Agent-based Safety Modelling and Simulation of Controlling Two Airports from One Remote Tower

Appendices A - E

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APPENDIX A Shannon Airport

Airport Layout

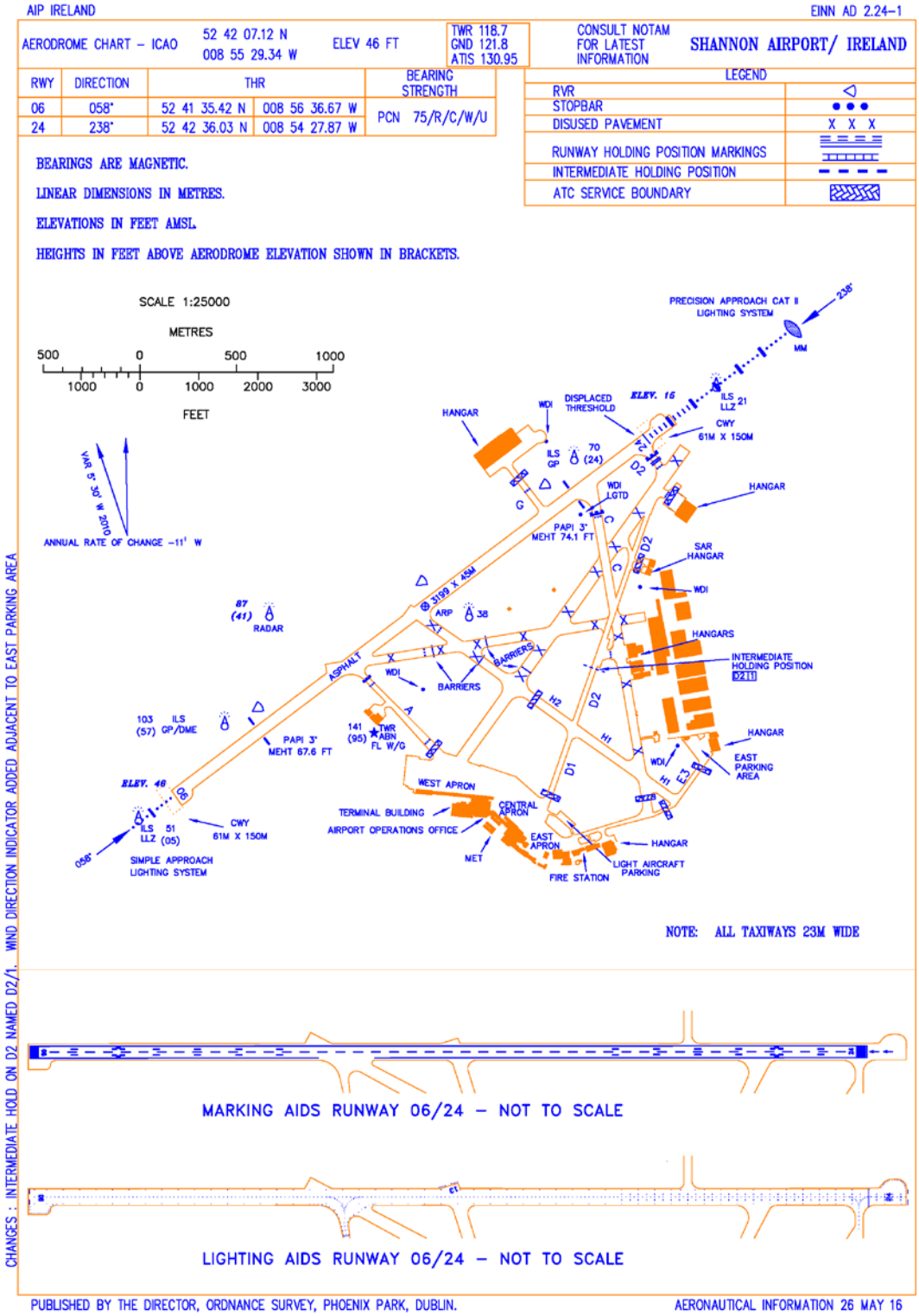


Figure A-1: Shannon Airport Layout (Irish Aviation Authority, 2019)

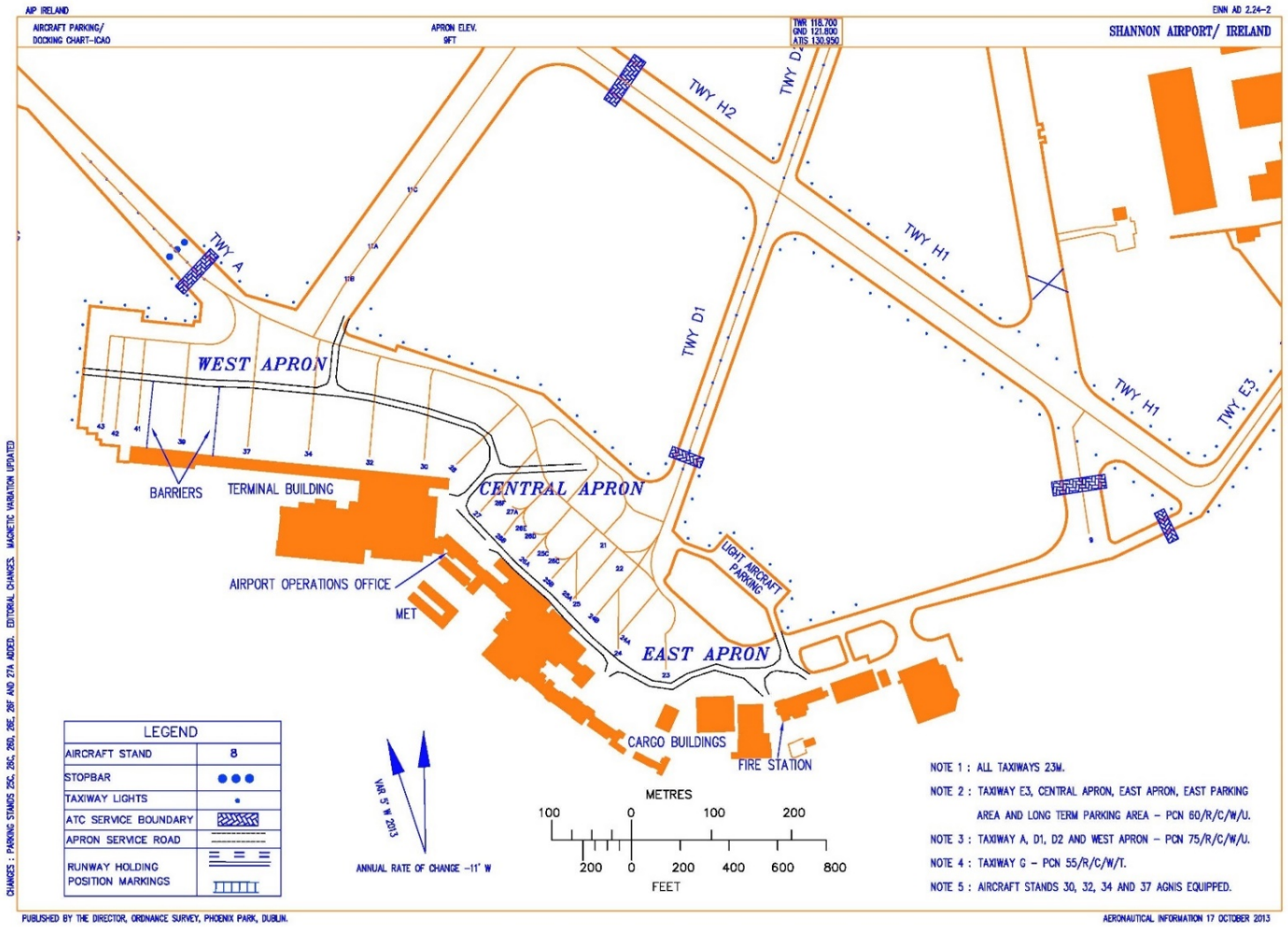


Figure A-2: Shannon Airport Ground Layout (Irish Aviation Authority, 2019)

Airport Hourly Departure Distribution[1]

	Hour	Totals	2017/01	2017/02	2017/03	2017/04	2017/05	2017/06	2017/07	2017/08	2017/09	2017/10	2017/11	2017/12	2018/01	2018/02	2018/03	2018/04	2018/05	2018/06	2018/07	2018/08
Departure	00:00 - 00:	119	6	6	3	7	1	1		1	1	9	12	8	2	6	18	6	7	5	12	8
Departure	01:00 - 01:	96	2	5	7	4	2	2	4	2	2	11	6	3	6	4	7	9	3	3	10	4
Departure	02:00 - 02:	82	3	6	2	2	3	1	2	2		13	2	6	6	3	4	7	5	6	5	4
Departure	03:00 - 03:	89	6	2	3	6	1	1	1	1		11	6	5	5	4	13	3	4	6	5	6
Departure	04:00 - 04:	114	3	6	4	8	2	3	1	3	2	4	8	9	4	9	7	6	6	20	6	3
Departure	05:00 - 05:	166	5	7	8	7	1	8	9	2		6	15	9	4	4	8	9	5	41	10	8
Departure	06:00 - 06:	331	10	17	13	4	9	35	73	2	4	15	19	22	20	10	12	9	17	18	9	13
Departure	07:00 - 07:	1,661	38	29	52	92	112	118	117	109	97	103	63	59	55	54	63	84	99	113	95	109
Departure	08:00 - 08:	592	57	50	60	27	29	21	29	14	18	40	33	22	26	32	23	27	20	20	22	22
Departure	09:00 - 09:	1,039	55	38	70	47	74	100	88	74	63	59	48	33	44	29	43	31	34	46	25	38
Departure	10:00 - 10:	1,203	80	56	61	52	58	79	44	54	64	44	86	39	53	65	94	57	58	51	51	57
Departure	11:00 - 11:	2,518	112	88	118	119	148	171	163	137	148	119	109	89	96	73	123	120	145	160	148	132
Departure	12:00 - 12:	2,742	64	50	106	137	146	172	154	159	155	134	108	87	121	92	159	152	165	200	198	183
Departure	13:00 - 13:	1,134	71	62	86	50	44	66	54	42	71	43	36	47	72	57	79	49	54	61	52	38
Departure	14:00 - 14:	1,140	53	65	68	78	58	64	48	38	73	56	46	50	56	51	50	53	45	58	72	58
Departure	15:00 - 15:	1,167	56	57	63	42	46	51	58	51	66	75	56	54	44	52	54	63	65	73	82	59
Departure	16:00 - 16:	931	52	43	39	48	52	50	46	30	47	65	25	45	35	43	42	38	73	58	51	49
Departure	17:00 - 17:	1,533	65	52	75	96	107	85	80	56	106	89	57	56	65	52	55	72	71	101	91	102
Departure	18:00 - 18:	1,174	46	27	39	55	81	93	79	78	90	72	26	24	35	28	41	62	68	86	74	70
Departure	19:00 - 19:	1,324	58	53	61	58	74	79	78	79	83	60	53	45	55	51	52	51	73	83	97	81
Departure	20:00 - 20:	966	40	39	51	39	57	55	51	59	46	48	44	36	50	46	39	45	53	58	55	55
Departure	21:00 - 21:	604	57	40	41	21	27	29	23	26	27	41	47	32	37	39	35	17	15	23	16	11
Departure	22:00 - 22:	423	22	17	13	22	12	16	24	15	21	31	16	16	20	21	30	19	20	26	30	32
Departure	23:00 - 23:	189	7	7	5	6	8	2	7	4	5	19	8	6	6	11	14	16	8	23	17	10

[1] Source: Shannon Airport Authority

APPENDIX B Cork Airport Layout

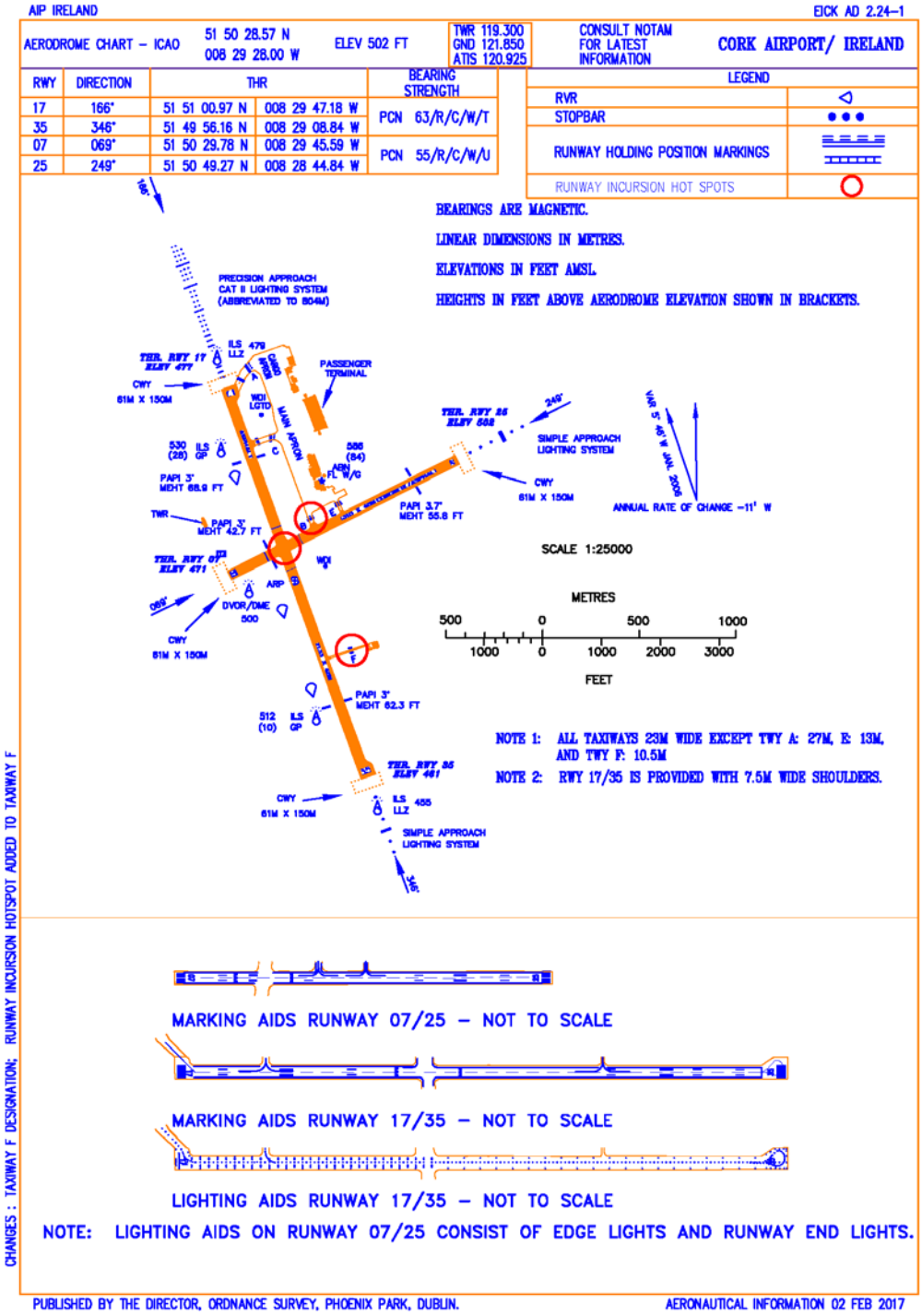


Figure B-3: Cork Airport Layout (Irish Aviation Authority, 2019)

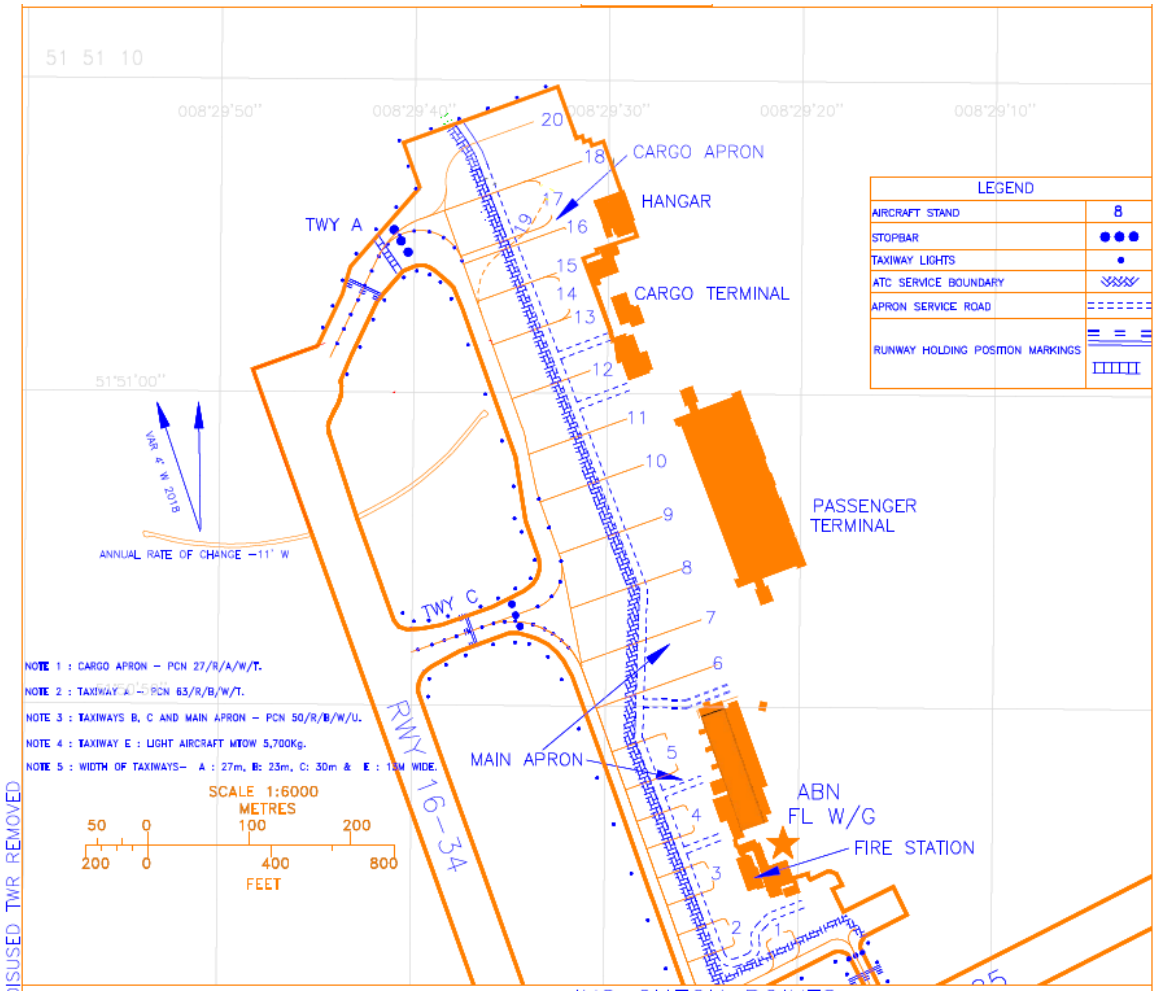
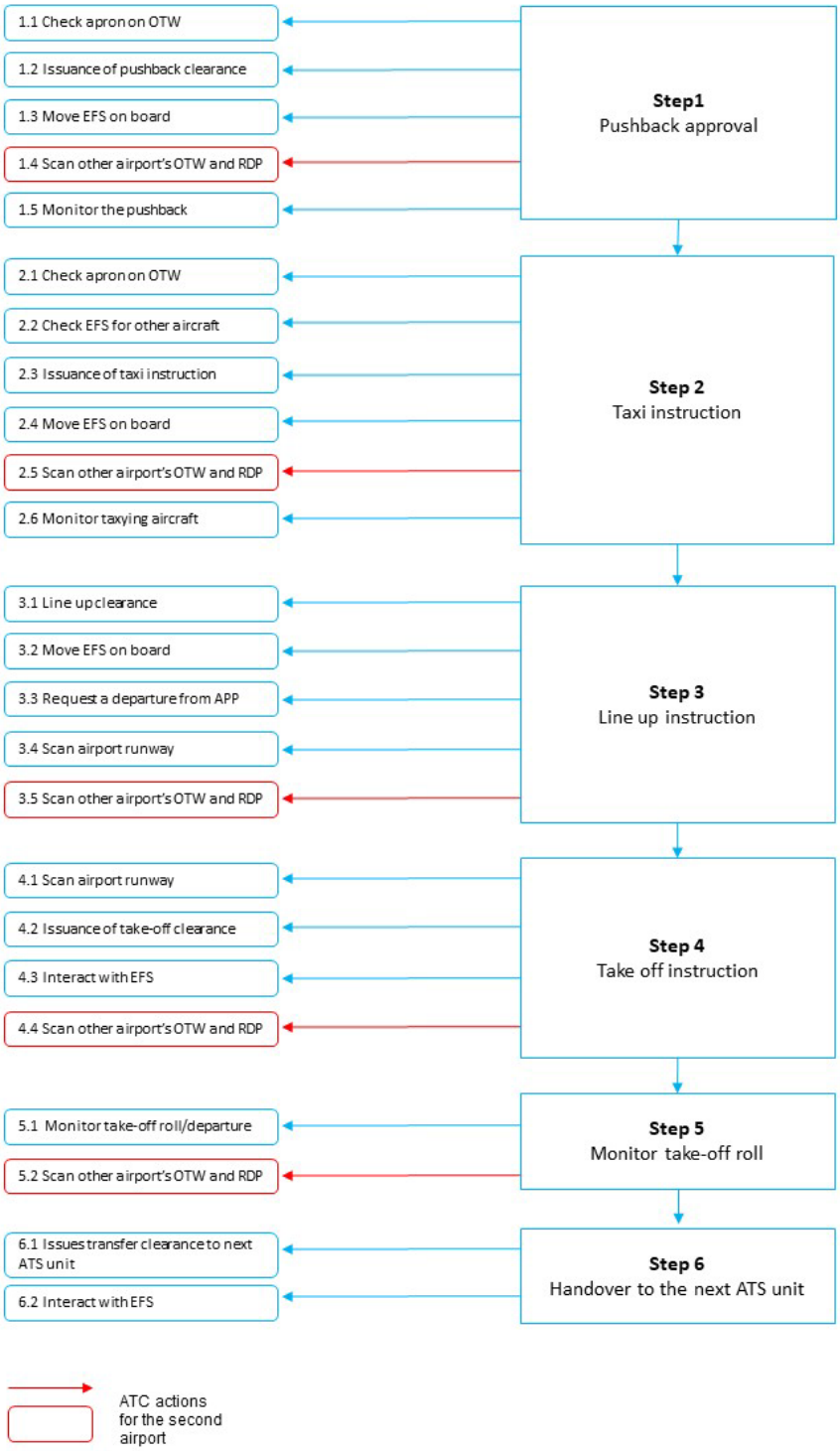


Figure B-4: Cork Airport Layout Aircraft Parking/Docking Chart (Irish Aviation Authority, 2019)

APPENDIX C Notes from the Hazard Identification and Initial Analysis HET

HET Template Departure procedure



Scenario: Departure Procedure			Task step 1.1: Pushback approval/ Check apron on the OTW									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not check apron on the OTW	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task execution incomplete	V	ATCO fails to scan apron thoroughly.	Lack of situational awareness regarding aircraft on apron.		V				V	v	
Task executed in wrong direction	V	ATCO scans apron at wrong airport.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Wrong task executed	V	ATCO performs other tasks and not scans apron on the OTW.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task repeated	V	ATCO scans apron multiple times.	Time consuming and impacts upon interaction with other interfaces.			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO scans apron too early.	ATCO has to scan again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan apron at this time.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task executed too much	V	Continuous scanning of apron.	Less interaction with other interfaces. Distracts from attending to situation in both airports.		V				V	V	
Task executed too little	V	ATCO does not scan apron thoroughly.	Lack of situational awareness regarding aircraft on apron.		V				V	V	
Misread information	V	ATCO does not fully comprehend the apron situation.	Lack of situational awareness regarding aircraft on apron.			V		V		V	
Other											

Scenario: Departure Procedure			Task step 1.2: Pushback approval/ Issuance of pushback clearance									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to issue push back clearance.	Aircraft delayed on the apron.			V			V	V	
Task execution incomplete	V	ATCO issues incomplete push back clearance.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to issue push back clearance.	a/c departure is delayed			V			V	V	
Task repeated	V	ATCO issues push back clearance several times.	Increased workload			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO issues pushback clearance too early.	No impact			V			V	V	
Task executed too late	V	ATCO issues push back clearance too late.	Increased coordination with APP required -> increased workload.		V				V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 1.3: Pushback approval/Move EFS on board									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved into on EFS.	EFS does not accurately represent traffic situation. No indication of aircraft pushback		V				V	V	
Task execution incomplete											
Task executed in wrong direction		Inserting strip into an	EFS does not accurately		V				V	V	

		incorrect bay on EFS	represent traffic situation. No indication of aircraft pushback								
Wrong task executed	V	Incorrect strip moved into bay.	EFS does not accurately represent traffic situation. No indication of aircraft pushback		V				V	V	
Task repeated											
Task executed on wrong interface element	V										
Task executed too early	V	Strip is put too early.	EFS does not accurately represent traffic situation. No indication of aircraft pushback			V			V	V	
Task executed too late	V	Strip is put too late.	EFS does not accurately represent traffic situation. No indication of aircraft pushback		V				V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 1.4: Pushback approval/ Scan the other airport OTW+RDP								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan the airport or look at RDP.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.			V	V			V	
Task execution incomplete		ATCO fails to scan the other airport thoroughly.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.			V	V			V	
Task executed in wrong direction		ATCO scans OTW and RDP	Runway incursion – miss obstacle on the			V	V			V	

		at wrong airport.	runway. Lack of situational awareness regarding the other airport.								
Wrong task executed	V	ATCO continually scans OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V	V			V	
Task repeated	V	ATCO scans OTW and RDP multiple time.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO scans OTW and RDP too early.	ATCO scans OTW and RDP again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan OTW and RDP at this time.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.			V	V			V	
Task executed too much		Continuous scanning of OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed too little		ATCO does not scan OTW and RDP thoroughly.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.			V	V			V	
Misread information		ATCO fails to notice obstruction on OTW and take cognizance of aircraft position on RDP.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.			V	V			V	
Other											

Scenario: Departure Procedure			Task step 1.5: Pushback approval/Monitor the pushback									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to monitor position.	Loss of situational awareness.			V			V	V	
Task execution incomplete		ATCO fails to accurately monitor position.	Loss of situational awareness			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO looks at one airport instead of the other.	Loss of situational awareness			V			V	V	
Task repeated		ATCO looks at aircraft again.	Time consuming. Impacts upon available time to monitor other interfaces			V			V	V	
Task executed on wrong interface element	V										
Task executed too early	V	Aircraft not yet pushing back.	ATCO to monitor again – Time consuming. Impacts upon available time to monitor other interfaces			V			V	V	
Task executed too late	V	ATCO doesn't monitor pushback enough.	Loss of situational awareness			V			V	V	
Task executed too much		ATCO continuously looks at aircraft.	Time consuming. Impacts upon available time to monitor other interfaces			V			V	V	
Task executed too little											
Misread information											
Other		…if an increase in the workload occurs → the likelihood of certain error modes may increase as well									V

Scenario: Departure Procedure			Task step 2.1: Taxi Instruction/ Check apron on the OTW									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not check apron on the OTW	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task execution incomplete	V	ATCO fails to scan apron thoroughly.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task executed in wrong direction	V	ATCO scans apron at wrong airport.	Lack of situational awareness regarding aircraft on apron.			V		V		V	
Wrong task executed	V	ATCO performs other tasks and not scans apron on the OTW.	Lack of situational awareness regarding aircraft on apron.			V		V		V	
Task repeated	V	ATCO scans apron multiple times.	Time consuming and impacts upon interaction with other interfaces.			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO scans apron too early.	ATCO has to scan again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan apron at this time.	Lack of situational awareness regarding aircraft on apron.			V		V		V	
Task executed too much	V	Continuous scanning of apron.	Less interaction with other interfaces. Distracts from attending to situation in both airports.			V			V	V	
Task executed too little	V	ATCO does not scan apron thoroughly.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Misread information	V	ATCO does not fully comprehend the apron situation.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Other											

Scenario: Departure Procedure			Task step 2.2: Taxi Instruction/ Check EFS for vehicle/aircraft									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not check for vehicle/aircraft	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task execution incomplete		ATCO fails to check EFS for vehicle/aircraft thoroughly.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task executed in wrong direction		ATCO check EFS for vehicle/aircraft at wrong airport.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Wrong task executed	V	ATCO performs other tasks and not check EFS for vehicle/aircraft.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task repeated		ATCO check EFS for vehicle/aircraft multiple times.	Time consuming and impacts upon interaction with other interfaces.			V			V	V	
Task executed on wrong interface element	V										
Task executed too early	V	ATCO checks EFS for vehicle/aircraft too early.	ATCO has to scan again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to check EFS for vehicle/aircraft at this time.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Task executed too much		Continuous check of EFS for vehicle/aircraft.	Less interaction with other interfaces. Distracts from attending to situation in both airports.			V			V	V	
Task executed too little		ATCO does not check EFS for vehicle/aircraft apron thoroughly.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Misread information		ATCO does not fully comprehend the apron situation.	Lack of situational awareness regarding aircraft on apron.			V			V	V	
Other											

Scenario: Departure Procedure			Task step 2.3: Taxi Instruction/ Issuance of taxi instruction									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to issue taxi clearance.	Aircraft delayed on the apron.			V			V	V	
Task execution incomplete		ATCO issues incomplete taxi clearance.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when s/he meant to issue taxi clearance.	a/c departure is delayed			V			V	V	
Task repeated		ATCO issues taxi clearance several times.	Increased workload			V			V	V	
Task executed on wrong interface element											
Task executed too early	V	ATCO issues taxi clearance too early.	No impact			V			V	V	
Task executed too late	V	ATCO issues taxi clearance too late.	Increased coordination with APP required -> increased workload.			V			V	V	
Task executed too much						V			V	V	
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 2.4: Taxi Instruction/ Move EFS on board									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved into on EFS.	EFS does not accurately represent traffic situation. No indication of aircraft pushback		V				V	V	
Task execution incomplete											
Task executed in wrong direction		Inserting strip into an incorrect bay on EFS	EFS does not accurately represent traffic situation. No		V				V	V	

			indication of aircraft pushback								
Wrong task executed	V	Incorrect strip moved into bay.	EFS does not accurately represent traffic situation. No indication of aircraft pushback		V				V	V	
Task repeated											
Task executed on wrong interface element	V										
Task executed too early	V	Strip is put too early.	EFS does not accurately represent traffic situation. No indication of aircraft pushback			V			V	V	
Task executed too late	V	Strip is put too late.	EFS does not accurately represent traffic situation. No indication of aircraft pushback		V				V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 2.5: Taxi Instruction/ Scan of the other airport OTW+RDP								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan the airport or look at RDP.	Runway incursion – miss obstacle on the taxiway. Lack of situational awareness regarding the other airport.			V	V			V	
Task execution incomplete		ATCO fails to scan the other airport thoroughly.	Runway incursion – miss obstacle on the taxiway. Lack of situational awareness regarding the other airport.			V	V			V	
Task executed in wrong direction		ATCO scans OTW and RDP at wrong airport.	Runway incursion – miss obstacle on the taxiway. Lack of situational awareness			V	V			V	

			regarding the other airport.								
Wrong task executed	V	ATCO continually scans OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task repeated		ATCO scans OTW and RDP multiple time.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed on wrong interface element	V										
Task executed too early	V	ATCO scans OTW and RDP too early.	ATCO scans OTW and RDP again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan OTW and RDP at this time.	Runway incursion – miss obstacle on the taxiway. Lack of situational awareness regarding the other airport.			V			v	V	
Task executed too much		Continuous scanning of OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed too little		ATCO does not scan OTW and RDP thoroughly.	Runway incursion – miss obstacle on the taxiway. Lack of situational awareness regarding the other airport.			V	V			V	
Misread information		ATCO fails to notice obstruction on OTW and take cognizance of aircraft position on RDP.	Runway incursion – miss obstacle on the taxiway. Lack of situational awareness regarding the other airport.			V	V			V	
Other											

Scenario: Departure Procedure			Task step 2.6: Taxi Instruction/ Monitoring taxiing aircraft									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to monitor position.	Loss of situational awareness.			V			V	V	
Task execution incomplete		ATCO fails to accurately monitor position.	Loss of situational awareness			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO looks at one airport instead of the other.	Loss of situational awareness			V			V	V	
Task repeated		ATCO looks at aircraft again.	Time consuming. Impacts upon available time to monitor other interfaces			V			V	V	
Task executed on wrong interface element	V										
Task executed too early	V	Aircraft not yet taxing.	ATCO to monitor again – Time consuming. Impacts upon available time to monitor other interfaces			V			V	V	
Task executed too late	V	ATCO doesn't monitor taxing enough.	Loss of situational awareness			V			V	V	
Task executed too much		ATCO continuously looks at aircraft.	Time consuming. Impacts upon available time to monitor other interfaces			V			V	V	
Task executed too little											
Misread information											
Other		…if an increase in the workload occurs → the likelihood of certain error modes may increase as well									V

Scenario: Departure Procedure			Task step 3.1: Line up instruction/ Line up clearance									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not issue line up clearance	a/c is delayed			V			V	V	

Task execution incomplete		ATCO issues an incomplete line up clearance	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to issue a line up clearance	a/c is delayed			V			V	V	
Task repeated		ATCO issues line up clearance repeatedly	Increased workload leading to a loss of time to perform other tasks.			V			V	V	
Task executed on wrong interface element	V	Line up clearance issued for wrong airport	Runway conflict		V		V				V
Task executed too early	V	ATCO issues line up clearance too early	No impact			V			V	V	
Task executed too late	V	ATCO issues line up clearance too late	a/c is delayed			V			V	V	
Task executed too much		ATCO does not issue line up clearance	a/c is delayed			V			V	V	
Task executed too little		ATCO issues an incomplete line up clearance	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Misread information											
Other											

Scenario: Departure Procedure			Task step 3.2: Line up instruction/ Move EFS on board								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved on EFS.	EFS does not accurately represent traffic situation. No indication Runway blocked			V			V	V	
Task execution incomplete											
Task executed in wrong direction		Inserting strip into an incorrect bay on EFS	EFS does not accurately represent traffic situation. No indication Runway blocked			V			V	V	

Wrong task executed	V	Incorrect strip moved.	EFS does not accurately represent traffic situation. No indication Runway blocked			V			V	V	
Task repeated											
Task executed on wrong interface element	V										
Task executed too early	V	Strip is put too early.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too late	V	Strip is put too late.	EFS does not accurately represent traffic situation. No indication Runway blocked.			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 3.3: Line up instruction/ Request departure from APP								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to request departure from APP clearance.	Aircraft delayed on the taxiway.			V			V	V	
Task execution incomplete		ATCO incomplete request from APP.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when s/he is meant to request departure from APP.	a/c departure is delayed			V			V	V	
Task repeated		ATCO requests departure from APP multiple times.	Increased workload			V			V	V	
Task executed on wrong interface element											

Task executed too early	V	ATCO requests APP departure too early.	No impact			V			V	V	
Task executed too late	V	ATCO requests departure from APP too late.	Increased coordination with APP required -> increased workload.			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 3.4: Line up instruction/ Scan airport runway								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan runway.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task execution incomplete		ATCO fails to scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other task and does not scan runway.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task repeated		ATCO continually scans runway.	Time consuming and impacts upon interaction with other interfaces.			V			V	V	
Task executed on wrong interface element	V	ATCO scans runway at incorrect airport.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task executed too early	V	ATCO scans runway too early.	ATCO scans runway again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan runway at this time.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task executed too much		Continuous scanning of runway.	Less interaction with other interfaces.			V			V	V	
Task executed too little		ATCO does not scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Misread information		ATCO fails to notice	Runway incursion – miss		V	V	V			V	v

		obstruction on runway.	obstacle on the runway.								
Other		* …if an increase in the workload occurs → the likelihood of certain error modes may increase as well									

Scenario: Departure Procedure			Task step 3.5: Line up instruction/ Scan the other airport OTW+RDP								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan the airport or look at RDP.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	**v**
Task execution incomplete		ATCO fails to scan the other airport thoroughly.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	**v**
Task executed in wrong direction		ATCO scans OTW and RDP at wrong airport.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	**v**
Wrong task executed	V	ATCO continually scans OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task repeated		ATCO scans OTW and RDP multiple time.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed on wrong interface element	V										

Task executed too early	V	ATCO scans OTW and RDP too early.	ATCO scans OTW and RDP again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan OTW and RDP at this time.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Task executed too much		Continuous scanning of OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed too little		ATCO does not scan OTW and RDP thoroughly.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Misread information		ATCO fails to notice obstruction on OTW and take cognizance of aircraft position on RDP.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Other											

Scenario: Departure Procedure			Task step 4.1: Take off instruction/ Scan the airport runway								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan runway.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task execution incomplete		ATCO fails to scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks and does not scan runway airport.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task repeated		ATCO continually scans runway.	Time consuming and impacts upon interaction with other interfaces.			V			V	V	

Task executed on wrong interface element	V	ATCO scans runway at incorrect airport.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task executed too early	V	ATCO scans runway too early.	ATCO scans runway again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan runway at this time.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task executed too much		Continuous scanning of runway.	Less interaction with other interfaces.								
Task executed too little		ATCO does not scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Misread information		ATCO fails to notice obstruction on runway.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Other		* …if an increase in the workload occurs → the likelihood of certain error modes may increase as well									

Scenario: Departure Procedure			Task step 4.2: Take off instruction/ Issuance take off clearance								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to issue take off clearance.	Aircraft delayed on the runway.			V			V	V	
Task execution incomplete		ATCO issues incomplete take-off clearance.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to issue take off clearance.	a/c departure is delayed			V			V	V	
Task repeated		ATCO issues take off clearance several times.	Increased workload			V			V	V	
Task executed on wrong interface element	V	Take off instruction issued on the wrong frequency			V	V	V				v

Task executed too early	V	ATCO issues take off clearance too early.	No impact			V			V	V	
Task executed too late	V	ATCO issues take off clearance too late.	Increased coordination with APP required -> increased workload.							V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 4.3: Take off instruction/ Interact with EFS								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved on EFS.	EFS does not accurately represent traffic situation. No indication Runway blocked			V			V	V	
Task execution incomplete											
Task executed in wrong direction		Inserting strip into an incorrect bay on EFS.	EFS does not accurately represent traffic situation. No indication Runway blocked			V			V	V	
Wrong task executed	V	Incorrect strip moved.	EFS does not accurately represent traffic situation. No indication Runway blocked								
Task repeated											
Task executed on wrong interface element	V					V			V	V	
Task executed too early	V	Strip is put too early.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too late	V	Strip is put too late.	EFS does not accurately represent traffic situation. No indication Runway blocked.			V			V	V	

Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 4.4: Take off instruction/ Scan the other airport OTW+RDP								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan the airport or look at RDP.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Task execution incomplete		ATCO fails to scan the other airport thoroughly.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Task executed in wrong direction		ATCO scans OTW and RDP at wrong airport.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Wrong task executed	V	ATCO continually scans OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task repeated		ATCO scans OTW and RDP multiple time.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed on wrong interface element	V										
Task executed too early	V	ATCO scans OTW and RDP too early.	ATCO scans OTW and RDP again. Time consuming.			V			V	V	

Task executed too late	V	ATCO fails to scan OTW and RDP at this time.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Task executed too much		Continuous scanning of OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed too little		ATCO does not scan OTW and RDP thoroughly.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Misread information		ATCO fails to notice obstruction on OTW and take cognizance of aircraft position on RDP.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Other											

Scenario: Departure Procedure			Task step 5.1: Monitor take-off roll/ Monitor take off roll/departure								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to monitor position.	Loss of situational awareness.		V	V	V			V	v
Task execution incomplete		ATCO fails to accurately monitor take off roll/departure position.	Loss of situational awareness		V	V	V			V	v
Task executed in wrong direction											
Wrong task executed	V	ATCO looks at one airport instead of the other.	Loss of situational awareness		V	V	V			V	v
Task repeated		ATCO looks at aircraft again.	Time consuming. Impacts upon available time to monitor other interfaces			V			V	V	

Task executed on wrong interface element	V										
Task executed too early	V	Aircraft not yet taxing.	ATCO to monitor take off roll/departure again – Time consuming. Impacts upon available time to monitor take off roll/departure other interfaces			V			V	V	
Task executed too late	V	ATCO doesn't monitor take off roll/departure taxing enough.	Loss of situational awareness		V	V	V			V	v
Task executed too much		ATCO continuously looks at aircraft.	Time consuming. Impacts upon available time to monitor take off roll/departure other interfaces.			V			V	V	
Task executed too little											
Misread information											
Other		…if an increase in the workload occurs → the likelihood of certain error modes may increase as well									

Scenario: Departure Procedure			Task step 5.2: Monitor take-off roll/ Scan the other airport OTW+RDP								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan the airport or look at RDP.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Task execution incomplete		ATCO fails to scan the other airport thoroughly.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	v
Task executed in wrong direction		ATCO scans OTW and RDP at wrong airport.	Runway incursion – miss obstacle on the runway. Lack of situational		V	V	V			V	v

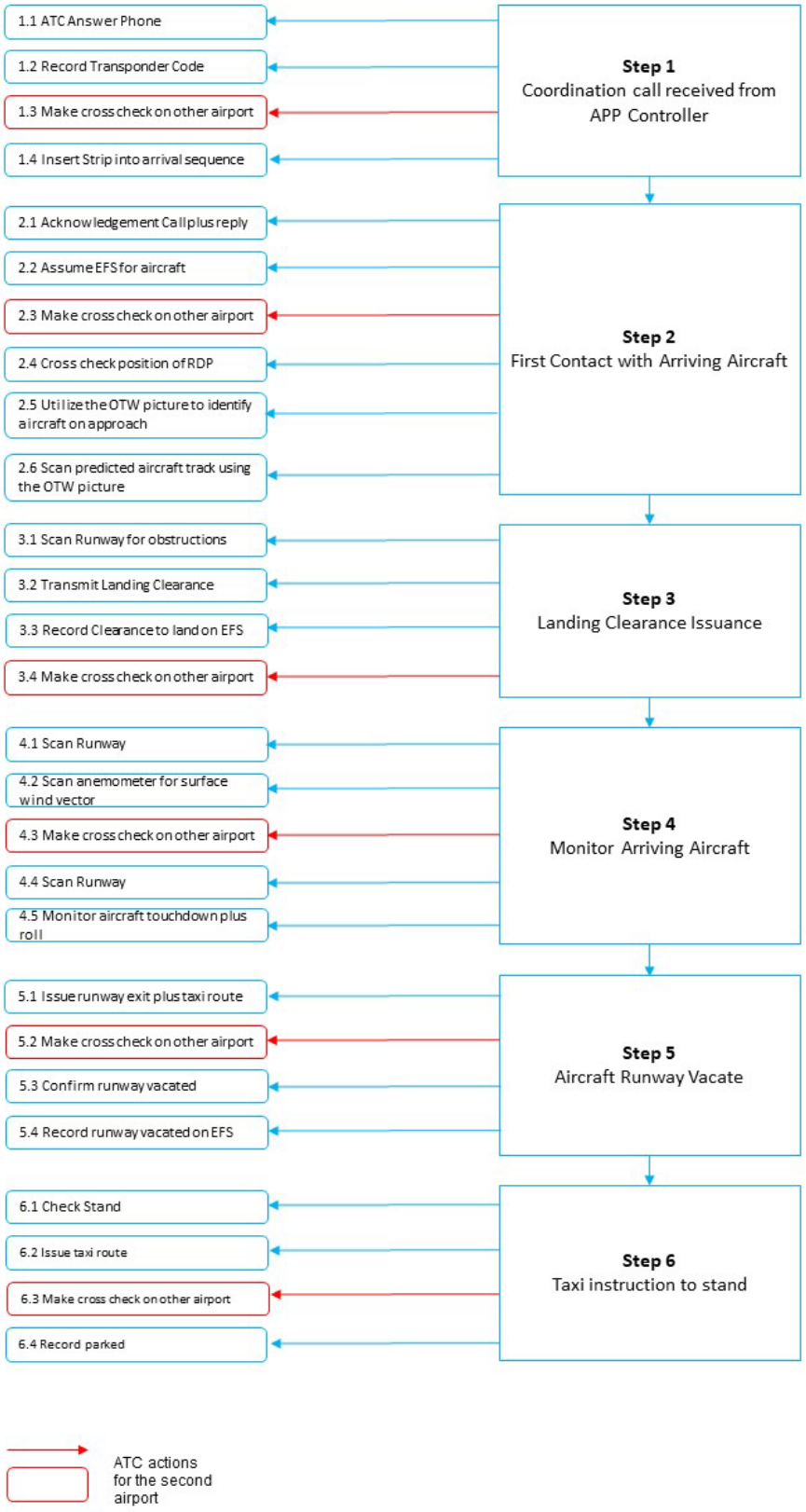
			awareness regarding the other airport.								
Wrong task executed	V	ATCO continually scans OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task repeated		ATCO scans OTW and RDP multiple time.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed on wrong interface element	V										
Task executed too early	V	ATCO scans OTW and RDP too early.	ATCO scans OTW and RDP again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan OTW and RDP at this time.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	**v**
Task executed too much		Continuous scanning of OTW and RDP.	Time consuming and impacts upon interaction with other interfaces. Distracts from attending to situation in other airports.			V			V	V	
Task executed too little		ATCO does not scan OTW and RDP thoroughly.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	**v**
Misread information		ATCO fails to notice obstruction on OTW and take cognizance of aircraft position on RDP.	Runway incursion – miss obstacle on the runway. Lack of situational awareness regarding the other airport.		V	V	V			V	**v**
Other											

Scenario: Departure Procedure			Task step 6.1: Handover to the next ATS unit/ Issue transfer clearance to the next ATS unit								
Error Mode	TICK	Description	Outcome	Likelihood	Criticality			PASS		CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to issue transfer clearance to the next ATS unit.	Aircraft delayed on handover.			V			V	V	
Task execution incomplete		ATCO issues incomplete transfer clearance to the next ATS unit.	Confirmation sought by the pilot leading to an increase in ATCO's workload.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO performs other tasks when he meant to issue transfer clearance to the next ATS unit.	a/c handover is delayed			V			V	V	
Task repeated		ATCO issues transfer clearance to the next ATS unit several times.	Increased workload			V			V	V	
Task executed on wrong interface element	V										
Task executed too early	V	ATCO issues transfer clearance to the next ATS unit too early.	No impact			V			V	V	
Task executed too late	V	ATCO issues transfer clearance to the next ATS unit too late.	Increased coordination with APP required -> increased workload.								
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Departure Procedure			Task step 6.2: Handover to the next ATS unit/ Interact with EFS							
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		

Fail to execute	V	No strip moved on EFS.	EFS does not accurately represent traffic situation. No indication aircraft is transferred.			V			V	V	
Task execution incomplete											
Task executed in wrong direction		Inserting strip into an incorrect bay on EFS.	EFS does not accurately represent traffic situation.								
Wrong task executed	V	Incorrect strip moved.	EFS does not accurately represent traffic situation.			V			V	V	
Task repeated											
Task executed on wrong interface element	V										
Task executed too early	V	Strip is put too early.	EFS does not accurately represent traffic situation			V			V	V	
Task executed too late	V	Strip is put too late.	EFS does not accurately represent traffic situation. No indication Runway blocked.						V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

HET Template Arrival Procedure



Scenario: Arrival Procedure			Task step 1.1: Coordination call received from APP Controller/ Answer phone									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO not able to answer the phone due to workload	Lack of coordination and information deficit			V			V	V	
Task execution incomplete	V	Message not fully received	Incomplete information		V	V			V	V	
Task executed in wrong direction	V	Failure to identify the correct source	Momentary confusion			V			V	V	
Wrong task executed	V	Call-sign/SSR confusion	Incorrect coupling		V				V	V	
Task repeated	V	Coordination repeated	Distraction and time consuming might increase workload		V	V			V	V	
Task executed on wrong interface element											
Task executed too early											
Task executed too late	V	ATCO not able to answer the phone in time due to workload	Lack of coordination and time consuming		V				V	V	
Task executed too much											
Task executed too little											
Misread information	V	Misinterpretation of runway information	Wrong runway selection		V	V		V		V	
Other											

Scenario: Arrival Procedure			Task step 1.2: Coordination call received from APP Controller/ Record transponder code									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	The transponder code is not input	No Squawk correlation			V			V	V	
Task execution incomplete											
Task executed in wrong direction	V	SSR code assigned to wrong a/c	Incorrect correlation		V				V	V	

Wrong task executed	V	SSR code assigned to wrong a/c	Incorrect correlation		V				V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early											
Task executed too late	V	Delayed inputting of the SSR code	Delayed display of the callsign		V				V	V	
Task executed too much											
Task executed too little											
Misread information	V	Wrong squawk assigned	No correlation on the FDP		V				V	V	
Other											

Scenario: Arrival Procedure			Task step 1.3: Coordination call received from APP Controller/Make check of the other airport								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on other airport	Possible Runway incursion			V			V	V	
Task execution incomplete	V	Incomplete scan the other airport	Possible Runway incursion			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	Scanning one airport thinking it is the other airport	Possible Runway incursion			V			V	V	
Task repeated	V	Repeated scan of the other airport	Time consuming			V			V	V	
Task executed on wrong interface element	V	Scanning one airport thinking it is the other airport	Possible Runway incursion			V			V	V	
Task executed too early	V	Scanning of the other airport is done at an early stage	Increased workload as subsequent scans will be carried out			V			V	V	
Task executed too late	V	Scanning of the other airport is done at a later stage	Delayed situational awareness			V			V	V	

Task executed too much	V	Repeated scan of the other airport	Time consuming			V			V	V	
Task executed too little	V	Incomplete scan the other airport	Possible Runway incursion			V			V	V	
Misread information	V	Scanning without paying sufficient attention and thereby missing an obstruction	Possible Runway incursion		V	V		V			V
Other											

Scenario: Arrival Procedure			Task step 1.4: Coordination call received from APP Controller/ Insert strip into ARR sequence								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No strip moved into the ARR sequence	EFS does not accurately represent traffic situation			V			V	V	
Task execution incomplete											
Task executed in wrong direction	V	Inserting strip into an incorrect bay on EFS	EFS does not accurately represent traffic situation			V			V	V	
Wrong task executed	V	Incorrect strip moved into the ARR sequence	EFS does not accurately represent traffic situation			V			V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early		Strip is put too early in the ARR sequence	EFS does not accurately represent traffic situation			V			V	V	
Task executed too late		Strip is put too late in the ARR sequence	EFS does not accurately represent traffic situation			V			V	V	
Task executed too much											
Task executed too little											
Misread information		Incorrect arrival sequence represented on EFS	EFS does not accurately represent traffic situation		V	V	V			V	V

Other											
Scenario: Arrival Procedure			Task step 2.1: First Contact with arriving aircraft/ Acknowledge call + reply								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not acknowledge and reply to aircraft	Aircraft must call again.			V			V	V	
Task execution incomplete	V	ATCO does not acknowledge and reply to aircraft.	Aircraft must call again.								
Task executed in wrong direction											
Wrong task executed	V	ATCO replies to wrong aircraft.	Aircraft must call again.			V			V	V	
Task repeated	V	ATCO acknowledges aircraft again.	Time consuming.			V			V	V	
Task executed on wrong interface element	V	ATCO Replies to aircraft on wrong frequency	Increase workload having to repeat the transmission		V				V	V	
Task executed too early	V	ATCO calls aircraft before it has been handed over.	Repeat transmission when aircraft calls.			V			V	V	
Task executed too late	V	ATCO does not acknowledge and reply to aircraft immediately.	Aircraft will call again.		V				V	V	
Task executed too much											
Task executed too little											
Misread information	V	ATCO replies to wrong aircraft.	Wrong aircraft will query the call and right. Aircraft will call again resulting in higher RT workload		V	V			V	V	
Other											
Scenario: Arrival Procedure			Task step 2.2: First Contact with arriving aircraft/ Assume EFS for aircraft								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		

Fail to execute	V	ATCO fails to assume relevant Strip in EFS.	EFS does not accurately represent traffic situation			V			V	V	
Task execution incomplete	V	ATCO fails to assume relevant Strip in EFS.	EFS does not accurately represent traffic situation			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	ATCO assumes Strip for incorrect flight.	EFS does not accurately represent traffic situation.			V			V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	ATCO Assumes Strip before flight becomes active.	EFS does not accurately represent traffic situation.			V			V	V	
Task executed too late	V	ATCO fails to assume Strip when flight becomes active.	EFS does not accurately represent traffic situation.			V			V	V	
Task executed too much											
Task executed too little											
Misread information	V	ATCO might assume Strip for incorrect flight	Impaired awareness of situation			V		V		V	
Other											

Scenario: Arrival Procedure			Task step 2.3: First Contact with arriving aircraft/ Make check to the other airport								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on the other airport	Possible Runway incursion			V			V	V	
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	Scanning current airport thinking it is the other airport	Possible Runway incursion			V			V	V	

Task repeated	V	Repeated scan of the other airport	Time consuming			V			V	V	
Task executed on wrong interface element	V	Scanning current airport thinking it is the other airport	Possible Runway incursion			V			V	V	
Task executed too early	V	Scanning of the other airport is done at an early stage	Increased workload as subsequent scans will be carried out			V			V	V	
Task executed too late	V	Scanning of the other airport is done at a later stage	Delayed situational awareness			V			V	V	
Task executed too much	V	Repeated scan of the other airport	Time consuming			V			V	V	
Task executed too little	V	Incomplete scan of the the other airport	Possible Runway incursion		V	V		V		V	
Misread information	V	Scanning without paying sufficient attention and thereby missing an obstruction	Possible Runway incursion		V	V		V			V
Other											

Scenario: Arrival Procedure			Task step 2.4: First Contact with arriving aircraft/Cross check position on RDP								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not look at RDP	Delayed situational awareness			V			V	V	
Task execution incomplete	V	ATCO looks at RDP but fails to comprehend “Big Picture”	Delayed situational awareness			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	Looking at incorrect RDP.	Delayed situational awareness			V			V	V	
Task repeated	V	ATCO continually looks at RDP.	Time consuming.			V			V	V	
Task executed on wrong interface element	V	ATCO interacts with OTW instead of RDP.	Delayed situational awareness			V			V	V	
Task executed too early	V	ATCO looks at RDP before flight information has been passed by adjacent ATC Unit.	Require checking RDP again when information on flight received. Time consuming.			V			V	V	

Task executed too late	V	ATCO does not look at RDP when flight information received.	Delayed situational awareness			V			V	V	
Task executed too much	V	Continuous looking at RDP.	Less interaction with other interfaces therefore reduced awareness of traffic.			V			V	V	
Task executed too little		ATCO not looking at RDP or fully comprehending "Big Picture"	Delayed situational awareness			V			V	V	
Misread information	V	Incorrectly assess aircraft speed from RDP.	Incorrect workload prioritisation		V	V	V	V		V	V
Other											
Scenario: Arrival Procedure			Task step 2.5: First Contact with arriving aircraft/ Utilize OTW picture to locate A/C on approach								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not observe aircraft OTW.	No significant impact on operations.			V			V	V	
Task execution incomplete	V	ATCO looks at OTW without comprehending "Big Picture"	No significant impact upon operations.			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	Looking at incorrect OTW.	Delayed situational awareness			V			V	V	
Task repeated	V	ATCO continually looks at OTW.	Time consuming and impacts upon interaction with other interfaces.			V			V	V	
Task executed on wrong interface element	V	ATCO interacts with RDP instead of OTW.	Delayed situational awareness			V			V	V	
Task executed too early	V	ATCO looks at OTW before flight information has been passed by adjacent ATC Unit.	Require checking OTW again when information on flight received. Time consuming.			V			V	V	
Task executed too late	V	ATCO does not look at OTW when flight information received.	Delayed situational awareness			V			V	V	

Task executed too much	V	Continuous looking at OTW.	Less interaction with other interfaces.			V		V		V	
Task executed too little	V	ATCO does not look at OTW when flight information received.	Delayed situational awareness			V			V	V	
Misread information	V	Misjudging the location of an inbound flight on OTW.	Delayed situational awareness.		V	V	V	V		V	V
Other											

Scenario: Arrival Procedure			Task step 2.6: First Contact with arriving aircraft/ Scan predicted A/C track using OTW								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to scan predicted track of inbound A/C OTW.	No significant impact on operations.			V			V	V	
Task execution incomplete	V	ATCO fails to thoroughly scan predicted track – from present position to touchdown.	Task will be repeated		V	V			V	V	
Task executed in wrong direction											
Wrong task executed	V	Scanning incorrect OTW.	Delayed situational awareness			V			V	V	
Task repeated	V	ATCO continually looks at predicted track OTW.	Time consuming and impacts upon interaction with other interfaces.			V			V	V	
Task executed on wrong interface element	V	ATCO interacts with RDP instead of OTW.	Delayed situational awareness			V			V	V	
Task executed too early	V	ATCO looks at OTW before flight information has been passed by adjacent ATC Unit.	Require checking OTW again when information on flight received. Time consuming.			V			V	V	
Task executed too late	V	ATCO does not look at OTW when or immediately after flight makes first contact.	Delayed situational awareness			V			V	V	
Task executed too much	V	Continuous looking at OTW.	Less interaction with other interfaces.			V			V	V	

Task executed too little	V	ATCO does not scan predicted track OTW or fails to thoroughly scan predicted track.	Delayed situational awareness			V			V	V	
Misread information	V	Incorrectly identify predicted track of inbound flight OTW.	Delayed situational awareness.			V			V	V	
Other											

Scenario: Arrival Procedure			Task step 3.1: Landing Clearance Issuance/ Scan Rwy for obstruction								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan runway.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task execution incomplete	V	ATCO fails to scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		V	V	V			V	V (depends on the traffic scenario)
Task executed in wrong direction											
Wrong task executed	V	ATCO scans runway at wrong airport.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task repeated	V	ATCO continually scans runway.	Time consuming and impacts upon interaction with other interfaces.			V		V		V	
Task executed on wrong interface element	V	ATCO scans runway at incorrect airport.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task executed too early	V	ATCO scans runway again.	Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan runway at this time.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task executed too much	V	Continuous scanning of runway.	Less interaction with other interfaces.			V		V		V	
Task executed too little	V	ATCO does not scan runway thoroughly.	Runway incursion – miss obstacle on the runway.			V	V			V	
Misread information	V	ATCO fails to notice obstruction on runway.	Runway incursion – miss obstacle on the runway.			V	`V			V	
Other											

Scenario: Arrival Procedure			Task step 3.2: Landing Clearance Issuance/ Transmit landing clearance									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to transmit landing clearance.	Aircraft requests/confirms landing clearance.			V			V	V	
Task execution incomplete	V	Landing clearance issued without appropriate aircraft callsign.	Aircraft queries/confirms landing clearance.			V			V	V	
Task executed in wrong direction	V	Landing clearance issued to wrong aircraft.	Aircraft inbound acknowledges clearance. Airport runway might not have been scanned at this time – possible obstacle unobserved on runway.			V	V			V	
Wrong task executed	V	Aircraft cleared to land at wrong airport.	Aircraft queries/confirms landing clearance.			V			V	V	
Task repeated	V	Landing clearance reissued.	Time consuming.			V			V	V	
Task executed on wrong interface element		Landing clearance issued on wrong frequency	Aircraft requests/confirms landing clearance.		V	V			V		
Task executed too early	V	Landing clearance issued before runway scanned.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task executed too late	V	Landing clearance issued late.	Aircraft requests/confirms landing clearance.			V			V	V	
Task executed too much											
Task executed too little											
Misread information	V	Aircraft inbound reads back landing clearance for aircraft inbound to the other airport.	Airport runway might not have been scanned – possible obstacle unobserved on runway.			V	V			V	
Other											
Scenario: Arrival Procedure			Task step 3.3: Landing Clearance Issuance/ Record clearance to land on EFS									

Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to record landing clearance on relevant Strip in EFS.	EFS does not accurately represent traffic situation.			V			V	V	
Task execution incomplete	V	ATCO fails to record landing clearance on relevant Strip in EFS.	EFS does not accurately represent traffic situation			V			V	V	
Task executed in wrong direction											
Wrong task executed	V	Clearance to land recorded on wrong flight strip.	EFS does not accurately represent traffic situation.			V			V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	Clearance to land recorded on EFS before being issued to aircraft.	EFS does not accurately represent traffic situation.			V			V	V	
Task executed too late	V	ATCO records clearance to land on EFS late.	EFS does not accurately represent traffic situation.			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											
Scenario: Arrival Procedure			Task step 3.4: Landing Clearance Issuance/ Make cross check on the other airport								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on the other airport	Possible Runway incursion			V			V	V	
Task execution incomplete	V	Incomplete scan of the on the other airport	Possible Runway incursion			V			V	V	
Task executed in wrong direction											

Wrong task executed	V	Scanning current airport thinking it is the other airport	Possible Runway incursion			V			V	V	
Task repeated	V	Repeated scan of on the other airport	Time consuming			V			V	V	
Task executed on wrong interface element	V	Scanning current airport thinking it is the other airport	Possible Runway incursion			V			V	V	
Task executed too early	V	Scanning of on the other airport is done at an early stage	Increased workload as subsequent scans will be carried out			V			V	V	
Task executed too late	V	Scanning of the other airport is done at a later stage	Delayed situational awareness			V			V	V	
Task executed too much	V	Repeated scan of the other airport	Time consuming			V			V	V	
Task executed too little	V	Incomplete scan of the Runway	Possible Runway incursion			V			V	V	
Misread information	V	Scanning without paying attention	Possible Runway incursion		V	V		V			
Other											

Scenario: Arrival Procedure			Task step 4.1: Monitor Arriving aircraft/ Scan Rwy									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan runway.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task execution incomplete	V	ATCO fails to scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		V	V	V			V	**V**
Task executed in wrong direction											
Wrong task executed	V	ATCO scans runway at wrong airport.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task repeated	V	ATCO continually scans runway.	Time consuming and impacts upon interaction with other interfaces.			V		V		V	
Task executed on wrong interface element	V	ATCO scans runway at incorrect airport.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task executed too early	V	ATCO scans runway too early.	ATCO scans runway again. Time consuming.			V			V	V	

Task executed too late	V	ATCO fails to scan runway at this time.	Runway incursion – miss obstacle on the runway.		V	V	V			V	V
Task executed too much	V	Continuous scanning of runway.	Less interaction with other interfaces.			V		V		V	
Task executed too little	V	ATCO does not scan runway thoroughly.	Runway incursion – miss obstacle on the runway.			V	V			V	
Misread information	V	ATCO fails to notice obstruction on runway.	Runway incursion – miss obstacle on the runway.		V	V	V			V	V
Other											
Scenario: Arrival Procedure			Task step 4.2: Monitor Arriving aircraft/ Scan anemometer issue surface wind vector								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to pass wind vector information to landing aircraft.	Pilot unaware of wind vector information and potential associated hazards.		V	V		V		V	V
Task execution incomplete	V	ATCO issues incomplete wind vector information.	Pilot unaware of wind vector information and potential associated hazards.			V		V		V	
Task executed in wrong direction	V	Wind vector information issued to aircraft landing at the other airport.	Pilot unaware of wind vector information and potential associated hazards.			V		V		V	
Wrong task executed	V	The other airport's wind vector information issued to aircraft landing at the airport.	Pilot unaware of wind vector information and potential associated hazards.			V		V		V	V
Task repeated	V	ATCO reissues wind vector information.	Time consuming.			V			V	V	
Task executed on wrong interface element											
Task executed too early											
Task executed too late	V	ATCO first issues wind vector information	Pilot unaware of wind vector information and potential			V		V		V	

		when aircraft close to landing.	associated hazards.								
Task executed too much	V	ATCO continually issues wind vector information.	Frequency congestion. Time consuming.			V			V	V	
Task executed too little	V	ATCO fails to issue wind vector information.	Pilot unaware of wind vector information and potential associated hazards. Pilot requests updated information.			V			V	V	
Misread information	V	ATCO issues incorrect wind vector information.	Pilot unaware of wind vector information and potential associated hazards.			V		V		V	
Other											
Scenario: Arrival Procedure			Task step 4.3: Monitor Arriving aircraft/ Make cross check on the other airport								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on the other airport	Possible Runway incursion		V	V		V		V	V
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion		V	V		V		V	V
Task executed in wrong direction											
Wrong task executed	V	Scanning the current airport thinking it is the other	Possible Runway incursion			V		V		V	
Task repeated	V	Repeated scan of the other airport	Time consuming may impact upon ability to observe traffic landing current airport.			V		V		V	
Task executed on wrong interface element	V	Scanning current airport thinking it is the other airport	Possible Runway incursion			V		V		V	
Task executed too early	V	Scanning of the other airport is done at an early stage	Increased workload as subsequent scans will be carried out			V		V		V	
Task executed too late	V	Scanning of the other airport is done at a later stage	Delayed situational awareness		V	V		V		V	V

Task executed too much	V	Repeated scan of the other airport	Time consuming. Impacts upon time spent scanning runway in current airport.			V		V		V	
Task executed too little	V	Incomplete scan of the the other airport	Possible Runway incursion			V		V		V	
Misread information	V	Scanning without paying attention	Possible Runway incursion		V	V		V		V	v
Other											

Scenario: Arrival Procedure			Task step 4.4: Monitor Arriving aircraft/Scan Rwy									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not scan runway.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task execution incomplete	V	ATCO fails to scan runway thoroughly.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task executed in wrong direction											
Wrong task executed	V	ATCO scans runway at wrong airport.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task repeated	V	ATCO continually scans runway.	Time consuming and impacts upon interaction with other interfaces.			V		V		V	
Task executed on wrong interface element	V	ATCO scans runway at incorrect airport.	Runway incursion – miss obstacle on the runway.			V	V			V	
Task executed too early	V	ATCO scans runway again.	Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to scan runway at this time.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Task executed too much	V	Continuous scanning of runway.	Less interaction with other interfaces.			V		V		V	
Task executed too little	V	ATCO does not scan runway thoroughly.	Runway incursion – miss obstacle on the runway.			V	V			V	
Misread information	V	ATCO fails to notice obstruction on runway.	Runway incursion – miss obstacle on the runway.		V	V	V			V	v
Other											

Scenario: Arrival Procedure			Task step 4.5: Monitor Arriving aircraft/ Monitor A/C touchdown + roll									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to observe landing roll of aircraft.	ATCO may miss incident arising on landing.			V		V		V	
Task execution incomplete	V	ATCO fails to monitor landing roll of aircraft thoroughly.	ATCO may miss incident arising on landing.		V	V		V		V	v
Task executed in wrong direction											
Wrong task executed	V	ATCO scans runway at incorrect airport.	ATCO may miss incident arising on landing.			V		V		v	
Task repeated	V	ATCO continually scans runway current airport.	Time consuming and impacts upon interaction with other interfaces.			V		V		V	
Task executed on wrong interface element											
Task executed too early	V	ATCO scans runway before aircraft lands.	ATCO must scan runway again. Time consuming.			V			V	V	
Task executed too late	V	ATCO fails to monitor landing roll as aircraft landing.	ATCO may miss incident arising on landing.		V	V		V		V	v
Task executed too much	V	Continuous scanning of runway.	Less interaction with other interfaces.			V		V		V	
Task executed too little	V	ATCO does not continually observe landing roll of aircraft.	ATCO may miss incident arising on landing.			V		V		V	
Misread information	V	ATCO fails to observe incident arising as aircraft lands.	ATCO response in the event of an incident incorrect.		V	V		V		V	v
Other											
Scenario: Arrival Procedure			Task step 5.1: Aircraft Runway Vacate/ Issue runway exit + initial taxi route									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not issue taxying instructions to aircraft after landing.	Aircraft vacates on wrong taxiway causing tactical conflict		V	V		V		V	v

Task execution incomplete	V	ATCO does not give complete taxying instructions.	Aircraft vacates on wrong taxiway causing tactical conflict			V		V		V	
Task executed in wrong direction	V	Taxi instructions issued in wrong order.	Aircraft vacates on wrong taxiway causing tactical conflict			V		V		V	
Wrong task executed	V	Taxi instructions issued on wrong frequency	Aircraft vacates on wrong taxiway causing tactical conflict		V	V					v
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	Taxi clearance issued as aircraft landing before it has slowed.	Pilot unable to attend to clearance – will request reissuance of instructions.			V		V		V	
Task executed too late	V	Aircraft issued taxi instructions after it has already commenced taxying or entered taxiway.	Aircraft vacates on wrong taxiway causing tactical conflict		V	V		V		V	v
Task executed too much											
Task executed too little											
Misread information	V	Pilot reads back clearance incorrectly and mistake not noticed by ATCO.	Aircraft vacates on wrong taxiway causing tactical conflict		V	V		V		V	v
Other											

Scenario: Arrival Procedure			Task step 5.2: Aircraft Runway Vacate/ Cross check the other airport								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on the other airport	Possible Runway incursion		V	V		V		V	v
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion		V	V		V		V	v
Task executed in wrong direction											

Wrong task executed	V	Scanning current airport thinking it is the other airport	Possible Runway incursion			V		V		V	
Task repeated	V	Repeated scan of the other airport	Time consuming may impact upon ability to observe traffic landing at current airport.			V		V		V	
Task executed on wrong interface element	V	Scanning current airport thinking it is the other airport.	Possible Runway incursion			V		V		V	
Task executed too early	V	Scanning of the other airport is done at an early stage	Increased workload as subsequent scans will be carried out			V		V		V	
Task executed too late	V	Scanning of the other airport is done at a later stage	Delayed situational awareness		V	V		V		V	v
Task executed too much	V	Repeated scan of the other airport	Time consuming may impact upon ability to observe traffic landing at current airport.			V		V		V	
Task executed too little	V	Incomplete scan of the other airport	Possible Runway incursion			V		V		V	
Misread information	V	Scanning without paying attention	Possible Runway incursion		V	V		V		V	v
Other											

Scenario: Arrival Procedure			Task step 5.3: Aircraft Runway Vacate/ Confirm runway vacated								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not monitor aircraft vacating runway.	ATCO unsure if runway vacated.			V			V	V	
Task execution incomplete											
Task executed in wrong direction	V	ATCO checks aircraft clear of main rwy Forgets about traffic using the other airport	Potential Runway Incursion			V		V		V	
Wrong task executed											
Task repeated											
Task executed on wrong											

interface element											
Task executed too early	V	ATCO does not observe aircraft vacating Runway	ATCO must scan runway again to ensure aircraft vacated.			V			V	V	
Task executed too late	V	ATCO scans runway after aircraft vacated.	No impact upon operations at this time.			V			V	V	
Task executed too much	V	ATCO continually monitors aircraft vacating runway.	Time consuming. Impacts upon time spent scanning runway in the other airport.			V		V		V	
Task executed too little	V	ATCO does not observe aircraft vacating the runway.	No impact upon operations at this time.			V			V	V	
Misread information	V	ATCO believes aircraft has vacated runway.	No impact upon operations at this time.			V			V	V	
Other											

Scenario: Arrival Procedure			Task step 5.4: Aircraft Runway Vacate/ Record vacated on strip									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to record runway vacated on relevant Strip in EFS.	EFS does not accurately represent traffic situation.			V			V	V	
Task execution incomplete											
Task executed in wrong direction											
Wrong task executed	V	Vacated recorded on wrong flight strip.	EFS does not accurately represent traffic situation.			V			V	V	
Task repeated											
Task executed on wrong interface element											
Task executed too early	V	Vacated recorded on EFS before aircraft clear	EFS does not accurately represent traffic situation.			V			V	V	

Task executed too late	V	ATCO records vacated on EFS late.	EFS does not accurately represent traffic situation.			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											
Scenario: Arrival Procedure			Task step 6.1: Taxi instruction to stand/ Check stand								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not check stand no. allocated to landing aircraft.	ATCO unsure where aircraft is to park.			V			V	V	
Task execution incomplete											
Task executed in wrong direction	V	ATCO incorrectly reads stand number for a different aircraft	Aircraft instructed to proceed to incorrect stand.			V			V	V	
Wrong task executed	V	ATCO passes stand no. for aircraft landing the other airport.	Aircraft instructed to proceed to incorrect stand.			V			V	V	
Task repeated											
Task executed on wrong interface element	V	ATCO interacts with strip for flight inbounds the other airport.	EFS does not accurately represent traffic situation.			V			V	V	
Task executed too early	V	Stand changes	Aircraft instructed to proceed to incorrect stand.			V			V	V	
Task executed too late	V	ATCO does not issue stand information soon enough.	Possible tactical conflict if aircraft goes passed assigned stand			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

Scenario: Arrival Procedure			Task step 6.2: Taxi instruction to stand/ Issue taxi route								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO does not issue continued taxying instructions to aircraft	Aircraft taxis passed clearance limit resulting in tactical ground conflict		V	V		V		V	
Task execution incomplete	V	ATCO does not give complete taxying instructions.	Aircraft taxis passed clearance limit resulting in tactical ground conflict		V	V		V		V	
Task executed in wrong direction	V	Taxi instructions issued in wrong order.	Aircraft stops and queries - increasing R/T workload			V		V		V	
Wrong task executed	V	Taxi instructions given to wrong call-sign – aircraft landing the other airport.	Landed Aircraft unsure what actions to take.								
Task repeated											
Task executed on wrong interface element	V	Taxi instructions issued on incorrect frequency	Aircraft stops and queries taxi route - increasing R/T workload		V	V			V	V	
Task executed too early	V	Taxi clearance issued as aircraft landing before it has slowed.	Pilot unable to attend to clearance – will request reissuance of instructions.			V		V		V	
Task executed too late	V	ATCO late issuing continued taxying instructions to aircraft	Aircraft taxis passed clearance limit resulting in tactical ground conflict		V	V		V		V	
Task executed too much											
Task executed too little											
Misread information	V	ATCO misreads position of other aircraft on manoeuvring area on OTW	Wrong taxi route issued resulting in tactical conflict		V	V		V			V
Other											

Scenario: Arrival Procedure			Task step 6.3: Taxi instruction to stand/ Cross check the other airport									
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	No check on the other airport	Possible Runway incursion		V	V		V		V	v
Task execution incomplete	V	Incomplete scan of the Runway	Possible Runway incursion		V	V		V		V	v
Task executed in wrong direction											
Wrong task executed	V	Scanning current airport thinking it is the other airport	Possible Runway incursion			V		V		V	
Task repeated	V	Repeated scan of the other airport	Time consuming may impact upon ability to observe traffic landing airport.			V		V		V	
Task executed on wrong interface element	V	Scanning current airport thinking it is the other airport	Possible Runway incursion			V		V		V	
Task executed too early	V	Scanning of other airport is done at an early stage	Increased workload as subsequent scans will be carried out			V		V		V	
Task executed too late	V	Scanning of other airport is done at a later stage	Delayed situational awareness		V	V		V		V	v
Task executed too much	V	Repeated scan of the other airport	Time consuming. Impacts upon time spent scanning runway.			V		V		V	
Task executed too little	V	Incomplete scan of the Runway	Possible Runway incursion			V		V		V	
Misread information	V	Scanning without paying attention	Possible Runway incursion		V	V		V		V	v
Other											

Scenario: Arrival Procedure			Task step 6.4: Taxi instruction to stand/ Record parked								
Error Mode	TICK	Description	Outcome	Likelihood			Criticality			PASS	CAUTION
				H	M	L	H	M	L		
Fail to execute	V	ATCO fails to record aircraft parked on strip.	EFS does not accurately represent traffic situation.			V			V	V	

Task execution incomplete											
Task executed in wrong direction											
Wrong task executed	V	Aircraft parked recorded by ATCO on wrong flight strip.	EFS does not accurately represent traffic situation - Strip for flight inbound the other airport removed from EFS.			V			V	V	
Task repeated											
Task executed on wrong interface element	V	Aircraft parked recorded on flight inbound to the other airport.	EFS does not accurately represent traffic situation – Strip for flight inbound the other airport removed from EFS.			V		V		V	
Task executed too early	V	Aircraft parked recorded on EFS before being aircraft has parked on stand.	EFS does not accurately represent traffic situation.			V			V	V	
Task executed too late	V	ATCO records aircraft parked sometime after aircraft is on stand.	EFS does not accurately represent traffic situation.			V			V	V	
Task executed too much											
Task executed too little											
Misread information											
Other											

APPENDIX D List of Hazards from SESAR Safety Assessment

Table D-1 presents a list of hazards and their estimated effects on operations, as it is deducted by SESAR JU programme. These are generic hazards, that apply to both single and multiple modes of operations and has been used as input for the Hazard Identification and Analysis process described in Chapter 4 Hazard Identification and Initial Analysis. (SESAR Joint Undertaking, 2015), (SESAR Joint Undertaking, 2016 (a)) , (SESAR Joint Undertaking, 2016 (b)), (SESAR Joint Undertaking, 2015) (European Aviation Safety Agency(EASA), 2019)

Table D-1: List of Operational Hazards (SESAR safety assessment)

ID	Description	Operational effects
OH-01	Remote ATC incorrectly coordinates with other ATS unit with respect to inbound/outbound traffic.	A potential conflict can be induced. Imminent infringement.
OH-02	Remote ATC incorrectly manages the entry of a flight into traffic circuit.	A potential conflict can be induced. Imminent infringement.
OH-03	Remote ATC incorrectly manages arriving aircraft.	A potential conflict can be induced. Imminent infringement.
OH-04	Remote ATC incorrectly manages departing aircraft.	A potential conflict can be induced Imminent infringement
OH-05	Remote ATC fails to provide appropriate separation to traffic in the vicinity of the aerodrome.	Imminent infringement.
OH-06	Remote ATC fails to provide appropriate separation to traffic with respect to restricted areas.	Tactical conflict.
OH-07	Remote ATC incorrectly manages missed approach situation.	Imminent infringement.
OH-08	Remote ATC does not detect in time conflicts/ potential collision between aircraft in the vicinity of the aerodrome.	Imminent collision.
OH-09	Remote ATC does not detect in time restricted area infringements.	Tactical conflict.
OH-10	Remote ATC fails to provide appropriate instruction to resolve a conflict between traffic in the vicinity of the aerodrome.	Imminent collision.
OH-11	Remote ATC fails to provide appropriate instruction to resolve an airspace infringement.	Tactical conflict.

OH-12	Remote ATC fails to provide appropriate information to departing aircraft for the start-up.	Tactical taxiway conflict generated.

ID	Description	Operational effects
OH-13	Remote ATC fails to enable push-back/towing operations to appropriate aircraft.	Tactical taxiway conflict generated.
OH-14	Remote ATC provides inadequate taxiing instruction to aircraft on the manoeuvring area.	Encounter with aircraft, vehicle or obstacle.
OH-15	Remote ATC provides inadequate taxiing instruction to vehicle on the manoeuvring area.	Encounter with aircraft, vehicle or obstacle.
OH-16	Remote ATC does not detect in time potential conflict on the manoeuvring area.	Imminent collision.
OH-17	Remote ATC fails to provide appropriate instruction to resolve conflicts on the manoeuvring area.	Imminent collision.
OH-18	Remote ATC fails to provide (appropriate) navigation support to aircraft and vehicle on the manoeuvring area.	Tactical taxiway conflict generated.
OH-19	Remote ATC incorrectly manages runway entry for a departing aircraft (occupied runway).	Runway conflict.
OH-20	Remote ATC incorrectly manages runway exit for a landing aircraft.	Runway conflict.
OH-21	Remote ATC incorrectly manages runway crossing (occupied runway) for a vehicle or an aircraft.	Runway conflict.
OH-22	Remote ATC fails to properly support departing and landing aircraft (with respect to visual aids).	Runway conflict.
OH-23	Remote ATC incorrectly manages vehicle-related tasks on the runway.	Runway conflict.
OH-24	Remote ATC incorrectly manages aircraft take-off (occupied runway).	Runway conflict.
OH-25	Remote ATC incorrectly manages aircraft landing (occupied runway).	Runway conflict.
OH-26	Remote ATC fails to detect in time runway incursions (aircraft or vehicles).	Runway penetration.
OH-27	Remote ATC fails to provide appropriate instruction to resolve runway incursion and prevent potential collision on the runway.	Runway penetration.
OH-28	Remote ATC fails to detect in time a flight towards terrain in the vicinity of the aerodrome.	Imminent controlled flight into terrain (CFIT).
OH-29	Remote ATC fails to provide appropriate support to pilot in a CFIT situation.	Imminent CFIT.
OH-30	Remote ATC fails to establish sufficient wake-turbulence spacing between aircraft.	Turbulence in front of the aircraft at a distance less than the separation minima.
OH-31	Remote ATC fails to properly support landing/ take-off operations with respect to weather conditions.	Potential landing accident/runway excursion.

ID	Description	Operational effects
OH-32	Remote ATC fails to properly support landing/ take-off operations with respect to runway conditions and potential foreign object debris.	Potential landing accident/runway excursion.
OH-33	Remote ATC fails to properly support departing and arriving aircraft on the runway with respect to non-visual aids.	Potential landing accident/runway excursion.
OH-34	Remote ATC fails to detect in time an intrusion inside landing-air protection area.	Potential landing accident/runway excursion.
OH-35	Remote ATC fails to provide appropriate ATC services with respect to operational environment conditions on the aerodrome and its vicinity.	This hazard is already covered by more detailed hazards already identified above, potentially inducing conflicts in the vicinity of the aerodrome or on the manoeuvring area due to inappropriate understanding of the operational environment conditions. This hazard is related to all other hazards EXCEPT: OH-01, OH-08, OH-09, OH-13, OH-16, OH-26, OH-28, OH-34.
OH-36	ATC resources are incorrectly managed in the RTC for the remote provision of ATC services.	In case a controller has to manage more traffic than expected, the controller workload could be negatively impacted and so the capability to provide ATC services. This hazard is to be considered as part of ALL the other hazards in which controller errors are a potential cause.
OH-37	Remote ATC fails to provide appropriate ATC services due to inappropriate capability of the remote tower system.	This hazard is already considered as part of ALL other hazards already identified above in which equipment failure/errors are potential causes, potentially inducing conflicts in the vicinity of the aerodrome or on the manoeuvring area.

APPENDIX E SDCPN Specification of Agent-Based Model for Multiple Remote Tower

1. List of Agents of the Petri Net Model for Multiple Remote Tower

The Petri Net model for Multiple Remote Tower contains 12 agents and 2 Interconnecting Petri Nets, with their associated local Petri Nets (LPN) and interconnecting Petri Nets (IPN). The list of agents, IPNs and LPNs is presented below.

- **Agents**
  - ATCO
    - LPNs
      - ATCO MASA
      - ATCO Tasks
      - Memory
    - IPNs
      - Incoming Message
      - Outgoing Message
  - Pilots
    - Pilot Cork Landing_k
    - Pilot Cork Departing_k
    - Pilot Shannon_k
  - Aircraft
    - Aircraft Cork Landing_k
    - Aircraft Cork Departing_k
    - Aircraft Shannon_k
  - Airports
    - Airport Cork
    - Airport Shannon
  - Communication System
    - Communication System Cork
    - Communication System Shannon
  - Remote Tower System
- **IPNs**
  - Frequency Cork
  - Frequency Shannon

2. Petri Net Model Assumptions

The assumptions and choices for the agent-based model are presented in Chapter 5. In addition, the following were considered:

- The pilots will not mistake a line up clearance with a hold clearance and will always readback the given ATCO clearance. Other scenarios were considered out of scope for this simulation since the focus of the exercise is to check compliance with an expected instruction when the

pilot is waiting for it (not knowing there is another aircraft with the same intention at the other airport). Non-adherence to clearance is presented and analysed in single remote tower and was not considered in scope.

- The pilots will not make a mistake with the aircraft callsign, pilots know the callsign. Reason as above.
- If a pilot is given a holding clearance, he might request another line up clearance after 10-15 seconds.
- Pilot Shannon_k probability of being student is negligible and will not be considered. There is no training school in Shannon.
- 3rd Party Communications are modelled in the agents "Communication System Cork" and "Communication System Shannon". Interviews with ATCOs have indicated that multiple simultaneous communications are possible, yet ATCO will prioritize their work. In this scenario ATCO will prioritize the two aircraft at the line-up, and ATCO will not focus on other aircraft. However, since ground and air are coupled for both airports it is expected that communications will be initiated by other aircraft, but ATCO will ignore them until this priority tasks are over. To account for this, 3rd party communication will be solely modelled in the frequency occupancy since the ATCO will be unable to use the frequency if other aircraft are calling. The initiation of 3rd party communication is completely independent on other communication occurring on the frequency. Third party communication frequency will be determined for each airport.
- $t_{commsystemoccup}$, which is the duration of the transmission on frequency will be the same estimated for both airports.

3. Petri Net Model for Multiple Remote Tower Model

This section provides an overview of the agent-based model for multiple remote tower and the assumptions on which the model is based on.

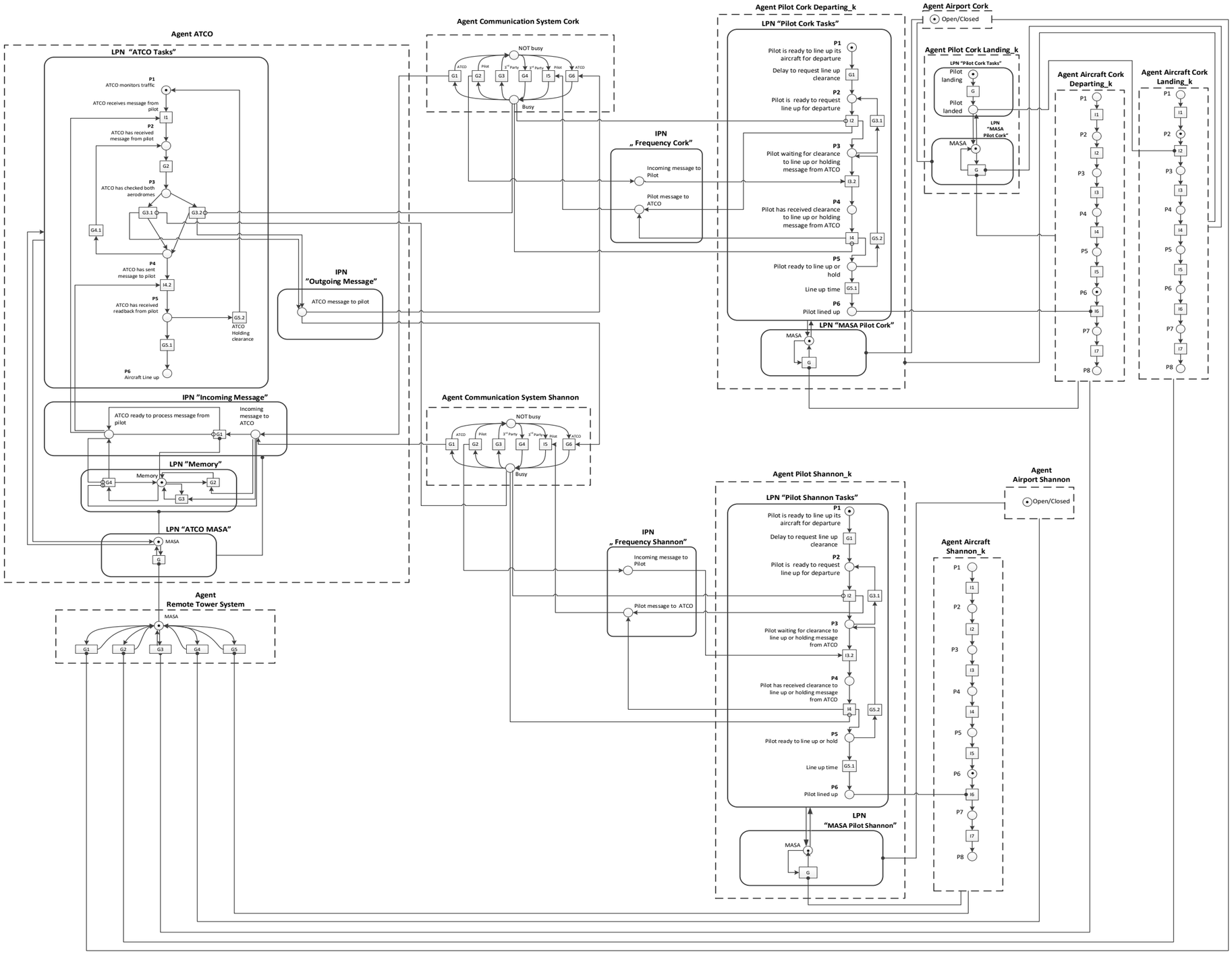


Figure E-5: Petri Net Model for Multiple Remote Tower

3.1. Agent „ATCO “

Agent ATCO consists of 3 LPNs and 2 IPNs. The LPNs are the following:

- LPNs
  - ATCO MASA
  - ATCO Tasks
  - Memory
- IPNs
  - Incoming Message
  - Outgoing Message

The LPNs and IPNs are shortly described in the sections below.

LPN “ATCO MASA”

LPN “ATCO MASA” has one place *MASA* which filters the messages for the ATCO, i.e. open to all aircraft or waiting for readback, and therefore not able to take in another message. It also contains information about the aircraft (callsign and location on the airport), pilots (callsign and intent) and ATC clearance.

There are incoming arcs from all transitions of LPNs “ATCO Tasks”” and outgoing arcs to all transitions of LPNs “ATCO Tasks”. However, only transitions I1 and I4.2 of LPNs “ATCO Tasks” are changing the colours of the token.

Initially, the ATCO is open to all messages, and then transition I1 sets the filter to let message through only if they are related to the current handled aircraft, while I4.2 will be changing the colour of the token such that the ATCO is open again to all messages.

This information is then used by all transitions of LPN “Memory” and IPN” Incoming Message” by enabling arcs.

LPN “ATCO Tasks”

LPN “ATCO Tasks” has 6 places and 8 transitions.

At place *P1* there is token which means that ATCO is monitoring traffic. When a message(token) is present in *ATCO ready to process message from pilot* of IPN “Incoming Message” then transition G1 is activated and a token in fired to place *P2 ATCO has received message from pilot*. G1 is also receiving a token from place *MASA* {Remote Tower System} and fires it back setting the filter to only let message through only if they are related to the current handled aircraft. Note that there is a probability that the ATCO can scramble the airports, thinking that the handled aircraft is at the wrong airport, which means that the filter will be set to the other airport.

After about 5 seconds when the ATCO has checked both aerodromes and decided on the instruction to be given and selected a frequency, the transition G2 is activated, firing the token to P3. G2 is also receiving a token from place *MASA* {Remote Tower System}, and it puts it back with the same colour. Note that this is true for all transitions except for I1 and I4.2.

When the token is in P3, then the ATCO is ready to send the instruction to the pilot on the chosen frequency. Depending on what frequency has been decided in transition G2 and that selected

frequency is not busy, either G3.1 or G3.2 is activated. Whether the frequency is busy, is modelled by inhibitor arc coming from the place *Busy* of agent Communication System Shannon for G3.1 or inhibitor arc coming from the place *Busy* of agent Communication System Cork for G3.2. The activated transition (G3.1 or G3.2) is then sending a token to place *ATCO message to pilot* of IPN "Outgoing message" and place P4. The token sent to place *ATCO message to pilot* of IPN "Outgoing message" will then be further processed to transport the message to agent pilot (Cork or Shannon).

A token in place P4 signifies that the ATCO has sent the clearance or hold message to the pilot and is waiting for a response. If no readback is received from pilot, the ATCO will resend the instruction through G4.1 back to place P2. Transition I4.2. will be activated if a readback is received from the pilot. As mentioned above, like transition I1, I4.2 is changing the colour of the token in place *MASA* {Remote Tower System} such that the ATCO is open again to all messages.

In *P5* the ATCO has received the readback from a pilot. The ATCO can receive, depending on the clearance, either a confirmation of hold message, confirmation of line up or a questioning of the ATCO instruction by the pilot. If it is a hold readback message, then transition G5.2 will be activated and the token is fired to P1. Else, if line up readback from Pilot Cork Departing or questioning from any Pilot is received than transition G5.2 is activated and fires the token to P6, indicating that the simulation can stop. This will only occur if the line up clearance is from the pilot in Cork, since it is assumed that if the pilot in Cork lines up, a collision will be imminent, and ATCO communication will freeze until a resolution is found (or in case of a collision until replaced with another ATCO fit for duty). However, if the pilot in Shannon lined up incorrectly (due to callsign confusion, i.e. the ATCO used callsign that did not belong to him/her), a Runway Incursion will occur in Shannon, however due to the fact that this will not be an emergency situation, the simulation will continue until either a runway incursion will occur in Cork or the aircraft on approach will land.

Whether a runway incursion occurs depends on the probability of ATCO being able to intervene if the spots the error and the landing aircraft identifying the situation and reacting to prevent collision.

The place *MASA* will copy information as necessary as described in the LPN "ATCO MASA".

IPN "Incoming Message"

The IPN "Incoming Message" contains two places *Incoming Message to ATCO* and *ATCO ready to process message from pilot*, and one transition G1.

Place *Incoming Message to ATCO* receives a token from agent "Communication System Cork" or "Communication System Shannon" which is a message from a pilot for the ATCO containing aircraft ID and pilot intention.

Transition G1 transfers the token from *Incoming Message to ATCO* to *ATCO ready to process message from pilot,* however some conditions apply. Therefore, there is one inhibitor arc from *ATCO ready to process message from pilot* to prevent overwriting any existing token in that place, one enabling arc from place *Memory* of LPN "Memory" and one enabling arc from place *MASA* of LPN "ATCO MASA".

The condition being checked by transition G1 is: if there is there is no message in the memory and ATCO is open for messages from both airports and the incoming message is not a readback OR if the ATCO is waiting for readback from the pilot and no readback in the memory and the incoming message

is a readback message (this message has priority for the ATCO since he/she has already sent an instructions and is waiting for a reply).

A token in place *ATCO ready to process message from pilot* can be picked up by LPN "ATCO Tasks" for further processing.

IPN "Outgoing Message"

IPN "Outgoing Message" contains one place *ATCO message to Pilot*. Similar to the non-agent entities Cork and Frequency Shannon, this IPN handles all the messages going from the ATCO by transferring a token to either agent "Communication System Cork" or agent "Communication System Shannon". The decision on which airport frequency the message will be transmitted in saved in the colour of the token.

LPN "Memory"

LPN "Memory" has one places and 3 transitions. There is always a token in place memory which may store a message that ATCO cannot or does not want to answer right away.

Transition G2 has two incoming arcs, one from *Incoming message to ATCO* of IPN "Incoming Message" and one from place *Memory*. The outgoing arc goes to place *Memory* ensuring that there is always a token in place *Memory*. Additionally, there is one enabling arc from place *MASA* of LPN "ATCO MASA. Transition G2 serves as a complement of transition G1 in IPN "Incoming Message" and therefore replaces the message in the memory if there is already a message in the place *ATCO ready to process message from pilot* and the ATCO is waiting for a readback and the message is a readback.

Transition G3 has two incoming arcs, one from *Incoming message to ATCO* of IPN "Incoming Message" and one from place *Memory*. The outgoing arc goes to place *Memory* ensuring that there is always a token in place *Memory*. Additionally, there is one enabling arc from place *MASA* of LPN "ATCO MASA".

If in memory there is a message that ATCO is waiting for, i.e. readback from the pilot, transition G3 will prevent this message from being overwritten, else it will overwrite the message in the memory, based on the assumption that ATCO will only remember the last or last important message sent to him/her.

Transition G4 has one incoming arc from place *Memory*. There are two outgoing arcs going to place *Memory* ensuring that there is always a token in place *Memory* and place *ATCO ready to process message from pilot* of IPN "Incoming message". Additionally, there is one inhibitor arc from place *ATCO ready to process message from pilot* of IPN "Incoming message" (ensuring a token in that place in not overwritten), one inhibitor arc from place *Incoming message to pilot* of IPN "Incoming message" and one enabling arc from place *MASA* of LPN "ATCO MASA". Transition G4 is checking for two conditions. The first condition is that the ATCO is open for all messages and the message in the memory is a line up request. The second condition is that there is a readback message in the memory on which the ATCO wants to react upon. If G4 fires, then a token will be sent to *ATCO ready to process message from pilot* of IPN "Incoming message" containing the message received from the pilot, and one token will be fired to place *Memory* resetting the memory to "no message" state.

3.2. Agent "Pilot Cork Departing_k"

There is one enabling arc from place Open/Closed of agent Airport Cork going through all transitions of this agent. This is indicating that the airport is open for operations.

LPN" MASA Pilot Cork"

There is one place in LPN" MASA Pilot Cork". The place *MASA* represents the situation awareness of the pilot and contains the SA of Pilot Cork Departing_k about Aircraft Cork Departing_k, SA of Pilot Cork Departing_k about Aircraft Cork Landing_k, SA of Pilot Cork Departing_k about Airport Cork and SA of Pilot Cork Departing_k about ATCO.

LPN "Pilot Cork Tasks"

Agent Pilot Cork Departing_k represents the Cork pilot waiting for line up clearance at the runway departure holding point (one token in P6). This agent has 6 places and 4 transitions and 3 instant transitions.

Place *P1* represents the pilot ready to line up the aircraft for departure and has an initial token containing the aircraft ID, intent of pilot (implicit, i.e. to line up) and whether the pilot is a student or not. Transition G1 is introduced to model the delay in the pilot requesting the line-up clearance.

At place *P2* the pilot is ready to line up and depart. The instant transition I2 fires a token to place *Pilot Message to ATCO* of IPN "Frequency Cork" and one to place *P3*. There is an inhibitor arc from place Busy of agent Communication System Cork ensuring that the communication will only take place if the frequency is free.

At place *P3* the pilot has sent the request and is now waiting for clearance or line up and hold message from ATCO. Transition G3 ensures that if a response from ATCO is not received in 15-20 s then the pilot will send another request and the token is put back in place *P2*.

At place *P4* the pilot has received clearance from ATCO. This is done through the instant transition I3.2 which fires a token when a message arrives in place *Incoming Message to Pilot* of IPN "Frequency Cork". Transition I4 is activated when pilot send the readback to ATCO. In the same manner as I2, this transition fires a token to place *Pilot Message to ATCO* of IPN "Frequency Cork" and one to place *P5*. There is an inhibitor arc from place Busy of agent Communication System Cork ensuring that the communication will only take place if the frequency is free.

In place *P5*, the pilot has sent the readback to ATCO and will now execute the ATCO instruction. If the instruction is to line up, then transition G5.1. will be firing a token to place P5, otherwise in the case of holding message of pilot questioning ATCO a token will be fired by transition G5.2. back to place *P3,* where the pilot will wait for further instructions.

The probability of runway incursion is dependent on the probability of the ATCO giving the wrong instruction, pilot following the instruction and the probability of ATCO intervening before aircraft is line-up.

Once there is a token in *P6*, then the aircraft has lined up. An enabling arc from place *P6* to transition G6 of agent Aircraft Cork Departing_k will update the location of the aircraft from Departure Holding Point to line up.

The place *MASA* will copy information as necessary as described in the LPN "MASA Pilot Cork".

3.3. Agent "Pilot Cork Landing_k"

LPN" MASA Pilot Cork"

There is one place in LPN" MASA Pilot Cork". The place *MASA* represents the situation awareness of the pilot and contains SA of Pilot Cork Landing_k about Aircraft Cork Landing_k, the SA of Pilot Cork Landing_k about Aircraft Cork Departing_k, SA of Pilot Cork Landing_k about Airport Cork and SA of Pilot Cork Departing_k about ATCO.

There is one enabling arc from place *Open/Closed* of agent Airport Cork going transition G of this LPN. This is indicating that the airport is open for operations.

LPN "Pilot Cork Tasks"

Agent Pilot Cork Landing_k represents the Cork pilot with landing clearance that is on final approach and heads for the runway. This agent has two places and one transition.

Place *Pilot landed* represents the pilot landed and the simulation ends. There is one enabling arc going from place *Pilot landed* to transition *I2* of agent Aircraft Cork Landing_k.

The place *MASA* will copy information as necessary as described in the LPN "MASA Pilot Cork".

3.4. Agent Pilot Shannon_k

LPN" MASA Pilot Shannon"

There is one place in LPN" MASA Pilot Cork". This place *MASA* represents the situation awareness of the pilot and contains the SA of Pilot Shannon Departing_k about Aircraft Shannon Departing_k, and SA of Pilot Shannon Departing_k about airport Shannon.

There is one enabling arc from place Open/Closed of agent Airport Shannon going to transition G of this LPN. This is indicating that the airport is open for operations.

LPN "Pilot Shannon Tasks"

Agent Pilot Shannon_k represents the Shannon pilot waiting for line up clearance at the runway departure holding point (one token in P6). This agent has 6 places and 4 transitions and 3 instant transitions.

Place *P1* represents the pilot ready to line up the aircraft for departure and has an initial token containing the aircraft ID and intent of pilot (implicit, i.e. to line up). Transition G1 is introduced to model the delay in the pilot requesting the line-up clearance.

At place *P2* the pilot is ready to line up and depart. The instant transition I2 fires a token to place *Pilot Message to ATCO* of IPN "Frequency Shannon" and one to place *P3*. There is an inhibitor arc from place Busy of agent Communication System Shannon ensuring that the communication will only take place if the frequency is free.

At place *P3* the pilot has sent the request and is now waiting for clearance or line up and hold message from ATCO. Transition G3 ensures that if a response from ATCO is not received in 15-20 s then the pilot will send another request and the token is put back in place *P2*.

At place *P4* the pilot has received clearance from ATCO. This is done through the instant transition I3.2 which fires a token when a message arrives in place *Incoming Message to Pilot* of IPN "Frequency Shannon". Transition I4 is activated when pilot send the readback to ATCO. In the same manner as I2, this transition fires a token to place *Pilot Message to ATCO* of IPN "Frequency Shannon" and one to place *P5*. There is an inhibitor arc from place *Busy* of agent Communication System Shannon ensuring that the communication will only take place if the frequency is free.

In place *P5* the pilot has sent the readback to ATCO and will now execute the ATCO instruction. If the instruction is to line up, then transition G5.1. will be firing a token to place *P5*, otherwise in the case of holding message of pilot questioning ATCO a token will be fired by transition G5.2. back to place *P3,* where the pilot will wait for further instructions.

The probability of runway incursion is dependent on the probability of the ATCO giving the wrong instruction, pilot following the instruction and the probability of ATCO intervening before aircraft is line-up.

Once there is a token in *P6*, then the aircraft has lined up. An enabling arc from place *P6* to transition G6 of agent Aircraft Shannon_k will update the location of the aircraft from Departure Holding Point to line up.

The place *MASA* will copy information as necessary as described in the LPN "MASA Pilot Shannon".

3.5. Agent "Aircraft Cork Landing_k"

Agent Aircraft Cork Landing_k has been designed to recreate aircraft landing in Cork.

This agent has 8 places *P1-P8*, i.e. *Approach*, *Landing*, *Taxi in*, *Gate*, *Taxi out*, *Departure Holding Point*, *Line up*, and *Departure* and 7 transitions.

There are three enabling arcs from all places: one to transition G2 of agent Remote Tower system (SA of Remote Tower System about Aircraft Cork Landing_k), second to transition G of LPN "MASA Pilot Cork" of agent Pilot Cork Landing_k (SA of pilot i about aircraft i), and third to transition G of LPN "MASA Pilot Cork" of agent Pilot Cork Departing_k.

There is one token present in place *P2* which signifies the aircraft is landing. The transition G in LPN" Pilot Cork Tasks" of agent Pilot Cork Landing_k fires a token in place *Pilot landed*, which activates through an enabling arc transition G2. The token in place *P3* signifies that the aircraft landed, it is taxing to the gate, so the conflict ceases to exist.

3.6. Agent "Aircraft Cork Departing_k"

Agent Aircraft Cork Departing_k has been designed to recreate aircraft departing in Cork.

This agent has 8 places, i.e. *Approach*, *Landing*, *Taxi in*, *Gate*, *Taxi out*, *Departure Holding Point*, *Line up*, and *Departure* and 7 transitions. One token is present in place *P6(Departure Holding Point).*

There are three enabling arcs: one from all places to transition G3 of agent Remote Tower system (SA of Remote Tower System about Aircraft Cork Landing_k), second to transition G of LPN "MASA Pilot Cork" of agent Pilot Cork Landing_k and third to transition G of LPN "MASA Pilot Cork" of agent Pilot Cork Departing_k (SA of pilot i about aircraft i).

There is one token present in place *P6* which signifies the aircraft is at the Departure Holding Point and waiting for the line-up clearance. The place *P6* of LPN "Pilot Cork Tasks" of agent Pilot Cork Departing_k activates through an enabling arc transition G6. The token in place *P7* signifies that the aircraft is lined up. This will mean that a runway incursion has occurred as the aircraft should not be on the runway.

3.7. Agent "Aircraft Shannon_k"

Agent Aircraft Shannon_k has been designed to recreate aircraft departing in Shannon.

This agent has 8 places, i.e. *Approach*, *Landing*, *Taxi in*, *Gate*, *Taxi out*, *Departure Holding Point*, *Line up*, and *Departure* and 7 transitions. One token is present in place *P6(Departure Holding Point).*

There is one enabling arc from all places to transition G of agent Remote Tower system (SA of Remote Tower System about Aircraft Shannon_k) and incoming and outgoing arcs from all places of the agent Aircraft Shannon_k to all transitions of agent Pilot Shannon _k (SA of pilot i about aircraft i).

In the scenario, agent Aircraft Shannon_k will only be modelled as one token in place Departure Holding Point with colour Aircraft_location=6(Departure Holding Point).

There are two enabling arcs: one from all places to transition G3 of agent Remote Tower system (SA of Remote Tower System about Aircraft Cork Landing_k), and second to transition G of LPN" MASA Pilot Shannon" of agent Pilot Shannon_k (SA of pilot i about aircraft i).

There is one token present in place *P6* which signifies the aircraft is at the Departure Holding Point and waiting for the line-up clearance. The place *P6* of LPN "Pilot Shannon Tasks" of agent Pilot Shannon_k activates through an enabling arc transition G6. The token in place *P7* signifies that the aircraft is lined up and the simulation stops.

3.8. Agent "Airport Cork"

Agent Airport Cork represents the Cork airport. This agent has one place *Open/Closed*. There are three enabling arcs, one to transition G1 of agent Remote Tower System (SA of Remote Tower System about airport Cork), second to all transitions of agent Pilot Cork Departing_k (SA of Pilot Cork Departing_k about airport Cork) and third to all transitions of agent Pilot Cork Landing_k (SA of Pilot Cork Landing_k about airport Cork)

In this scenario, the airport is open.

3.9. Agent "Airport Shannon"

Agent Airport Shannon represents the Shannon airport. This agent has one place *Open/Closed*. There are two enabling arcs, one to transition G1 of agent Remote Tower System (SA of Remote Tower System about airport Shannon), and second to all transitions of agent Pilot Shannon_k (SA of Pilot Shannon_k about airport Shannon).

In this scenario, the airport is open.

3.10. Agent "Communication System Cork"

Agent Communication System Cork has been designed to recreate the frequency in Cork Airport.

This agent has two places *Busy* and *NOT Busy* and 6 transitions. Communications can only be possible if frequency is free and therefore there is a token in place *NOT Busy*, so if there is token in place *Busy* communications cannot take place. To express this, inhibitor arcs have been added to all places where communications will be initiated, both by ATCO and Pilot.

There are three types of communications sent through the frequency: to and from ATCO, to and from Pilot and 3rd party communication.

The messages to and from ATCO are handled by transitions G1 and I6. Transition G1 sends the aircraft ID and pilot intent from Pilot to ATCO, i.e. and I6 send the aircraft ID and ATCO message from ATCO to Pilot.

The messages to and from Pilot and handled by transitions G2 and I5. Transition G2 sends the aircraft ID and ATCO message from ATCO to Pilot and I5 send the aircraft ID and pilot intent from Pilot to ATCO.

3rd Party Communications are handled by transitions G3 and G4. Interviews with ATCOs have indicated that multiple simultaneous communications are possible, yet ATCO will prioritize their work. In this scenario ATCO will prioritize the two aircraft at the line-up, and ATCO will not focus on other aircraft. However, since ground and air are coupled for both airports it is expected that communications will be initiated by other aircraft, but ATCO will ignore them until this priority tasks are over. To account for this, 3rd party communication will be solely modelled in the frequency occupancy since the ATCO will be unable to use the frequency if other aircraft are calling. The initiation of 3rd party communication is completely independent on other communication occurring on the frequency.

3.11. Agent “Communication System Shannon”

Agent Communication System Shannon has been designed to recreate the frequency in Shannon Airport.

This agent has two places *Busy* and *NOT Busy*. Communications can only be possible if frequency is free and therefore there is a token in place *NOT Busy*, so if there is token in place *Busy* communications cannot take place. To express this, inhibitor arcs have been added to all places where communications will be initiated, both by ATCO and Pilot.

There are three types of communications sent through the frequency: to and from ATCO, to and from Pilot and 3rd party communication.

The messages to and from ATCO are handled by transitions G1 and I6. Transition G1 sends the aircraft ID and pilot intent from Pilot to ATCO and I6 send the aircraft ID and ATCO message from ATCO to Pilot.

The messages to and from Pilot and handled by transitions G2 and I5. Transition G2 sends the aircraft ID and ATCO message from ATCO to Pilot and I5 send the aircraft ID and pilot intent from Pilot to ATCO.

3rd Party Communications are handled by transitions G3 and G4. Interviews with ATCOs have indicated that multiple simultaneous communications are possible, yet ATCO will prioritize their work. In this scenario ATCO will prioritize the two aircraft at the line-up, and ATCO will not focus on other aircraft.

However, since ground and air are coupled for both airport it is expected that communications will be initiated by other aircraft, but ATCO will ignore them until this priority tasks are over. To account for this, 3rd party communication will be solely modelled in the frequency occupancy since the ATCO will be unable to use the frequency if other aircraft are calling.

3.12. Agent "Remote Tower System"

Agent Remote Tower system replicated the remote tower screens in the remote tower modules and recreates what the ATCO sees outside. It acts like an extended mind for the ATCO.

The agent has one place *MASA* and five transitions to update *MASA* when necessary, coming from the two airports and three aircraft.

Place *MASA* contains information about both airports Cork and Shannon, and all aircraft at these airports which is obtained and updated through enabling arcs from both airports and the three aircraft present at these airports. This information is then transmitted to the ATCO as support to situation awareness and decision through the incoming/outgoing arcs to all LPNs of agent ATCO.

3.13. IPN "Frequency Cork"

This IPN has two places *Pilot Message to ATCO* and *Incoming Message to Pilot* and it is used to link the two agents: "Pilot Cork Departing_k" and "Communication System Cork".

Pilot Message to ATCO send the aircraft ID and pilot intent from LPN "Pilot Cork Tasks" of agent "Pilot Cork Departing_k" places *I2* and *I4* to agent "Communication System Cork" place *I5*.

Incoming Message to Pilot sends the aircraft ID and ATCO message from agent "Communication System Cork" place *G2* and send it to LPN "Pilot Cork Tasks "agent "Pilot Cork Departing_k" place *I3.2*.

3.14. IPN "Frequency Shannon"

This IPN has two places *Pilot Message to ATCO* and *Incoming Message to Pilot* and it is used to link the two agents: "Pilot Shannon_k" and "Communication System Shannon".

Pilot Message to ATCO send the aircraft ID and pilot intent from LPN "Pilot Shannon Tasks" of agent "Pilot Shannon_k" places *I2* and *I4* to agent "Communication System Shannon" place *I5*.

Incoming Message to Pilot sends the aircraft ID and ATCO message from agent "Communication System Shannon" place *G2* and send it to LPN "Pilot Shannon Tasks "agent "Pilot Shannon_k" place *I3.2*.

4. Agent „ATCO “

Agent “ATCO” is comprised of the following:

- Local Petri Net “MASA”
- Local Petri Net “ATCO Tasks”
- Interconnecting Petri Nets “Incoming Message”
- Interconnecting Petri Nets “Outgoing Message”
- Local Petri Net: “Memory”

4.1. LPN Local Petri net “ATCO MASA”

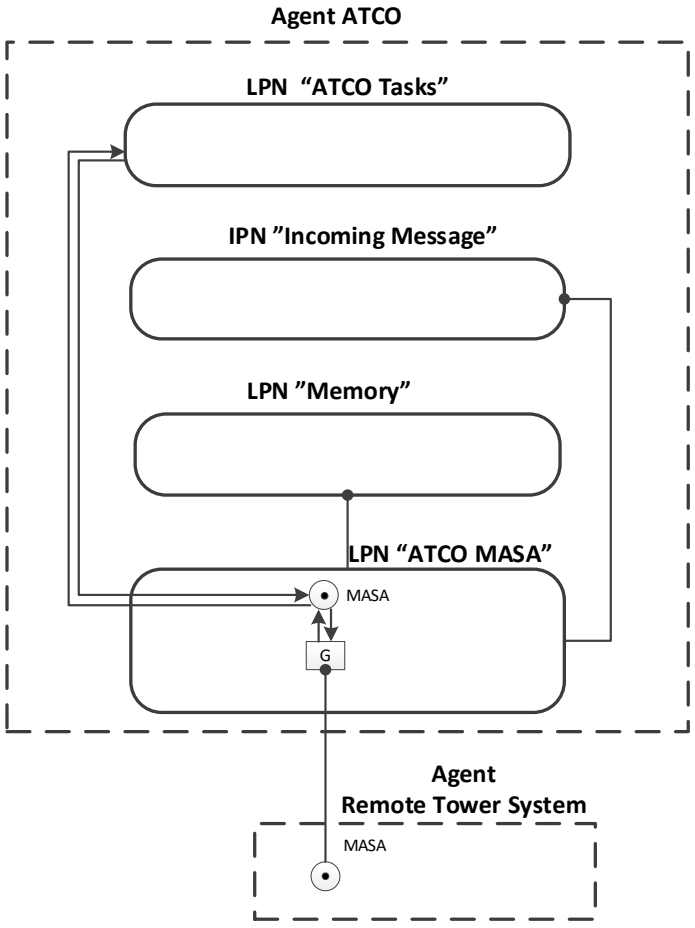


Figure E-6: Local Petri Net “ATCO MASA”

Incoming arcs within same agent

- Incoming arcs from all transitions of LPN “ATCO Tasks” to place *MASA*.

Outgoing arcs within same agent

- Outgoing arcs to all transitions of LPN “ATCO Tasks” from place *MASA*.
- Enabling arcs to all transitions of LPN “Memory”.
- Enabling arcs to all transitions of IPN” Incoming Message”.

Incoming arcs from another agent

- No incoming arc.

Outgoing arc to another agent

- No outgoing arc.

Places

Places	SA	Colour type	Explanation	Colour function
MASA	SA of ATCO about Aircraft Cork Landing_k *(through the Remote Tower System)*	$Callsign_{Aircraft\_Cork\_Landing\_k}$	Callsign of Aircraft Cork Landing_k.	None
		$2DPosition_{Aircraft\_Cork\_Landing\_k} \in$ {Cork, Shannon}	Location of the aircraft on the airport surface. This is simplified by indicating the airport where the aircraft is.	None
		$P1 - P8_{\ Aircraft\ Cork\ Landing\_k} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Line up, Departure}	Location of the aircraft on the airport surface	None
	SA of ATCO about Aircraft Cork Departing_k *(through the Remote Tower System)*	$Callsign_{Aircraft\_Cork\_Departing\_k}$	Callsign of Aircraft Cork Departing_k.	None
		$2DPosition_{Aircraft\_Cork\_Departing\_k} \in$ {Cork, Shannon}	Location of the aircraft on the airport surface. This is simplified by indicating the airport where the aircraft is.	None
		$P1 - P8_{\ Pilot\ Cork\ Departing\_k} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Line up, Departure}	Location of the aircraft on the airport surface.	None
	SA of ATCO about Aircraft Shannon_k *(through the Remote Tower System)*	$Callsign_{Aircraft\_Shannon\_k}$	Callsign of Aircraft Shannon_k.	None
		$2DPosition_{Aircraft\_Shannon\_k} \in$ {Cork, Shannon}	Location of the aircraft on the airport surface. This is simplified by indicating the airport where the aircraft is.	None
		$P_1 - P_{8\ Pilot\ Shannon\_k} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Line up, Departure}	Location of the aircraft on the airport surface.	None
	SA of ATCO about Pilot Cork Landing_k	$Callsign_{Pilot\_Cork\_Landing\_k}$	Callsign of Aircraft Cork Landing_k.	None
		Pilot_Landing-Pilot Landed	Not applicable because the ATCO doesn’t	N/A

			know about these places.	
		Intent $_{Pilot\_Cork\_Landing\_k}$ = Landing clearance received	The intent of the pilot is set from the start of the simulation, i.e. Landing clearance received.	None
		Active$_{Pilot_Cork_Landing_k}$	This indicates if the ATCO is currently handling this aircraft.	None
	SA of ATCO about pilot Cork Departing_k	Callsign$_{Pilot_Cork_Departing_k}$	Callsign of Aircraft Cork Departing_k.	None
		P_1 -P_6 Pilot Cork Departing_k	Not applicable because the ATCO doesn’t know about these places.	N/A
		Intent$_{Pilot_Cork_Departing_k}$	The intent of the pilot is captured in the PILOT$_{message}$. Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO” 99=”No intent”	None
		Active$_{Pilot_Cork_Departing_k}$	This indicates if the ATCO is currently handling this aircraft.	None
	SA of ATCO about Pilot Shannon_k	Callsign$_{Pilot_Shannon_k}$	Callsign of Aircraft Shannon_k.	None
		P_1 -P_6 Pilot Shannon_k	Not applicable because the ATCO doesn’t	N/A

			know about these places.	
		$Intent_{Pilot\_Shannon\_k}$	The intent of the pilot is captured in the $PILOT_{message}$. Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO” 99=” No intent”	None
		$Active_{Pilot\_Shannon\_k}$	This indicates if the ATCO is currently handling this aircraft.	None
	SA of ATCO about Airport Cork *(through the Remote Tower System)*	Name $_{Airport\_Cork}$	This is the name of the aircraft are located. This is not going to be modelled in the petri net model.	N/A
		Runway/taxiway layout $_{Airport\_Cork}$	This is the layout of the airport that the pilot is aware of. This is not modelled in the petri net model.	N/A
		Open/Closed $_{Airport\_Cork} \in \{0,1\}$	Airport is Open or Closed. 0=” Closed” 1=” Open”	None
	SA of ATCO about Airport Shannon *(through the Remote Tower System)*	Name $_{Airport\_Shannon}$	This is the name of the aircraft are located. This is not going to be modelled in the petri net model.	N/A
		Runway/taxiway layout $_{Airport\_Shannon}$	This is the layout of the airport that the pilot is aware of. This is	N/A

			not modelled in the petri net model.	
		Open/Closed $_{Airport\_Shannon} \in \{0,1\}$	Airport is Open or Closed. 0=” Closed” 1=” Open”	None
	SA of ATCO about Remote Tower System	Petri Net places of Remote Tower System	There is one place in the Remote Tower system, i.e. MASA. Through this place, the ATCO is gaining and maintaining MASA about the pilots, aircraft and airports (extended memory). This SA will not be modelled.	N/A
	Refresh rate	$t_G \in \mathbb{R}$	Refresh rate to check and update the position of all aircraft.	$\dot{t}_G = -1$

Transitions

ID	Transition	Condition
G	MASA ^ *MASA* {Remote Tower System}→ MASA	$t_G \leq 0$

Firing Functions

ID	Firing Function
G	One token is fired to place *MASA* with colours: *SA of Remote Tower System about Aircraft Cork Landing_k* $Callsign_{Aircraft\_Cork\_Landing\_k} = Callsign_{Aircraft\_Cork\_Landing\_k}$ {Remote Tower System} $2DPosition_{Aircraft\_Cork\_Landing\_k} = 2DPosition_{Aircraft\_Cork\_Landing\_k}$ {MASA} P_1-P_8 $_{Pilot\ Cork\ Landing\_k}$ = Name of incoming place of (*P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Remote Tower System} *SA of Remote Tower System about Aircraft Cork Departing_k* $Callsign_{Aircraft\_Cork\_Departing\_k} = Callsign_{Aircraft\_Cork\_Departing\_k}$ {Remote Tower System} $2DPosition_{Aircraft\_Cork\_Departing\_k} = 2DPosition_{Aircraft\_Cork\_Departing\_k}$ {MASA} P_1-P_8 $_{Pilot\ Cork\ Departing\_k}$ = Name of incoming place of (*P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Remote Tower System} *SA of Remote Tower System about Aircraft Shannon_k* $Callsign_{Aircraft\_Shannon\_k} = Callsign_{Aircraft\_Shannon\_k}$ {Remote Tower System} $2DPosition_{Aircraft\_Shannon\_k} = 2DPosition_{Aircraft\_Shannon\_k}$ {MASA} P_1-P_8 $_{Pilot\ Shannon\_k}$ = Name of incoming place of (*P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Remote Tower System}

	SA of Remote Tower System about Pilot Cork Landing_k $Callsign_{Aircraft\_Cork\_Landing\_k} = Callsign_{Aircraft\_Cork\_Landing\_k}$ {MASA} $Pilot_{\_Landing}$ - $Pilot_{Landed}$ is not modelled $Intent_{Pilot\_Cork\_Landing\_k}$ = Landing clearance received $Active_{Pilot\_Cork\_Landing\_k} = Active_{Pilot\_Cork\_Landing\_k}$ {MASA} *SA of Remote Tower System about Pilot Cork Departing_k* $Callsign_{Pilot\_Cork\_Departing\_k} = Callsign_{Aircraft\_Cork\_Departing\_k}$ {MASA} P_1 -P_6 $_{Pilot\ Cork\ Departing\_k}$ is not modelled $Intent_{Pilot\_Cork\_Departing\_k} = Intent_{Pilot\_Cork\_Departing\_k}$ {MASA} $Active_{Pilot\_Cork\_Departing\_k} = Active_{Pilot\_Cork\_Departing\_k}$ {MASA} *SA of Remote Tower System about Pilot Shannon_k* $Callsign_{Pilot\_Shannon\_k} = Callsign_{Pilot\_Shannon\_k}$ {MASA} P_1 -P_6 $_{Pilot\ Shannon\_k}$ is not modelled $Intent_{Pilot\_Shannon\_k} = Intent_{Pilot\_Shannon\_k}$ {MASA} $Active_{Pilot\_Shannon\_k} = Active_{Pilot\_Shannon\_k}$ {MASA} *SA of Remote Tower System about Airport Cork* $Name_{Airport\_Cork}$ = $Name_{Airport\_Cork}$ {Remote Tower System} Runway/taxiway layout $_{Airport\_Cork}$ = Runway/taxiway layout $_{Airport\_Cork}$ {Remote Tower System} Open/Closed= *Open/Closed* {{Remote Tower System} *SA of Remote Tower System about Airport Shannon* $Name_{Airport\_Shannon}$= $Name_{Airport\_Shannon}$ {Remote Tower System} Runway/taxiway layout $_{Airport\_Shannon}$= Runway/taxiway layout $_{Airport\_Shannon}$ {Remote Tower System} Open/Closed= *Open/Closed* {Remote Tower System} *refresh rate in seconds* t_G =1

Initial markings

One token is in MASA with the following colours:

SA of Remote Tower System about Aircraft Cork Landing_k

$Callsign_{Aircraft\_Cork\_Landing\_k} = 200$

$2DPosition_{Aircraft\_Cork\_Landing\_k}$ = Cork (1)

P1 -P8 $_{Aircraft\ Cork\ Landing\_k} = P2(Landing)$

SA of Remote Tower System about Aircraft Cork Departing_k

$Callsign_{Aircraft\_Cork\_Landing\_k} = 100$

$2DPosition_{Aircraft\_Cork\_Landing\_k}$ = Cork (1)

P1 -P8 $_{Aircraft\ Cork\ Landing\_k} = P6(Departure\ Holding\ Point)$

SA of Remote Tower System about Aircraft Shannon_k

$Callsign_{Aircraft\_Shannon\_k} = 300$

$2DPosition_{Aircraft\_Cork\_Landing\_k}$ =Shannon(2)

$P1 - P8_{\ Aircraft\ Cork\ Landing\_k} =$ *P6(Departure Holding Point)*

SA of Remote Tower System about Pilot Cork Landing_k

$Callsign_{Aircraft\_Cork\_Landing\_k} = 200$

$Pilot_{\_Landing}$ - $Pilot_{\ Landed}$ is not modelled

$Intent_{Pilot\_Cork\_Landing\_k}$ = Landing clearance received

$Active_{Pilot\_Cork\_Landing\_k}$ = 0

SA of Remote Tower System about Pilot Cork Departing_k

$Callsign_{Pilot\_Cork\_Departing\_k} = 100$

$P_1 - P_6$ $_{Pilot\ Cork\ Departing\_k}$ is not modelled

$Intent_{Pilot\_Cork\_Departing\_k}$ = 99

$Active_{Pilot\_Cork\_Departing\_k}$ = 0

SA of Remote Tower System about Pilot Shannon_k

$Callsign_{Pilot\_Shannon\_k} = Callsign_{Pilot\_Shannon\_k}$ {MASA}

$P_1 - P_6$ $_{Pilot\ Shannon\_k}$ is not modelled

$Intent_{Pilot\_Shannon\_k}$ = 99

$Active_{Pilot\_Shannon\_k}$ = 0

SA of Remote Tower System about Airport Cork

$Name_{\ Airport\_Cork}$ = Cork
$Runway/taxiway\ layout_{\ Airport\_Cork}$ is not modelled

Open/Closed = Open (1)

SA of Pilot Shannon Landing_k about Airport Shannon

$Name_{\ Airport\_Shannon}$ = Shannon
$Runway/taxiway\ layout_{\ Airport\_Shannon}$ is not modelled

Open/Closed = Open (1)

refresh rate in seconds

t_G =1

4.2. Local Petri Net „ ATCO Tasks”

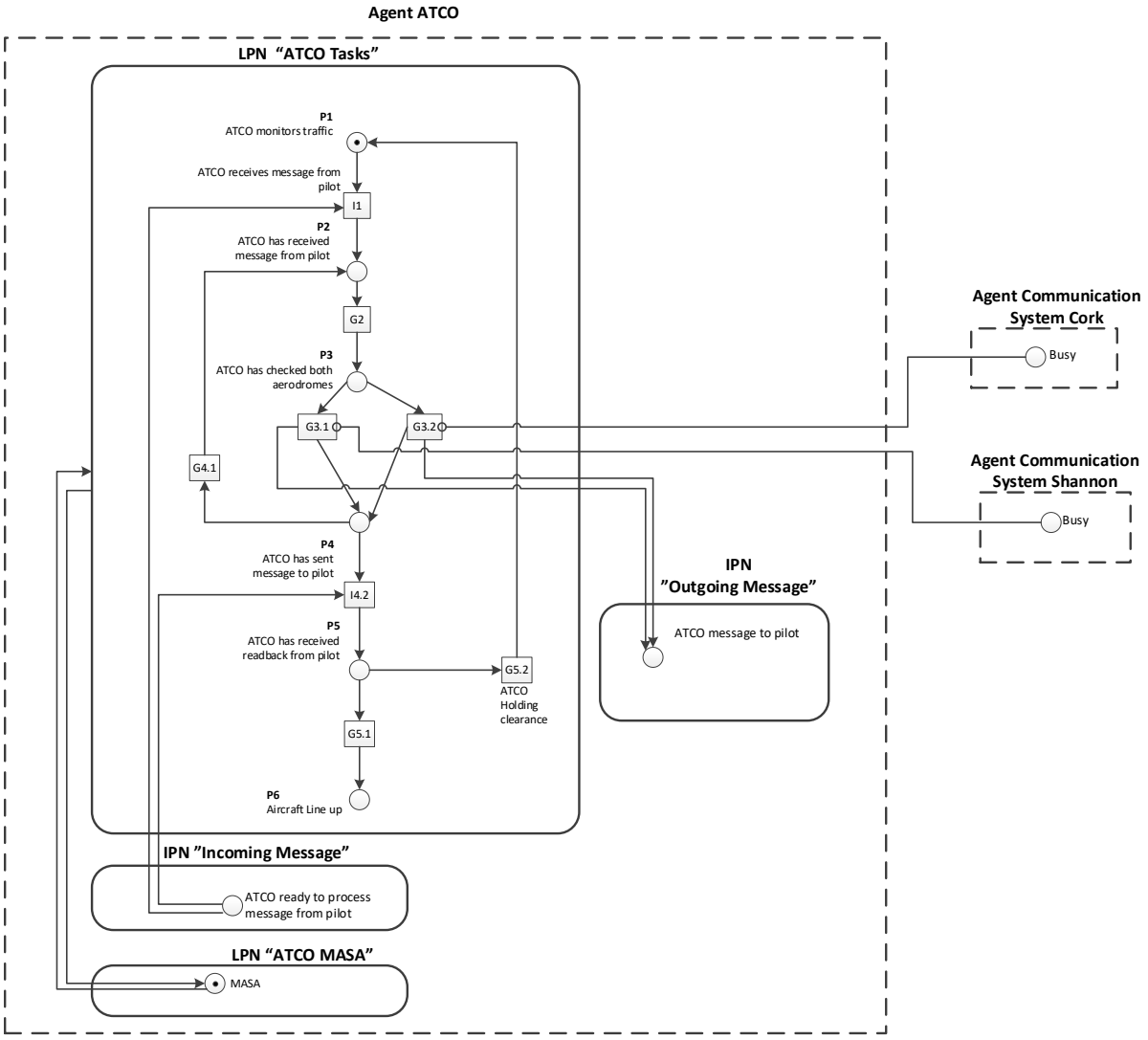


Figure E-7: Local Petri Net “ATCO Tasks”

Incoming arcs within same agent

- Incoming arcs from place *ATCO ready to process message from pilot* of IPN” Incoming Message” to transitions I1 and I4.2.
- Incoming arcs from place *MASA* of LPN “ATCO MASA” to all transitions.

Outgoing arcs within same agent

- Outgoing arcs from all transitions to place *MASA* of LPN “ATCO MASA”.
- Outgoing arcs from transition G3.1 and G3.2 to place *ATCO message to Pilot* of IPN” Outgoing Message”.

Incoming arcs from another agent

- Two inhibitor arcs from place *Busy* of agent “Communication System Shannon” and place *Busy* of agent “Communication System Cork” to transitions G3.1 and G3.2.

Outgoing arc to another agent

- No outgoing arcs.

Places

Places	Colour type	Explanation	Colour function
P1	None	No colour required.	
P2	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO (0 if no previous message sent)	None
	$ATCO_{message} \in \{0,1,2\}$	Message from ATCO 0= “No previous message” 1= “Line up clearance” 2= “Hold message”	None
	$t_{checkaerodromes} \in \mathbb{R}$	Time to check both aerodromes and deciding on course of action for aircraft.	$\dot{t}_{\text{checkaerodromes}} = -1$
P3	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO (0 if no previous message sent)	None
	$ATCO_{message} \in \{0,1,2\}$	Message from ATCO 0= “No previous message” 1= “Line up clearance” 2= “Hold message”	None
	$F \in \{\text{Cork}, \text{Shannon}\}$	Selected frequency to broadcast information: Cork=1 Shannon=2	None
P4	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO (0 if no previous message sent)	None
	$ATCO_{message} \in \{0,1,2\}$	Message from ATCO 0= “No previous message” 1= “Line up clearance” 2= “Hold message”	None

	$t_{recheck} \in \mathbb{R}$	If no readback is received from the pilot, the ATCO will recheck the aerodromes to see what happened. This duration of the rechecking is $t_{recheck}$.	$\dot{t}_{\text{recheck}} = -1$
P5	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO (0 if no previous message sent)	None
	$ATCO_{message} \in \{0,1,2\}$	Message from ATCO 0= “No previous message” 1= “Line up clearance” 2= “Hold message”	None
P6	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO (0 if no previous message sent)	None
	$ATCO_{message} \in \{0,1,2\}$	Message from ATCO 0= “No previous message” 1= “Line up clearance” 2= “Hold message”	None
	$RI \in \{0,1\}$	Runway Incursion Occurs 0=” No RI” (ATCO sports error) 1=” RI” (ATCO does **not** spot error)	None

Transitions

ID	Transition	Condition
I1	P1 ^ *MASA* {Remote Tower System} ^ *ATCO ready to process message from pilot* {Incoming Message [ATCO]}→ P2 ^ *MASA*	None
G2	P2 ^ *MASA* {Remote Tower System}→ P3^ *MASA {Remote Tower System}*	$t_{checkaerodromes} \leq 0$
G3.1	P3 ^ *MASA* {Remote Tower System} ^ NOT *Busy* {Communication System Shannon}→ P4 ^ *ATCO message to Pilot* {Outgoing Message [ATCO]} ^ *MASA* {Remote Tower System}	F(P3) = “Shannon”
G3.2	P3 ^ *MASA {Remote Tower System}* ^ NOT *Busy* {Communication System Cork}→ P4 ^ *ATCO message*	F = “Cork”

	to Pilot {Outgoing Message [ATCO]} ^ MASA {Remote Tower System}	
G4.1	P4 ^ *MASA {Remote Tower System}* →P2^ *MASA* {Remote Tower System}	$t_{recheck} \leq 0$
I4.2	P4 ^ *ATCO ready to process message from pilot* {Incoming Message [ATCO]} ^*MASA {Remote Tower System}* →P5^ *MASA* {Remote Tower System}	None
G5.1	P5 ^ *MASA {Remote Tower System}* →P6^ *MASA* {Remote Tower System}	($PILOT_{message}$ =2 and $PILOT_{aid}$=$Callsign_{Aircraft\_Cork\_Departing\_k}$) or ($PILOT_{message}$ =3)
G5.2	P5 ^ *MASA {Remote Tower System}* →P1^ *MASA* {Remote Tower System}	$PILOT_{message}$ =0 or ($PILOT_{message}$ =2 and $PILOT_{aid}$<>$Callsign_{Aircraft\_Cork\_Departing\_k}$)

Firing Functions

ID	Firing Function
I1	One token is fired to P2 with the following colours: $PILOT_{aid}$ = $PILOT_{aid}$ (*ATCO ready to process message from pilot* {Incoming Message [ATCO]}) $PILOT_{message}$ = $PILOT_{message}$ (*ATCO ready to process message from pilot* {Incoming Message [ATCO]}) $ATCO_{aid}$ =0 (no previous message from ATCO to pilot) $ATCO_{message}$ = 0 (no previous message from ATCO to pilot) $t_{checkaerodromes}$ = Uniform distribution between 2 and 7 seconds One token is fired to place *MASA* {ATCO MASA} with the colour: MASA= *MASA* {ATCO MASA} Except If $PILOT_{aid}$ =$Callsign_{Aircraft\_Cork\_Departing\_k}$, then $Intent_{Pilot\_Cork\_Departing\_k}$=$PILOT_{message}$ and $Active_{Pilot\_Cork\_Departing\_k}$=1 and $Callsign_{Pilot\_Cork\_Departing\_k}$ = $PILOT_{aid}$ Elseif $PILOT_{aid}$ =$Callsign_{Aircraft\_Shannon\_k}$ then $Intent_{Pilot\_Shannon\_k}$=$PILOT_{message}$ and $Active_{Pilot\_Shannon\_k}$=1 and $Callsign_{Pilot\_Shannon\_k}$ = $PILOT_{aid}$
G2	One token is fired to place *MASA* {ATCO MASA} with the colour: MASA= *MASA* {ATCO MASA} Except *(Note: if the ATCO sent a message already on the frequency with no pilot answer he/she will resend the same message)* If $ATCO_{aid}$<> 0 then If $ATCO_{aid}$ = $Callsign_{Aircraft\_Cork\_Departing\_k}$ then F=1 else F=2 If $Active_{Pilot\_Cork\_Departing\_k}$(MASA) =1 if abs($Callsign_{Pilot\_Cork\_Departing\_k}$ - $PILOT_{aid}$)<=10 (*callsign similarity: very similar)* if rand <(1/300) $Callsign_{Pilot\_Cork\_Departing\_k}$(MASA)= $Callsign_{Pilot\_Shannon\_k}$(MASA); End Else if abs($Callsign_{Pilot\_Cork\_Departing\_k}$ - $PILOT_{aid}$)<=50 *(callsign similarity: similar)* if rand <(1/500) $Callsign_{Pilot\_Cork\_Departing\_k}$(MASA)= $Callsign_{Pilot\_Shannon\_k}$(MASA); End

	Else (*callsign similarity: callsign totally different)* if rand <(1/5000) $Callsign_{Pilot\_Cork\_Departing\_k}$(MASA)= $Callsign_{Pilot\_Shannon\_k}$(MASA); If $Active_{Pilot\_Shannon\_k}$(MASA) =1 if abs($Callsign_{Pilot\_Shannon\_k}$ - $PILOT_{aid}$)<=10 *(callsign similarity: very similar)* if rand <(1/300) $Callsign_{Pilot\_Shannon\_k}$(MASA)= $Callsign_{Pilot\_Cork\_Departing\_k}$(MASA) Elseif abs($Callsign_{Pilot\_Shannon\_k}$ - $PILOT_{aid}$)<=50 (*callsign similarity: similar)* if rand <(1/500) $Callsign_{Pilot\_Shannon\_k}$(MASA)= $Callsign_{Pilot\_Cork\_Departing\_k}$(MASA) Else *(callsign similarity: totally different)* if rand <(1/5000) $Callsign_{Pilot\_Shannon\_k}$(MASA)= $Callsign_{Pilot\_Cork\_Departing\_k}$(MASA; One token is fired to P3 with the following colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P2) $PILOT_{message}$ = $PILOT_{message}$ (P2) $ATCO_{aid}$ = $ATCO_{aid}$(P2) $ATCO_{message}$ = $ATCO_{message}$(P2) $t_{recheck}$ = Uniform distribution between 20 and 30 seconds F = Probability of ATCO selection of wrong frequency is estimated:1 in 5000 *(hard coded value)*
G3.1	One token is fired to P4 with the following colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P3) $PILOT_{message}$ = $PILOT_{message}$ (P3) One token is fired to *ATCO message to Pilot* {Outgoing Message [ATCO]} with the following colours: If $ATCO_{aid}$<> 0 then $ATCO_{aid}$ = $ATCO_{aid}$ (P3) $ATCO_{message}$ = $ATCO_{message}$ (P3) *(Note: if the ATCO sent a message already with to pilot answer he/she will resend the same message)* Elseif $Active_{Pilot\_Cork\_Departing\_k}$(MASA) =1 then $ATCO_{aid}$ = $Callsign_{Pilot\_Cork\_Departing\_k}$(MASA) and $ATCO_{message}$=f($Intent_{Pilot\_Cork\_Departing\_k}$(MASA), $2DPosition_{Aircraft\_Cork\_Departing\_k}$(MASA), $2DPosition_{Aircraft\_Cork\_Landing\_k}$ (MASA)) P($2DPosition_{Aircraft\_Cork\_Landing\_k}$ (MASA)) =”Not applicable/Unknown” is 1 in 5000 *(hard coded value): This means that the ATCO forgets about aircraft Cork Landing_k.* P (ATCO wrong message|ATCO forgets about the aircraft landing) is 100%. *(hard coded value)* Elseif $Active_{Pilot\_Shannon\_k}$(MASA) =1 then $ATCO_{aid}$ = $Callsign_{Pilot\_Shannon\_k}$(MASA) and $ATCO_{message}$=f($Intent_{Pilot\_Shannon\_k}$(MASA), $2DPosition_{Aircraft\_Shannon\_k}$(MASA)) F=” Shannon”

	One token is fired to place *MASA* {ATCO MASA} with the colour: MASA= *MASA* {ATCO MASA} except if *P(2DPosition$_{Aircraft_Cork_Landing_k}$ (MASA)) =”Not applicable/Unknown” is 1 in 5000 (hard coded value): This means that the ATCO forgets about aircraft Cork Landing_k.* 2DPosition$_{Aircraft_Cork_Landing_k}$ (MASA)= ”Not applicable/Unknown”
G3.2	One token is fired to P4 with the following colours: PILOT$_{aid}$ = PILOT$_{aid}$ (P3) PILOT$_{message}$ = PILOT$_{message}$ (P3) One token is fired to *ATCO message to Pilot* {Outgoing Message [ATCO]} with the following colours: *(Note: if the ATCO sent a message already with to pilot answer he/she will resend the same message)* If ATCO$_{aid}$<> 0 then ATCO$_{aid}$ = ATCO$_{aid}$ (P3) ATCO$_{message}$ = ATCO$_{message}$ (P3) *(Note: if the ATCO sent a message already with to pilot answer he/she will resend the same message)* Elseif Active$_{Pilot_Cork_Departing_k}$(MASA) =1 then ATCO$_{aid}$ = Callsign$_{Pilot_Cork_Departing_k}$(MASA) and ATCO$_{message}$=f(Intent$_{Pilot_Cork_Departing_k}$(MASA), 2DPosition$_{Aircraft_Cork_Departing_k}$(MASA), 2DPosition$_{Aircraft_Cork_Landing_k}$ (MASA)) P(2DPosition$_{Aircraft_Cork_Landing_k}$ (MASA)) =”Not applicable/Unknown” is 1 in 5000 *(hard coded value): This means that the ATCO forgets about aircraft Cork Landing_k.* P (ATCO wrong message|ATCO forgets about the aircraft landing) is 100%. *(hard coded value)* Elseif Active$_{Pilot_Shannon_k}$(MASA) =1 then ATCO$_{aid}$ = Callsign$_{Pilot_Shannon_k}$(MASA) and ATCO$_{message}$=f(Intent$_{Pilot_Shannon_k}$(MASA), 2DPosition$_{Aircraft_Shannon_k}$(MASA)) F=” Cork” One token is fired to place *MASA* {ATCO MASA} with the colour: MASA= *MASA* {ATCO MASA} except if *P(2DPosition$_{Aircraft_Cork_Landing_k}$ (MASA)) =”Not applicable/Unknown” is 1 in 5000 (hard coded value): This means that the ATCO forgets about aircraft Cork Landing_k.* 2DPosition$_{Aircraft_Cork_Landing_k}$ (MASA)= ”Not applicable/Unknown”
G4.1	One token is fired to P2 with the following colours: PILOT$_{aid}$ = PILOT$_{aid}$ (P4) PILOT$_{message}$ = PILOT$_{message}$ (P4) ATCO$_{aid}$ = ATCO$_{aid}$ (P4)

	$ATCO_{message}$ = $ATCO_{message}$ (P4) $t_{checkaerodromes}$ = 0 *(Note: this is set to 0 as the ATCO will simply resend the message, the $t_{recheck}$ acts like a timer to check in this scenario)* One token is fired to place *MASA* {ATCO MASA} with the colour: MASA= *MASA* {ATCO MASA}

I4.2	One token is fired to P5 with the following colours:
	$PILOT_{aid}$ = $PILOT_{aid}$ (*ATCO ready to process message from pilot* {Incoming Message [ATCO]})
	$PILOT_{message}$ = $PILOT_{message}$ (*ATCO ready to process message from pilot* {Incoming Message [ATCO]})
	$ATCO_{aid}$ = $ATCO_{aid}$ (P4)
	$ATCO_{message}$ = $ATCO_{message}$ (P4)
	
	One token is fired to place *MASA* {ATCO MASA} with the colour:
	MASA= *MASA* {ATCO MASA}
	
	Except
	If $Active_{Pilot\_Cork\_Departing\_k}$ =1 then
	$Intent_{Pilot\_Cork\_Departing\_k}$= $PILOT_{message}$ (*ATCO ready to process message from pilot* {Incoming Message [ATCO]})
	Else
	$Intent_{Pilot\_Shannon\_k}$= $PILOT_{message}$ (*ATCO ready to process message from pilot* {Incoming Message [ATCO]})

G5.1	One token is fired to P6 with the following colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P5) $PILOT_{message}$ = $PILOT_{message}$ (P5) $ATCO_{aid}$ = $ATCO_{aid}$ (P5) $ATCO_{message}$ = $ATCO_{message}$ (P5) RI= 1 One token is fired to place *MASA* {ATCO MASA} with the colour: MASA= *MASA* {ATCO MASA}
G5.2	One token is fired to P1 without colours. One token is fired to place *MASA* {ATCO MASA} with the colour: MASA= *MASA* {ATCO MASA} except If $Active_{Pilot\_Cork\_Departing\_k}$(MASA) =1 then $Active_{Pilot\_Cork\_Departing\_k}$(MASA) =0 and $Intent_{Pilot\_Cork\_Departing\_k}$(MASA)= $PILOT_{message}$ Elseif $Active_{Pilot\_Shannon\_k}$(MASA) =1 then $Active_{Pilot\_Shannon\_k}$(MASA) =0 and $Intent_{Pilot\_Shannon\_k}$(MASA)= $PILOT_{message}$

Initial markings

One initial token in P1 with no colours.

4.3. Interconnecting Petri Net “Incoming message”

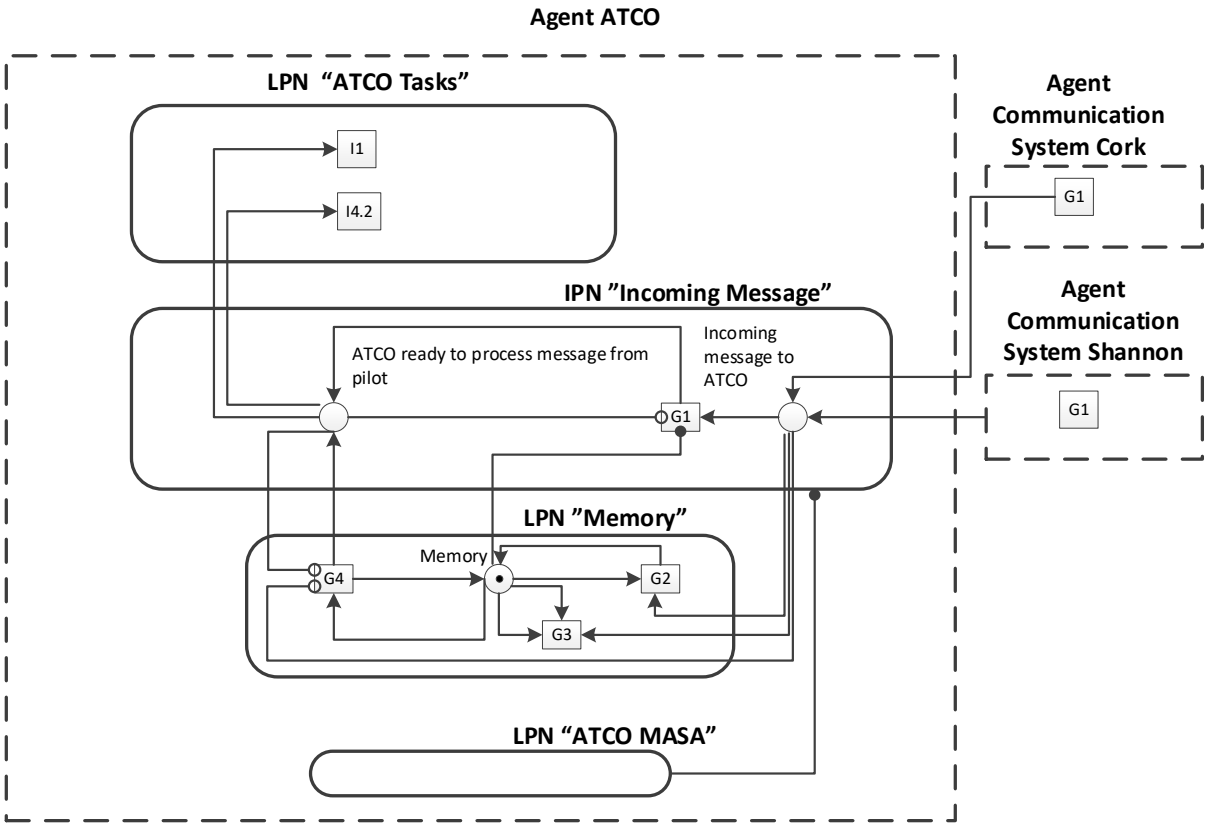


Figure E-8: Interconnecting Petri Net” Incoming Message”

Incoming arcs within same agent

- One enabling arc from place *MASA* of LPN “ATCO MASA” to transition G1.
- One enabling arc from place *Memory* of LPN “Memory” to transition G1.

Outgoing arcs within same agent

- Two outgoing arcs to transitions I1 and I4.2 of LPN “ATCO Tasks” from place *ATCO ready to process message from pilot*.
- One outgoing inhibitor arc from place *ATCO ready to process message from pilot* to transition G4 of LPN “Memory”.
- Two outgoing arcs from place *Incoming Message to ATCO* to transitions G2 and G3 of LPN “Memory”.

Incoming arcs from another agent

- Incoming arc from transition *G1* of agent “Communication System Cork” to place *Incoming message to Pilot*.
- Incoming arc from transition *G1* of agent “Communication System Shannon” to place *Incoming message to Pilot*.

Outgoing arc to another agent

- No outgoing arcs.

Places

Places	Colour type	Explanation	Colour function
Incoming message to ATCO	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
ATCO ready to process message from pilot	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None

Transitions

ID	Transition	Condition
G1	Incoming Message to ATCO ^ *MASA* {ATCO MASA} ^ NOT *ATCO ready to process message from pilot* ^ *Memory* {Memory [ATCO]} → ATCO ready to process	If ($Active_{Pilot\_Cork\_Landing\_k}$=0 and $Active_{Pilot\_Cork\_Departing\_k}$=0 and $Active_{Pilot\_Shannon\_k}$=0 and Message {Memory} =0 and $PILOT_{message}$ (Incoming Message to ATCO) =1) **OR** (If ($Active_{Pilot\_Cork\_Landing\_k}$(MASA)=1 and $PILOT_{message}$ {Memory} <>1 and $PILOT_{message}$ (Incoming Message to ATCO) <>1) Elseif ($Active_{Pilot\_Cork\_Departing\_k}$(MASA)=1 and $PILOT_{message}$ {Memory} <>1 and $PILOT_{message}$ (Incoming Message to ATCO) <>1) Elseif (($Active_{Pilot\_Shannon\_k}$(MASA)=1 and $PILOT_{message}$ {Memory} <>1 and $PILOT_{message}$ (Incoming Message to ATCO) <>1)

Firing Functions

ID	Firing Function
G1	One token is fired to ATCO ready to process message from Pilot with the colours: $PILOT_{aid}$ = $PILOT_{aid}$ (Incoming message to ATCO) $PILOT_{message}$ = $PILOT_{message}$ (Incoming message to ATCO)

Initial markings

There are no initial tokens in the IPN.

4.4. Interconnecting Petri Net “Outgoing message”

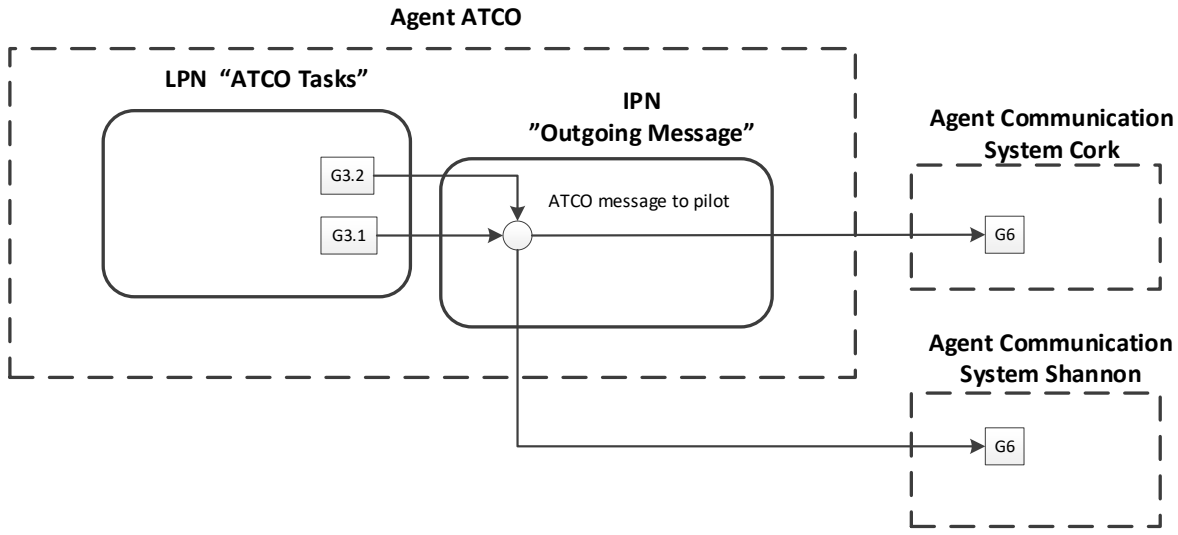


Figure E-9: Interconnecting Petri Net” Outgoing message”

Incoming arcs within same agent

- One incoming arc from transition G3.1 of LPN “ATCO Tasks”.
- One incoming arc from transition G3.2 of LPN “ATCO Tasks”.

Outgoing arcs within same agent

- No outgoing arc.

Incoming arcs from another agent

- No outgoing arc.

Outgoing arc to another agent

- One outgoing arc from place *ATCO message to pilot* to instant transition G6 of agent “Communication System Cork”.
- One outgoing arc from place *ATCO message to pilot* to instant transition G6 of agent “Communication System Shannon”.

Places

Places	Colour type	Explanation	Colour function
ATCO message to Pilot	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO	None
	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None
	$F \in \{Cork, Shannon\}$	Selected frequency to broadcast information	None

Transitions

None

Firing Functions

None

Initial markings

There are no initial tokens in the IPN.

4.5. Local Petri Net “Memory”

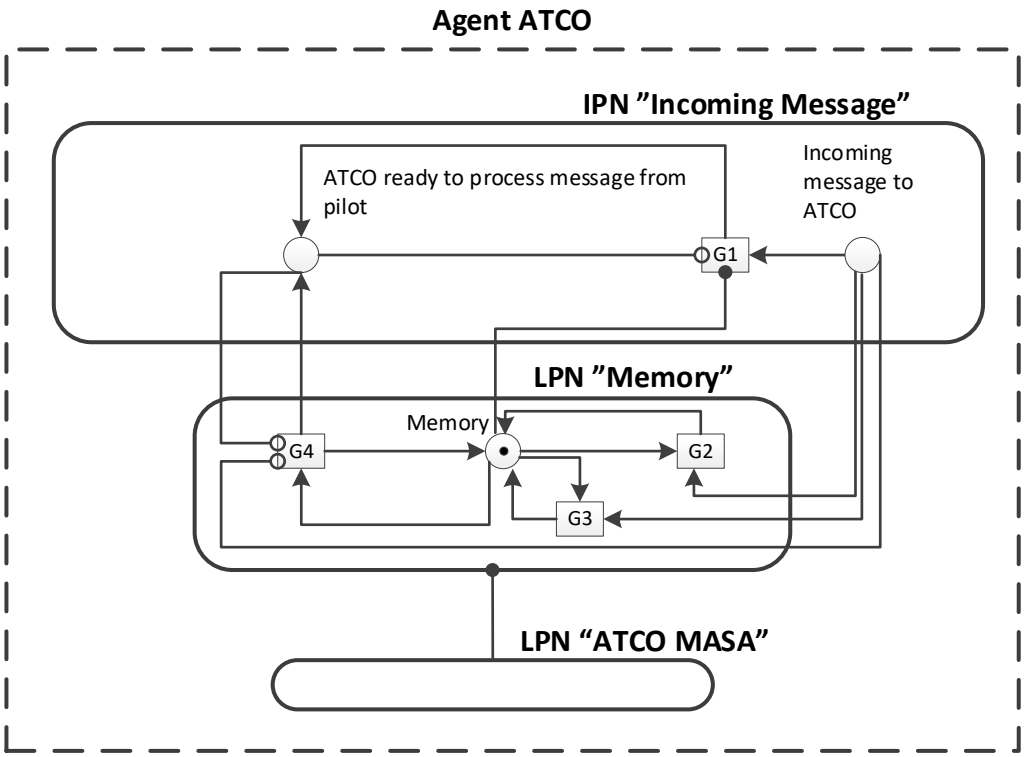


Figure E-10: Local Petri Net “Memory”

Incoming arcs within same agent

- Three enabling arcs from place *MASA* of LPN “ATCO MASA” to each transition.
- Two incoming arcs from place *Incoming message to ATCO* of IPN” Incoming Message” to transitions G2 and G3.
- One inhibitor arc from place *ATCO ready to process message from pilo*t of IPN” Incoming Message” to G4.
- One inhibitor arc from place *Incoming message to ATCO* of IPN” Incoming Message” to G4.

Outgoing arcs within same agent

- One outgoing arc to place *ATCO ready to process message from pilot* of IPN “Incoming Message” from transition G4.
- One enabling arc to transition *G1* of IPN “Incoming Message” from place *Memory*.

Incoming arcs from another agent

- No incoming arc.

Outgoing arc to another agent

- No outgoing arc.

Places

Places	Colour type	Explanation	Colour function
Memory	Message	Identifies whether or not there is a message in the memory of the ATCO. 0=” No message” 1=” Message”	None
	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance”	None

Transitions

ID	Transition	Condition
G2	*Incoming Message to ATCO* {Incoming Message [ATCO]} ^ *ATCO ready to process* {Incoming Message [ATCO]} ^ *MASA* {Remote Tower System} ^ *Memory* → *Memory*	If ($Active_{Pilot\_Cork\_Landing\_k}$(MASA)=1 or $Active_{Pilot\_Cork\_Departing\_k}$(MASA)=1 or $Active_{Pilot\_Shannon\_k}$(MASA)=1) **and** *Incoming Message to ATCO* {Incoming Message [ATCO]} <>1
G3	*Incoming message to ATCO* {Incoming Message [ATCO]} ^ *MASA* {Remote Tower System} ^ *Memory* → *Memory*	(If ($Active_{Pilot\_Cork\_Landing\_k}$(MASA)=0 and $Active_{Pilot\_Cork\_Departing\_k}$(MASA)=0 and $Active_{Pilot\_Shannon\_k}$(MASA)=0) **OR** ($PILOT_{message}$ {Memory}=1))
G4	*Memory* ^ NOT *ATCO ready to process message from pilot* {Incoming Message [ATCO]} ^ NOT *Incoming message to ATCO* {Incoming Message [ATCO]} → *ATCO ready to process* message from pilot {Incoming Message [ATCO]} ^ *Memory*	If ($Active_{Pilot\_Cork\_Landing\_k}$(MASA)=0 and $Active_{Pilot\_Cork\_Departing\_k}$(MASA)=0 and $Active_{Pilot\_Shannon\_k}$(MASA)=0 and $PILOT_{message}$ {Memory}=1) **OR** (($Active_{Pilot\_Cork\_Landing\_k}$(MASA)=1 or $Active_{Pilot\_Cork\_Departing\_k}$(MASA)=1 or $Active_{Pilot\_Shannon\_k}$(MASA)=1) and $PILOT_{message}$ {Memory}<>1)

Firing Functions

ID	Firing Function
G2	One token is fired to Memory with the colours: $PILOT_{aid}$ = $PILOT_{aid}$ (*Incoming Message to ATCO* {Incoming Message [ATCO]}) $PILOT_{message}$ = $PILOT_{message}$ (*Incoming Message to ATCO* {Incoming Message [ATCO]}) Message=1
G3	One token is fired to Memory with the colours: $PILOT_{aid}$ = $PILOT_{aid}$ (*Incoming Message to ATCO* {Incoming Message [ATCO]}) $PILOT_{message}$ = $PILOT_{message}$ (*Incoming Message to ATCO* {Incoming Message [ATCO]}) Message=1
G4	One token is fired to Memory with the colours:

	$PILOT_{aid}$ =0 $PILOT_{message}$ =0 Message = 0 One token is fired to *ATCO ready to process message from pilot* {Incoming Message [ATCO]} with the colours: $PILOT_{aid}$ = $PILOT_{aid}$ (*Memory)* $PILOT_{message}$ = $PILOT_{message}$ (*Memory*)

Initial markings

There is always a token in the place M with initial colours:

$PILOT_{aid}$ =0

$PILOT_{message}$ =0

Message = 0

The first two colours do no matter since there is no message present.

5. Agent „Pilot Cork Departing_k “

5.1. Local Petri Net “MASA Pilot Cork”

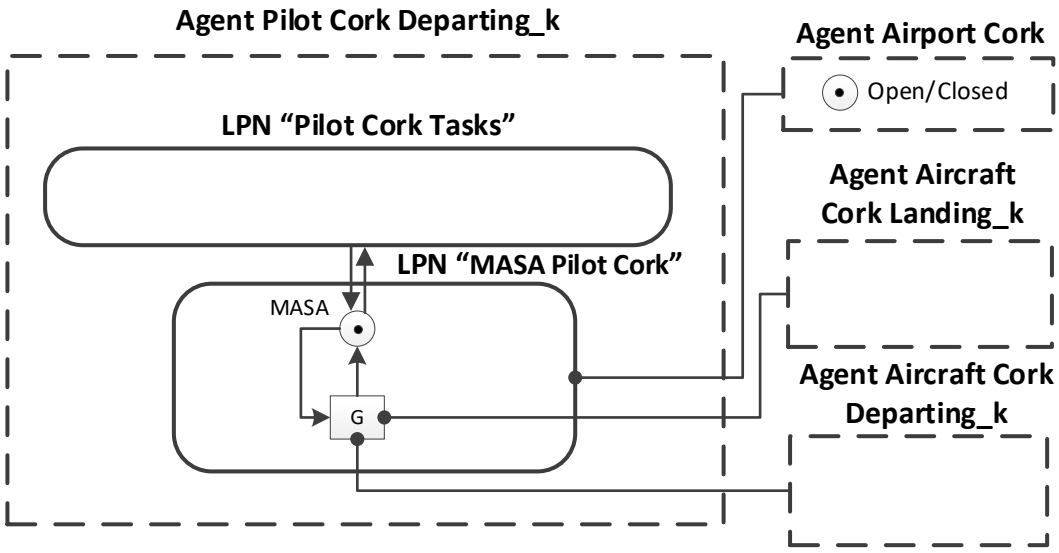


Figure E-11: Pilot Cork Departing_k Local Petri Net “MASA Pilot Cork”

Incoming arcs within same agent

- Incoming arc from all transitions of LPN” Pilot Cork Tasks” to place *MASA*.

Outgoing arcs within same agent

- Outgoing arc from place *MASA* to all transitions of LPN” Pilot Cork Tasks”.

Incoming arcs from another agent

- Enabling arc from place *Open/Closed* of agent Airport Cork to transition G.
- Enabling arc from all places of agent Aircraft Cork Departing_k to transition G.
- Enabling arc from all places of agent Aircraft Cork Landing_k to transition G.

Outgoing arc to another agent

- No outgoing arcs.

Places

Places	SA	Colour type	Explanation	Colour function
MASA	SA of Pilot Cork Departing_k about Aircraft Cork Departing_k	$\text{Callsign}_{\text{Aircraft\_Cork\_Departing\_k}}$	Callsign of Aircraft Cork Departing_k	None
		$\text{2DPosition}_{\text{Aircraft\_Cork\_Departing\_k}}$	Location of the aircraft on the airport surface. This is not going to be modelled in the petri net model.	None
		P_1 -P_8 $_{\text{Pilot Cork Departing\_k}} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Line up, Departure}	Location of the aircraft on the airport surface	None

	SA of Pilot Cork Departing_k about Aircraft Cork Landing_k	P1 -P8 $_{\text{Aircraft Cork Landing\_k}} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Line up, Departure}	Location of the aircraft on the airport surface	None
	SA of Pilot Cork Departing_k about Airport Cork	Name $_{\text{Airport\_Cork}}$	This is the name of the aircraft are located. This is not going to be modelled in the petri net model.	N/A
		Runway/taxiway layout $_{\text{Airport\_Cork}}$	This is the layout of the airport that the pilot is aware of. This is not modelled in the petri net model.	N/A
		Open/Closed $_{\text{Airport\_Cork}} \in \{0,1\}$	Airport is Open or Closed. 0=” Closed” 1=” Open”	None
	Refresh rate	$t_G \in \mathbb{R}$	Refresh rate to check and update the position of all aircraft.	$\dot{t}_G = -1$

Transitions

ID	Transition	Condition
G	MASA ^ *(P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Aircraft Cork Departing_k} ^ *(P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Aircraft Cork Landing_k} *Open/Closed* {Airport Cork} → MASA	$t_G \leq 0$

Firing Functions

ID	Firing Function
G	One token is fired to place *MASA* with colours: *SA of Pilot Cork Departing_k about Aircraft Cork Departing_k* Callsign$_{\text{Aircraft_Cork_Departing_k}}$ = Callsign {MASA} 2DPosition$_{\text{Aircraft_Cork_Departing_k}}$ is not modelled, therefore not updated P_1 -P_8 $_{\text{Pilot Cork Departing\_k}}$ = Name of incoming place of *(P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Pilot Cork Tasks [Pilot Cork Departing_k]} *SA of Pilot Cork Departing_k about Aircraft Cork Landing_k* P1 -P8 $_{\text{Aircraft Cork Landing\_k}}$ = Name of incoming place of *(P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Pilot Cork Tasks [Pilot Cork Landing_k]} *SA of Pilot Cork Departing_k about Airport Cork* Name $_{\text{Airport\_Cork}}$ = Name $_{\text{Airport\_Cork}}$ (MASA) Runway/taxiway layout $_{\text{Airport\_Cork}}$ = Runway/taxiway layout $_{\text{Airport\_Cork}}$ (MASA) Open/Closed= *Open/Closed* {Airport Cork}

	refresh rate in seconds t_G =1

Initial markings

One token is in MASA with the following colours:

SA of Pilot Cork Departing_k about Aircraft Cork Departing_k

Callsign$_{Aircraft_Cork_Departing_k}$ = 100

2DPosition$_{Aircraft_Cork_Departing_k}$ is not modelled

P_1 -P_8 $_{Pilot\ Cork\ Departing\_k}$ = *P6*

SA of Pilot Cork Departing_k about Aircraft Cork Landing_k

P1 -P8 $_{Aircraft\ Cork\ Landing\_k}$ = P2

SA of Pilot Cork Departing_k about Airport Cork

Name $_{Airport\_Cork}$ = Cork
Runway/taxiway layout $_{Airport\_Cork}$ is not modelled

Open/Closed = Open

refresh rate in seconds

t_G =1

5.2. Local Petri Net “Pilot Cork Tasks”

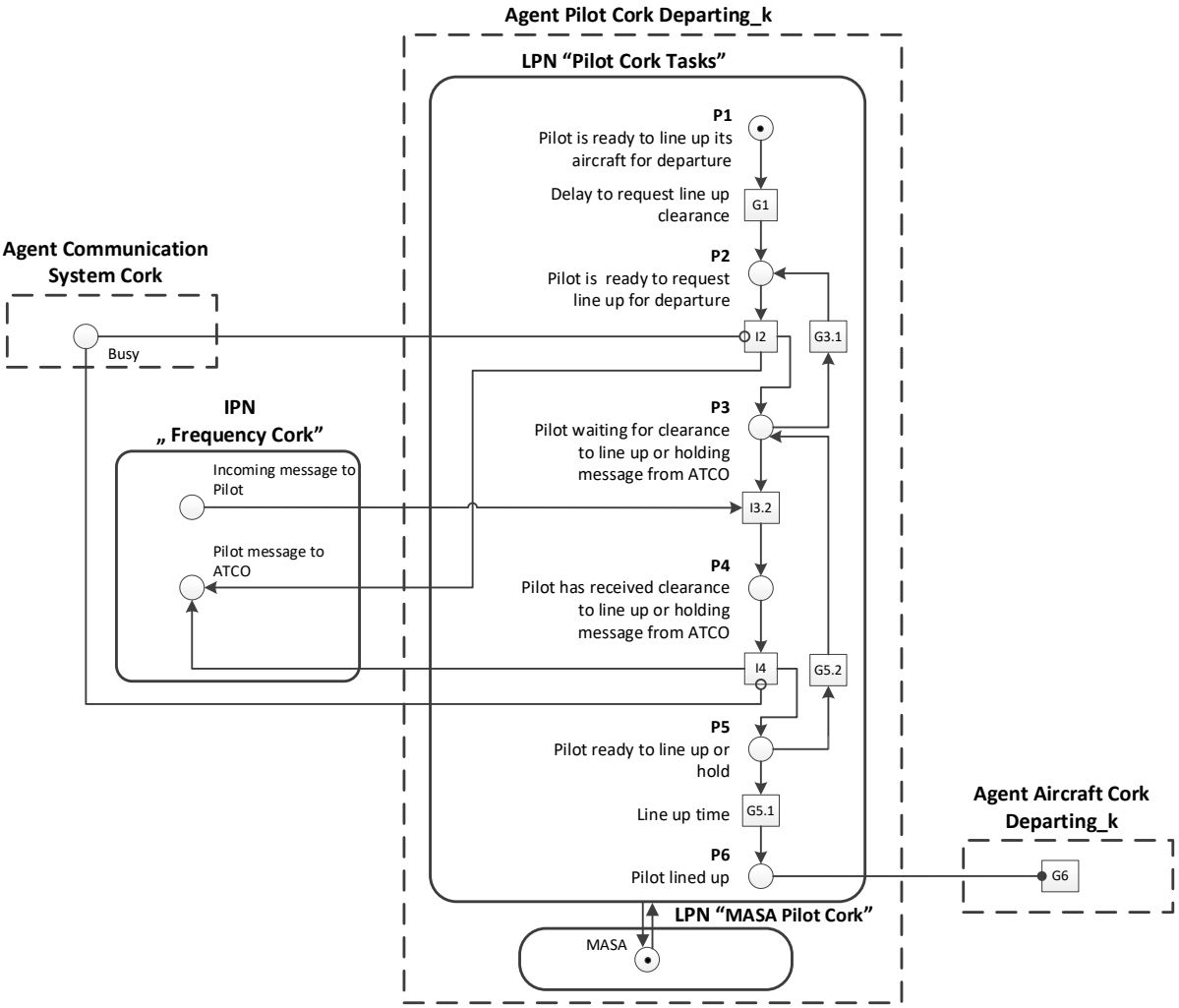


Figure E-12: Local Petri Net “Pilot Cork Tasks”

Incoming arcs within same agent

- Incoming arc from LPN “MASA Pilot Cork” to all transitions of LPN” Pilot Cork Tasks”.

Outgoing arcs within same agent

- Outgoing arc from all transitions of LPN” Pilot Cork Tasks” to place MASA of LPN “MASA Pilot Cork”.

Incoming arcs from another agent

- Incoming arcs from place *Incoming Message to Pilot* in IPN “Frequency Cork” to transition I3.2.
- Two inhibitor arcs from place *Busy* in agent “Communication System Cork” to transitions I2 and I4.

Outgoing arc to another agent

- 2 outgoing arcs from transitions I2 and I4 to place *Pilot message to ATCO* in IPN “Frequency Cork”.
- One enabling arc to from place *P6* to transition G6 of agent Aircraft Cork Departing_k.

Places

Places	Colour type	Explanation	Colour function
P1	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$t_{G1} \in \mathbb{R}$	Pilot time delay to request line up clearance from ATCO.	$\dot{t}_{G1} = -1$
P2	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
P3	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$t_{RRG3} \in \mathbb{R}$	Time to repeat request by pilot.	$\dot{t}_{RRG3} = -1$
P4	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO	None
	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None
P5	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO 1=” Totally Different” Aircraft Cork 2=” Similar” Aircraft Cork 3=” Very Similar” Aircraft Cork 4=” Totally Different” Aircraft Shannon 5=” Similar” Aircraft Shannon	None

		6=” Very Similar” Aircraft Shannon	
	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None
	$t_{G5.1} \in \mathbb{R}$	Time it takes the aircraft to start and complete line up from the moment of receiving clearance.	$\dot{t}_{G5.1} = -1$
P6	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO	None
	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None

Transitions

ID	Transition	Condition
G1	P1^MASA {MASA Pilot Cork} → P2 ^MASA {MASA Pilot Cork}	$t_{G1} \leq 0$
I2	P2 ^ NOT *Busy* {Communication System Cork} ^MASA {MASA Pilot Cork} → P3 ^ *Pilot Message to ATCO* {Frequency Cork} ^MASA {MASA Pilot Cork}	None
G3.1	P3 ^MASA {MASA Pilot Cork}→ P2^MASA {MASA Pilot Cork}	$t_{RRG3} \leq 0$
I3.2	P3 ^ *Incoming Message to Pilot* {Frequency Cork} ^MASA {MASA Pilot Cork} → P4^MASA {MASA Pilot Cork}	None
I4	P4 ^ NOT *Busy* {Communication System Cork} ^MASA {MASA Pilot Cork}→ P5 ^ *Pilot Message to ATCO* {Frequency Cork} ^MASA {MASA Pilot Cork}	None
G5.1	P5 ^MASA {MASA Pilot Cork}→ P6^MASA {MASA Pilot Cork}	$PILOT_{message}$ (P5) = 2 (Pilot confirms line up clearance) and $t_{G5.1} <= 0$
G5.2	P5^MASA {MASA Pilot Cork} → P3^MASA {MASA Pilot Cork}	$PILOT_{message}$ (P5) = 0 (Pilot confirms hold) or $PILOT_{message}$ (P5) = 3 (Pilot questions ATCO)

Firing Functions

ID	Firing Function
G1	One token is fired to place P2 with colours: $PILOT_{student}$ = $PILOT_{student}$ (P1) One token is fired to MASA with the colours equal to incoming colours from place MASA.
I2	One token is fired to place P3 with colours: $PILOT_{aid}$ = $Callsign_{Aircraft\_Cork\_Departing\_k}$ MASA {MASA Pilot Cork}

	$PILOT_{message}$ = 1 (Pilot is ready to line up and depart) $PILOT_{student}$ = $PILOT_{student}$ (P2) t_{RRG3}= sample ≥ 0 from Gaussian distribution with: Mean=30 s Std Dev=5 s One token is fired to place *Pilot Message to ATCO* {Frequency Cork} with colours: $PILOT_{aid}$ = $Callsign_{Aircraft\_Cork\_Departing\_k}$ MASA {MASA Pilot Cork} $PILOT_{message}$ = 1 (Pilot is ready to line up and depart) One token is fired to MASA with the colours equal to incoming colours from place MASA.
G3	One token is fired to place P2 with colours: $PILOT_{student}$ = $PILOT_{student}$ (P3) One token is fired to MASA with the colours equal to incoming colours from place MASA.
I3	One token is fired to place P4 with colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P3) $PILOT_{message}$= $PILOT_{message}$(P3) $PILOT_{student}$ = $PILOT_{student}$ (P3) $ATCO_{aid}$ = $ATCO_{aid}$ (*Incoming Message to pilot* {Frequency Cork}) $ATCO_{message}$= $ATCO_{message}$ (*Incoming Message to pilot* {Frequency Cork}) One token is fired to MASA with the colours equal to incoming colours from place MASA.

I4	One token is fired to place *Pilot Message to ATCO* {Frequency Cork} with colours:
	$PILOT_{aid}$ = $PILOT_{aid}$ (P4)
	
	if $PILOT_{aid}$= $ATCO_{aid}$
	  if $ATCO_{message}$ =1
	  $PILOT_{message}$ =2;
	  else
	  $PILOT_{message}$ =0;
	  end
	elseif abs ($PILOT_{aid}$ - $ATCO_{aid}$) <=10 *(callsign similarity: very similar)*
	  if rand < ((1/300) +(student/300*0.25))
	  if $ATCO_{message}$ =1
	  $PILOT_{message}$ =2;
	  else
	  $PILOT_{message}$ =0;
	  end
	  else
	  $PILOT_{message}$ =3;
	  end
	else *(callsign similarity: similar)*
	  if rand < ((1/500) +(student/500*0.25))
	  if $ATCO_{message}$ =1
	  $PILOT_{message}$ =2;
	  else
	  $PILOT_{message}$ =0;
	  end
	  else
	  $PILOT_{message}$ =3;

	end else *(callsign similarity: totally different)* if rand < ((1/5000) +(student/500*0.25)) if $ATCO_{message}$ =1 $PILOT_{message}$ =2; else $PILOT_{message}$ =0; end else $PILOT_{message}$ =3; end One token is fired to place P5 with colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P4) $PILOT_{message}$= $PILOT_{message}$(P4) $PILOT_{student}$ = $PILOT_{student}$ (P4) $ATCO_{aid}$ = $ATCO_{aid}$ (P4) $ATCO_{message}$= $ATCO_{message}$ (P4) $t_{G5.1}$= Sample ≥ 0 from Gaussian distribution with: Mean=3 s Std Dev=1 s One token is fired to MASA with the colours equal to incoming colours from place MASA.
G5.1	One token is fired to place P6 with colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P5) $PILOT_{message}$= $PILOT_{message}$(P5) $PILOT_{student}$ = $PILOT_{student}$ (P5) $ATCO_{aid}$ = $ATCO_{aid}$ (P5) $ATCO_{message}$= $ATCO_{message}$ (P5) One token is fired to MASA with the colours equal to incoming colours from place MASA.
G5.2	One token is fired to place P3 with colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P5) $PILOT_{message}$= $PILOT_{message}$(P5) $PILOT_{student}$ = $PILOT_{student}$ (P5) t_{RRG3} = sample ≥ 0 from Gaussian distribution with: Mean=60 s Std Dev=5 s One token is fired to MASA with the colours equal to incoming colours from place MASA.

Initial markings

There is an initial token in P1 with colours:

$PILOT_{student}$ = 0 or 1 based on scenario parameters.

t_{G1}= Sample ≥ 0 from Gaussian distribution with:

Mean=5 s

Std Dev=1 s

6. Agent „Pilot Cork Landing_k “

6.1. Local Petri Net “MASA Pilot Cork”

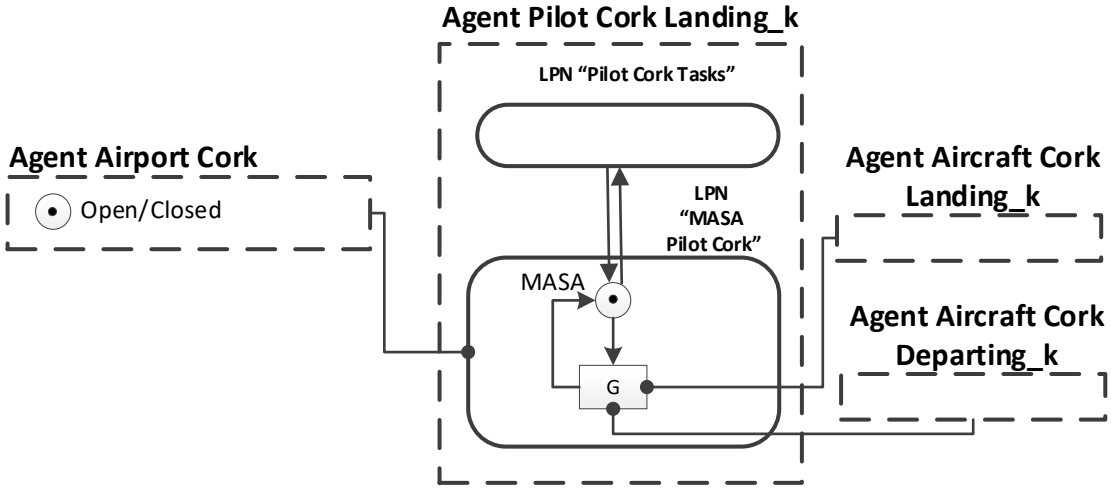


Figure E-13: Pilot Cork Landing_k Local Petri Net “MASA Pilot Cork”

Incoming arcs within same agent

- Incoming arc from all transitions of LPN” Pilot Cork Tasks” to place *MASA*.

Outgoing arcs within same agent

- Outgoing arc from place *MASA* to all transitions of LPN” Pilot Cork Tasks”.

Incoming arcs from another agent

- Enabling arc from place *Open/Closed* of agent Airport Cork to transition G.
- Enabling arc from all places of agent Aircraft Cork Departing_k to transition G.
- Enabling arc from all places of agent Aircraft Cork Landing_k to transition G.

Outgoing arc to another agent

- No outgoing arcs.

Places

Places	SA	Colour type	Explanation	Colour function
MASA	SA of Pilot Cork Landing_k about Aircraft Cork Landing_k	$Callsign_{Aircraft\_Cork\_Landing\_k}$	Callsign of Aircraft Cork Landing_k	None
		$2DPosition_{Aircraft\_Cork\_Landing\_k}$	Location of the aircraft on the airport surface. This is not going to be modelled in the petri net model.	None
		$P1\text{-}P8_{\text{Aircraft Cork Landing\_k}} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Line up, Departure}	Location of the aircraft on the airport surface	None

	SA of Pilot Cork Landing_k about Aircraft Cork Departing_k	P_1 -P_8 $_{\text{Pilot Cork Departing\_k}} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Line up, Departure}	Location of the aircraft on the airport surface	None
	SA of Pilot Cork Landing_k about Airport Cork	Name $_{\text{Airport\_Cork}}$	This is the name of the aircraft are located. This is not going to be modelled in the petri net model.	N/A
		Runway/taxiway layout $_{\text{Airport\_Cork}}$	This is the layout of the airport that the pilot is aware of. This is not modelled in the petri net model.	N/A
		$\text{Open/Closed}_{\text{Airport\_Cork}} \in \{0,1\}$	Airport is Open or Closed. 0=” Closed” 1=” Open”	None
	Refresh rate	$t_G \in \mathbb{R}$	Refresh rate to check and update the position of all aircraft.	$\dot{t}_G = -1$

Transitions

ID	Transition	Condition
G	MASA ^ *(P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Aircraft Cork Departing_k} ^ *(P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Aircraft Cork Landing_k} *Open/Closed* {Airport Cork} → MASA	$t_G \leq 0$

Firing Functions

ID	Firing Function
G	One token is fired to place *MASA* with colours: *SA of Pilot Cork Landing_k about Aircraft Cork Landing_k* $\text{Callsign}_{\text{Aircraft\_Cork\_Landing\_k}} = \text{Callsign}$ {MASA} $\text{2DPosition}_{\text{Aircraft\_Cork\_Landing\_k}}$ is not modelled, therefore not updated $\text{P1 -P8}_{\text{Aircraft Cork Landing\_k}} = \text{Name of incoming place of } (P1 \veebar P2 \veebar P3 \veebar P4 \veebar P5 \veebar P6 \veebar P7 \veebar P8)$ {Pilot Cork Tasks [Pilot Cork Landing_k]} *SA of Pilot Cork Landing_k about Aircraft Cork Departing_k* P_1 -P_8 $_{\text{Pilot Cork Departing\_k}} = \text{Name of incoming place of } (P1 \veebar P2 \veebar P3 \veebar P4 \veebar P5 \veebar P6 \veebar P7 \veebar P8)$ {Pilot Cork Tasks [Pilot Cork Departing_k]} *SA of Pilot Cork Landing_k about Airport Cork* Name $_{\text{Airport\_Cork}}$ = Name $_{\text{Airport\_Cork}}$ (MASA) Runway/taxiway layout $_{\text{Airport\_Cork}}$ = Runway/taxiway layout $_{\text{Airport\_Cork}}$ (MASA)

	Open/Closed= *Open/Closed* {Airport Cork} *refresh rate in seconds* t_G =1

Initial markings

One token is in MASA with the following colours:

SA of Pilot Cork Landing_k about Aircraft Cork Landing_k

$Callsign_{Aircraft\_Cork\_Landing\_k} = 200$

$2DPosition_{Aircraft\_Cork\_Landing\_k}$ is not modelled

$P1\text{-}P8_{\ Aircraft\ Cork\ Landing\_k} = P6$

SA of Pilot Cork Landing_k about Aircraft Cork Departing_k

$P_1\text{-}P_{8\ Pilot\ Cork\ Departing\_k} = P2$

SA of Pilot Cork Landing_k about Airport Cork

$Name_{\ Airport\_Cork}$ = Cork
$Runway/taxiway\ layout_{\ Airport\_Cork}$ is not modelled

Open/Closed = Open

refresh rate in seconds

t_G =1

6.2. Local Petri Net “Pilot Cork Tasks”

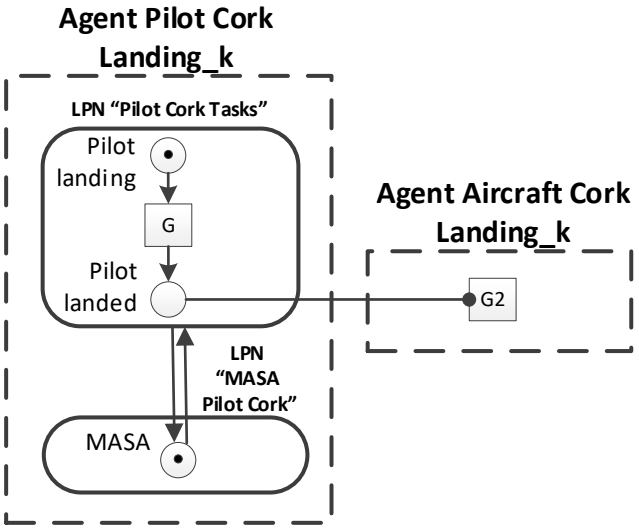


Figure E-14: Local Petri Net “Pilot Cork Tasks”

Incoming arcs within same agent

- Incoming arc from place *MASA* of LPN” MASA Pilot Cork” to all transitions.

Outgoing arcs within same agent

- Outgoing arc from all transitions to place *MASA* of LPN “MASA Pilot Cork”.

Incoming arcs from another agent

- No incoming arcs.

Outgoing arc to another agent

- No outgoing arcs.

Places

Places	Colour type	Explanation	Colour function
Pilot Landing	$t_{simulation}$	Simulation time based on the time to give landing clearance in Cork.	$\dot{t}_{simulation} = -1$
Pilot Landed	None		

Transitions

ID	Transition	Condition
G	Pilot Landing ^*Open/Closed* {Airport Cork} ^MASA {MASA Pilot Cork} → Pilot Landing ^MASA {MASA Pilot Cork}	$t_{simulation} \leq 0$

Firing Functions

ID	Firing Function
G	One token is fired to place *Pilot Landed* with no colours.

Initial markings

One token in place Pilot landing with the following colours:

$t_{simulation}$ = Average time of 3 minutes (minimum landing clearance given at 30 s, decision height).

7. Agent „Pilot Shannon_k “

7.1. Local Petri Net “MASA Pilot Shannon”

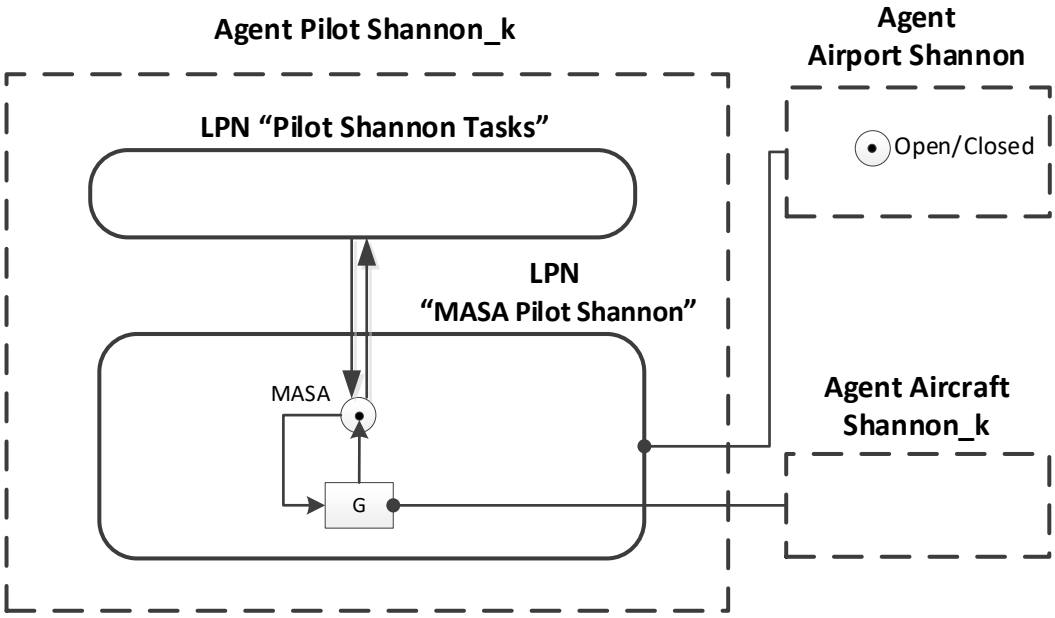


Figure E-15: Pilot Shannon_k Local Petri Net “MASA Pilot Shannon”

Incoming arcs within same agent

- Incoming arc from all transitions of LPN” Pilot Shannon Tasks” to place *MASA*.

Outgoing arcs within same agent

- Outgoing arc from place *MASA* to all transitions of LPN” Pilot Shannon Tasks”.

Incoming arcs from another agent

- Enabling arc from place *Open/Closed* of agent Airport Shannon to transition G.
- Enabling arc from all places of agent Aircraft Shannon_k to transition G.

Outgoing arc to another agent

- No outgoing arcs.

Places

Places	SA	Colour type	Explanation	Colour function
MASA	SA of Pilot Shannon_k about Aircraft Shannon_k	$\text{Callsign}_{\text{Aircraft\_Shannon\_k}}$	Callsign of Aircraft Shannon_k	None
		$\text{2DPosition}_{\text{Aircraft\_Shannon\_k}}$	Location of the aircraft on the airport surface. This is not going to be modelled in the petri net model.	None
		P_1 -P_8 $_{\text{Pilot Shannon\_k}} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure	Location of the aircraft on the airport surface	None

		Holding Point, Line up, Departure}		
	SA of Pilot Shannon_k about Airport Shannon	Name $_{Airport\_Shannon}$	This is the name of the aircraft are located. This is not going to be modelled in the petri net model.	N/A
		Runway/taxiway layout $_{Airport\_Shannon}$	This is the layout of the airport that the pilot is aware of. This is not modelled in the petri net model.	N/A
		Open/Closed $_{Airport\_Shannon} \in \{0,1\}$	Airport is Open or Closed. 0=” Closed” 1=” Open”	None
	Refresh rate	$t_G \in \mathbb{R}$	Refresh rate to check and update the position of all aircraft.	$\dot{t}_G = -1$

Transitions

ID	Transition	Condition
G	MASA ^ *(P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Aircraft Shannon_k} ^ *Open/Closed* {Airport Shannon} → MASA	$t_G \leq 0$

Firing Functions

ID	Firing Function
G	One token is fired to place *MASA* with colours: *SA of Pilot Shannon_k about Aircraft Shannon_k* Callsign$_{Aircraft_Shannon_k}$ = Callsign {MASA} 2DPosition$_{Aircraft_Shannon_k}$ is not modelled, therefore not updated P_1-P_8 $_{Pilot\ Shannon\_k}$ = Name of incoming place of *(P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Pilot Shannon Tasks [Pilot Shannon_k]} *SA of Pilot Shannon_k about Airport Shannon* Name $_{Airport\_Shannon}$ = Name $_{Airport\_Shannon}$ (MASA) Runway/taxiway layout $_{Airport\_Shannon}$ = Runway/taxiway layout $_{Airport\_Shannon}$ (MASA) Open/Closed= *Open/Closed* {Airport Shannon} *refresh rate in seconds* t_G =1

Initial markings

One token is in MASA with the following colours:

SA of Pilot Shannon_k about Aircraft Shannon_k

Callsign$_{Aircraft_Shannon_k}$ = 300

2DPosition$_{Aircraft_Shannon_k}$ is not modelled

P_1-P_8 $_{Pilot\ Shannon\_k}$ = *P6*

SA of Pilot Shannon_k about Airport Shannon

Name $_{Airport\_Shannon}$ = Shannon
Runway/taxiway layout $_{Airport\_Shannon}$ is not modelled

Open/Closed = Open

refresh rate in seconds

t_G =1

7.2. Local Petri Net “Pilot Shannon Tasks”

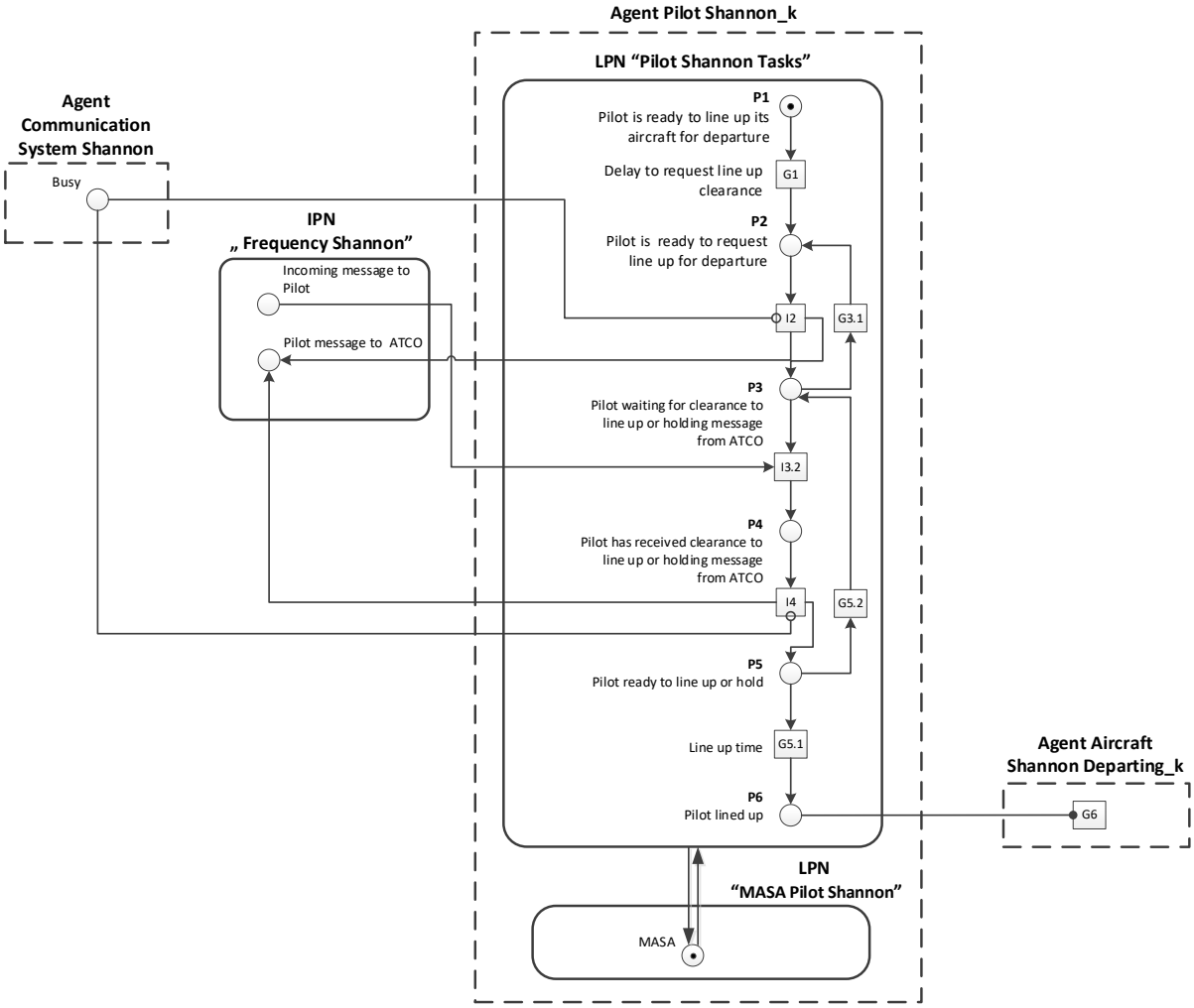


Figure E-16: Local Petri Net “Pilot Shannon Tasks”

Incoming arcs within same agent

- Incoming arc from LPN “MASA Pilot Shannon” to all transitions of LPN” Pilot Shannon Tasks”.

Outgoing arcs within same agent

- Outgoing arc from all transitions of LPN” Pilot Shannon Tasks” to place MASA of LPN “MASA Pilot Shannon”.

Incoming arcs from another agent

- Incoming arcs from place *Incoming Message to Pilot* in IPN “Frequency Shannon” to transition I3.2.
- Two inhibitor arcs from place *Busy* in agent “Communication System Shannon” to transitions I2 and I4.

Outgoing arc to another agent

- 2 outgoing arcs from transitions I2 and I4 to place *Pilot message to ATCO* in IPN “Frequency Shannon”.
- One enabling arc to from place *P6* to transition G6 of agent Aircraft Shannon_k.

Places

Places	Colour type	Explanation	Colour function
P1	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$t_{G1} \in \mathbb{R}$	Pilot time delay to request line up clearance from ATCO.	$\dot{t}_{G1} = -1$
P2	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
P3	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$t_{RRG3} \in \mathbb{R}$	Time to repeat request by pilot.	$\dot{t}_{RRG3} = -1$
P4	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO 1=” Totally Different” Aircraft Shannon 2=” Similar” Aircraft Shannon 3=” Very Similar” Aircraft Shannon 4=” Totally Different” Aircraft Shannon 5=” Similar” Aircraft Shannon 6=” Very Similar” Aircraft Shannon	None

	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None
P5	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO 1=” Totally Different” Aircraft Shannon 2=” Similar” Aircraft Shannon 3=” Very Similar” Aircraft Shannon 4=” Totally Different” Aircraft Shannon 5=” Similar” Aircraft Shannon 6=” Very Similar” Aircraft Shannon	None
	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None
	$t_{G5.1} \in \mathbb{R}$	Time it takes the aircraft to start and complete line up from the moment of receiving clearance.	$\dot{t}_{G5.1} = -1$
P6	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$PILOT_{student} \in \{0,1\}$	Pilot is a student or not. 0=” NOT Student” 1=” Student”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO 1=” Totally Different” Aircraft Shannon 2=” Similar” Aircraft Shannon 3=” Very Similar” Aircraft Shannon 4=” Totally Different” Aircraft Shannon 5=” Similar” Aircraft Shannon 6=” Very Similar” Aircraft Shannon	None
	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None

Transitions

ID	Transition	Condition
G1	P1^MASA {MASA Pilot Shannon} → P2 ^MASA {MASA Pilot Shannon}	$t_{G1} \leq 0$

I2	P2 ^ NOT *Busy* {Communication System Shannon} ^MASA {MASA Pilot Shannon} → P3 ^ *Pilot Message to ATCO* {Frequency Shannon} ^MASA {MASA Pilot Shannon}	None
G3.1	P3 ^MASA {MASA Pilot Shannon}→ P2^MASA {MASA Pilot Shannon}	t_{RRG3} ≤0
I3.2	P3 ^ *Incoming Message to Pilot* {Frequency Shannon} ^MASA {MASA Pilot Shannon} → P4^MASA {MASA Pilot Shannon}	None
I4	P4 ^ NOT *Busy* {Communication System Shannon} ^MASA {MASA Pilot Shannon}→ P5 ^ *Pilot Message to ATCO* {Frequency Shannon} ^MASA {MASA Pilot Shannon}	None
G5.1	P5 ^MASA {MASA Pilot Shannon}→ P6^MASA {MASA Pilot Shannon}	$PILOT_{message}$ (P5) = 2 (Pilot confirms line up clearance) and $t_{G5.1}<=0$
G5.2	P5^MASA {MASA Pilot Shannon} → P3^MASA {MASA Pilot Shannon}	$PILOT_{message}$ (P5) = 0 (Pilot confirms hold) or $PILOT_{message}$ (P5) = 3 (Pilot questions ATCO)

Firing Functions

ID	Firing Function
G1	One token is fired to place P2 with colours: $PILOT_{student}$ = $PILOT_{student}$ (P1) One token is fired to MASA with the colours equal to incoming colours from place MASA.
I2	One token is fired to place P3 with colours: $PILOT_{aid}$ = $Callsign_{Aircraft\_Shannon\_k}$ MASA {MASA Pilot Shannon} $PILOT_{message}$ = 1 (Pilot is ready to line up and depart) $PILOT_{student}$ = $PILOT_{student}$ (P2) t_{RRG3}= sample ≥ 0 from Gaussian distribution with: Mean=30 s Std Dev=5 s One token is fired to place *Pilot Message to ATCO* {Frequency Shannon} with colours: $PILOT_{aid}$ = $Callsign_{Aircraft\_Shannon\_k}$ MASA {MASA Pilot Shannon} $PILOT_{message}$ = 1 (Pilot is ready to line up and depart) One token is fired to MASA with the colours equal to incoming colours from place MASA.
G3.1	One token is fired to place P2 with colours: $PILOT_{student}$ = $PILOT_{student}$ (P3) One token is fired to MASA with the colours equal to incoming colours from place MASA.
I3.2	One token is fired to place P4 with colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P3) $PILOT_{message}$= $PILOT_{message}$(P3) $PILOT_{student}$ = $PILOT_{student}$ (P3) $ATCO_{aid}$ = $ATCO_{aid}$ (*Incoming Message to pilot* {Frequency Shannon}) $ATCO_{message}$= $ATCO_{message}$ (*Incoming Message to pilot* {Frequency Shannon}) One token is fired to MASA with the colours equal to incoming colours from place MASA.

I4	One token is fired to place *Pilot Message to ATCO* {Frequency Shannon} with colours:
	$PILOT_{aid}$ = $PILOT_{aid}$ (P4)
	
	if $PILOT_{aid}$= $ATCO_{aid}$
	  if $ATCO_{message}$ =1
	  $PILOT_{message}$ =2;
	  else
	  $PILOT_{message}$ =0;
	  end
	elseif abs ($PILOT_{aid}$ - $ATCO_{aid}$) <=10 *(callsign similarity: very similar)*
	  if rand < ((1/300) +(student/300*0.25))
	  if $ATCO_{message}$ =1
	  $PILOT_{message}$ =2;
	  else
	  $PILOT_{message}$ =0;
	  end
	  else
	  $PILOT_{message}$ =3;
	  end
	else *(callsign similarity: similar)*
	  if rand < ((1/500) +(student/500*0.25))
	  if $ATCO_{message}$ =1
	  $PILOT_{message}$ =2;
	  else
	  $PILOT_{message}$ =0;
	  end
	  else
	  $PILOT_{message}$ =3;
	  End
	else *(callsign similarity: similar)*
	  if rand < ((1/5000) +(student/500*0.25))
	  if $ATCO_{message}$ =1
	  $PILOT_{message}$ =2;
	  else
	  $PILOT_{message}$ =0;
	  end
	  else
	  $PILOT_{message}$ =3;
	
	end
	
	One token is fired to place P5 with colours:
	$PILOT_{aid}$ = $PILOT_{aid}$ (P4)
	$PILOT_{message}$= $PILOT_{message}$(P4)
	$PILOT_{student}$ = $PILOT_{student}$ (P4)
	$ATCO_{aid}$ = $ATCO_{aid}$ (P4)
	$ATCO_{message}$= $ATCO_{message}$ (P4)
	$t_{G5.1}$= Sample ≥ 0 from Gaussian distribution with:
	Mean=3 s
	Std Dev=1 s
	One token is fired to MASA with the colours equal to incoming colours from place MASA.

G5.1	One token is fired to place P6 with colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P5) $PILOT_{message}$= $PILOT_{message}$(P5) $PILOT_{student}$ = $PILOT_{student}$ (P5) $ATCO_{aid}$ = $ATCO_{aid}$ (P5) $ATCO_{message}$= $ATCO_{message}$ (P5) One token is fired to MASA with the colours equal to incoming colours from place MASA.
G5.2	One token is fired to place P3 with colours: $PILOT_{aid}$ = $PILOT_{aid}$ (P5) $PILOT_{message}$= $PILOT_{message}$(P5) $PILOT_{student}$ = $PILOT_{student}$ (P5) t_{RRG3} = sample ≥ 0 from Gaussian distribution with: Mean=60 s Std Dev=5 s One token is fired to MASA with the colours equal to incoming colours from place MASA.

Initial markings

There is an initial token in P1 with colours:

$PILOT_{student}$ = 0 or 1 based on scenario parameters.

t_{G1}= Sample ≥ 0 from Gaussian distribution with:

Mean=5 s

Std Dev=1 s.

8. Agent "Aircraft Cork Departing_k"

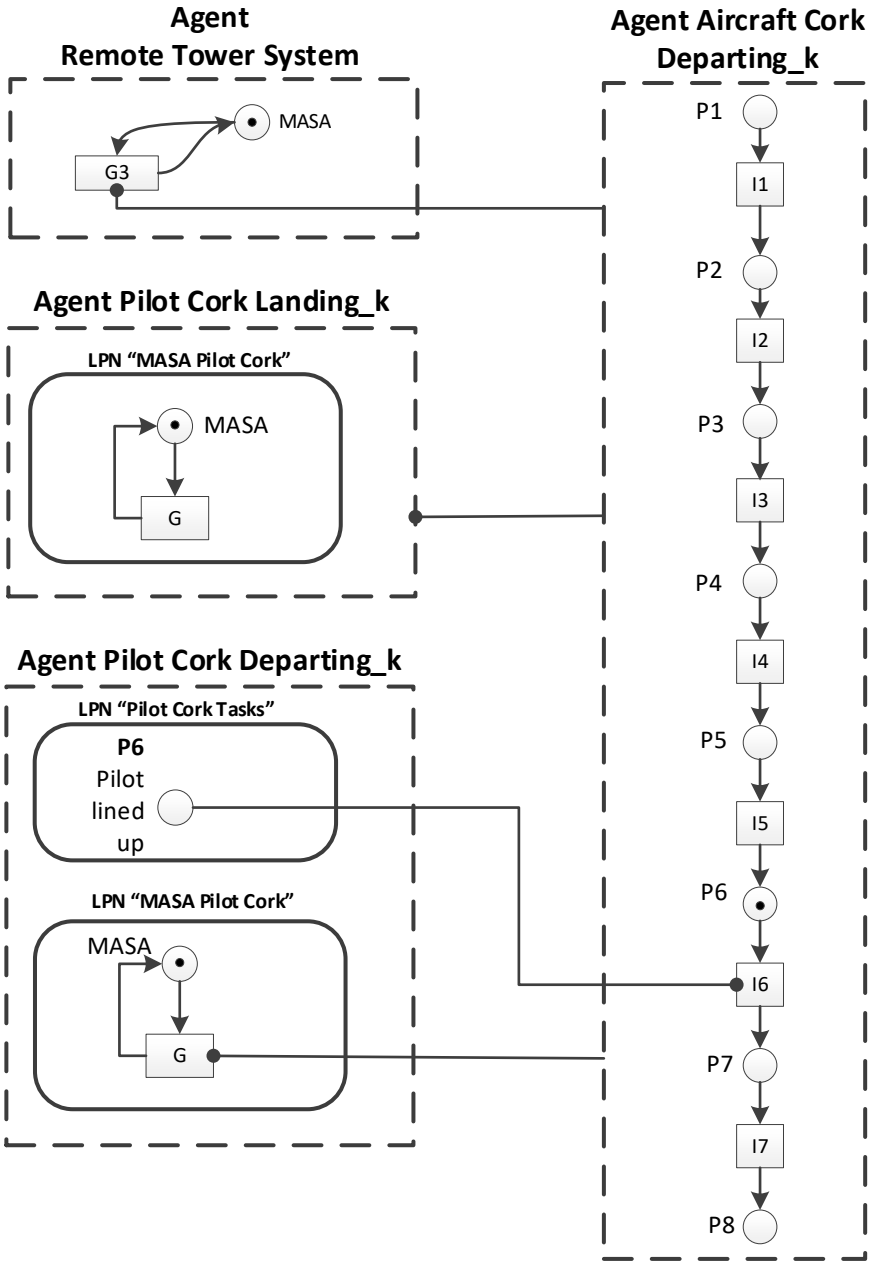


Figure E-17: Agent Aircraft Cork Departing_k

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from other agents

- One enabling arc from place *P6* of LPN "Pilot Cork Tasks "agent Pilot Cork Departing_k to transition I6.

Outgoing arc to other agents

- Enabling arcs from all places to transition G3 of agent Remote Tower System.
- Enabling arcs from all places to transition G of LPN” MASA Pilot Cork” of agent Pilot Cork Landing_k.
- Enabling arcs from all places to transition G of LPN” MASA Pilot Cork” of agent Pilot Cork Departing_k.

Places

Places	Colour type	Explanation	Colour function
P1 *(Approach)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P2 *(Landing)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P3 *(Taxi in)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P3 *(Gate)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P4 *(Taxi out)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P6 *(Departure Holding Point)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P7 *(Line up)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P8 *(Departure)*	Callsign ∈ ℝ	Callsign of the aircraft	None

Transitions

There are 7 transitions in this LPN. I.e. between places P1 and P2, between P2 and P3, etc.

However, the scope of this simulation includes only the status change of agent “Aircraft Cork Departing_k” from place P6 (Departure Holding Point) to place P7 (Line up).

ID	Transition	Condition
I6	P2 ^ P6(Pilot Lined up) {Pilot Cork Tasks [Pilot Cork Landing_k]} → P7(Line up)	None

Firing Functions

None

Initial markings

One token present in P6 with the following colours:

Callsign=100

9. Agent "Aircraft Cork Landing_k"

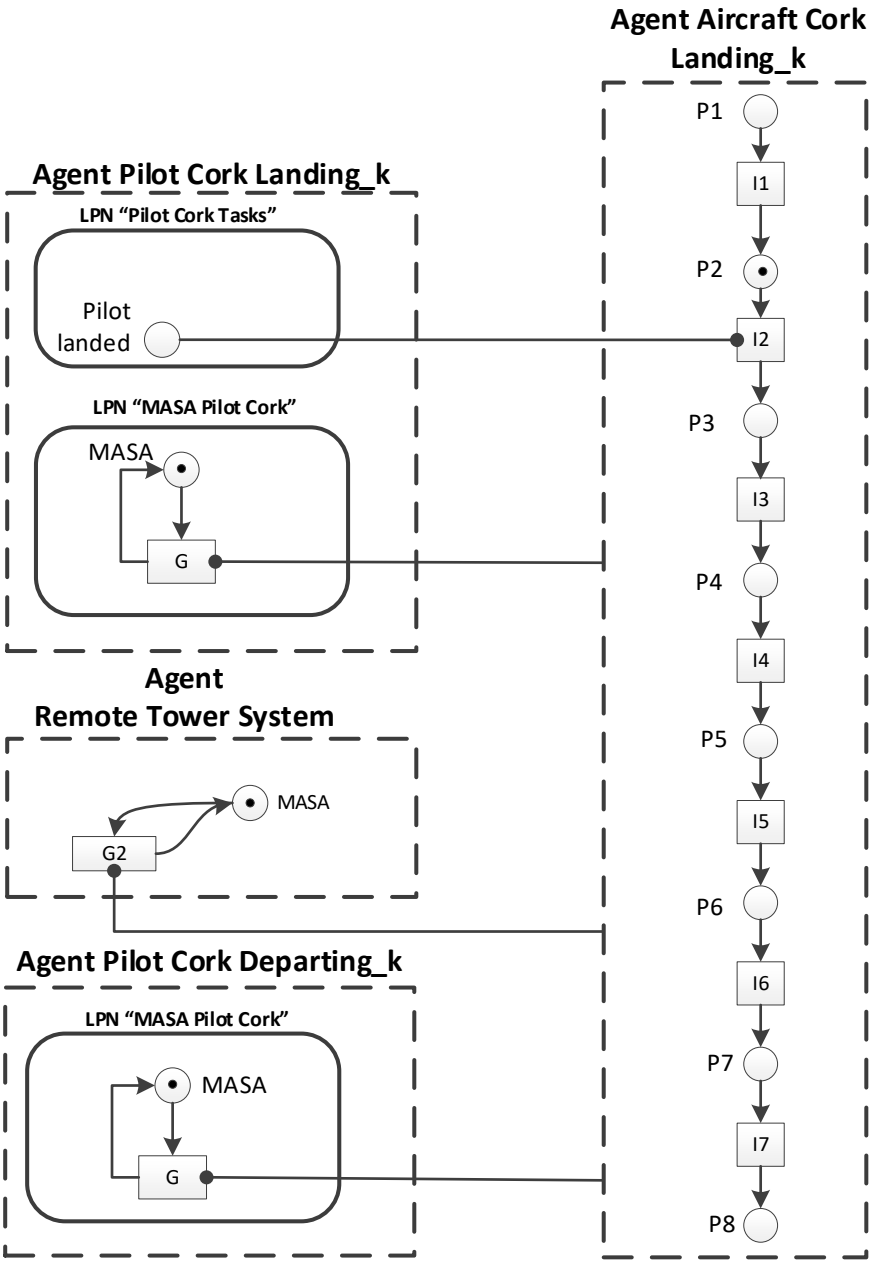


Figure E-18: Agent Aircraft Cork Landing_k

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from other agents

- One enabling arc from place *Pilot landed* of LPN"" agent Pilot Cork Landing_k to transition I2.

Outgoing arc to other agents

- Enabling arcs from all places to transition G2 of agent Remote Tower System.

- Enabling arcs from all places to transition G of LPN” MASA Pilot Cork” of agent Pilot Cork Landing_k.
- Enabling arcs from all places to transition G of LPN” MASA Pilot Cork” of agent Pilot Cork Departing_k.

Places

Places	Colour type	Explanation	Colour function
P1 *(Approach)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P2 *(Landing)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P3 *(Taxi in)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P3 *(Gate)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P4 *(Taxi out)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P6 *(Departure Holding Point)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P7 *(Line up)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P8 *(Departure)*	Callsign ∈ ℝ	Callsign of the aircraft	None

Transitions

There are 7 transitions in this LPN. I.e. between places P1 and P2, between P2 and P3, etc.

However, the scope of this simulation includes only the status change of agent Aircraft Cork Landing_k from place *P2 (Landing)* to place *P3 (Taxi in).*

ID	Transition	Condition
I2	P2 ^ *Pilot landed* {Pilot Cork Tasks [Pilot Cork Landing_k]} → P3	None

Firing Functions

None

Initial markings

One token present in P2 with the following colours:

Callsign= 200

10. Agent “Aircraft Shannon_k”

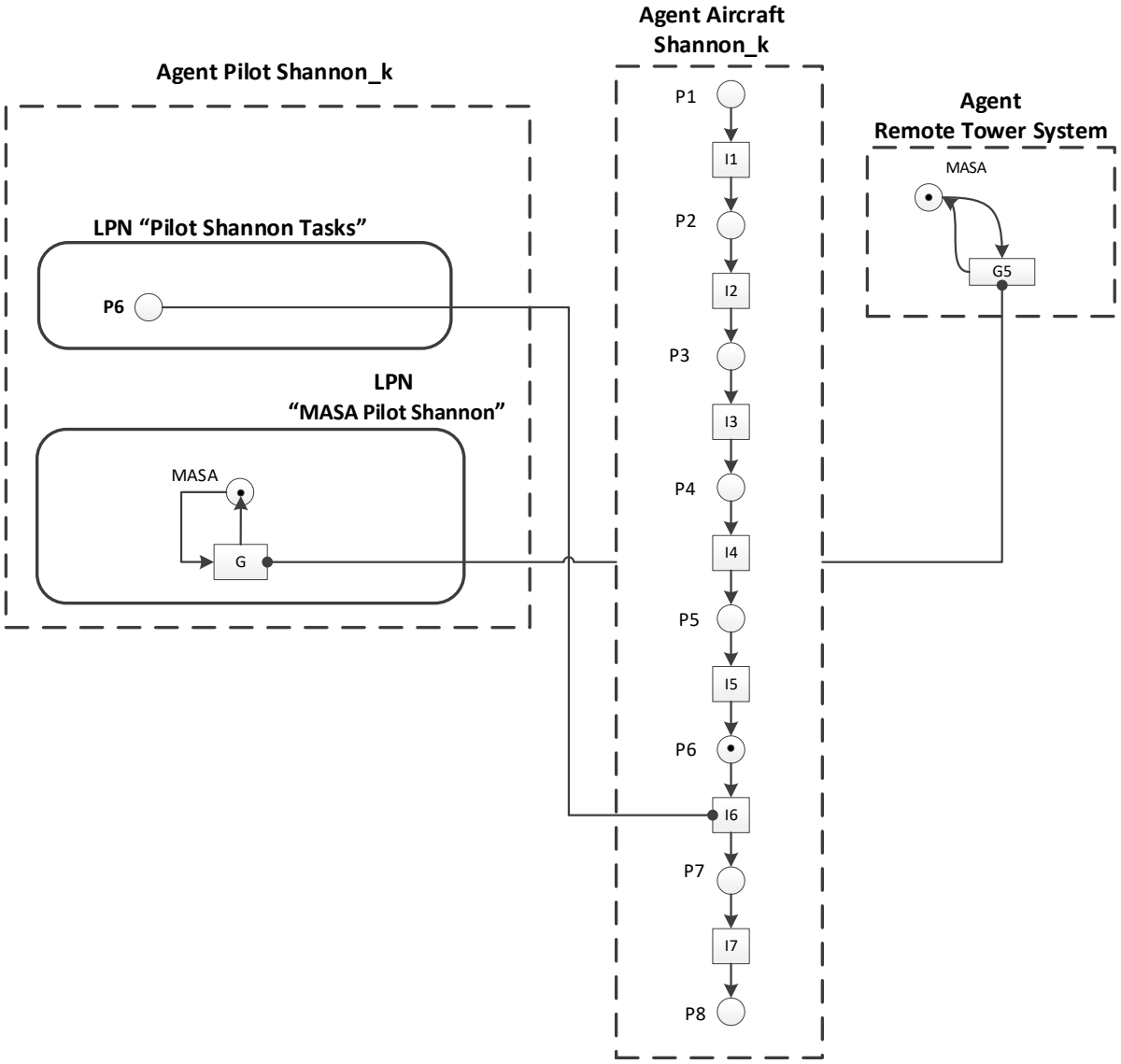


Figure E-19: Agent Aircraft Shannon_k

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from other agents

- One enabling arc from place *P6* of LPN “Pilot Shannon Tasks “agent Pilot Shannon Departing_k to transition I6.

Outgoing arc to other agents

- Enabling arcs from all places to transition G5 of agent Remote Tower System.
- Enabling arcs from all places to all transitions of LPN” MASA Pilot Shannon” of agent Pilot Shannon_k.

Places

Places	Colour type	Explanation	Colour function
P1 *(Approach)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P2 *(Landing)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P3 *(Taxi in)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P3 *(Gate)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P4 *(Taxi out)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P6 *(Departure Holding Point)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P7 *(Lined up)*	Callsign ∈ ℝ	Callsign of the aircraft	None
P8 *(Departure)*	Callsign ∈ ℝ	Callsign of the aircraft	None

Transitions

There are 7 transitions in this LPN. I.e. between places P1 and P2, between P2 and P3, etc.

However, the scope of this simulation includes only the status change of agent “Aircraft Shannon Departing_k” from place P6 (Departure Holding Point) to place P7 (Lined up).

ID	Transition	Condition
I6	P2 ^ P6(Pilot Lined up) {Pilot Shannon Tasks [Pilot Shannon_k]} → P7(Lined up)	None

Firing Functions

None

Initial markings

One token present in P6 with the following colours:

Callsign=300

11. Agent "Airport Cork"

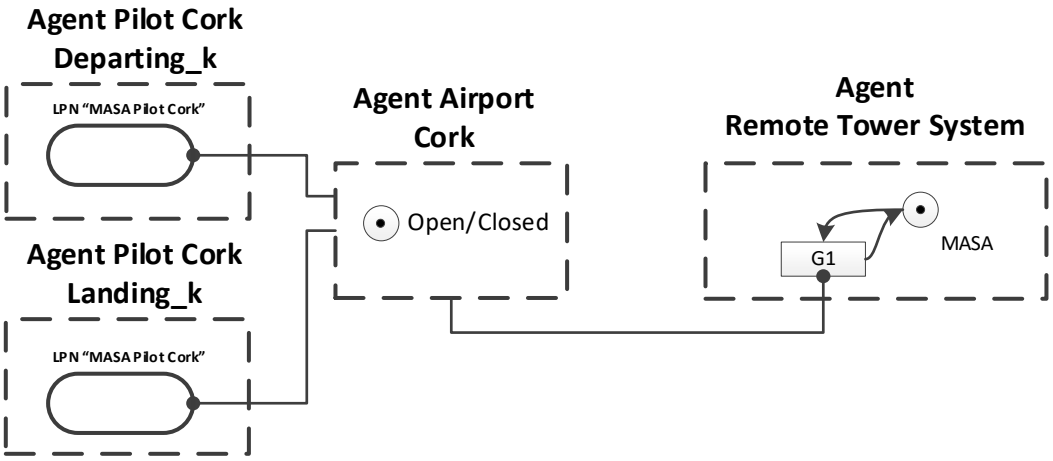


Figure E-20: Agent Airport Cork

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from other agents

- No incoming arcs.

Outgoing arc to other agents

- Enabling arc to from place *Open/Closed* to LPN "MASA Pilot Cork "of agent Pilot Cork Departing_k.
- Enabling arc to from place *Open/Closed* to LPN "MASA Pilot Cork "of agent Pilot Cork Landing_k.
- Enabling arc to from place *Open/Closed* to transition G1 of agent Remote Tower System.

Places

Places	Colour type	Explanation	Colour function
Open/Closed	$\text{Open/Closed} \in \{0,1\}$	Airport is Open or Closed. 0=" Closed" 1=" Open"	None

Transitions

None

Firing Functions

None

Initial markings

One token in Open/Closed with the colour:

Open/Closed=1

12. Agent "Airport Shannon"

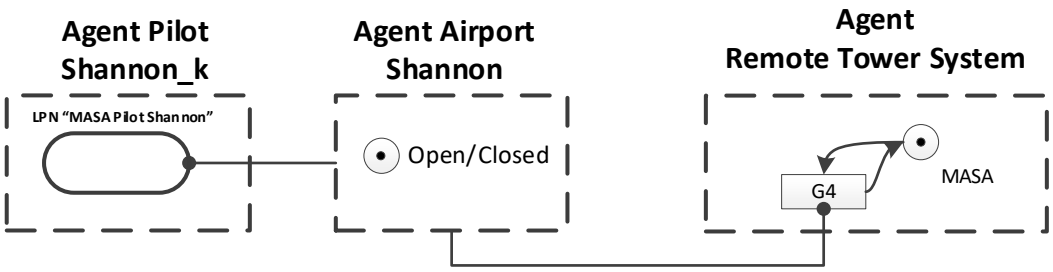


Figure E-21: Agent Airport Shannon

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from other agents

- No incoming arcs.

Outgoing arc to other agents

- Enabling arc to from place *Open/Closed* to LPN "MASA Pilot Shannon "of agent Pilot Shannon_k.
- Enabling arc to from place *Open/Closed* to transition G4 of agent Remote Tower System.

Places

Places	Colour type	Explanation	Colour function
Open/Closed	$\text{Open/Closed} \in \{0,1\}$	Airport is Open or Closed. 0=" Closed" 1=" Open"	None

Transitions

None

Firing Functions

None

Initial markings

One token in Open/Closed with the colour:

Open/Closed=1

13. Agent „Communication System Cork “

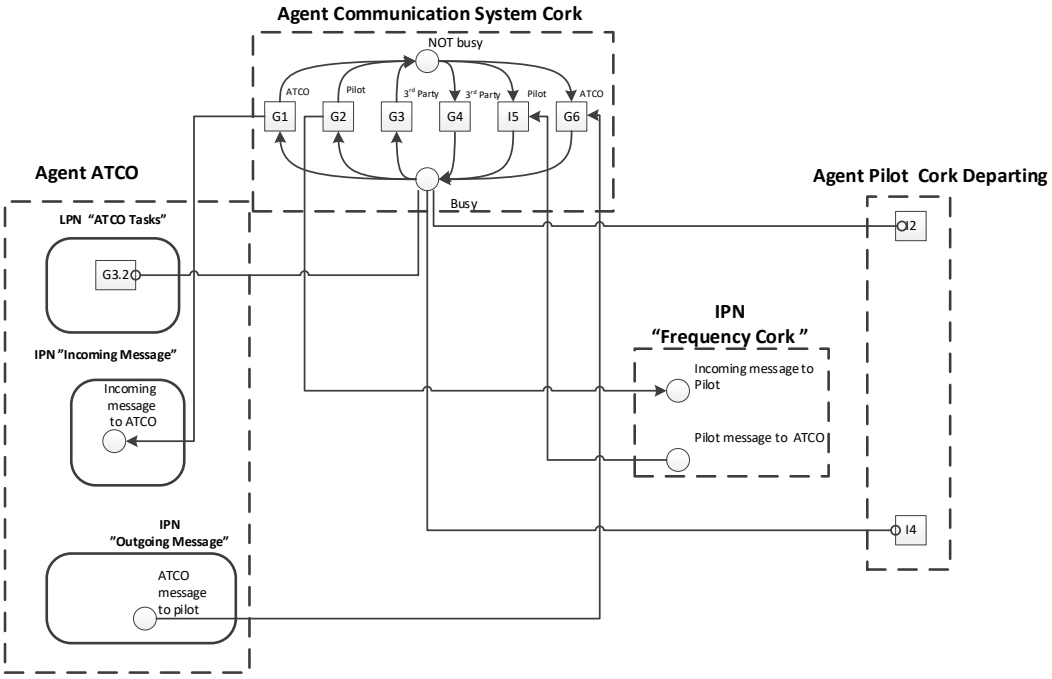


Figure E-22: Agent Communication System Cork

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from another agent

- One incoming arc to transition I5 from place *Pilot Message to ATCO* of IPN “Frequency Cork”.
- One incoming arc to transition G6 from place ATCO *message to Pilot of IPN “Outgoing Message”* of agent “ATCO”

Outgoing arc to another agent

- One outgoing arc from G1 to place *Incoming Message to ATCO of IPN “Incoming Message”* of agent “ATCO”.
- One outgoing arc from G2 to place *Incoming Message to Pilot* of IPN “Frequency Cork”.
- Two inhibitor arcs to transitions I2 and I4 of agent “Pilot Cork Departing_k” from place *Busy*.
- One inhibitor arc to transition G3.2 of LPN “ATCO Tasks” of agent “ATCO” from place *Busy*.

Places

Places	Colour type	Explanation	Colour function
Busy	Callsign ∈ $\mathbb{R}$	Callsign communicated in message	None
	Message∈ {0,1,2,3,99}	The message can be from Pilot or ATCO If from ATCO: Message from ATCO	None

		1= “Line up clearance” 2= “Hold message” If from Pilot: Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO” Or if from 3rd Party: 99=”3rd Party Message”	
	$t_{commsystemoccup} \in \mathbb{R}$	Duration of the transmission of communication system.	$\dot{t}_{commsystemoccup} = -1$
	$t_{commsystem3rdpartyfree} \in \mathbb{R}$	Duration of communication system being free from 3rd party communication. When $t_{commsystem3rdpartyfree} \leq 0$, a 3rd party communication occurs on the communication system.	$\dot{t}_{commsystem3rdpartyfree} = -1$
	Destination $\in \{0,1,2\}$	Where the message is intended to go 0=” ATCO” 1=” PILOT” 2=”3rd Party”	None
Not busy	$t_{commsystem3rdpartyfree} \in \mathbb{R}$	Duration of communication system being free from 3rd party communication. When $t_{commsystem3rdpartyfree} \leq 0$, a 3rd party communication occurs on the communication system.	$\dot{t}_{commsystem3rdpartyfree} = -1$

Transitions

ID	Transition	Condition
G1	Busy → NOT Busy ^ *Incoming Message to ATCO* {*Incoming Message* [ATCO]}	$t_{commsystemoccup} \leq 0$ and Destination=0
G2	Busy → NOT Busy ^ *Incoming Message to Pilot* {*Frequency Cork*}	$t_{commsystemoccup} \leq 0$ and Destination=1
G3	Busy → NOT Busy	$t_{commsystemoccup} \leq 0$ and Destination=2
G4	NOT Busy → Busy	$t_{commsystem3rdpartyfree} \leq 0$
I5	NOT Busy ^ *Pilot Message to ATCO* {*Frequency Cork*}→ Busy	None

G6	NOT Busy ^ *ATCO message to Pilot* {*Outgoing Message* [ATCO]} → Busy	*F* {Outgoing message [ATCO]} =” Cork”

Firing Functions

ID	Firing Function
G1	One token is fired to NOT Busy with the colours: $t_{commsystem3rdpartyfree}$ = $t_{commsystem3rdpartyfree}$(Busy) One token is fired to *Incoming Message to ATCO* {*Incoming Message* [ATCO]} with the colours: $PILOT_{aid}$ = $PILOT_{aid}$ (Busy) $PILOT_{message}$ = $PILOT_{message}$ (Busy)
G2	One token is fired to NOT Busy with the colours: $t_{commsystem3rdpartyfree}$ = $t_{commsystem3rdpartyfree}$ (Busy) One token is fired to *Incoming Message to Pilot* {*Frequency Cork*} with the colours: $ATCO_{aid}$ = $ATCO_{aid}$ (Busy) $ATCO_{message}$ = $ATCO_{message}$ (Busy)
G3	One token is fired to NOT Busy with the colours: $t_{commsystem3rdpartyfree}$= Sample ≥ 0 from Gaussian distribution with: Mean=30 s Std Dev=10 s
G4	One token is fired to Busy with the colours: $t_{commsystemoccup}$ = Sample ≥ 0 from Gaussian distribution with: Mean= 5 s Std Dev=2 s $t_{commsystem3rdpartyfree}$= 0 Destination=2 Message = 99 Callsign=99
I5	One token is fired to Busy with the colours: Callsign = $PILOT_{aid}$ (*Pilot Message to ATCO* {*Frequency Cork*}) Message= $PILOT_{message}$ (*Pilot Message to ATCO* {*Frequency Cork*}) $t_{commsystemoccup}$ = Sample ≥ 0 from Gaussian distribution with: Mean= 5 s Std Dev=2 s $t_{commsystem3rdpartyfree}$= $t_{commsystem3rdpartyfree}$ (NOT Busy) Destination=0
G6	One token is fired to Busy with the colours: Callsign = $PILOT_{aid}$ (*ATCO message to Pilot* {*Outgoing Message* [ATCO]}) Message= $ATCO_{message}$ (*ATCO message to Pilot* {*Outgoing Message* [ATCO]}]}) $t_{commsystemoccup}$ = Sample ≥ 0 from Gaussian distribution with: Mean= 5 s Std Dev=2 s $t_{commsystem3rdpartyfree}$ = $t_{commsystem3rdpartyfree}$ (NOT Busy) Destination=1

Initial markings

There are no initial tokens in any of the places.

14. Agent „Communication System Shannon “

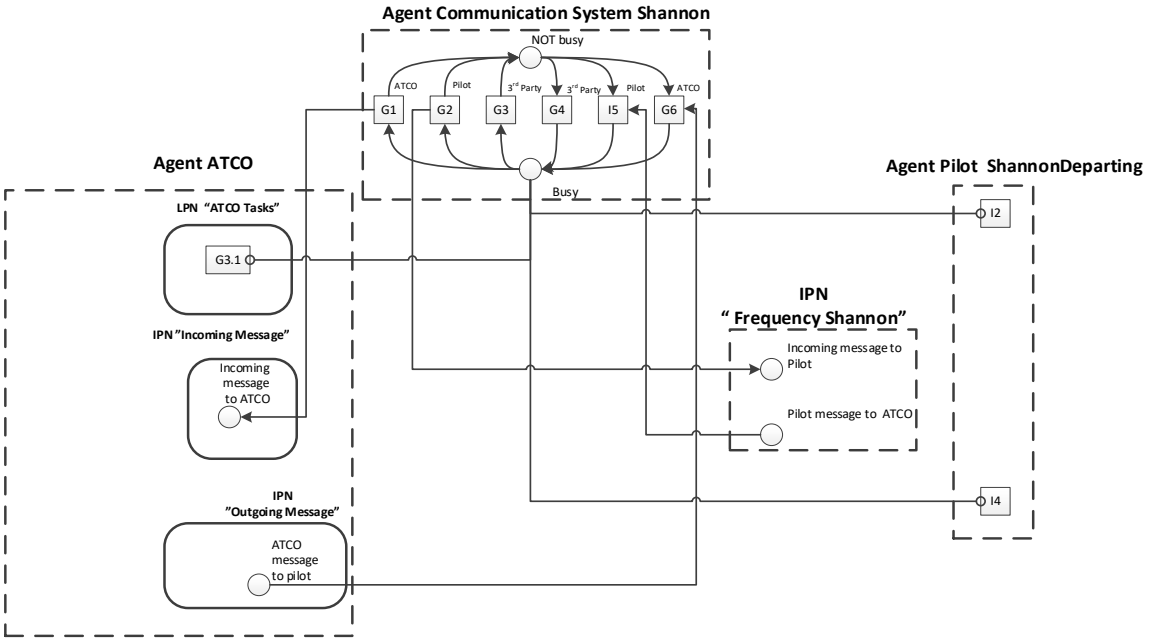


Figure E-23: Agent Communication System Shannon

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from another agent

- One incoming arc to transition I5 from place *Pilot Message to ATCO* of IPN “Frequency Shannon”.
- One incoming arc to transition G6 from place ATCO *message to Pilot of IPN “Outgoing Message”* of agent “ATCO”

Outgoing arc to another agent

- One outgoing arc from G1 to place *Incoming Message to ATCO of IPN “Incoming Message”* of agent “ATCO”.
- One outgoing arc from G2 to place *Incoming Message to Pilot* of IPN “Frequency Shannon”.
- Two inhibitor arcs to transitions I2 and I4 of agent “Pilot Shannon_k” from place *Busy*.
- One inhibitor arc to transition G3.1 of LPN “ATCO Tasks” of agent “ATCO” from place *Busy*.

Places

Places	Colour type	Explanation	Colour function
Busy	Callsign $\in \mathbb{R}$	Callsign communicated in message	None
	Message $\in \{0,1,2,3,99\}$	The message can be from Pilot or ATCO If from ATCO: Message from ATCO	None

		1= “Line up clearance” 2= “Hold message” If from Pilot: Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO” Or if from 3rd Party: 99=”3rd Party Message”	
	$t_{commsystemoccup} \in \mathbb{R}$	Duration of the transmission of communication system.	$\dot{t}_{commsystemoccup} = -1$
	$t_{commsystem3rdpartyfree} \in \mathbb{R}$	Duration of communication system being free from 3rd party communication. When $t_{commsystem3rdpartyfree} \leq 0$, a 3rd party communication occurs on the communication system.	$\dot{t}_{commsystem3rdpartyfree} = -1$
	Destination $\in \{0,1,2\}$	Where the message is intended to go 0=” ATCO” 1=” PILOT” 2=”3rd Party”	None
Not busy	$t_{commsystem3rdpartyfree} \in \mathbb{R}$	Duration of communication system being free from 3rd party communication. When $t_{commsystem3rdpartyfree} \leq 0$, a 3rd party communication occurs on the communication system.	$\dot{t}_{commsystem3rdpartyfree} = -1$

Transitions

ID	Transition	Condition
G1	Busy → NOT Busy ^ *Incoming Message to ATCO* {*Incoming Message* [ATCO]}	$t_{commsystemoccup} \leq 0$ and Destination=0
G2	Busy → NOT Busy ^ *Incoming Message to Pilot* {*Frequency Shannon*}	$t_{commsystemoccup} \leq 0$ and Destination=1
G3	Busy → NOT Busy	$t_{commsystemoccup} \leq 0$ and Destination=2
G4	NOT Busy → Busy	$t_{commsystem3rdpartyfree} \leq 0$
I5	NOT Busy ^ *Pilot Message to ATCO* {*Frequency Shannon*}→ Busy	None
G6	NOT Busy ^ *ATCO message to Pilot* {*Outgoing Message* [ATCO]} → Busy	*F* {Outgoing message [ATCO]} =” Shannon”

Firing Functions

ID	Firing Function
G1	One token is fired to NOT Busy with the colours: $t_{commsystem3rdpartyfree}$ = $t_{commsystem3rdpartyfree}$ (Busy) One token is fired to *Incoming Message to ATCO* {*Incoming Message* [ATCO]} with the colours: $PILOT_{aid}$ = Callsign (Busy) $PILOT_{message}$ = Message (Busy)
G2	One token is fired to NOT Busy with the colours: $t_{commsystem3rdpartyfree}$ = $t_{commsystem3rdpartyfree}$ (Busy) One token is fired to *Incoming Message to Pilot* {*Frequency Shannon*} with the colours: $ATCO_{aid}$ = Callsign (Busy) $ATCO_{message}$ = Message (Busy)
G3	One token is fired to NOT Busy with the colours: $t_{commsystem3rdpartyfree}$= Sample ≥ 0 from Gaussian distribution with: Mean=30 s Std Dev=10 s
G4	One token is fired to Busy with the colours: $PILOT_{aid}$ =99 $ATCO_{message}$= 99 $PILOT_{message}$ = 99 $t_{commsystemoccup}$ = Sample ≥ 0 from Gaussian distribution with: Mean= 5 s Std Dev=2 s $t_{commsystem3rdpartyfree}$= 0
I5	One token is fired to Busy with the colours: $PILOT_{aid}$ = $PILOT_{aid}$ (*Pilot Message to ATCO* {*Frequency Shannon*}) $ATCO_{message}$= 99 $PILOT_{message}$ = $PILOT_{message}$ (*Pilot Message to ATCO* {*Frequency Shannon*}) $t_{commsystemoccup}$ = Sample ≥ 0 from Gaussian distribution with: Mean= 5 s Std Dev=2 s $t_{commsystem3rdpartyfree}$ = $t_{commsystem3rdpartyfree}$ (NOT Busy)
I6	One token is fired to Busy with the colours: $PILOT_{aid}$ = $PILOT_{aid}$ (*ATCO message to Pilot* {*Outgoing Message* [ATCO]})

	$ATCO_{message}$= $ATCO_{message}$ (*ATCO message to Pilot* {*Outgoing Message* [ATCO]}]}) $PILOT_{message}$ = 99 $t_{commsystemoccup}$ = Sample ≥ 0 from Gaussian distribution with: Mean= 5 s Std Dev=2 s $t_{commsystem3rdpartyfree}$ = $t_{commsystem3rdpartyfree}$ (NOT Busy)

Initial markings

There are no initial tokens in any of the places.

15. Agent "Remote Tower System"

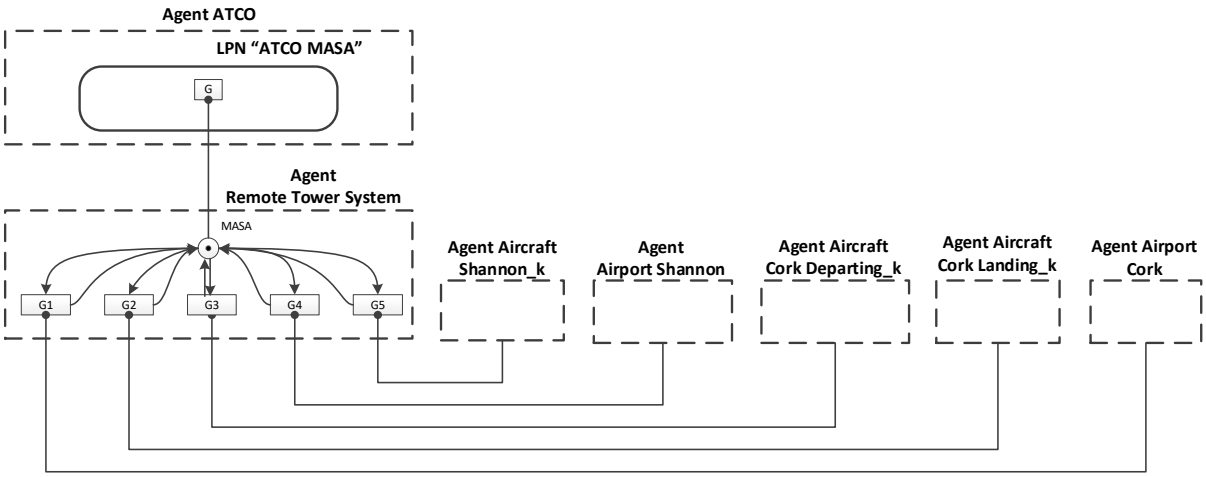


Figure E-24: Agent Remote Tower System

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from other agents

- Enabling arcs to from all places of agent Aircraft Shannon_k to transition G5.
- Enabling arcs to from all places of agent Airport Shannon to transition G4.
- Enabling arcs to from all places of agent Aircraft Cork Departing_k to transition G3.
- Enabling arcs to from all places of agent Aircraft Cork Landing_k to transition G2.
- Enabling arcs to from all places of agent Airport Cork to transition G1.

Outgoing arc to other agents

- Enabling arc from place *MASA* to transition G of LPN "ATCO MASA" of agent ATCO.

Places

Places	SA	Colour type	Explanation	Colour function
MASA	SA of Remote Tower System about Aircraft Cork Landing_k	$Callsign_{Aircraft\_Cork\_Landing\_k}$	Callsign of Aircraft Cork Landing_k	None
		$2DPosition_{Aircraft\_Cork\_Landing\_k} \in$ {Cork, Shannon}	Location of the aircraft on the airport surface. This is simplified by indicating the airport where the aircraft is.	None
		P1 -P8 $_{Aircraft\ Cork\ Landing\_k} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Lined up, Departure}	Location of the aircraft on the airport surface	None

	SA of Remote Tower System about aircraft Cork Departing_k	$Callsign_{Aircraft\_Cork\_Departing\_k}$	Callsign of Aircraft Cork Departing_k	None
		$2DPosition_{Aircraft\_Cork\_Departing\_k} \in$ {Cork, Shannon}	Location of the aircraft on the airport surface. This is simplified by indicating the airport where the aircraft is.	None
		P_1 -P_8 $_{Pilot\ Cork\ Departing\_k} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Lined up, Departure}	Location of the aircraft on the airport surface	None
	SA of Remote Tower System about Aircraft Shannon_k	$Callsign_{Aircraft\_Shannon\_k}$	Callsign of Aircraft Shannon_k	None
		$2DPosition_{Aircraft\_Shannon\_k} \in$ {Cork, Shannon}	Location of the aircraft on the airport surface. This is simplified by indicating the airport where the aircraft is.	None
		P_1 -P_8 $_{Pilot\ Shannon\_k} \in$ {Approach, Landing, Taxi, Gate, Taxi out, Departure Holding Point, Lined up, Departure}	Location of the aircraft on the airport surface	None
	SA of Remote Tower System about airport Cork	Name $_{Airport\_Cork}$	This is the name of the aircraft are located. This is not going to be modelled in the petri net model.	N/A
		Runway/taxiway layout $_{Airport\_Cork}$	This is the layout of the airport that the pilot is aware of. This is not modelled in the petri net model.	N/A
		Open/Closed $_{Airport\_Cork} \in \{0,1\}$	Airport is Open or Closed. 0=” Closed” 1=” Open”	None
	SA of Remote Tower System about Airport Shannon	Name $_{Airport\_Shannon}$	This is the name of the aircraft are located. This is not going to be modelled in the petri net model.	N/A
		Runway/taxiway layout $_{Airport\_Shannon}$	This is the layout of the airport that the pilot is aware of.	N/A

			This is not modelled in the petri net model.	
		Open/Closed $_{Airport\_Shannon} \in \{0,1\}$	Airport is Open or Closed. 0=" Closed" 1=" Open"	None
	Refresh rate	$t_G \in \mathbb{R}$	Refresh rate to check and update the position of all aircraft.	$\dot{t}_G = -1$

Transitions

ID	Transition	Condition
G1	MASA ^ *Open/Closed* {Airport Cork}→ MASA	$t_G \leq 0$
G2	MASA ^ *P1-P8* {Aircraft Cork Landing_k}→ MASA	$t_G \leq 0$
G3	MASA ^ *P1-P8* {Aircraft Cork Departing_k}→ MASA	$t_G \leq 0$
G4	MASA ^ *Open/Closed* {Airport Shannon}→ MASA	$t_G \leq 0$
G5	MASA ^ *P1-P8* {Aircraft Shannon_k}→ MASA	$t_G \leq 0$

Firing Functions

ID	Firing Function
G1	One token is fired to place *MASA* with colours: *SA of Remote Tower System about Airport Cork* Name $_{Airport\_Cork}$ = Name $_{Airport\_Cork}$ (MASA) Runway/taxiway layout $_{Airport\_Cork}$ = Runway/taxiway layout $_{Airport\_Cork}$ (MASA) Open/Closed= *Open/Closed* {Airport Cork} *refresh rate in seconds* t_G =1
G2	One token is fired to place *MASA* with colours: *SA of Remote Tower System about Aircraft Cork Landing_k* Callsign$_{Aircraft_Cork_Landing_k}$ = Callsign {MASA} 2DPosition$_{Aircraft_Cork_Landing_k}$ = Cork P_1 -P_8 $_{Pilot\ Cork\ Landing\_k}$ = Name of incoming place of (*P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Pilot Cork Tasks [Pilot Cork Landing_k]} *refresh rate in seconds* t_G =1
G3	One token is fired to place *MASA* with colours: *SA of Remote Tower System about Aircraft Cork Departing_k* Callsign$_{Aircraft_Cork_Departing_k}$ = Callsign {MASA} 2DPosition$_{Aircraft_Cork_Departing_k}$ = Cork P_1 -P_8 $_{Pilot\ Cork\ Departing\_k}$ = Name of incoming place of (*P1 ᵛ P2 ᵛ P3 ᵛ P4 ᵛ P5 ᵛ P6 ᵛ P7 ᵛ P8)* {Pilot Cork Tasks [Pilot Cork Departing_k]} *refresh rate in seconds* t_G =1
G4	One token is fired to place *MASA* with colours: *SA of Remote Tower System about Airport Shannon* Name $_{Airport\_Shannon}$= Name $_{Airport\_Shannon}$ (MASA) Runway/taxiway layout $_{Airport\_Shannon}$= Runway/taxiway layout $_{Airport\_Shannon}$ (MASA) Open/Closed= *Open/Closed* {Airport Shannon}
G5	One token is fired to place *MASA* with colours: *SA of Remote Tower System about Aircraft Shannon_k*

	$Callsign_{Aircraft\_Shannon\_k}$ = Callsign {MASA} $2DPosition_{Aircraft\_Shannon\_k}$ = Shannon P_1 -P_8 $_{Pilot\ Shannon\_k}$ = Name of incoming place of (*P1 ˅ P2 ˅ P3 ˅ P4 ˅ P5 ˅ P6 ˅ P7 ˅ P8)* {Pilot Cork Tasks [Pilot Shannon_k]} *refresh rate in seconds* t_G =1

Initial markings

One token is in MASA with the following colours:

SA of Remote Tower System about Aircraft Cork Departing_k

$Callsign_{Aircraft\_Cork\_Landing\_k}$ = 100

$2DPosition_{Aircraft\_Cork\_Landing\_k}$ = Cork

P1 -P8 $_{Aircraft\ Cork\ Landing\_k}$ = *P2*

SA of Remote Tower System about Aircraft Cork Landing_k

$Callsign_{Aircraft\_Cork\_Landing\_k}$ = 200

$2DPosition_{Aircraft\_Cork\_Landing\_k}$ = Cork

P1 -P8 $_{Aircraft\ Cork\ Landing\_k}$ = *P6*

SA of Remote Tower System about Aircraft Shannon_k

$Callsign_{Aircraft\_Shannon\_k}$ = 300

$2DPosition_{Aircraft\_Cork\_Landing\_k}$ = Shannon

P1 -P8 $_{Aircraft\ Cork\ Landing\_k}$ = *P6*

SA of Remote Tower System about Airport Cork

Name $_{Airport\_Cork}$ = Cork
Runway/taxiway layout $_{Airport\_Cork}$ is not modelled

Open/Closed = Open

SA of Pilot Shannon Landing_k about Airport Shannon

Name $_{Airport\_Shannon}$ = Shannon
Runway/taxiway layout $_{Airport\_Shannon}$ is not modelled

Open/Closed = Open

refresh rate in seconds

t_G =1

16. IPN „ Frequency Cork “

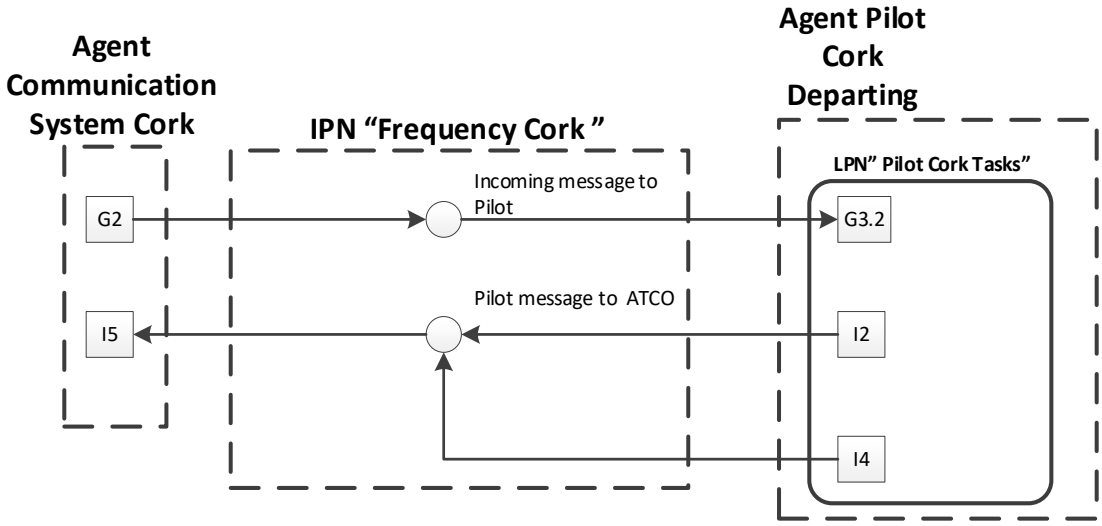


Figure E-25: IPN Frequency Cork

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from other agents

- Incoming arc from transition G2 in agent “Communication System Cork” to place *Incoming Message to Pilot.*
- Two incoming arcs from transitions I2 and I4 of LPN “Pilot Cork Tasks” of agent “Pilot Cork Departing_k” to place *Pilot message to ATCO.*

Outgoing arc to other agents

- Outgoing arc from place *Incoming Message to Pilot* to transition I3.2 in LPN” Pilot Cork Tasks” of agent “Pilot Cork Departing_k”.
- Outgoing arc from place *Pilot message to ATCO* to transition I5 of agent “Communication System Cork”.

Places

Places	Colour type	Explanation	Colour function
Pilot message to ATCO	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO	None

Incoming Message to Pilot	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None

Transitions

There are no transitions present.

Initial markings

There are no tokens initially present.

17. IPN „Frequency Shannon “

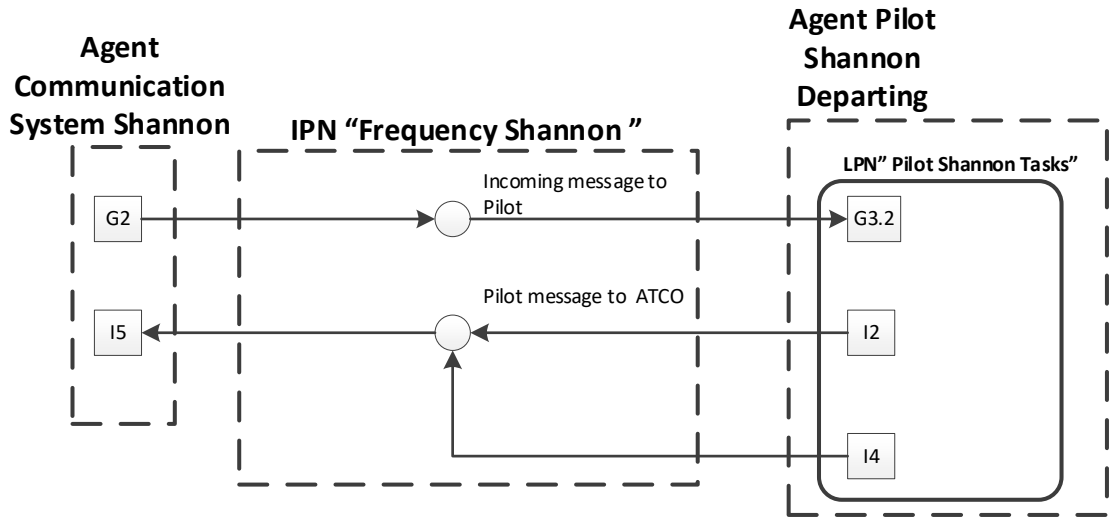


Figure E-26: IPN Frequency Shannon

Incoming arcs within same agent

- No incoming arcs.

Outgoing arcs within same agent

- No outgoing arcs.

Incoming arcs from other agents

- Incoming arc from transition G2 in agent “Communication System Shannon” to place *Incoming Message to Pilot.*
- Two incoming arcs from transitions I2 and I4 of LPN “Pilot Shannon Tasks” of agent “Pilot Shannon_k” to place *Pilot message to ATCO.*

Outgoing arc to other agents

- Outgoing arc from place *Incoming Message to Pilot* to transition I3.2 in LPN” Pilot Shannon Tasks” of agent “Pilot Shannon_k”.
- Outgoing arc from place *Pilot message to ATCO* to transition I5 of agent “Communication System Shannon”.

Places

Places	Colour type	Explanation	Colour function
Pilot message to ATCO	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	None
	$PILOT_{message} \in \{0,1,2,3\}$	Intent of Pilot 0= “Pilot confirms hold” 1= “Pilot requesting to line up and depart” 2= “Pilot confirms line up clearance” 3=” Pilot questions ATCO”	None
	$ATCO_{aid} \in \mathbb{R}$	Aircraft ID returned by ATCO	None

Incoming Message to Pilot	$ATCO_{message} \in \{1,2\}$	Message from ATCO 1= “Line up clearance” 2= “Hold message”	None

Transitions

There are no transitions present.

Initial markings

There are no tokens initially present.

18. List of model parameters, estimations and initial values

For each MC Simulation, each agent will be initiated with a list of parameters as per the table below. Note this list was built in consultation SMEs from each of the airports.

Table E-2: Parameter values used for the simulated scenario

Agent	Parameter	Description	Estimation/Initial values
Pilot Cork Departing	$t_{G1} \in \mathbb{R}$	Pilot time delay to request line up clearance from ATCO.	Sample ≥ 0 from Gaussian distribution with: Mean=5 s Std Dev=1 s
	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	Scenarios will be defined with aircraft ID being very similar, similar and totally different than the one at the other airport.
	$P(PILOT_{student}) \in \mathbb{R}$	Probability that the pilot is a student or experienced.	The MC simulation is only considering the experienced pilots. $P(PILOT_{student})=0$
	$t_{RRG3} \in \mathbb{R}$	Time to repeat request by pilot.	If fired by I2: Sample ≥ 0 from Gaussian distribution with: Mean=30 s Std Dev=5 s If fired by G5.2.: Sample ≥ 0 from Gaussian distribution with: Mean=60 s Std Dev=5 s
	$t_{G5.1} \in \mathbb{R}$	Time it takes the aircraft to start and enter the runway from the moment of receiving clearance.	Sample ≥ 0 from Gaussian distribution with: Mean=3 s Std Dev=1 s
	P (Callsign confusion by pilot|callsigns are very similar) $\in \mathbb{R}$ P (Callsign confusion by pilot|callsigns are similar) $\in \mathbb{R}$ P (Callsign confusion by pilot|callsigns are	Conditional probability of callsign confusion by pilot given callsigns are very similar, similar or totally different.	If callsigns of the aircraft are: - P (Callsign confusion by pilot|callsigns are very similar): 1 in 300 *(hard coded value)* - P (Callsign confusion by pilot|callsigns are similar): 1 in 500 *(hard coded value)* - P (Callsign confusion by pilot|callsigns are totally different: 1 in

	totally different∈ $\mathbb{R}$		5000 *(hard coded value)*
Pilot Shannon_k	$t_{G1} \in \mathbb{R}$	Pilot time delay to request line up clearance from ATCO.	Sample ≥ 0 from Gaussian distribution with: Mean=5 s Std Dev=1 s
	$PILOT_{aid} \in \mathbb{R}$	Initial callsign of aircraft and known to pilot.	Scenarios will be defined with aircraft ID being very similar, similar and totally different than the one at the other airport.
	P ($PILOT_{student}$) ∈ $\mathbb{R}$	Probability that the pilot is a student or experienced.	The MC simulation is only considering the experienced pilots. P ($PILOT_{student}$)=0
	$t_{RRG3} \in \mathbb{R}$	Time to repeat request by pilot.	If fired by I2: Sample ≥ 0 from Gaussian distribution with: Mean=30 s Std Dev=5 s If fired by G5.2.: Sample ≥ 0 from Gaussian distribution with: Mean=60 s Std Dev=5 s
	$t_{G5.1} \in \mathbb{R}$	Time it takes the aircraft to start and enter the runway from the moment of receiving clearance.	Sample ≥ 0 from Gaussian distribution with: Mean=3 s Std Dev=1 s
	P (Callsign confusion by pilot|callsigns are very similar) ∈ $\mathbb{R}$ P (Callsign confusion by pilot|callsigns are similar) ∈ $\mathbb{R}$ P (Callsign confusion by pilot|callsigns are totally different∈ $\mathbb{R}$	Conditional probability of callsign confusion by pilot given callsigns are very similar, similar or totally different.	If callsigns of the aircraft are: - P (Callsign confusion by pilot|callsigns are very similar): 1 in 300 *(hard coded value)* - P (Callsign confusion by pilot|callsigns are similar): 1 in 500 *(hard coded value)* - P (Callsign confusion by pilot|callsigns are totally different: 1 in 5000 *(hard coded value)*
Agent Communication System Cork	$t_{commsystem3rdpartyfree} \in \mathbb{R}$	Duration of communication system being free from 3rd party communication.	Sample ≥ 0 from Gaussian distribution with: Mean=30 s

		When $t_{commsystem3rdpartyfree} \leq 0$, a 3rd party communication occurs on the communication system.	Std Dev=10 s
	$t_{commsystemoccup} \in \mathbb{R}$	Duration of the transmission of communication system.	Sample ≥ 0 from Gaussian distribution with: Mean= 5 s Std Dev=2 s
Agent Communication System Shannon	$t_{commsystem3rdpartyfree} \in \mathbb{R}$	Duration of communication system being free from 3rd party communication. When $t_{commsystem3rdpartyfree} \leq 0$, a 3rd party communication occurs on the communication system.	Sample ≥ 0 from Gaussian distribution with: Mean=30 s Std Dev=10 s
	$t_{commsystemoccup} \in \mathbb{R}$	Duration of the transmission of communication system.	Sample ≥ 0 from Gaussian distribution with: Mean= 5 s Std Dev=2 s
Agent ATCO	$t_{checkaerodromes} \in \mathbb{R}$	Time to check both aerodromes and deciding on course of action for aircraft.	Uniform distribution between 2 and 7 seconds.
	$t_{recheck} \in \mathbb{R}$	If no readback is received from the pilot, the ATCO will recheck the aerodromes to see what happened. This duration of the rechecking is $t_{recheck}$.	Uniform distribution between 20 and 30 seconds.
	P (wrong frequency) $\in \mathbb{R}$	Probability of selection of wrong frequency for ATCO.	Probability of ATCO selection of wrong frequency is estimated: 1 in 5000 *(hard coded value)*
	P (Callsign confusion by ATCO|callsigns are very similar) $\in \mathbb{R}$ P (Callsign confusion by ATCO|callsigns are similar) $\in \mathbb{R}$ P (Callsign confusion by ATCO|callsigns	Conditional probability of callsign confusion by ATCO given callsigns are very similar, similar or totally different.	If callsigns of the aircraft are: - P (Callsign confusion by ATCO|callsigns are very similar): 1 in 300 *(hard coded value)* - P (Callsign confusion by ATCO|callsigns are similar): 1 in 500 *(hard coded value)* - P (Callsign confusion by ATCO|callsigns are totally different: 1 in

	are totally different) ∈ ℝ		5000 *(hard coded value)*
	P (ATCO forgets about the aircraft landing) ∈ ℝ	Probability of ATCO forgetting about the aircraft landing.	Probability of ATCO forgetting about the aircraft landing: 1 in 5000 *(hard coded value)*
	P (ATCO wrong message|ATCO forgets about the aircraft landing) ∈ ℝ	Conditional probability of ATCO message to Pilot Cork Departing is wrong given the ATCO forgets about the aircraft landing.	Probabilities of wrong instruction due to ATCO forgetting about the landing aircraft: 100% *(hard coded value)* *If the ATCO forgets about the landing aircraft, then the ATCO thinks the runway is free and therefore clears aircraft Cork Departing_k to line up.*