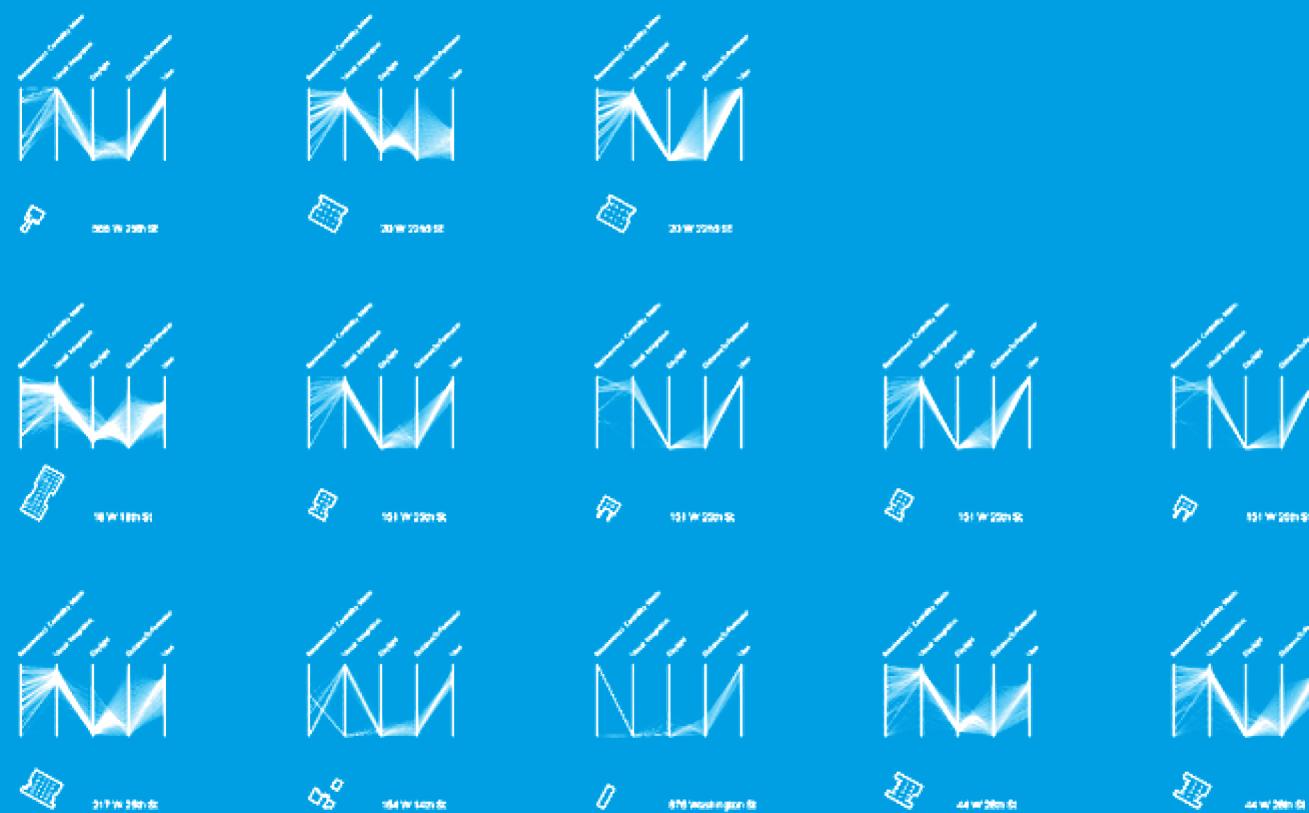
- Time spent at specific ammenities by passenger/flight type
 - Average/min/max distance covered
 - Spatial experience in terms of visibility



PASSENGER DENSITY BY PROGRAM ON THE END OF CONCOURSE

04

Evaluation and Benchmarking

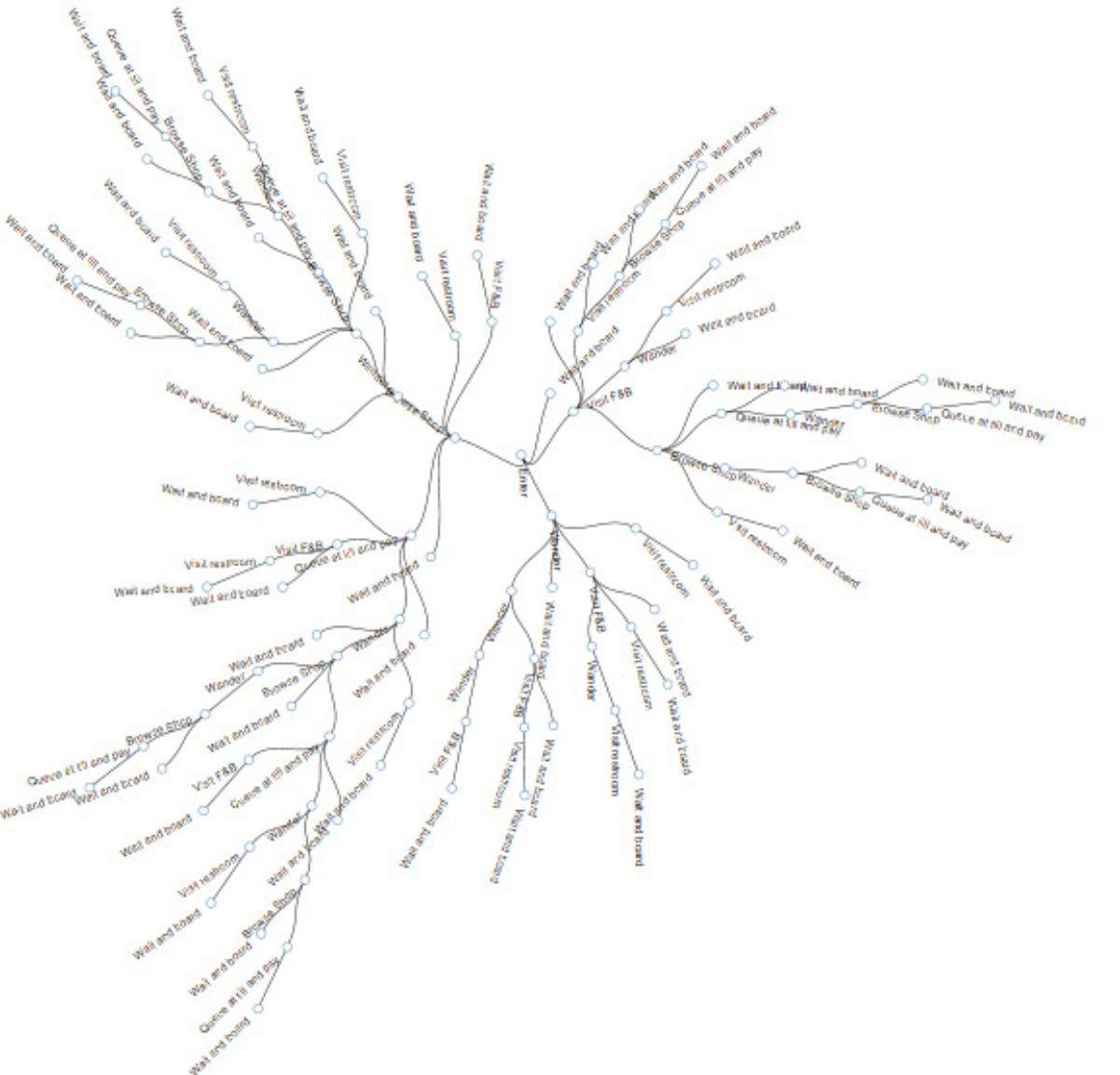


Post processing evaluation of the simulation data across multiple schemes can determine performative differences relative to changes in program.

EVALUATION AND BENCHMARKING

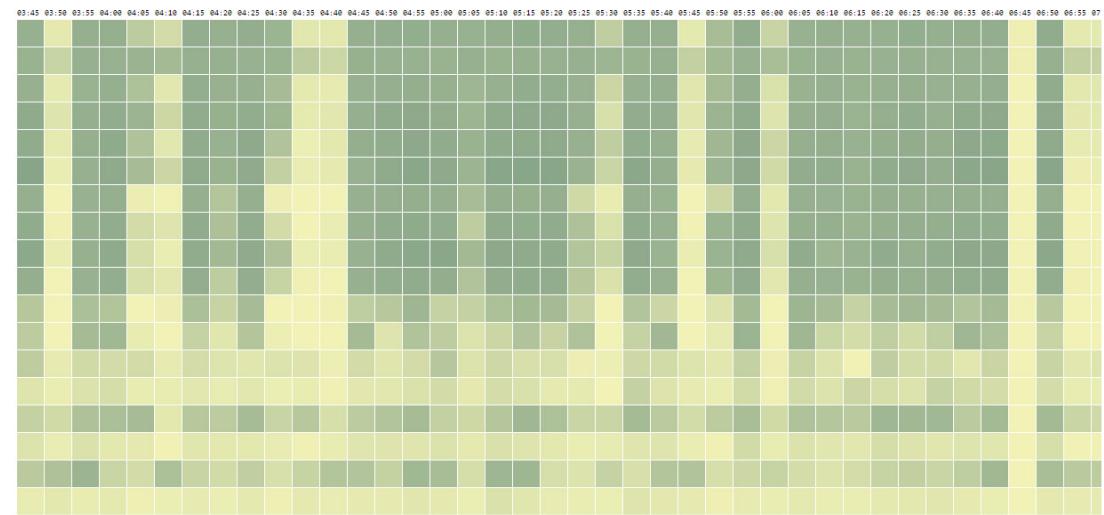
OUTPUT ANALYSIS

Concession usage output statistics include total average and instantaneous values on passenger occupancy densities. By standard LoS measures of acceptable square footage per person, this is capped at a 0.4 persons per m² during simulation. Average density per amenity can reflect adequate program sizing (seating, holdrooms, bathrooms), and inform retail and F&B placement optimization strategies.

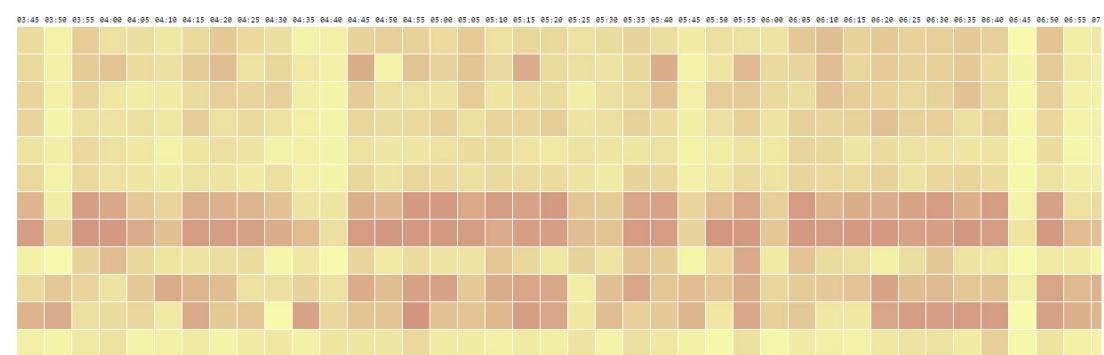


DESIGN SCHEME SPATIAL GRAPH AND PASSENGER DECISION PATHS

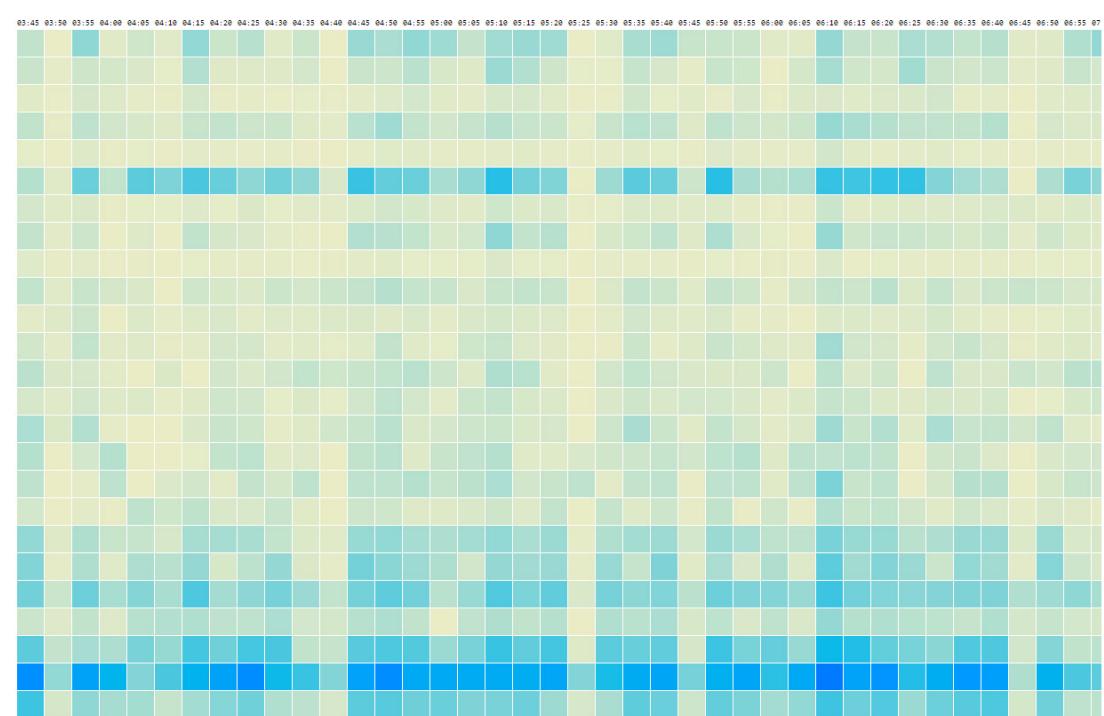
Concession usage output statistics include total average and instantaneous values on passenger occupancy densities. By standard LoS measures of acceptable square footage per person, this is capped at a 0.4 persons per m² during simulation. Average density per amenity can reflect adequate program sizing (seating, holdrooms, bathrooms), and inform retail and F&B placement optimization strategies.



PASSENGER FOOD AND BEVERAGE DENSITIES OVER TIME



PASSENGER RETAIL DENSITIES OVER TIME

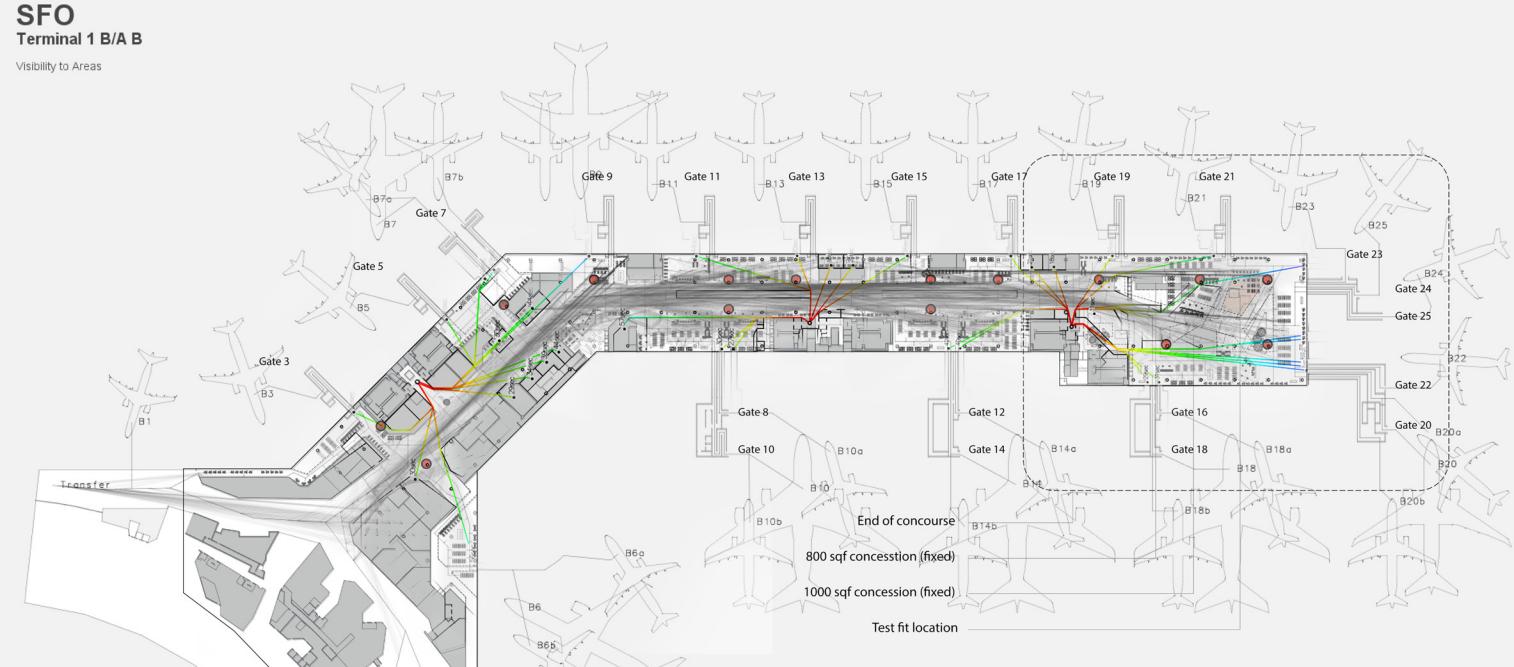


PASSENGER GATE SEATING DENSITIES OVER TIME

EVALUATION AND BENCHMARKING

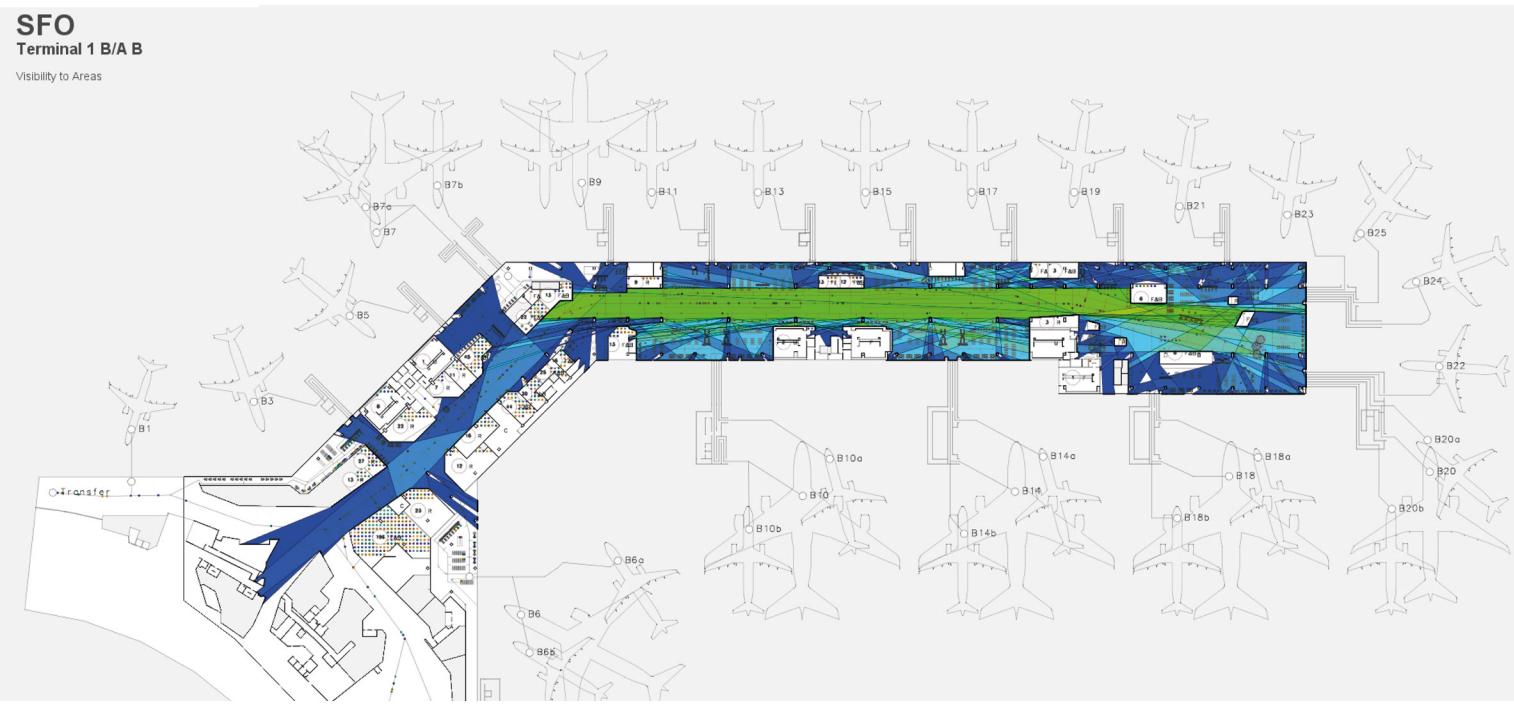
OPTIMIZATION METRICS

Optimizing program location can be achieved through a recursive analysis of spatial conditions (e.g visibility, access, egress, distance to bathrooms) and/or simulation results (e.g. occupant density, estimated revenue). Single-objective optimization suggests a potential maximum fitness output within a test scope, without looking at the larger contextual model.

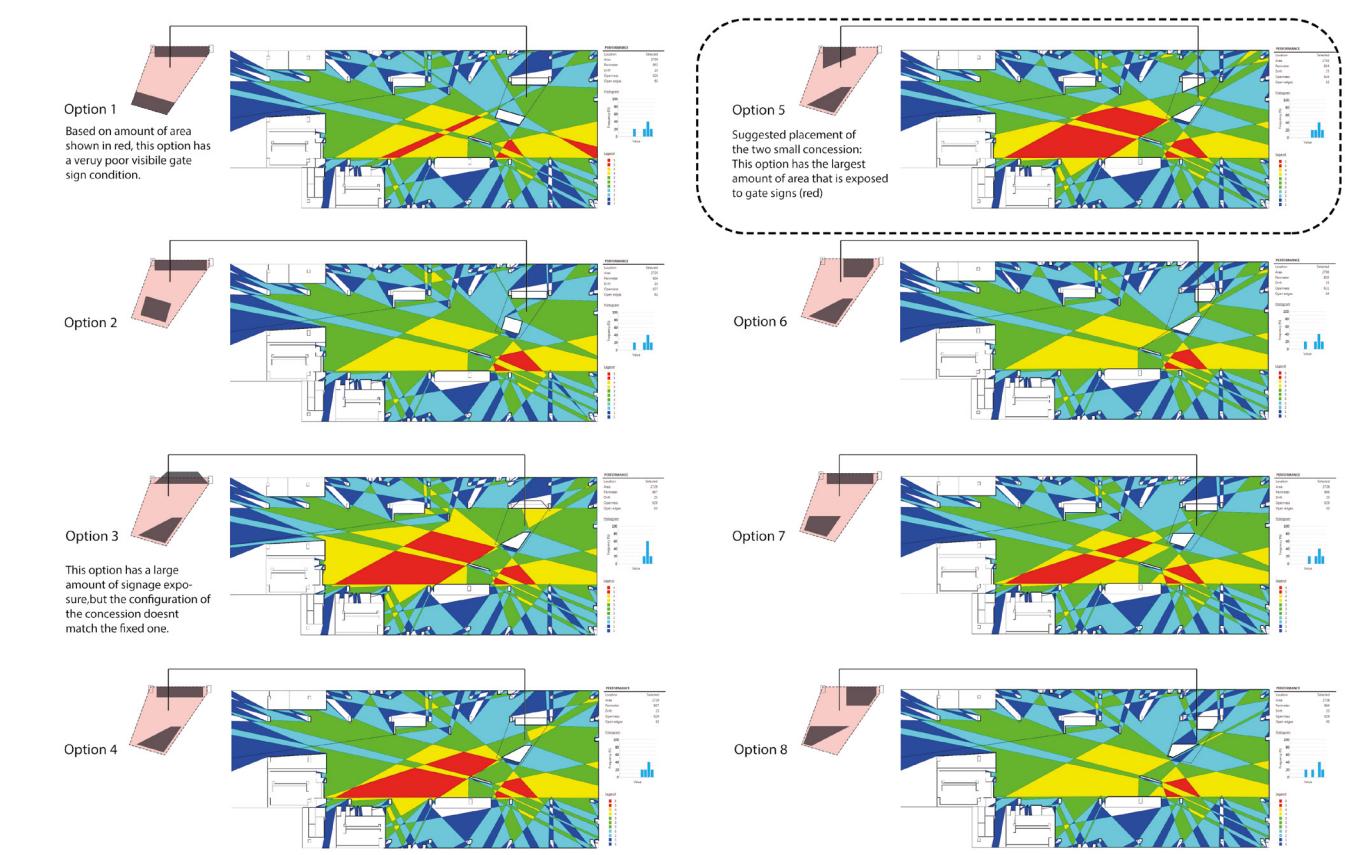


CONCOURSE WAYFINDING LOCATIONS AND SHORTEST DISTANCE PATHS FROM GATE TO NEAREST BATHROOM.

Multi-objective optimization assumes and tracks the effects of every variable design parameter in the design space, and attempts to configure best case scenarios on a pareto front in the case of counter productive outcomes.(e.g. changes that benefit visibility may negatively effect egress and daylighting). Given appropriate constraints, both methods can highlight opportunities for data-driven design decisions.



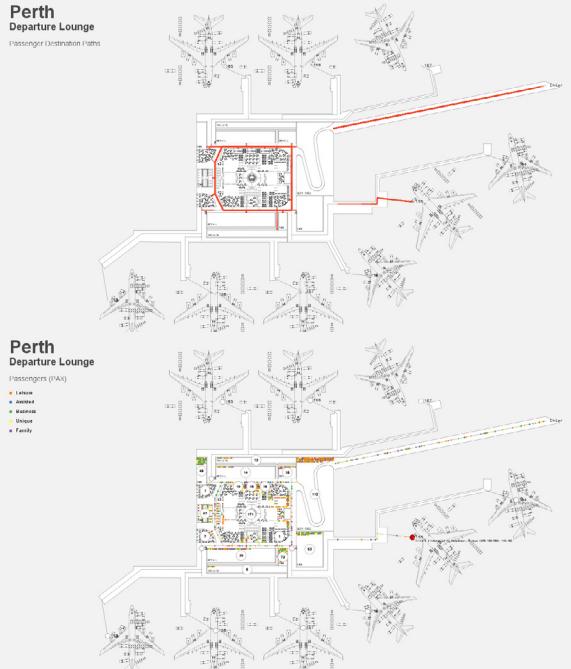
VISIBILITY FROM WAYFINDING LOCATIONS



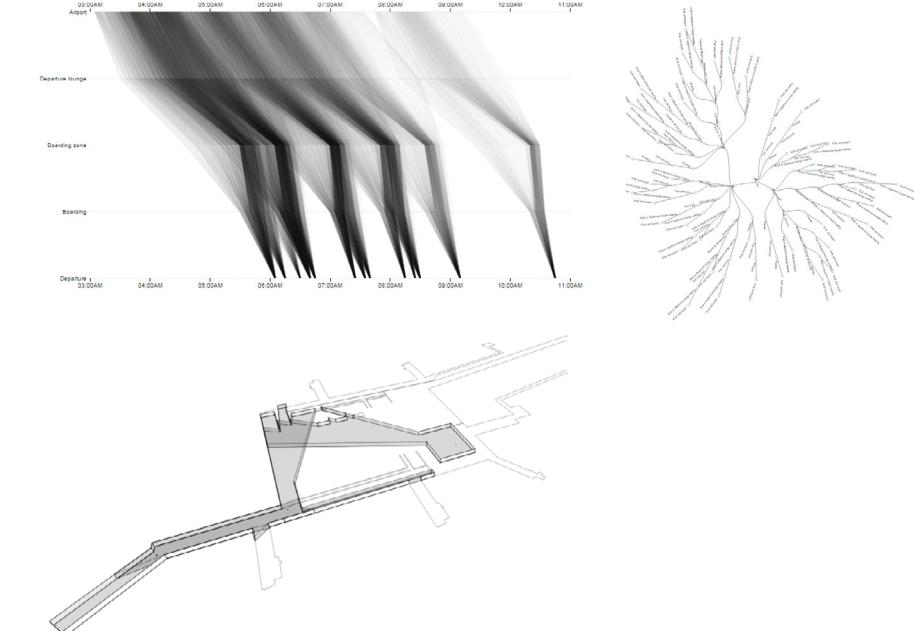
EVALUATION AND BENCHMARKING

PERFORMANCE COMPARISON

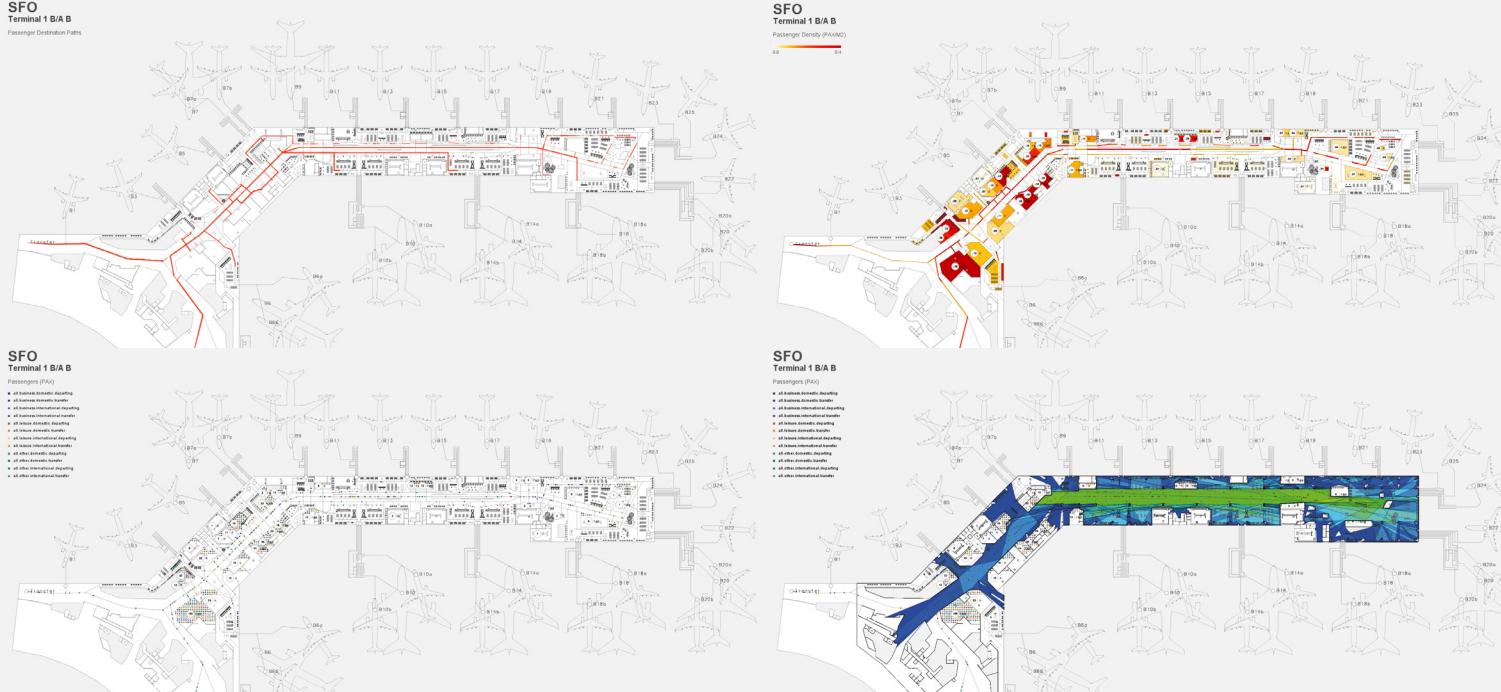
Multi-objective optimization assumes and tracks the effects of every variable design parameter in the design space, and attempts to configure best case scenarios on a pareto front in the case of counter productive outcomes.(e.g. changes that benefit visibility may negatively effect egress and daylighting). Given appropriate constraints, both methods can highlight opportunities for data-drivent design decisions.



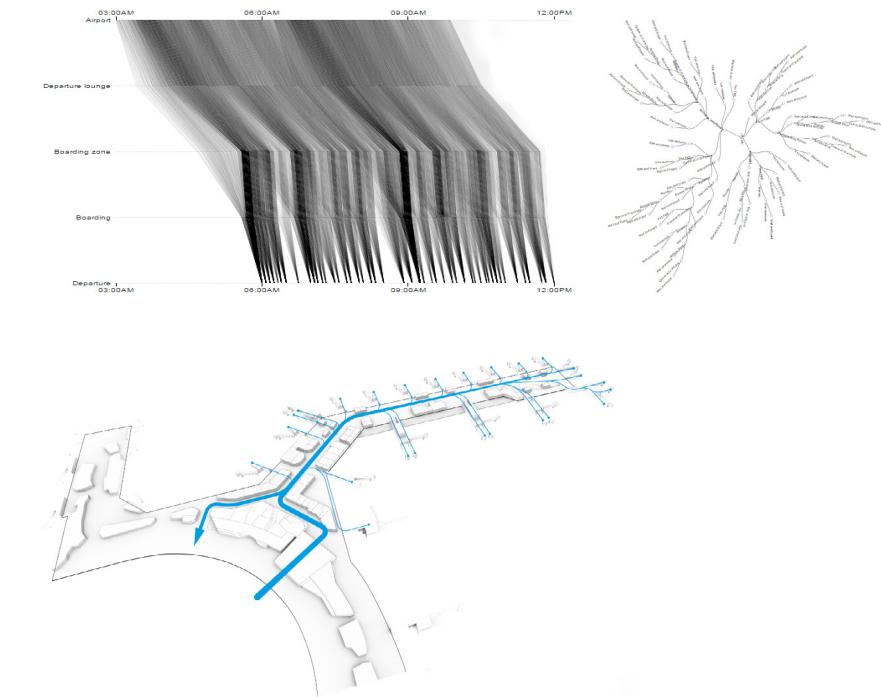
CONCOURSE WAYFINDING LOCATIONS AND SHORTEST DISTANCE PATHS FROM GATE TO NEAREST BATHROOM.



END OF CONCOURSE CONCESSION LOCATION OPTIMIZATION



VISIBILITY FROM WAYFINDING LOCATIONS



ISOVIST VIEWS TO WAYFINDING POINTS FOR POTENTIAL CONCESSIONS