Air traffic forecast and its impact on runway capacity. A System Dynamics approach

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11/28/2019

Agenda

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- Methodology
  - Approach and methodological references
  - Definition and structuring of the dynamic behavior of the system
  - Conceptual mapping of the model
  - Quantification of the model
- Results
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- References

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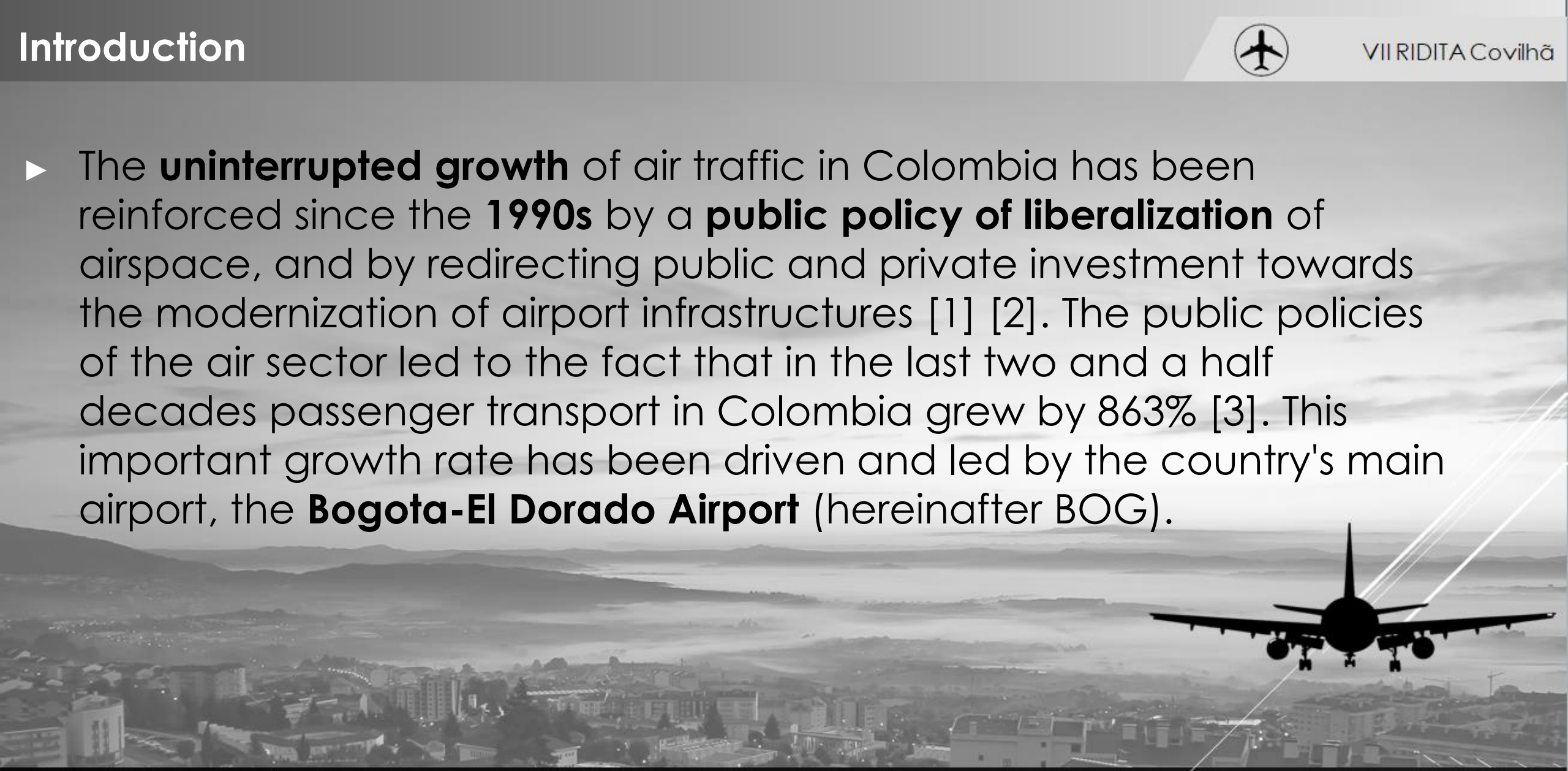
Introduction

- The **uninterrupted growth** of air traffic in Colombia has been reinforced since the **1990s** by a **public policy of liberalization** of airspace, and by redirecting public and private investment towards the modernization of airport infrastructures [1] [2]. The public policies of the air sector led to the fact that in the last two and a half decades passenger transport in Colombia grew by 863% [3]. This important growth rate has been driven and led by the country's main airport, the **Bogota-El Dorado Airport** (hereinafter BOG).



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Introduction

- Some technical reports **estimate that the airport will reach its maximum capacity in the short term** mainly because of its inability to expand its flight field (currently two runways) [4]. Due to this circumstance, **the aeronautical public authority of Colombia gave direction to the planning, design and construction of a new airport** (complementary) to the outskirts of the city of Bogotá, which is estimated to enter into operations in 2025/2026 [5].

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Introduction

- The development of a **traffic forecast** for BOG in the short term and to **evaluate the impact** of future demand **on the runway capacity** of the airport was proposed.
- Due to the **complexity of the forecast of air transport**, the use of the **System Dynamics** (hereinafter SD) approach is founded appropriate for the investigation
- **With SD** it is possible to **develop a model** to forecast the demand of operations on runway and evaluate its impact over the capacity of the BOG runway.
- In accordance with the **principles of SD**, a **better understanding** of the behavior of the system is achieved.
- The data for the investigation are obtained from the aeronautical public authority of Colombia (hereinafter Aerocivil).

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Methodology

- The use of Systems Dynamics, in the modeling and simulation of complex systems, implies the execution of a set of tasks that are synthesized here:

Activity	Method	Product
Definition and structuring of the dynamic behavior of the system	It focuses on the definition and elaboration of a system mapping that involves the following elements: -Limits of the model -Subsystems -Causality structures -Flows and levels	Conceptual mapping
Quantification of the model	The quantification implies: -Definition of decision rules that govern the system. -Estimation of parameters, correlations and initial conditions. -Execution of consistency tests	Quantified model
Simulation	Simulation and analysis of the behavior of response variables	Results of the simulation and its analysis

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Methodology

- **SD** incorporates a **set of tools** that allow the **understanding** of **complex** environments; tools such as **causality diagrams**, that encourage **systemic thinking** among managers of processes, capture the **dynamic complexity** of a given system and provide the considerable advantage of simulating the model to evaluate the interaction results and thus **anticipate the effects long-term** collateral policies before its implementation [7].
- The **use of the runway depends on** the **demand of flights** that are affected by **external and internal factors**. The demand for air transport tends to evolve based on changes in prices and economic conditions. There are **several factors** that affect the demand for air travel, which are basically **socio-economic and demographic** [9].

Methodology:
Definition and structuring of the dynamic behavior of the system

- The analysis was focused on the **impact of demand forecasts on the management of the runway capacity** of the terminal area, so it was decided to work the forecast directly in terms of **demand for landings and take-offs** (flights), for which data and statistics were taken from the Aerocivil [10], the socio-economic data was obtained from the Bank of the Republic of Colombia [11] and DANE [12].
- Initially, we started **with a set of variables** (both response and input), which are considered to be **typically relevant for air traffic forecast**, thus, a preliminary analysis consisted in **determining the correlation** between these variables, obtaining the results shown next.

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Methodology:
Definition and structuring of the dynamic behavior of the system

Correlation indexes between preliminary variables

	Flights	Year	Month	GDP	GDP per capita	population	IPI	Total exports	Total imports	CPI	Exchange rate
Flights	1,00										
Year	0,93	1,00									
Month	0,09	0,00	1,00								
GDP	0,91	0,99	0,00	1,00							
GDP per capita	0,91	0,99	0,00	1,00	1,00						
population	0,92	1,00	0,00	0,99	0,99	1,00					
IPI	0,85	0,93	0,00	0,91	0,92	0,94	1,00				
Total exports	0,82	0,76	0,00	0,70	0,72	0,76	0,78	1,00			
Total imports	0,91	0,88	0,00	0,84	0,85	0,88	0,86	0,96	1,00		
CPI	0,90	1,00	0,00	0,99	1,00	1,00	0,94	0,73	0,84	1,00	
Exchange rate (USD to COP)	0,06	0,17	0,00	0,25	0,22	0,17	-0,01	-0,41	-0,17	0,20	1,00

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Methodology:
Definition and structuring of the dynamic behavior of the system

Socio-economic indicators to be included in the model

Indicators
GDP per capita
population
Total exports
Total imports
Consumer price index (CPI)
Exchange rate (USD to COP)

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Methodology:
Definition and structuring of the dynamic behavior of the system

Variables and parameters of the model

Variable / Parameter	Type	Observations / source
Runway capacity	Parameter	Historical data
Year	Auxiliary	Counts the years of operation that are being simulated
Flights/month	Auxiliary	Equation of the model, built from historical data
Runway capacity utilization (%)	Auxiliary	Equation of the model
GDP per capita	Auxiliary	Equation of the model, built from historical data
Total exports	Auxiliary	Equation of the model, built from historical data
Total imports	Auxiliary	Equation of the model, built from historical data
Consumer price index (CPI)	Auxiliary	Equation of the model, built from historical data
Exchange rate (USD to COP)	Auxiliary	Equation of the model, built from historical data
Average capacity per runway	Parameter	Historical data
Existing runways	Parameter	Historical data
Required runways factor	Auxiliary	Equation of the model
Increase in required runways	Flow	Equation of the model
Additional runways required	Level	Equation of the model
Total required runways	Auxiliary	Equation of the model

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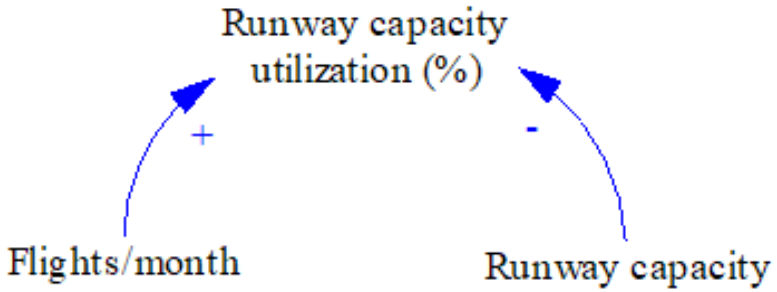
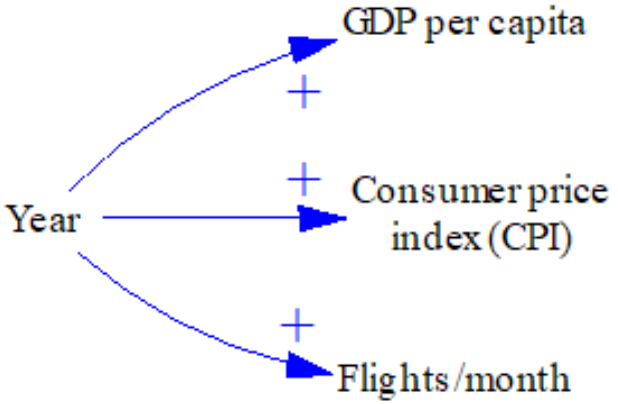
Methodology:
Conceptual mapping of the model

Representation of some relationships and model feedback cycles

Type of relationship	Graphic representation
This fraction of the model indicates that as the number of flights increases, the runway utilization increase. And an increase in runway capacity would means a decrease in runway utilization.	
Here the influence of the passage of time (year), on variables such as the CPI, GDP per capita and the demand for operations is represented; which is incremental for all these cases	

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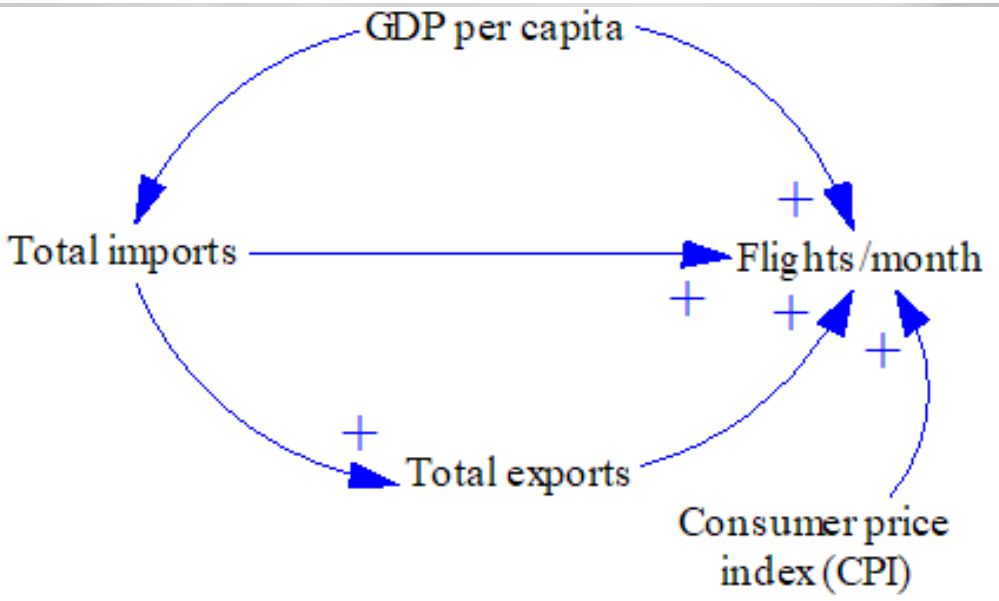
Methodology:
Conceptual mapping of the model

Representation of some relationships and model feedback cycles

Type of relationship	Graphic representation
This fraction of the conceptual map emphasizes on the variables that impact the flights per month. It is shown that an increase in any of the related variables would lead to an increase in the number of flights	

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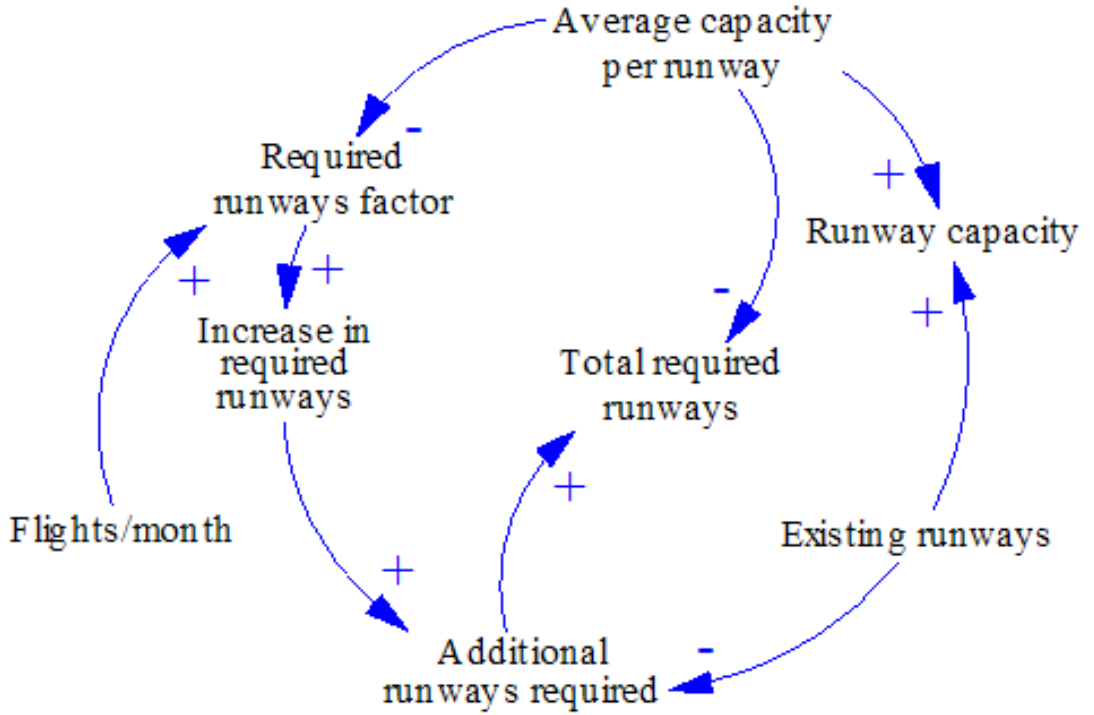
Methodology:
Conceptual mapping of the model

Representation of some relationships and model feedback cycles

Type of relationship	Graphic representation
Finally are shown causality relationships such as: If current the existing runways increases, the amount of additional runways required will decrease. If the average capacity per runway increases, the required runways factor will decrease. Other relations can be observed in the graphic.	

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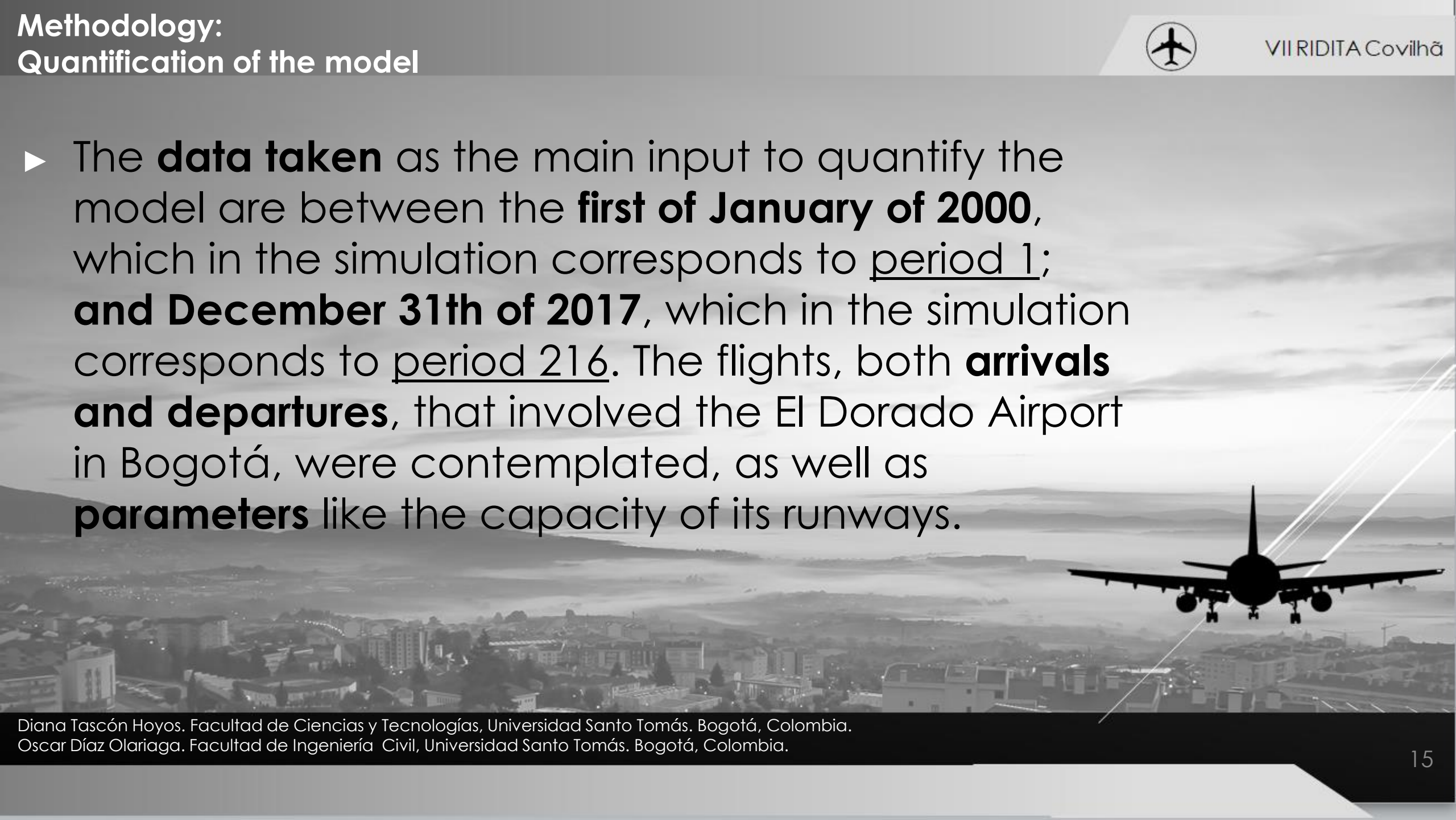
Methodology: Quantification of the model

- The **data taken** as the main input to quantify the model are between the **first of January of 2000**, which in the simulation corresponds to period 1; **and December 31th of 2017**, which in the simulation corresponds to period 216. The flights, both **arrivals and departures**, that involved the El Dorado Airport in Bogotá, were contemplated, as well as **parameters** like the capacity of its runways.



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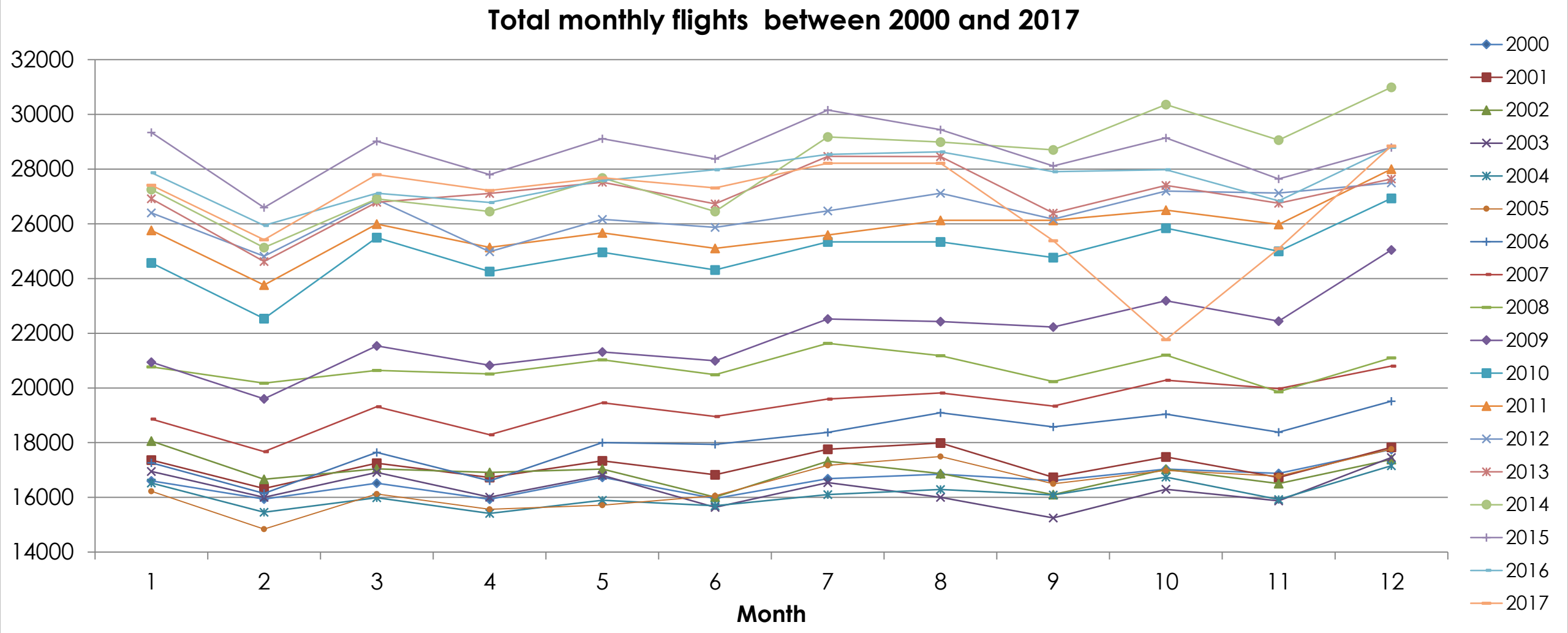
Methodology: Quantification of the model

- The **runway capacity** data comes from **Aerocivil** [13], and corresponds to the operating capacity averages given in annual terms and taken for convenience of the model to their monthly equivalences. In order to forecast the behavior of the demand for operations, **monthly data is available from January 2000 to December 2017**. The behavior of the total execution of monthly operations for the referenced year is reflected next

Methodology:
Quantification of the model



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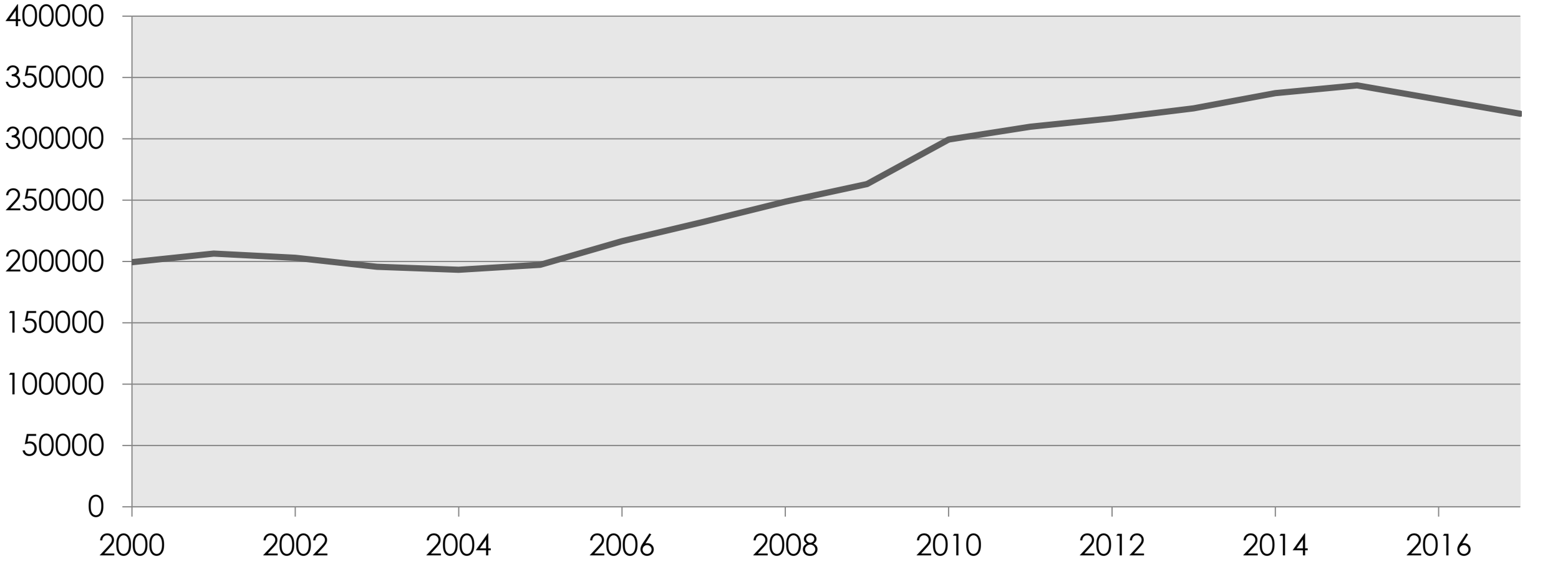
Methodology:
Quantification of the model



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Methodology: Quantification of the model

- By using **data analysis** and in several cases **linear regressions**, the **relationships between** variables and the **equations** that described them were established. **The quantified model was simulated** by using Vensim, software for SD. The flows and levels diagram related with the quantified model is shown in the next illustration

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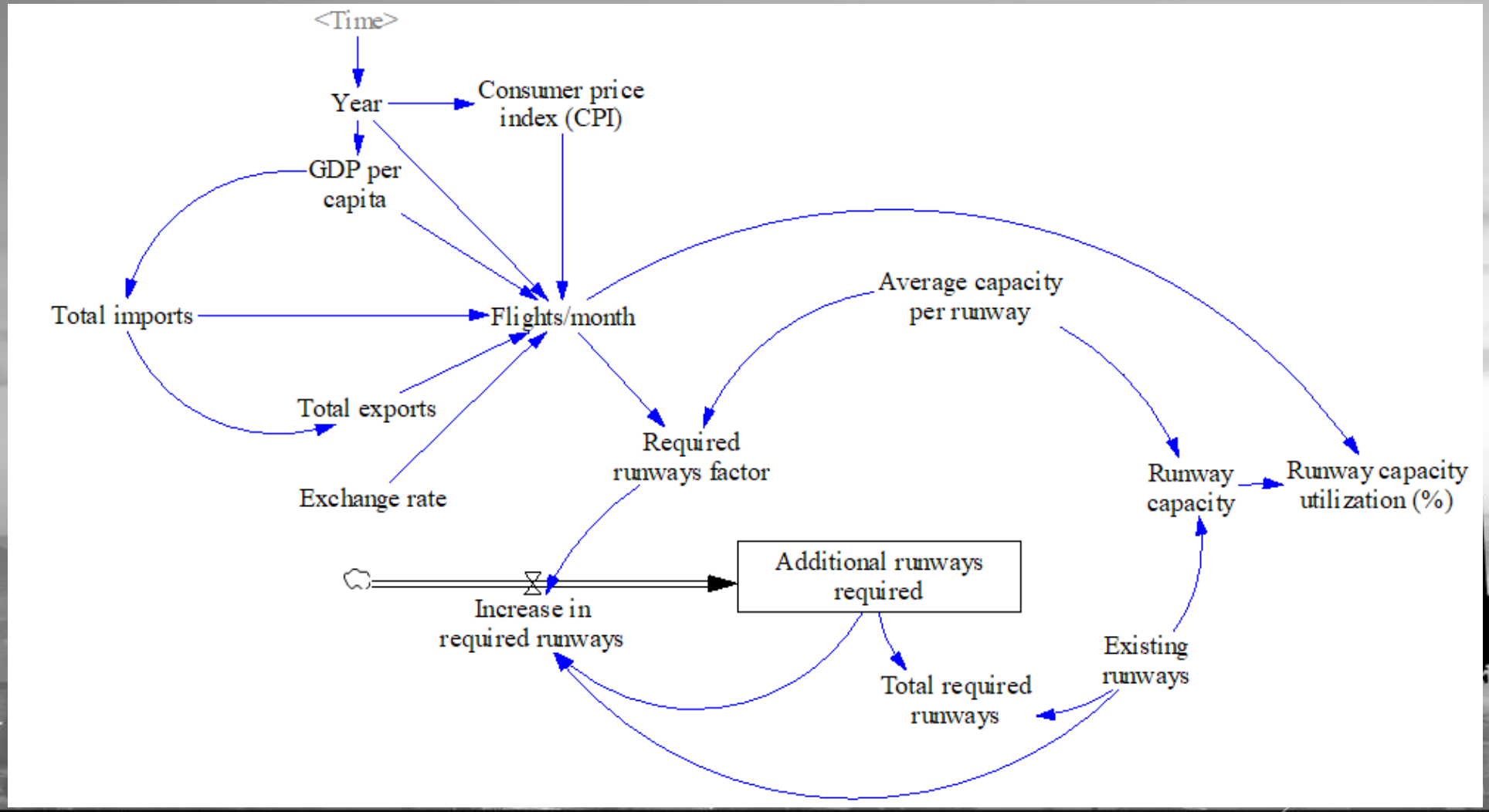
Methodology: Quantification of the model

Flows and levels diagram



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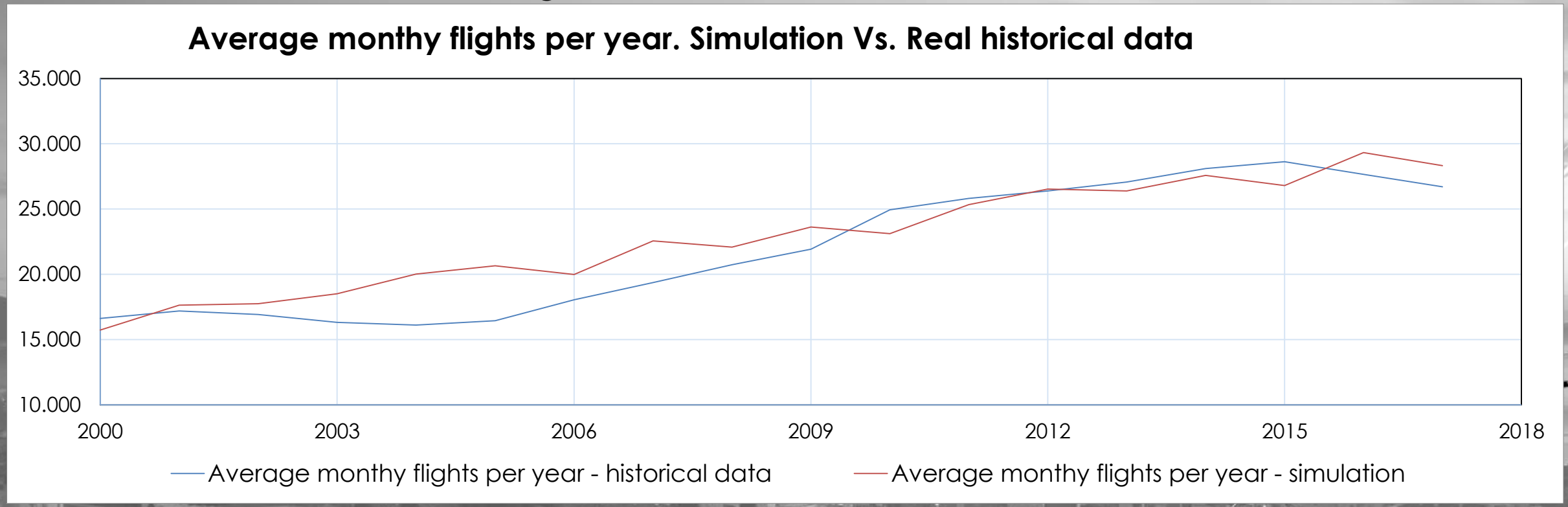
Results

- To evaluate the **performance** of the model with respect to the historical data behavior, a simulation, for the period between January 2000 and December 2017, was run. The average of monthly flights per year for both, the historical available data and the simulation is shown in next figure.



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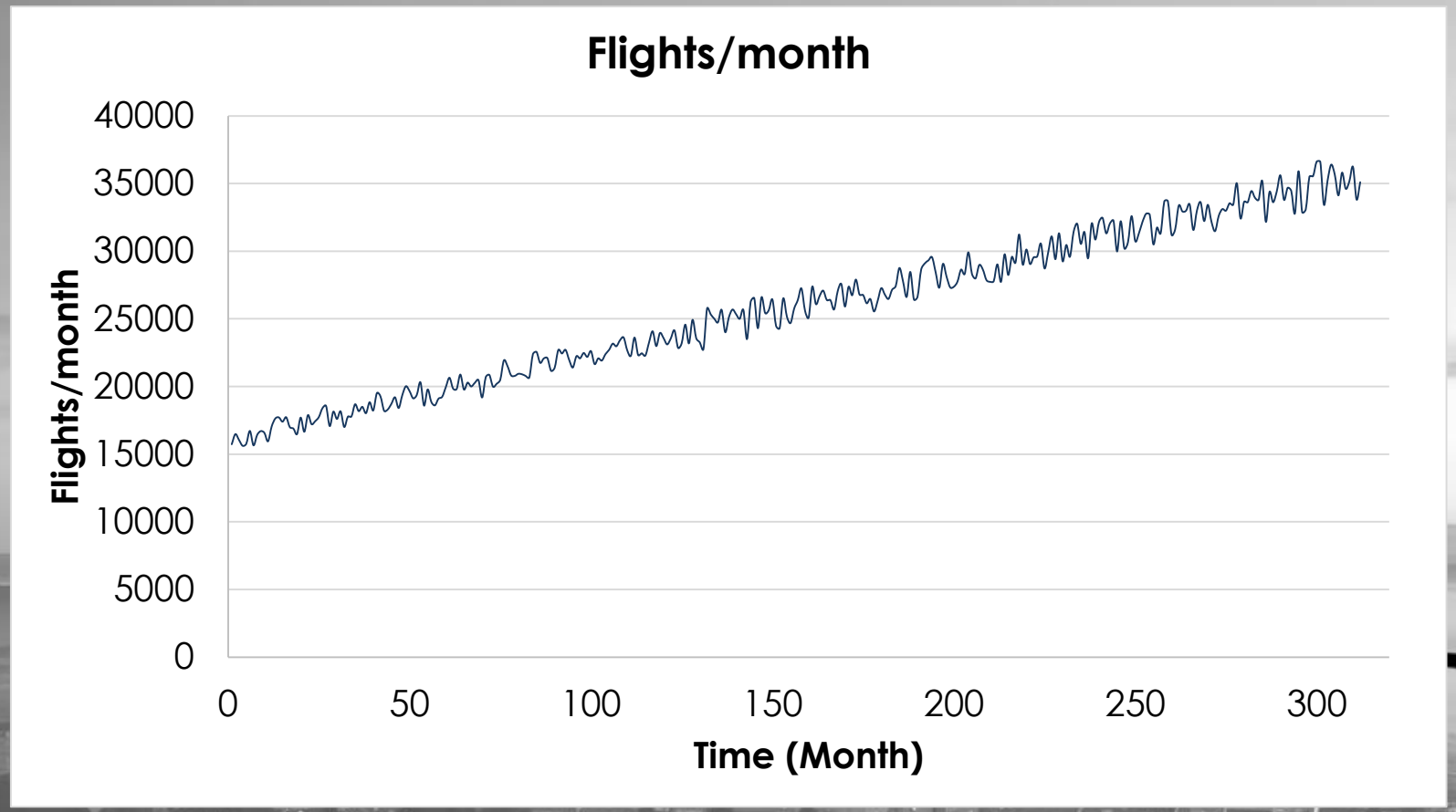
Results

Number of flights per month. Simulation between 2000 and 2023



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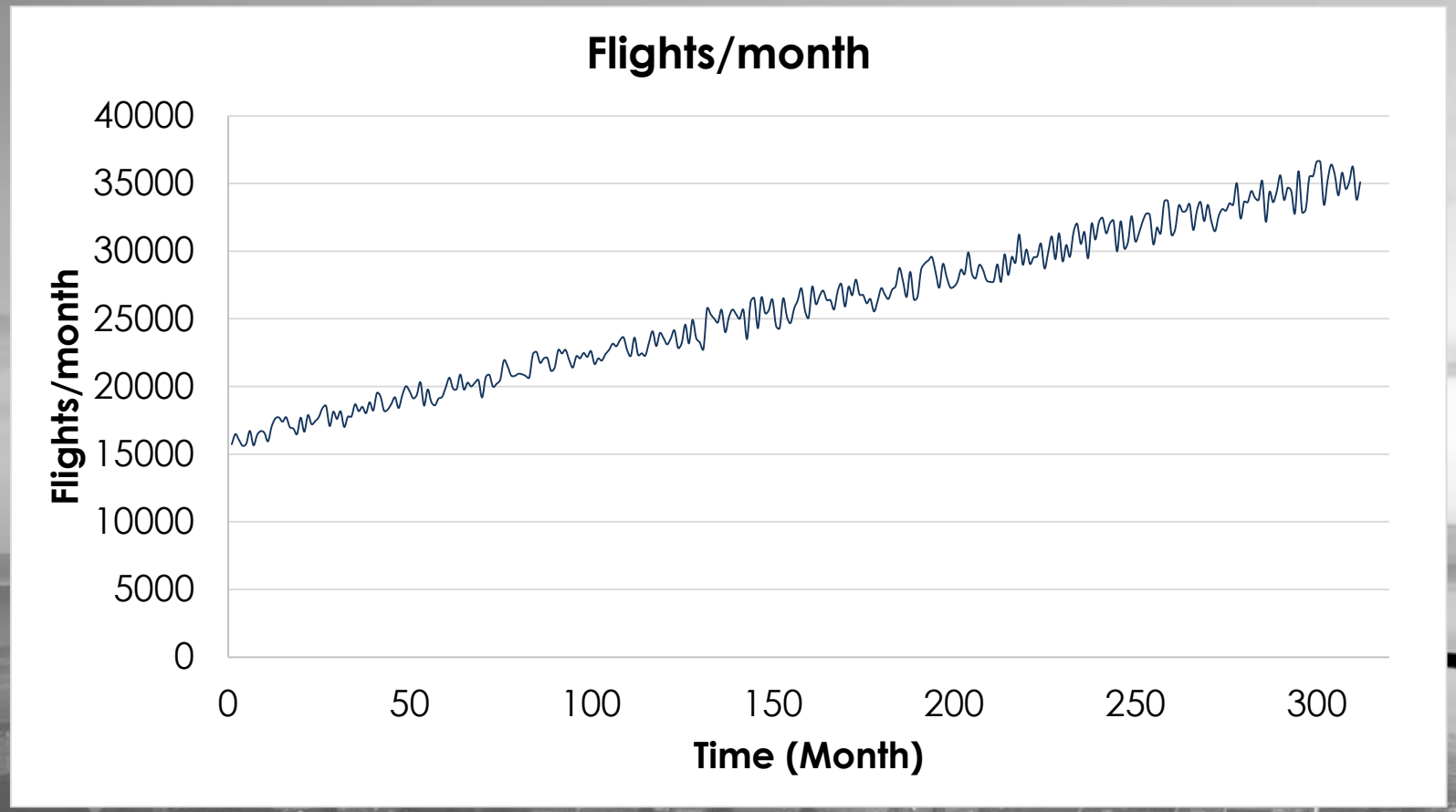
Results

Number of flights per month. Simulation between 2000 and 2023



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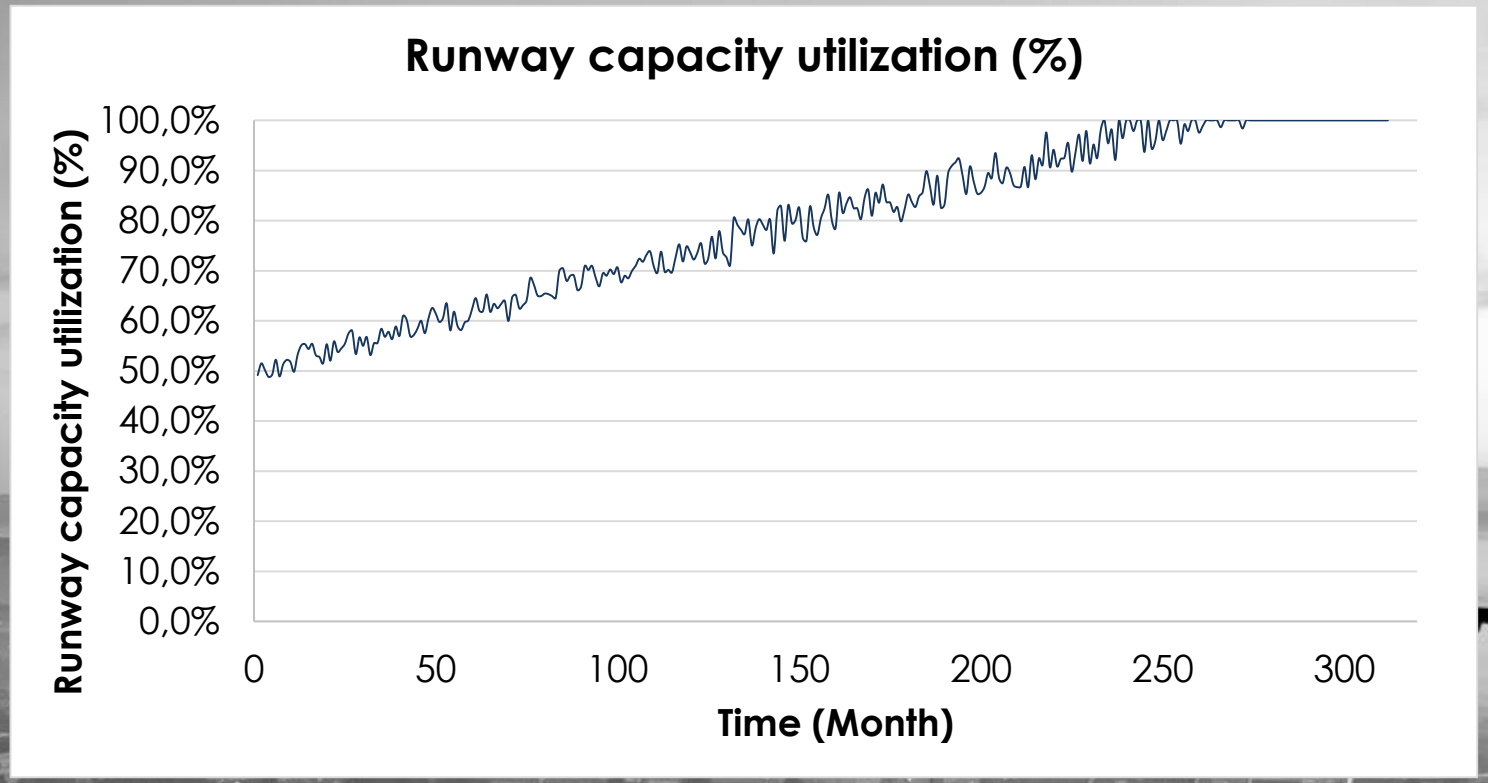
Results

Runway utilization (%). Simulation between 2000 and 2023



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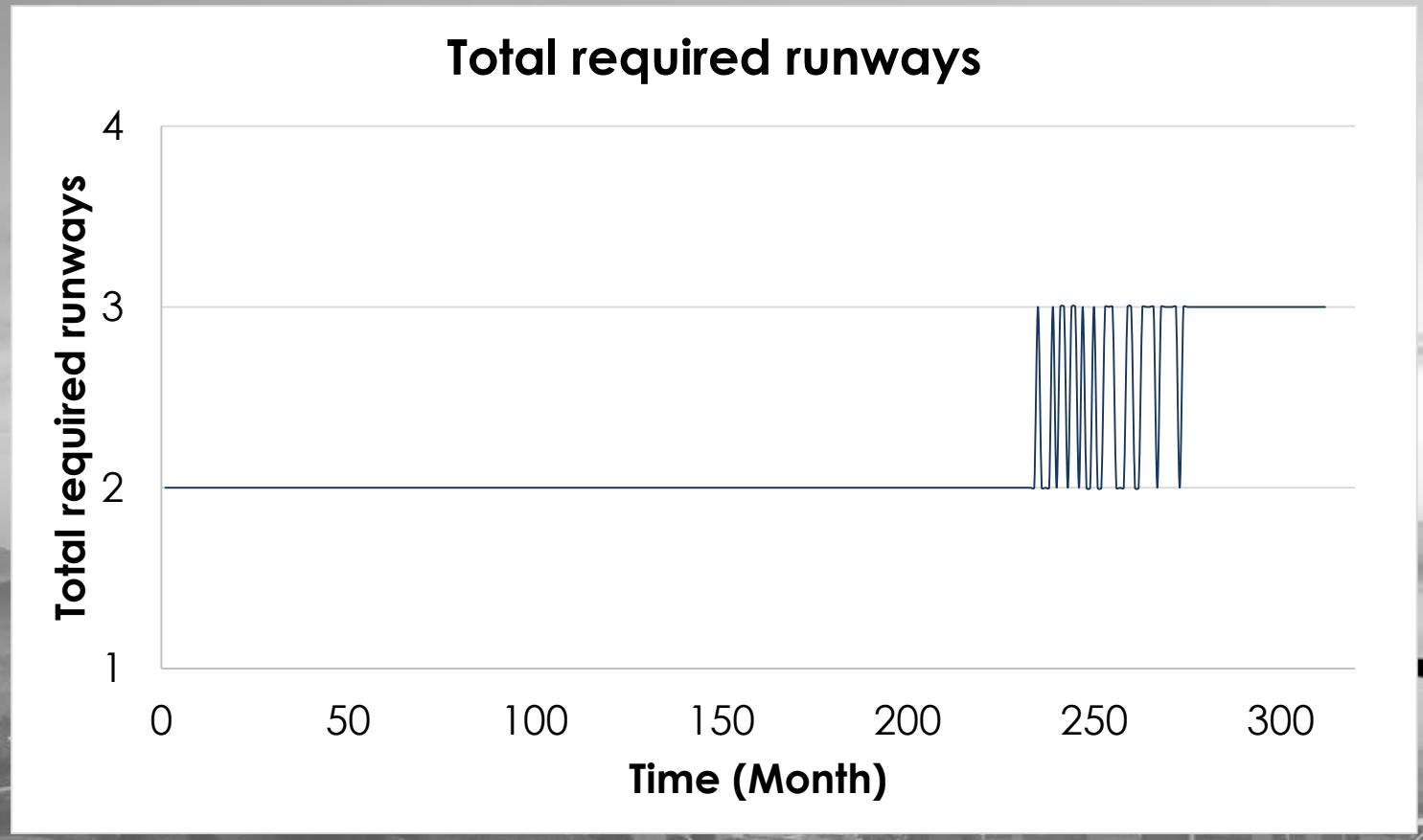
Results

Simulation of total required runways from 2000 to 2030



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Conclusions

- Through the use of a **Systems Dynamics** model it has been **possible** to **analyze the behavior of the demand for runway** operations (flights), associated with air transport in a high growth liberalized market.
- The simulation gives evidence of a **need to expand the airport** case study after mid-2019, where the current capacity utilization factor is around 100% and two to three runways will be required for the normal operation; after October 2022, the number runways required is set to three until the last period simulated, which corresponds to December 2023.

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References

[1] Díaz Olariaga, O. (2017). Políticas de privatización de aeropuertos. El caso de Colombia. Documentos y Aportes en Administración Pública y Gestión Estatal, 29, 7-35.

[2] Díaz Olariaga, O. (2016). Análisis del desarrollo reciente del transporte aéreo en Colombia. Revista Transporte y Territorio, 14, 122-143.

[3] Díaz Olariaga, O. (2018). Prognosis de tráfico aéreo en contexto de post-liberalización del transporte aéreo. El caso de Colombia. Working Paper. doi: 10.13140/RG.2.2.11443.73760

[4] Aerocivil (2016). Análisis técnico de la viabilidad operacional y elaboración del plan maestro aeroportuario para el proyecto de infraestructura El Dorado II. Bogotá: Aeronáutica Civil de Colombia.

[5] ANI (2018). Factibilidad y Estructuración - APP Aeropuerto El Dorado II. Bogotá: Agencia Nacional de Infraestructura.

[6] Suryan, E.; Chou, S.; Chen, C. (2010). Air passenger demand forecasting and passenger terminal capacity expansion: A system dynamics framework. *Expert Systems with* Applications, 37(3), 2324-2339

References

[7] J. D., Sterman (2000). *Business Dynamics, Systems thinking and modeling for a complex word*. Boston: Irwin McGraw-Hill.

[8] Tascón Hoyos, D. (2017). Modelo Dinámico para Contrastar el Desempeño Ambiental, Social y Económico de Estrategias para la Gestión de Residuos de Construcción y Demolición en Bogotá D.C. http://hdl.handle.net/11349/6318

[9] Suryan, E.; Chou, S.; Chen, C. (2012). Dynamic simulation model of air cargo demand forecast and terminal capacity planning. *Simulation Modelling Practice and Theory*, 28, 27-41.

[10] Aerocivil (2019). Estadísticas de transporte aéreo. http://www.aerocivil.gov.co

[11] Banco de la República de Colombia (2019). Estadísticas. http://www.banrep.gov.co/es/-estadisticas

[12] DANE (2019). Estadísticas por tema. https://www.dane.gov.co/index.php/estadisticas-por-tema

[13] Aerocivil (2014). *Actualización del Plan Maestro del Aeropuerto Internacional El Dorado*. Bogotá: Aeronáutica Civil de Colombia.

[14] Aerocivil (2019). *Declaración de Capacidad Aeropuerto Eldorado*. Bogotá: Aeronáutica Civil de Colombia.

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