Maternity Service Capacity - Model, Simulation & Analysis

CONTENTS

Objective 1 - Model current Maternity Service activity using process mapping and queuing network analysis

1.1. RAW DATA MANIPULATION & VARIABILITY ANALYSIS

Aim: Convert the raw data from the extracted hospital data into a form that can be analysed.\ Analysis how different events vary the three critical inputs for the mathematical model;

- Inter-arrival Time,
- Length of Stay, and
- Patient Flow Probability

IMPORT PROJECT LIBRARIES

In [2]:
```
import pandas as pd
import datetime
import time
import os
#import dash  # USE THIS IF RUNNING ON SERVER
import dash_core_components as dcc
import dash_html_components as html
from dash.dependencies import Input, Output
import plotly.express as px
#import plotly.io as pio
import plotly.graph_objects as go
from plotly.subplots import make_subplots
from jupyter_dash import JupyterDash # USE THIS IF RUNNING ON JUPYTER
import numpy as np
import math
```

CONVERSION OF EVENTS INTO LIKE GROUPINGS

Based on results of variability analysis events that have the same profile for the three mathematical models are grouped together.\ Grouping like factors together improves the accuracy of the model by providing more historical data points

In [3]:
```
##### CONVERSION FACTORS BASED ON FINDINGS FROM VARIABILITY ANALYSIS
timeconv = {'Admission_Period':['Planned','Unplanned','Unplanned','Unplanne
                                'Planned','Planned','Planned','Unplanned',
                                'Unplanned','Unplanned','Unplanned','Unplar
                                'Planned','Planned','Planned','Planned','Pl
            'Hour_of_Day': [0,1,2,3,4,5,
                            6,7,8,9,10,11,
                            12,13,14,15,16,17,
                            18,19,20,21,22,23]}


dayconv = {'Day_Type':['Weekday','Weekday','Weekday','Weekday','Weekday','W
           'Day': [0,1,2,3,4,5,6]}


event_activity = {'Event_Activity':['High','High','High','Low','Normal','No
                  'Event':['AFTERXMAS','B4EASTER','BEFOREXMAS','EASTER','NO
                  'Event_Significance':[3,3,3,1,3,3,1,2]
                 }
```

In [4]:
```
timeconv_df = pd.DataFrame.from_dict(timeconv)
timeconv_df
```

Out[4]:

	Admission_Period	Hour_of_Day
0	Planned	0
1	Unplanned	1
2	Unplanned	2
3	Unplanned	3
4	Unplanned	4
5	Planned	5
6	Planned	6
7	Planned	7
8	Planned	8
9	Unplanned	9
10	Unplanned	10
11	Unplanned	11
12	Unplanned	12
13	Unplanned	13
14	Unplanned	14
15	Unplanned	15
16	Unplanned	16
17	Planned	17
18	Planned	18
19	Planned	19
20	Planned	20
21	Planned	21
22	Planned	22
23	Planned	23

In [5]:
```
dayconv_df = pd.DataFrame.from_dict(dayconv)
dayconv_df
```

Out[5]:

	Day_Type	Day
0	Weekday	0
1	Weekday	1
2	Weekday	2
3	Weekday	3
4	Weekday	4
5	Weekend	5
6	Weekend	6

In [6]:
```
event_activity_df = pd.DataFrame.from_dict(event_activity)
event_activity_df
```

Out[6]:

	Event_Activity	Event	Event_Significance
0	High	AFTERXMAS	3
1	High	B4EASTER	3
2	High	BEFOREXMAS	3
3	Low	EASTER	1
4	Normal	NONE	3
5	Normal	SCHOOL	3
6	Low	XMAS	1
7	Low	PUBLIC	2

FUNCTIONS FOR DATA MANIPULATION

In [7]:
```
def clean_transfers_data():
    ##### CLEAN TRANSFERS DATA
    df = pd.read_csv('transfers.csv')
    df = df.rename(columns = {'Start_Bed_Dttm':'Start', 'End_Bed_Dttm':'End
    df = df.drop(columns=['Transfers', 'Bed_Code', 'Full Flow Code', 'Curre
    date_cols = ['Start', 'End']
    df[date_cols] = df[date_cols].apply(pd.to_datetime, format='%d/%m/%y %H
    return df

def clean_events_data():
    ###### CLEAN EVENTS AND PUBLIC HOLIDAY DATA
    df = pd.read_csv('exception_dates.csv')
    df = df.rename(columns = {'DATE':'Date', 'EVENT':'Event'})
    df['Date'] = df['Date'].apply(pd.to_datetime, format='%d/%m/%Y', errors
    df['Date'] = df['Date'].dt.date
    df = pd.merge(df, event_activity_df, how='left', on='Event')
    df = df.sort_values(['Date', 'Event_Significance'], ascending = True)
    df = df.groupby(['Date']).first().reset_index()
    df = df.drop(columns=['Event_Significance'])
```

```
    return df

def drop_records(df):
    ###### DROPS WARD CODES DPS AND ON FROM THE ANALYSIS
    index_names = df.loc[(df.Ward_Code == 'DPS') | (df.Ward_Code == 'ON')
    df = df.drop(index_names)
    return df

def add_next_ward(df):
    ##### ADDS A COLUMN TO THE DATA TABLE THAT SHOWS WHICH WARD THE PATIEN
    df = df.sort_values(['Link', 'Start'])
    df['Next_Ward'] = np.where(df.Link == df.Link.shift(-1), df.Ward_Code.s
                               np.where(df.Ward_Code != 'OUT', 'OUT','NONE'
    return df

def add_out_transfer(df):
    ###### ADDS RECORD IN ROW IN RECORD TO SHOW WHENT THE PATIENT LEAVES T
    df  = df.loc[df.Next_Ward == 'OUT',:].copy()
    df['Start'] = df['End']
    df['Ward_Code'] = 'OUT'
    df['Next_Ward'] = 'NONE'
    return df

def add_hierarical_data(df):
    ####### ADD HIERARICAL DATA TO THE DATASET
    #DAY OF THE WEEK
    df = df.dropna(subset=['Start'])
    df = df.copy()
    df['Day'] = df.Start.dt.weekday
    df = pd.merge(df, dayconv_df, how='left', on='Day')
    #MONTH NAME
    df['Month'] = df.Start.dt.month_name()
    #YEAR
    df['Year'] = df.Start.dt.year
    #HOUR OF DAY
    df['Hour_of_Day'] = df.Start.dt.hour
    df = pd.merge(df, timeconv_df, how='left', on='Hour_of_Day')
    df.drop(columns='Hour_of_Day')
    #DATE WITHOUT TIME
    df['Date'] = df.Start.dt.date
    return df

def add_events_data(df):
    ### ADD EVENTS TO DATASET
    df = pd.merge(df, events_df, how='left', on='Date')
    df['Event'] = df['Event'].fillna('NONE')
    df['Event_Activity'] = df['Event_Activity'].fillna('Normal')
    return df

def prev_flow(df, n):
    ##### ADD A CALCULATES WHERE THE PATIENT HAS BEEN PRIOR TO THE CURRENT
    for i in range(n, 0, -1):
        df.Prev_Flow = np.where(df.Link == df.Link.shift(i),
                                df.Prev_Flow + '-' + df.Ward_Code.shift(i),
    return df.Prev_Flow

def ideal_flow_conversion(df):
    ####### RENAME WARD_CODES THAT ARE NOT PART OF THE IDEAL PATH AND DELE
    #CA, CL & HE Codes are converted to MT
    df.loc[(df['Ward_Code'] == 'CA') | (df['Ward_Code'] == 'CL') | (df['Wa
    df.loc[(df['Next_Ward'] == 'CA') | (df['Next_Ward'] == 'CL') | (df['Ne
```

```
    # PATIENT PREVIOUS FLOW PATH
    df = df.sort_values(['Link', 'Start'])
    df['Prev_Flow'] = 'IN'
    df['Prev_Flow'] = prev_flow(df, 7)
    # REMOVE DUPLICATE ENTRIES CAUSED BY REPLACING WARD CODES WITH IDEAL WA
    duplicate_df = df.loc[(df.Ward_Code == df.Next_Ward)|(df.Ward_Code == c
    duplicate_grp_df = duplicate_df.groupby(['Link', 'Ward_Code'])
    #get the min start date and max end date from the grouped results
    df['min_start'] = duplicate_grp_df['Start'].transform('min')
    df['max_end'] = duplicate_grp_df['End'].transform('max')
    #Drop the Original start & end dates & rename the new calculated start
    df['Start'] = np.where(df.min_start.notnull(), df.min_start, df.Start)
    df['End'] = np.where(df.max_end.notnull(), df.max_end, df.End)
    df = df.sort_values(['Link', 'Start'], ascending = True)
    df= df.drop_duplicates(keep='first', subset=['Link', 'Ward_Code','Start
    df = df.drop(columns=['min_start', 'max_end'])
    df= df.dropna(subset=['Start'])
    return df

def add_analysis_info(df):
    ######## CALCULATE THE CRITICAL VARIABLES FOR COMPARISON ON THE SIMULA
    duration = df['End'] - df['Start']
    df['LOS'] = (duration.dt.days * 24) + (duration.dt.seconds / (60*60)) #
    df['LOS'] = df['LOS'].round(2)
    # DETERMINE PREVIOUS PATIENT FLOW PATH
    #if ('Prev_Flow' in df.columns) == False:
    df = df.sort_values(['Sim_Name','Sim_No','Link', 'Start'])
    df['Prev_Flow'] = 'IN'
    df['Prev_Flow'] = prev_flow(df, 7)
    # SHOW ALL OF THE FLOW CODES FOR PATIENT
    df['Full_Flow_Code'] = 1
    df['Full_Flow_Code'] = df.groupby(['Sim_Name','Sim_No','Link'])['Ward_C
    df['Full_Flow_Code'] ='IN' + '-' + df.Full_Flow_Code
    #INTERARRIVAL TIME
    df = df.sort_values(['Sim_Name','Sim_No','Start'])
    temp_df = df.loc[df.Prev_Flow == 'IN', 'Start'] - df.loc[df.Prev_Flow =
    df['Int_Arrival'] = pd.to_numeric(temp_df.dt.days*24 + temp_df.dt.secon
    df['Int_Arrival'] = df.Int_Arrival.round(2)
    return df
```

UPDATE HISTORICAL DATA TABLE

Calculate the input variables; Inter-Arrival Time, Patient Flow Path and Length of Stay(LOS).\ Add event information that affect input variables, include; Year, Month, Holidays, Day of Week, Time of Day

In [8]:

```
base_df = clean_transfers_data()
events_df = clean_events_data()

orig_df = base_df.copy(deep=True)
orig_df = drop_records(orig_df)
orig_df = add_next_ward(orig_df)
orig_df = pd.concat([orig_df, add_out_transfer(orig_df)])
orig_df = add_hierarical_data(orig_df)
orig_df = add_events_data(orig_df)
orig_df['Sim_Name'] = 'orig_hist'
orig_df['Sim_No'] = 1
orig_df = add_analysis_info(orig_df)
orig_df
```

Out[8]:

	Link	Ward_Code	Start	End	Next_Ward	Day	Day_Type	Month	Year
1	ADE-271206	DS	2013-06-27 12:40:00	2013-06-28 10:20:00	MT	3	Weekday	June	2013
280	ADE-282775	MT	2013-06-27 16:00:00	2013-07-01 11:05:00	OUT	3	Weekday	June	2013
3	ADE-271551	MT	2013-06-27 23:54:00	2013-07-01 09:25:00	OUT	3	Weekday	June	2013
286	ADE-282886	MT	2013-06-28 06:30:00	2013-07-02 10:09:00	OUT	4	Weekday	June	2013
2	ADE-271206	MT	2013-06-28 10:20:00	2013-07-03 09:59:00	OUT	4	Weekday	June	2013
...	...	...	...	...	...	...	...	...	...
14657	ADE-501861	OUT	2020-07-29 10:57:00	2020-07-29 10:57:00	NONE	2	Weekday	July	2020
14756	ADE-506202	OUT	2020-07-29 15:58:00	2020-07-29 15:58:00	NONE	2	Weekday	July	2020
14738	ADE-505713	OUT	2020-07-30 09:52:00	2020-07-30 09:52:00	NONE	3	Weekday	July	2020
14633	ADE-501132	OUT	2020-07-31 10:04:00	2020-07-31 10:04:00	NONE	4	Weekday	July	2020
14631	ADE-501113	OUT	2020-08-01 10:01:00	2020-08-01 10:01:00	NONE	5	Weekend	August	2020

14802 rows × 20 columns

MODIFY HISTORICAL DATA TO THE IDEAL FLOW PATH

Convert non-ideal patient flow paths seen in the historical data to a path that the hospital is aiming to achieve to improve patient care and hosipital resourcing.

In [9]:
```
ideal_df = ideal_flow_conversion(orig_df.copy())
ideal_df = add_next_ward(ideal_df)
ideal_df['Sim_Name'] = 'ideal_hist'
ideal_df = add_analysis_info(ideal_df)
ideal_df
```

Out[9]:

	Link	Ward_Code	Start	End	Next_Ward	Day	Day_Type	Month	Year
1	ADE-271206	DS	2013-06-27 12:40:00	2013-06-28 10:20:00	MT	3	Weekday	June	2013
280	ADE-282775	MT	2013-06-27 16:00:00	2013-07-01 11:05:00	OUT	3	Weekday	June	2013
3	ADE-271551	MT	2013-06-27 23:54:00	2013-07-01 09:25:00	OUT	3	Weekday	June	2013
286	ADE-282886	MT	2013-06-28 06:30:00	2013-07-02 10:09:00	OUT	4	Weekday	June	2013
2	ADE-271206	MT	2013-06-28 10:20:00	2013-07-03 09:59:00	OUT	4	Weekday	June	2013
...	...	...	...	...	...	...	...	...	...
14657	ADE-501861	OUT	2020-07-29 10:57:00	2020-07-29 10:57:00	NONE	2	Weekday	July	2020
14756	ADE-506202	OUT	2020-07-29 15:58:00	2020-07-29 15:58:00	NONE	2	Weekday	July	2020
14738	ADE-505713	OUT	2020-07-30 09:52:00	2020-07-30 09:52:00	NONE	3	Weekday	July	2020
14633	ADE-501132	OUT	2020-07-31 10:04:00	2020-07-31 10:04:00	NONE	4	Weekday	July	2020
14631	ADE-501113	OUT	2020-08-01 10:01:00	2020-08-01 10:01:00	NONE	5	Weekend	August	2020

14315 rows × 20 columns

1.2 ESTABLISH INPUT PROFILES FOR MATHEMATICAL MODEL

CALCULATE SUMMARY TABLES

Convert input probability distributions into a mathematical model that can be used by the Monte Carlo Simulation

In [10]:

```
def interarrival_summary(df):
    ######## CREATE SUMMARY TABLE FOR INTERARRIVAL TIME
    df = df.loc[df.Int_Arrival.notnull(),:]
    df = df.drop(columns=['Link','Ward_Code','Day', 'Month','Year','Hour_o
    #create bins for all of counts
    df['Int_Arrival_Bins'] = pd.cut(x=df['Int_Arrival'], bins=[0,9,19,29,4
    #temp_df.Int_Arrival.max()  #used to find the biggest number
    df = df.groupby(['Event_Activity', 'Day_Type', 'Admission_Period','Int_
```

```
    df = df.reset_index()
    df['Total_Counts'] = df.groupby(['Event_Activity', 'Day_Type', 'Admiss
    df['Arrival_Probability'] = df.Int_Arrival / df.Total_Counts
    df['Arrival_Probability'] = df.groupby(['Event_Activity', 'Day_Type',
    df = df.dropna()
    df = df.drop(columns = ['Int_Arrival', 'Total_Counts'])
    df = df.set_index(['Event_Activity', 'Day_Type', 'Admission_Period','In
    return df

def year_modification(df):
    ######## CREATE MODIFIER FOR ARRIVAL INTERVAL YEAR TO YEAR & MONTH TO M
    overall_mean = df.groupby(['Prev_Flow']).Int_Arrival.mean().loc['IN']
    df = df.groupby(['Prev_Flow','Year']).Int_Arrival.mean().loc['IN'].rese
    df['Int_Arrival'] = df.Int_Arrival / overall_mean
    annual_plot_df = df.copy(deep=True)
    min_date = df.Year[0]
    max_date = df.Year[7]
    min_date_modifier = df.Int_Arrival[0]
    max_date_modifier = df.Int_Arrival[7]
    # Determine Linear equation for year modifier based on 2013 to 2020
    x_yr = np.array([2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029,
    A = np.array([[min_date, 1],[max_date, 1]])
    B = np.array([min_date_modifier, max_date_modifier])
    m, b = np.linalg.solve(A,B)
    y_mod = m * x_yr + b
    x_yr = np.append(df['Year'], x_yr)
    y_mod = np.append(df['Int_Arrival'], y_mod)
    # Look up table for year modifier
    year_modifier={'year': x_yr,
                   'modifier': y_mod}
    return pd.DataFrame.from_dict(year_modifier)

def month_modification(df):
    # Determine Month by Month modifier
    overall_mean = df.groupby(['Prev_Flow']).Int_Arrival.mean().loc['IN']
    df = df.groupby(['Prev_Flow', 'Month']).Int_Arrival.mean().loc['IN'].re
    df['Int_Arrival'] = df.Int_Arrival / overall_mean
    month_modifier = {'month': df['Month'].values.tolist(),
                      'modifier': df['Int_Arrival'].values.tolist()}
    return pd.DataFrame.from_dict(month_modifier)

def patient_flow_summary(df):
    ####### CREATE SUMMARY TABLE FOR PATIENT FLOW CODE
    df = df.loc[:,['Prev_Flow','Ward_Code','Link']]
    df = df.groupby(['Prev_Flow','Ward_Code']).count()['Link']
    df = df.reset_index()
    df = df.rename(columns = {'Link':'Next_Ward_Count'})
    df['Total_Counts'] = df.groupby(['Prev_Flow']).transform('sum')['Next_W
    df['Cummulative_Count'] = df.groupby(['Prev_Flow']).cumsum()['Next_Ward
    df['Next_Ward_Cum_Prob'] = df.Cummulative_Count / df.Total_Counts
    df = df.drop(columns=['Next_Ward_Count', 'Total_Counts','Cummulative_Co
    df = df.set_index(['Prev_Flow','Ward_Code'])
    return df

def LOS_summary(df):
    ####### CREATE SUMMARY TABLE FOR LENGTH OF STAY
    df = df.loc[:,['Ward_Code','Prev_Flow','LOS']]
    #df = df.drop(columns=['Link',  'Start', 'End','Day', 'Month','Year','I
    #print(df.LOS.describe())  #used to find the biggest number
    df['LOS_Bins'] = pd.cut(x=df['LOS'], bins=[0,19,39,59,79,99,119,139,159
                                               359,379,399,419,439,459,479,
```

```
                                                    699,719,739,750,779,799,819,
    df = df.groupby(['Prev_Flow','Ward_Code','LOS_Bins']).count()
    df = df.reset_index()
    df['Total_Counts'] = df.groupby(['Prev_Flow','Ward_Code']).transform('s
    df['LOS_Probability'] = df.LOS / df.Total_Counts
    df['LOS_Cum_Probability'] = df.groupby(['Prev_Flow','Ward_Code']).cumsu
    df = df.dropna()
    df = df.drop(columns = ['Total_Counts', 'LOS','LOS_Probability'])
    df = df.set_index(['Prev_Flow','Ward_Code','LOS_Bins'])
    return df
```

SUMMARY TABLES

In [11]:
```
arrivalsum_df = interarrival_summary(ideal_df.copy(deep=True))
arrivalsum_df
```

Out[11]:

				Arrival_Probability
Event_Activity	**Day_Type**	**Admission_Period**	**Int_Arrival_Bins**	
High	**Weekday**	**Planned**	**(0, 9]**	0.727599
			(9, 19]	0.903226
			(19, 29]	0.978495
			(29, 49]	0.985663
			(49, 59]	0.992832
...	...	...	...	...
Normal	**Weekend**	**Unplanned**	**(9, 19]**	0.641975
			(19, 29]	0.836420
			(29, 49]	0.984568
			(49, 59]	0.990741
			(59, 69]	1.000000

74 rows × 1 columns

In [12]:
```
year_mod_df = year_modification(ideal_df.copy(deep=True))
year_mod_df
```

Out[12]:

	year	modifier
0	2013	1.051309
1	2014	0.956950
2	2015	1.025211
3	2016	1.008904
4	2017	1.115643
5	2018	1.008395
6	2019	0.945023
7	2020	0.894929
8	2021	0.872590
9	2022	0.850250
10	2023	0.827910
11	2024	0.805570
12	2025	0.783230
13	2026	0.760890
14	2027	0.738550
15	2028	0.716210
16	2029	0.693870
17	2030	0.671530
18	2031	0.649190

In [13]:
```
month_mod_df = month_modification(ideal_df.copy(deep=True))
month_mod_df
```

Out[13]:

	month	modifier
0	April	1.028202
1	August	1.063501
2	December	1.000796
3	February	1.012897
4	January	0.907832
5	July	1.154971
6	June	0.963055
7	March	0.981020
8	May	0.974898
9	November	1.054925
10	October	0.926893
11	September	0.962463

In [14]:
```
patientflowsum_df = patient_flow_summary(ideal_df.copy())
patientflowsum_df
```

Out[14]:

Prev_Flow	Ward_Code	Next_Ward_Cum_Prob
IN	DS	0.383094
	ICU	0.391663
	MT	1
IN-DS	ICU	0.00602151
	MT	0.877849
	OUT	1
IN-DS-ICU	MT	1
IN-DS-ICU-MT	OUT	1
IN-DS-MT	DS	0.00296004
	ICU	0.00641342
	OUT	1
IN-DS-MT-DS	MT	1
IN-DS-MT-DS-MT	OUT	1
IN-DS-MT-ICU	MT	1
IN-DS-MT-ICU-MT	OUT	1
IN-ICU	MT	0.961538
	OUT	1
IN-ICU-MT	OUT	1
IN-MT	DS	0.00379198
	ICU	0.00568797
	OUT	1
IN-MT-DS	ICU	0.0714286
	MT	1
IN-MT-DS-ICU	DS	1
IN-MT-DS-ICU-DS	MT	1
IN-MT-DS-ICU-DS-MT	OUT	1
IN-MT-DS-MT	OUT	1
IN-MT-ICU	MT	1
IN-MT-ICU-MT	ICU	0.142857
	OUT	1
IN-MT-ICU-MT-ICU	MT	1
IN-MT-ICU-MT-ICU-MT	OUT	1

In [15]:
```
LOSsum_df = LOS_summary(ideal_df.copy())
LOSsum_df
```

Out[15]:

			LOS_Cum_Probability
Prev_Flow	**Ward_Code**	**LOS_Bins**	
IN	**DS**	**(0, 19]**	0.396129
		(19, 39]	0.934194
		(39, 59]	0.991398
		(59, 79]	0.998710
		(79, 99]	0.999570
...	**...**	**...**	...
IN-MT-ICU	**MT**	**(59, 79]**	0.714286
		(79, 99]	0.857143
		(239, 259]	1.000000
IN-MT-ICU-MT	**ICU**	**(0, 19]**	1.000000
IN-MT-ICU-MT-ICU	**MT**	**(139, 159]**	1.000000

106 rows × 1 columns

Objective 2 - Determine current capacity requirements using simulation and mathematical modeling

2.1 - CURRENT CAPACITY REQUIREMENTS - HISTORICAL DATA

CALCULATE CURRENT OCCUPANCY

In [16]:
```
def add_patient_occupancy(df):
    ### ADDS PATIENT OCCUPANCY TO THE DATA
    #### add for loop that runs through all sims and all sim numbers
    sim_names = df.Sim_Name.unique()
    for sim_name in sim_names:
        sim_nos = df.Sim_No.unique()
        for sim_no in sim_nos:
            df = df.loc[(df.Sim_Name == sim_name) & (df.Sim_No == sim_no),
            df = df.sort_values(['Start'])
            df['MT_Occupancy'] = 0
            df['DS_Occupancy'] = 0
            df['MT_Occupancy'] = np.where((df.Prev_Flow.str[-2:] == 'MT') &
                                          np.where((df.Ward_Code == 'MT
            df['DS_Occupancy'] = np.where((df.Prev_Flow.str[-2:] == 'DS') &
                                          np.where((df.Ward_Code == 'DS
    return df
```

HISTOGRAM FUNCTION FOR DATA VISUALISATION

In [17]:
```
def plot_histogram(df, x_axis, plot_type, folder_loc, name, sim_name):
    filename = folder_loc + '/' + sim_name + '_' + x_axis + '_' + plot_type
    if plot_type == 'Histogram':
        fig = px.histogram(df, x=x_axis, nbins=20)
        #fig.show()
        fig.write_image(filename)
    if plot_type == 'Cummulative Histogram':
        x_axis_values = df.loc[:,x_axis]
        fig = go.Figure(data=[go.Histogram(x=x_axis_values, cumulative_enab
    fig.update_layout(
        title = sim_name + " - " + name,
        xaxis_title = x_axis,
        yaxis_title = "Count"
    )
    fig.write_image(filename)
    fig.show()


def new_dir(folder_name):
    today = datetime.date.today()
    todaystr = today.isoformat()
    full_path = folder_name + todaystr
    if not(os.path.isdir(full_path)):
        os.mkdir(full_path)
    return full_path
```

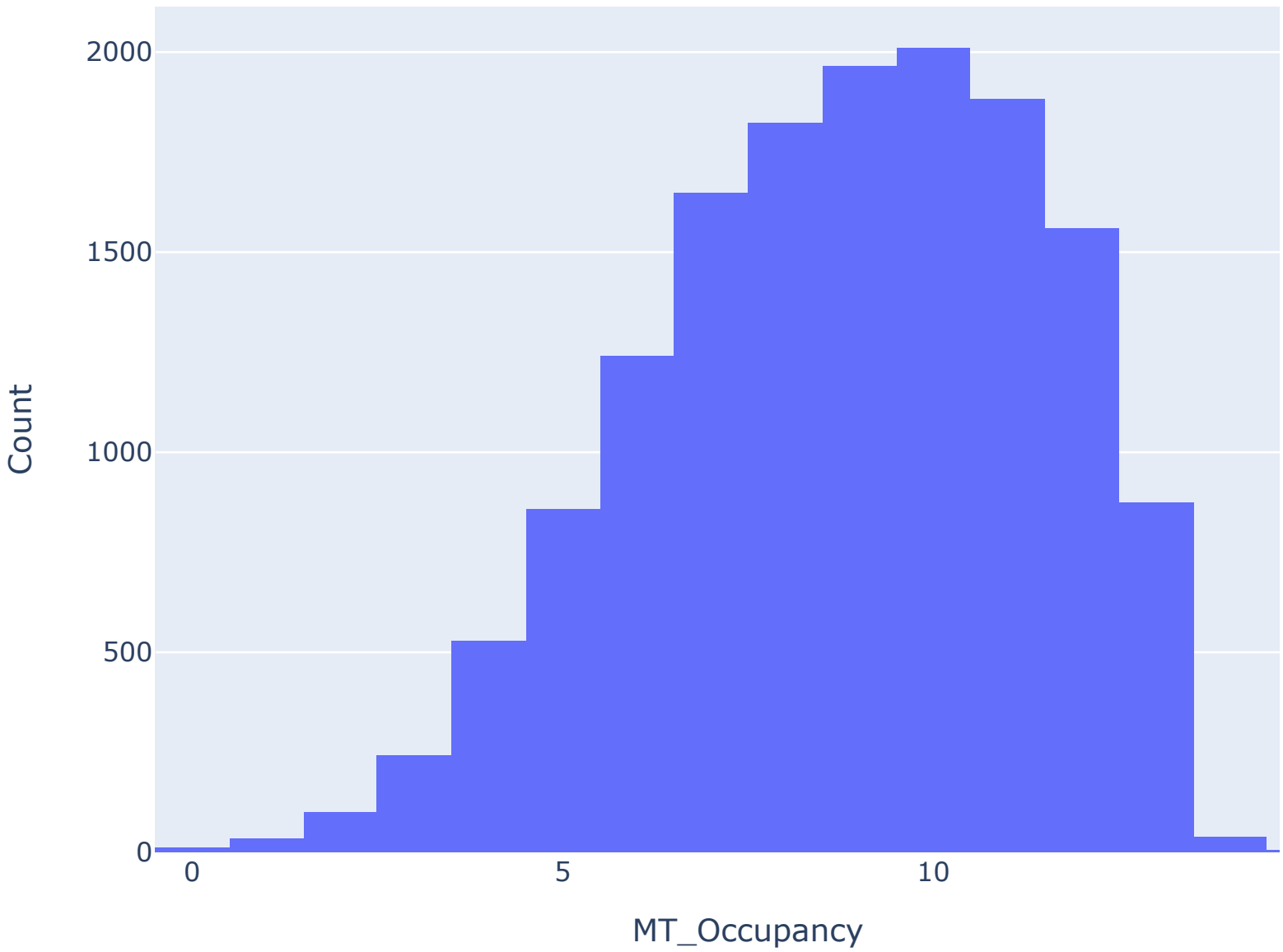
OCCUPANCY PROFILE VISUALISATION - ORIGINAL HISTORICAL

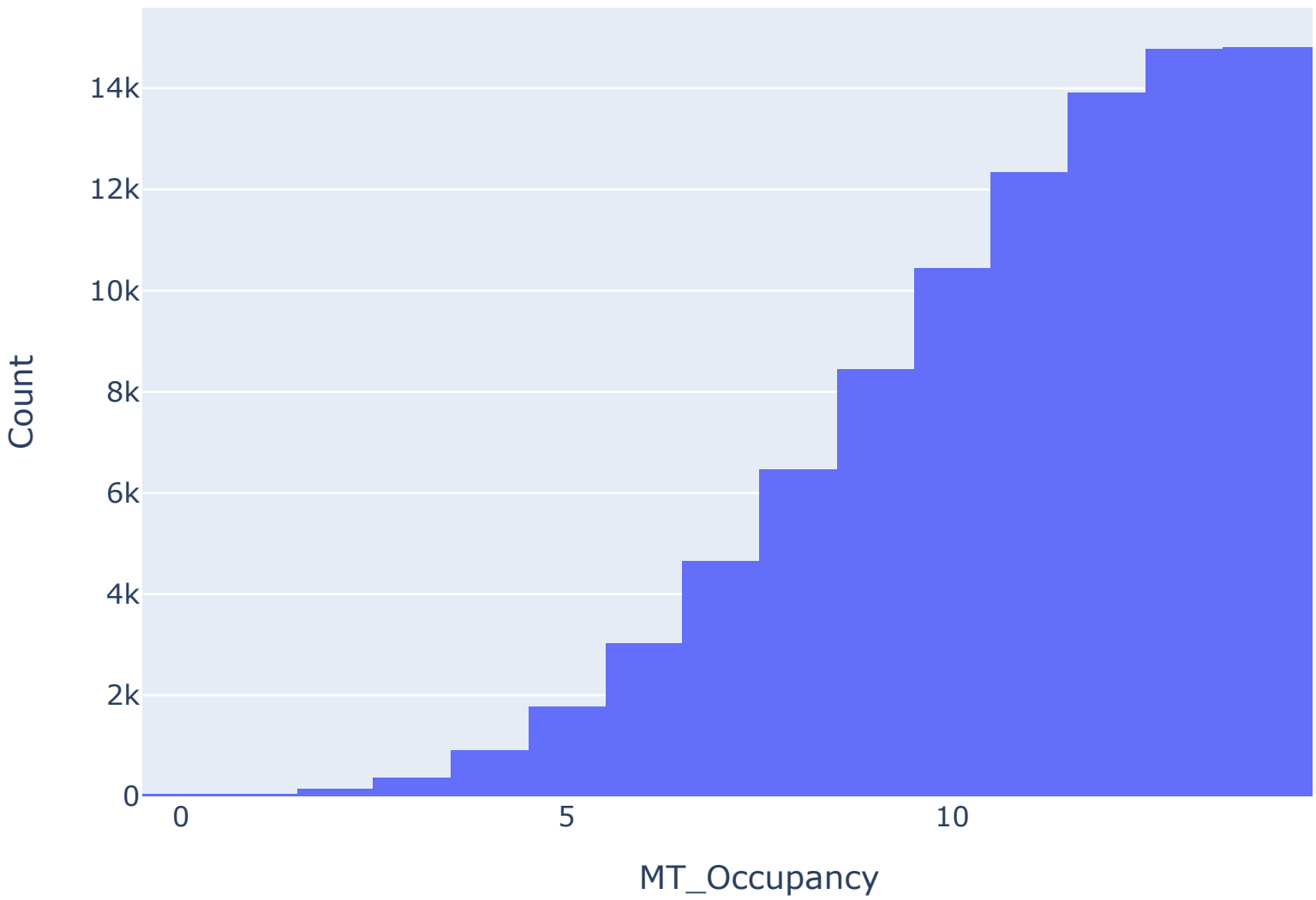
In [18]:
```
orig_df = add_patient_occupancy(orig_df)
orig_df.loc[:,['MT_Occupancy','DS_Occupancy']].describe()
```

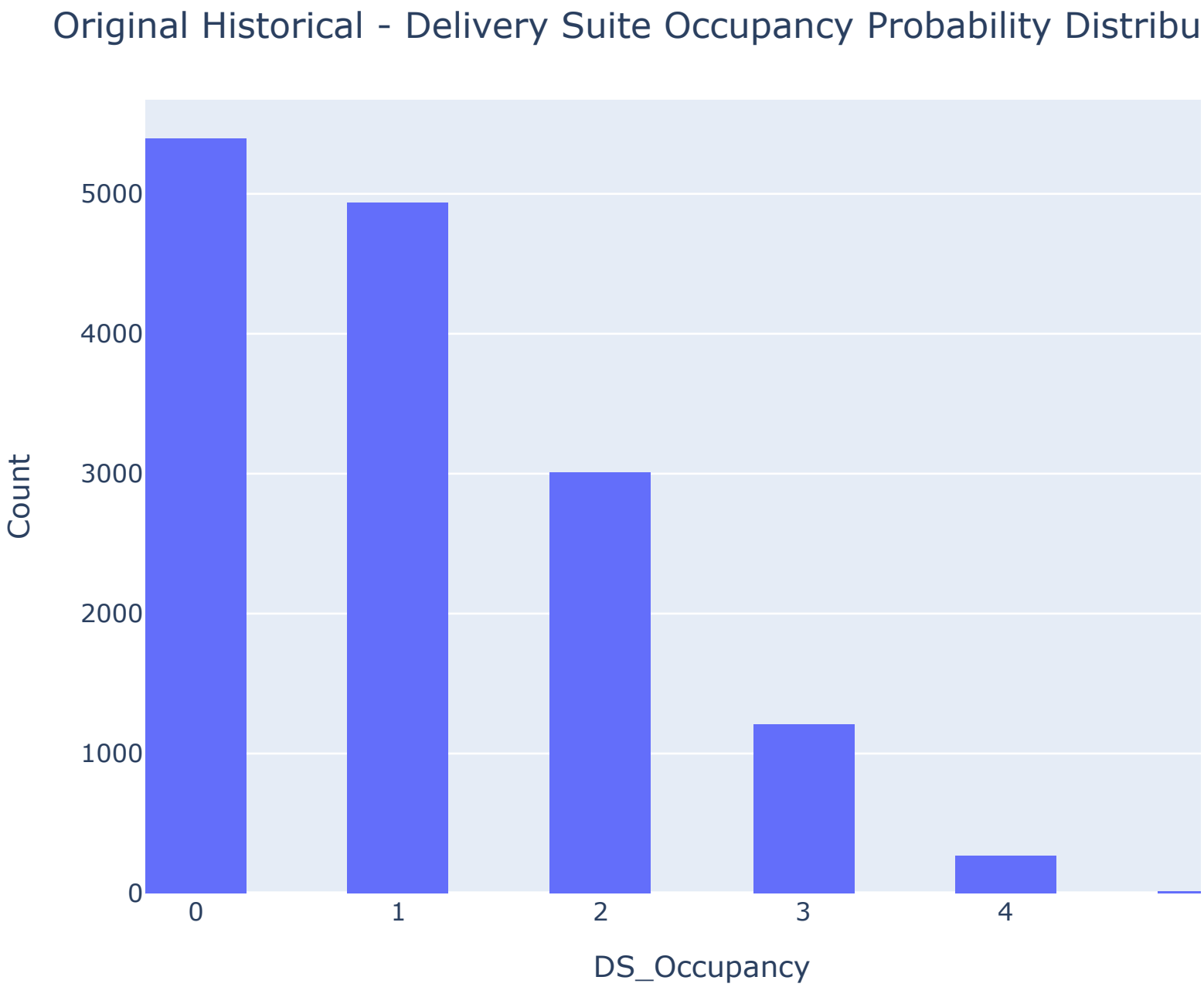
Out[18]:

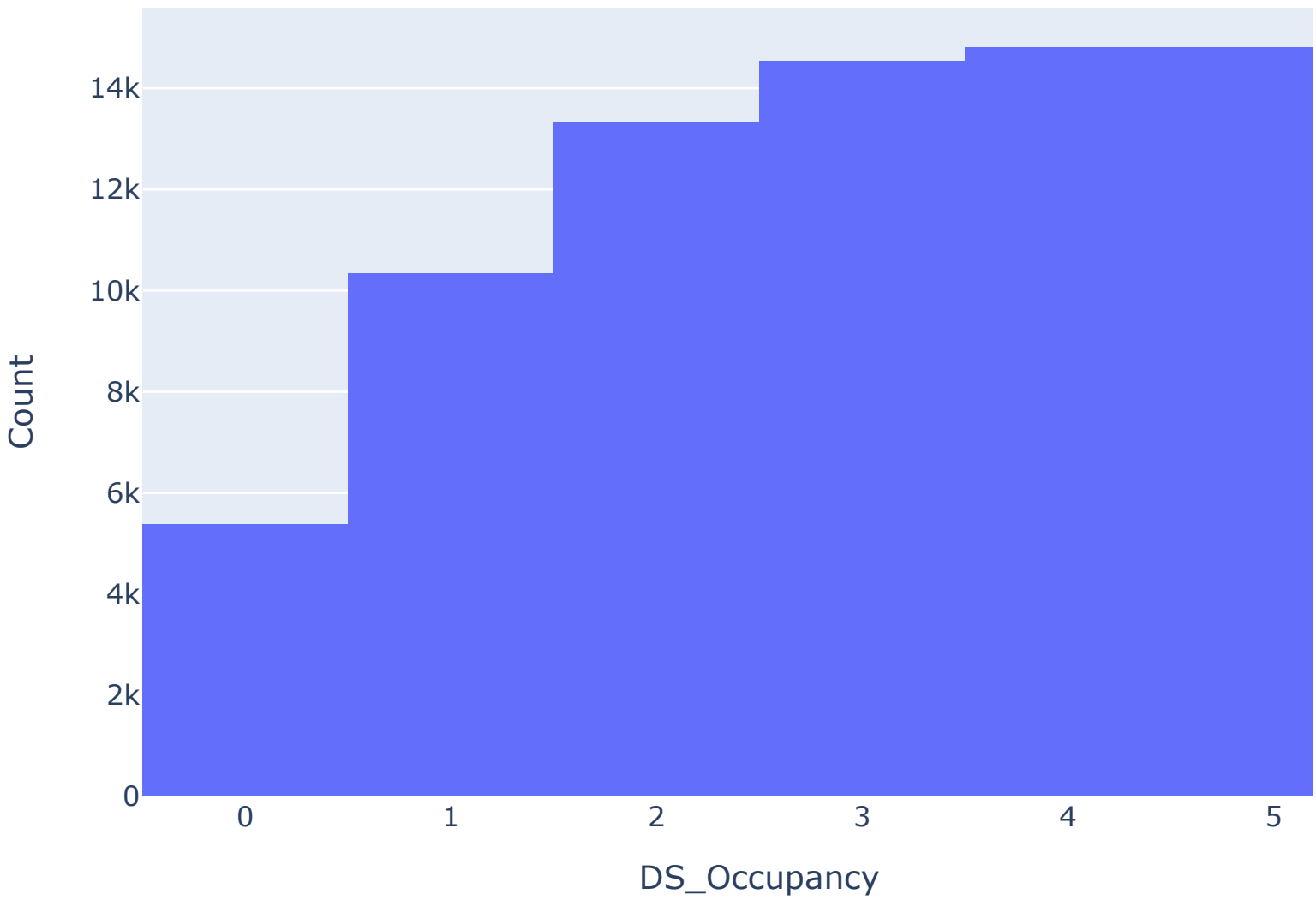
	MT_Occupancy	DS_Occupancy
count	14802.000000	14802.000000
mean	8.781921	1.054655
std	2.607231	1.024357
min	0.000000	0.000000
25%	7.000000	0.000000
50%	9.000000	1.000000
75%	11.000000	2.000000
max	15.000000	5.000000

In [19]:
```
plot_histogram(orig_df, 'MT_Occupancy', 'Histogram', new_dir('plots/'), 'Ma
plot_histogram(orig_df, 'MT_Occupancy', 'Cummulative Histogram', new_dir('p
plot_histogram(orig_df, 'DS_Occupancy', 'Histogram', new_dir('plots/'), 'De
plot_histogram(orig_df, 'DS_Occupancy', 'Cummulative Histogram', new_dir('p
```


Original Historical - Maternity Occupancy Probability Distribution
Count
2000
1500
1000
500
0
0
5
10
MT_Occupancy


Original Historical - Maternity Occupancy Cumulative Probability I
Count
14k
12k
10k
8k
6k
4k
2k
0
0
5
10
MT_Occupancy


Original Historical - Delivery Suite Occupancy Probability Distribu
Count
5000
4000
3000
2000
1000
0
0
1
2
3
4
DS_Occupancy



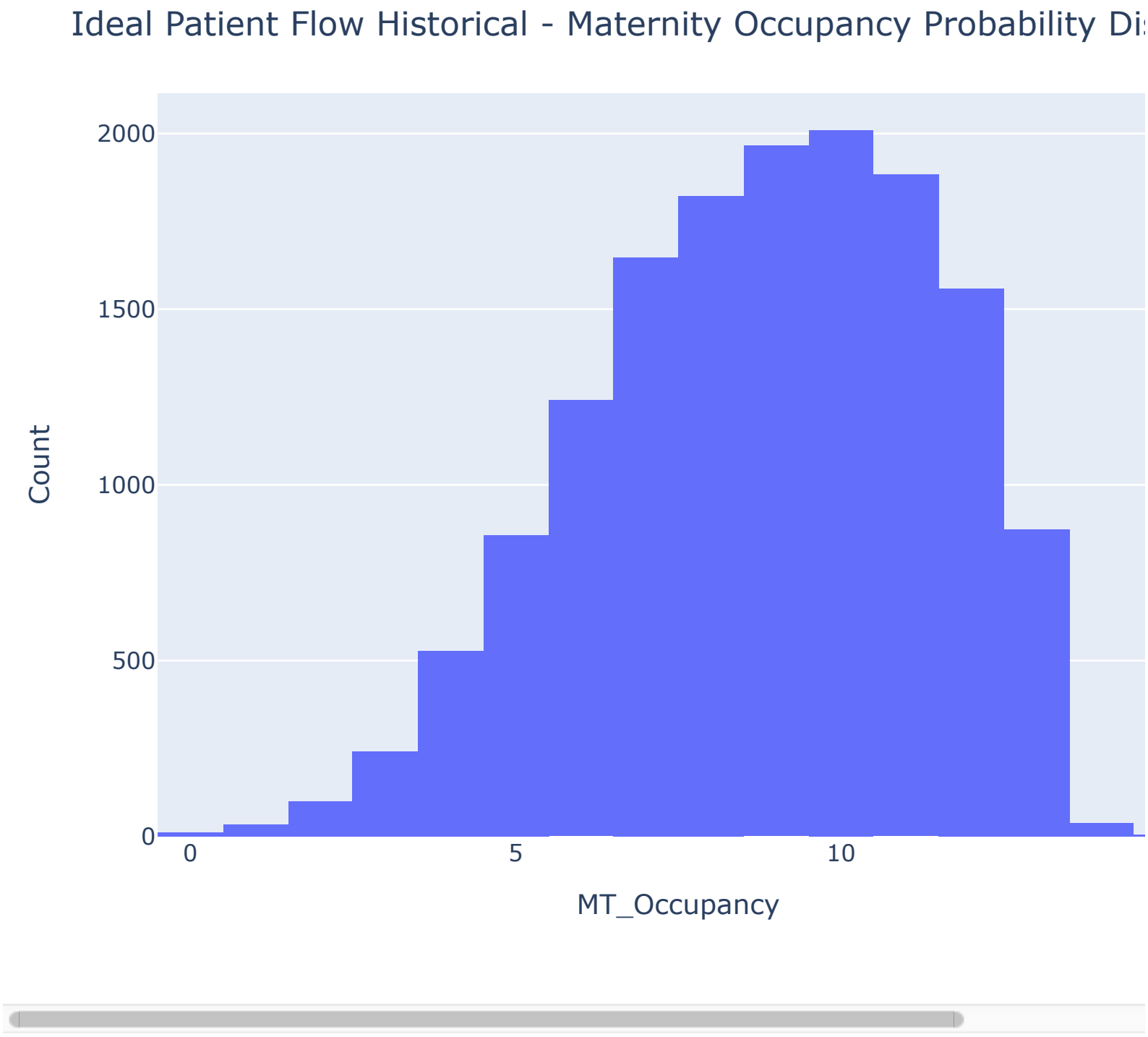
OCCUPANCY PROFILE VISUALISATION - IDEAL FLOW HISTORICAL

In [20]:
```
ideal_df = add_patient_occupancy(ideal_df)
ideal_df.loc[:,['MT_Occupancy','DS_Occupancy']].describe()
```

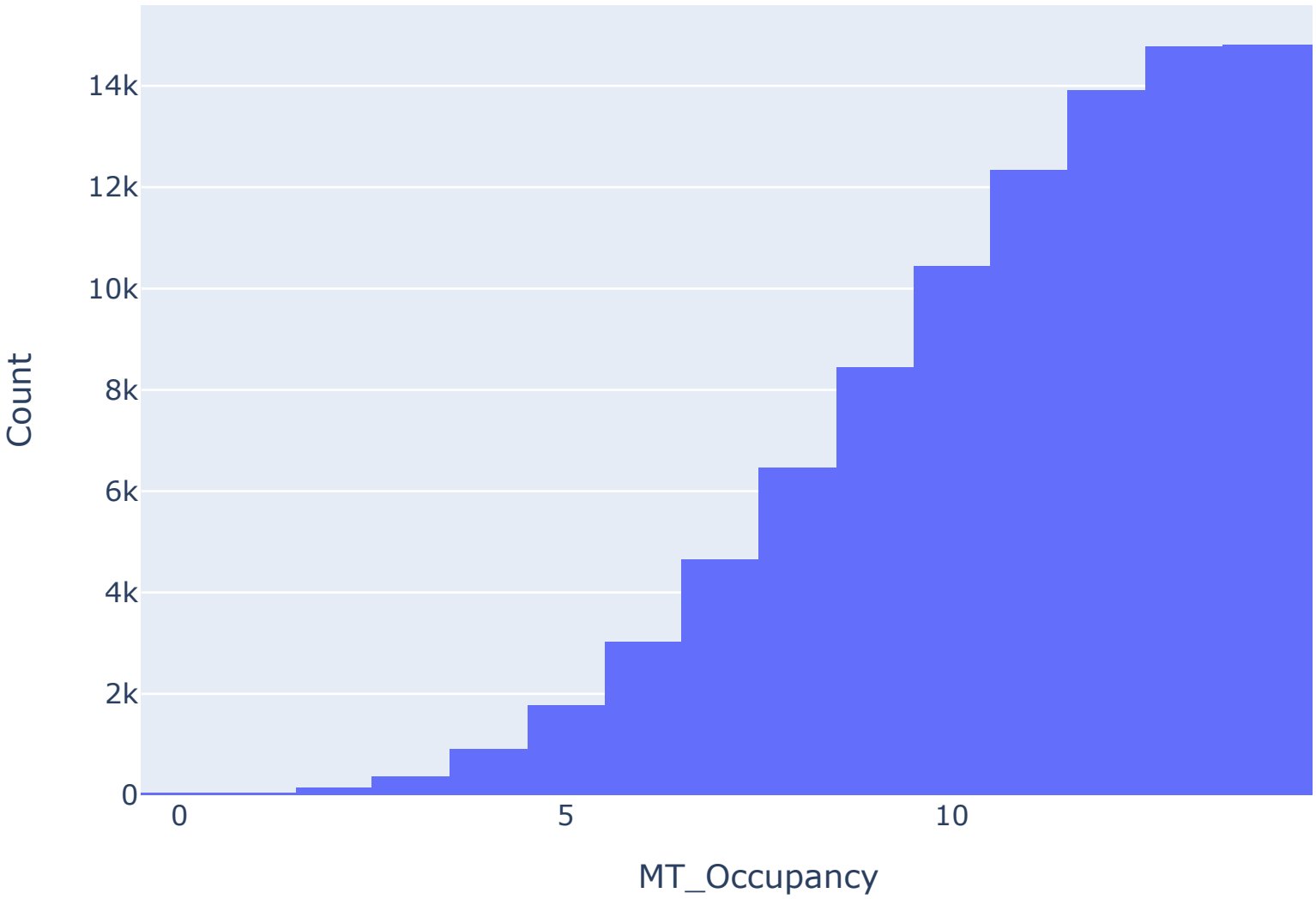
Out[20]:

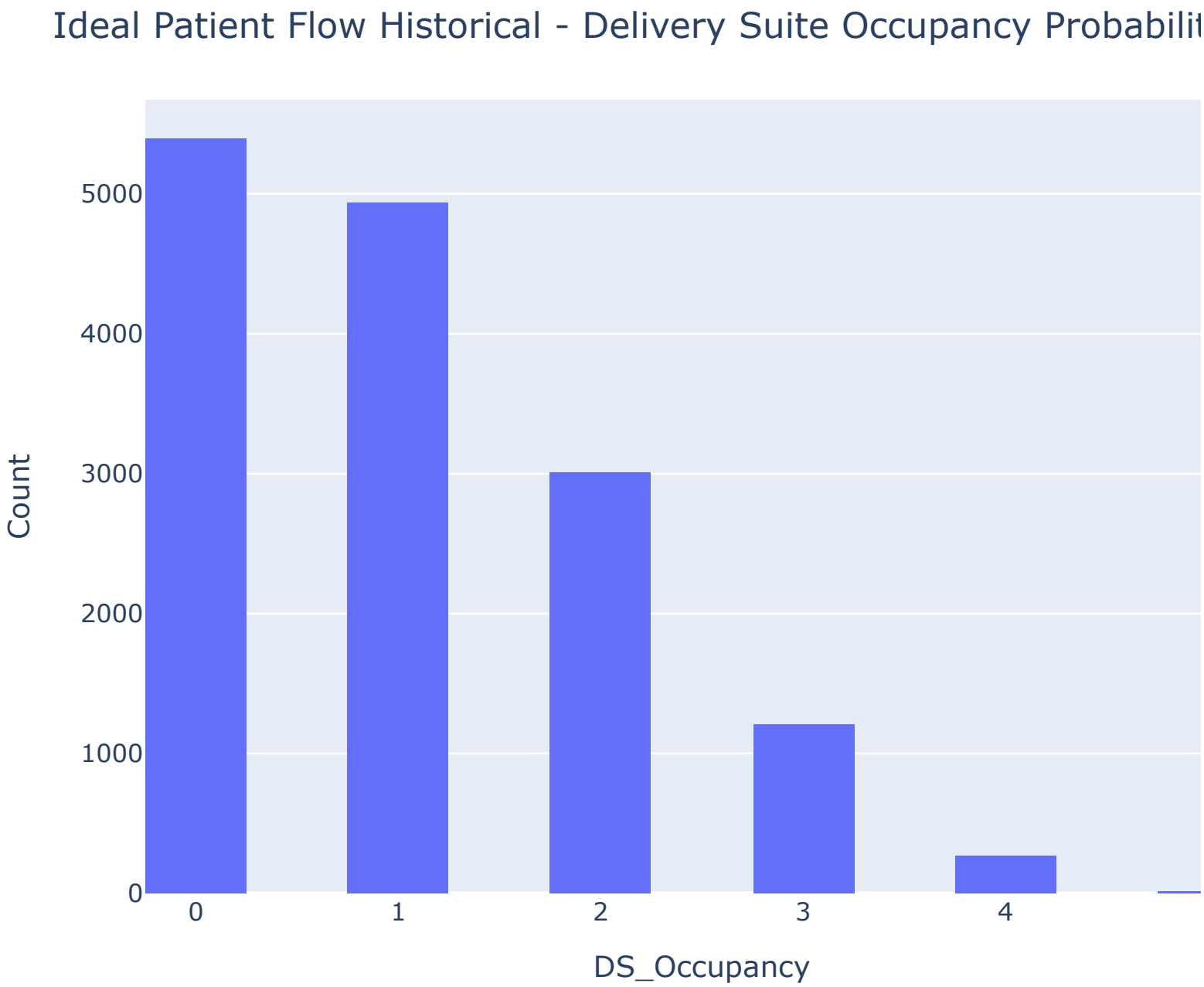
	MT_Occupancy	DS_Occupancy
count	14315.000000	14315.000000
mean	9.064198	1.059029
std	2.964369	1.023857
min	0.000000	0.000000
25%	7.000000	0.000000
50%	9.000000	1.000000
75%	11.000000	2.000000
max	20.000000	5.000000

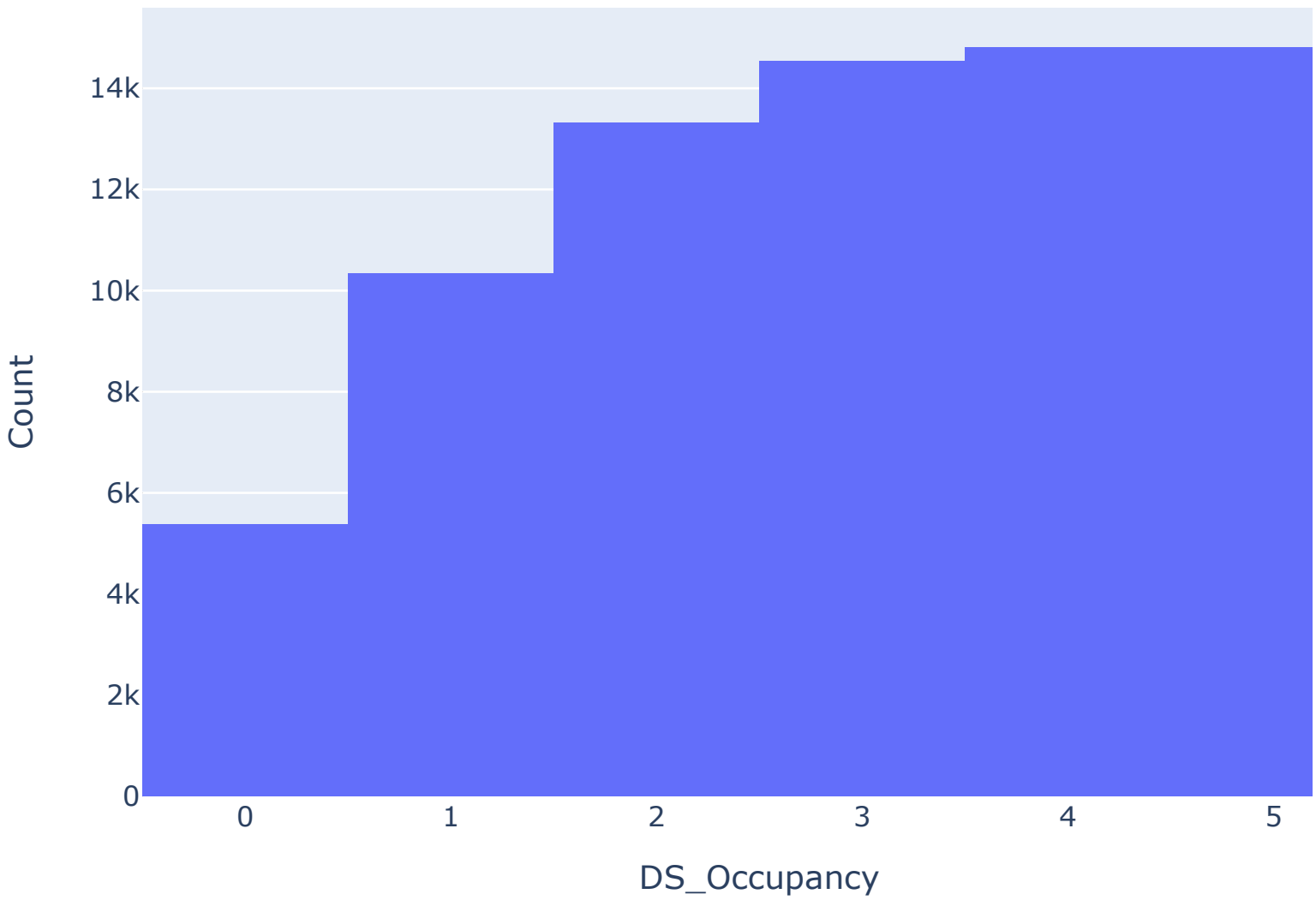
In [21]:
```
plot_histogram(orig_df, 'MT_Occupancy', 'Histogram', new_dir('plots/'), 'Ma
plot_histogram(orig_df, 'MT_Occupancy', 'Cummulative Histogram', new_dir('p
plot_histogram(orig_df, 'DS_Occupancy', 'Histogram', new_dir('plots/'), 'De
plot_histogram(orig_df, 'DS_Occupancy', 'Cummulative Histogram', new_dir('p
```



Ideal Patient Flow Historical - Maternity Occupancy Cumulative Pr




Ideal Patient Flow Historical - Delivery Suite Occupancy Probabilit
Count
5000
4000
3000
2000
1000
0
0
1
2
3
4
DS_Occupancy



SIMULATION CODE

In [22]:

```
def next_arrival(df, event_activity, day_type, admission_period, from_year,
    xp = pd.Series([0]).append(df.loc[event_activity, day_type, admission_p
    fp = pd.Index([0]).append(df.loc[event_activity, day_type, admission_pe
    random_no = np.random.rand()
    result = np.interp(random_no, xp, fp) # Straight result based on Mean
    year_mod = year_mod_df.loc[year_mod_df.year == from_year,'modifier'].il
    month_mod = month_mod_df.loc[month_mod_df.month == from_month,'modifier
    result_modified = result * year_mod * month_mod
    return result_modified
#print(next_arrival(arrivalsum_df, 'High', 'Weekday', 'Planned', 2020, 'Ja

def date_to_hierarcy(date_stamp):
    date_stamp = pd.Timestamp(date_stamp, unit='%d/%m/%Y %H:%M:%S')
    #Extract time period
    hour_of_day = date_stamp.hour
    admission_period = timeconv['Admission_Period'][hour_of_day]
    #Extract type of day (i.e Weekday or Weekend)
    day_of_week = date_stamp.dayofweek
    day_type = dayconv['Day_Type'][day_of_week]
    #Extract Event based activity
    date_only = date_stamp.date()
```

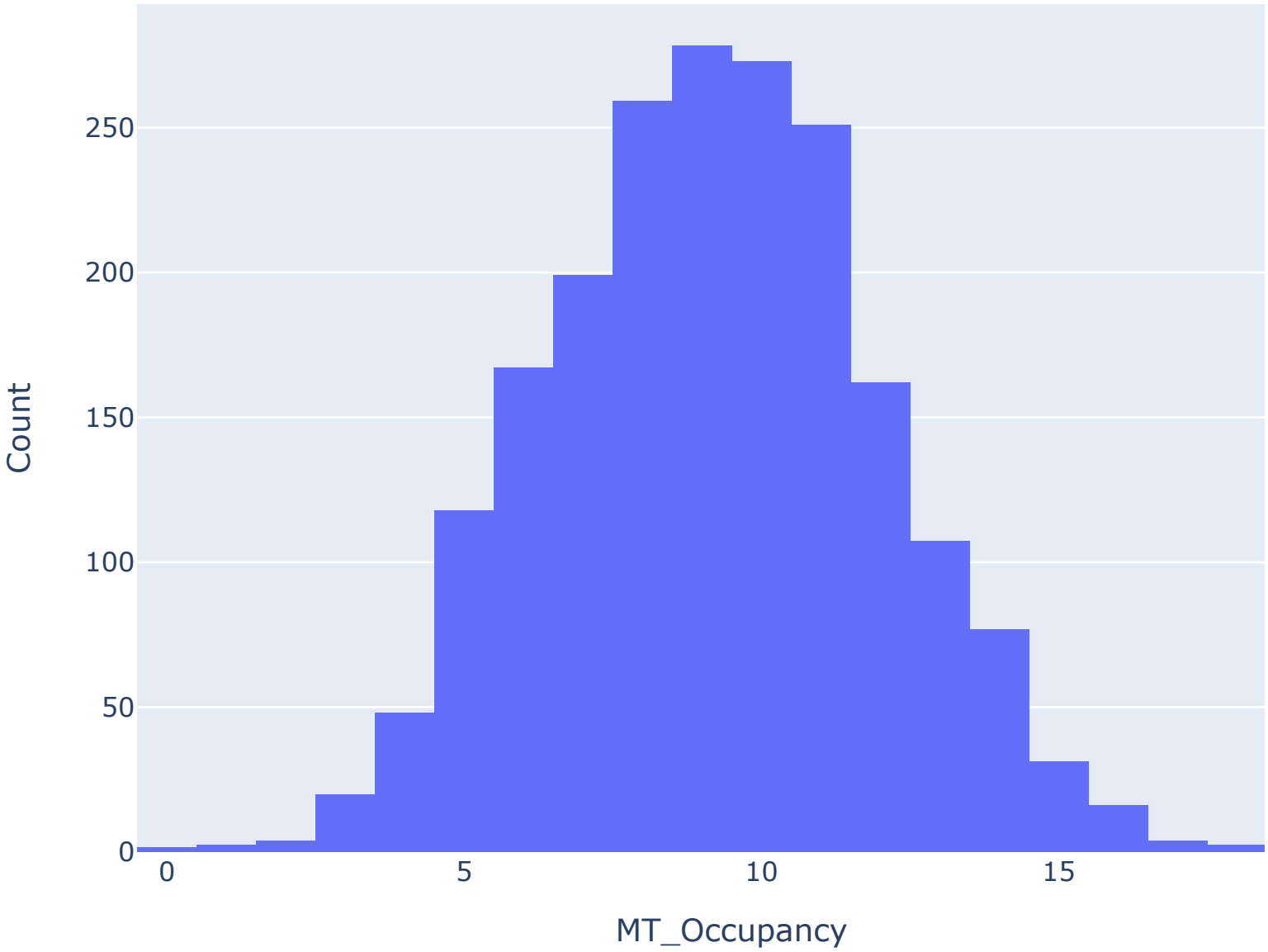
```
    try: event = events_df.groupby('Date').Event.first().loc[date_only]
    except: event = 'NONE'
    event_index_no = event_activity['Event'].index(event)
    event_activity_level = event_activity['Event_Activity'][event_index_no
    #Extract Month
    month = date_stamp.month_name()
    #Extract Year
    year = date_stamp.year
    return {'Admission_Period':admission_period, 'Day_Type':day_type, 'Ever
#print(date_to_hierarcy('01/01/2020 05:00:00'))

def simulate_arrivals(df, n_sims, start, finish):
    results = {'Sim_No':[],'Arrival_Time':[]}
    current_timestamp = pd.Timestamp(start, unit='%d/%m/%Y')
    finish_timestamp = pd.Timestamp(finish, unit='%d/%m/%Y')
    for i in range(0, n_sims):
        while current_timestamp < finish_timestamp:
            hierarcy = date_to_hierarcy(current_timestamp)
            arrival_interval = round(next_arrival(df, hierarcy['Event_Activ
            try: current_timestamp += datetime.timedelta(seconds=arrival_ir
            except: print(arrival_interval)
            results['Sim_No'].append(i)
            results['Arrival_Time'].append(current_timestamp)
        current_timestamp = pd.Timestamp(start, unit='%d/%m/%Y')
        i += 1
        return results
#print(simulate_arrivals(arrivalsum_df, 2, start, finish))

def simulate_patient_flow(df, group_cat, prev_flow):
    ward_prob = df.loc[(prev_flow)] #group_cat['Event_Activity'], group_cat
    n = ward_prob.count().iloc[0]
    random_no = np.random.rand()
    for i in range(0, n):
        if random_no <= ward_prob.iloc[i,0]:
            ward_code = ward_prob.index[i]
            if (prev_flow == 'IN-MT') & (ward_code == 'MT'):
                    print(random_no)
            break
    return ward_code
#print(simulate_patient_flow(patientflow_df, date_to_hierarcy(start), 'IN-M

def simulate_patient_end(df, start, group_cat, prev_flow, ward_code):
    xp = pd.Series([0]).append(df.loc[prev_flow, ward_code].iloc[:,0]) #gro
    fp = pd.Index([0]).append(df.loc[prev_flow, ward_code].index.remove_unu
    #print (xp, fp)
    random_no = np.random.rand()
    dec_result = np.interp(random_no, xp, fp)
    end = start + datetime.timedelta(seconds = int(dec_result*60*60))
    return end
#print(simulate_patient_end(LOS_df, start, date_to_hierarcy(start), 'IN',

def run_simulation(n_sims, arrival_df, LOS_df, patientflow_df, start, finis
    arrivals_data = simulate_arrivals(arrival_df, n_sims, start, finish)
    no_of_admissions = len(arrivals_data['Sim_No'])
    transfer_info = {'Sim_No':[],'Link':[],'Ward_Code':[],'Start':[],'End':
    sim_no = 1
    print(sim_no)
    for i in range(0, no_of_admissions):
        prev_flow, prev_ward = 'IN','IN'
        if sim_no != arrivals_data['Sim_No'][i]:
            sim_no = arrivals_data['Sim_No'][i]
```

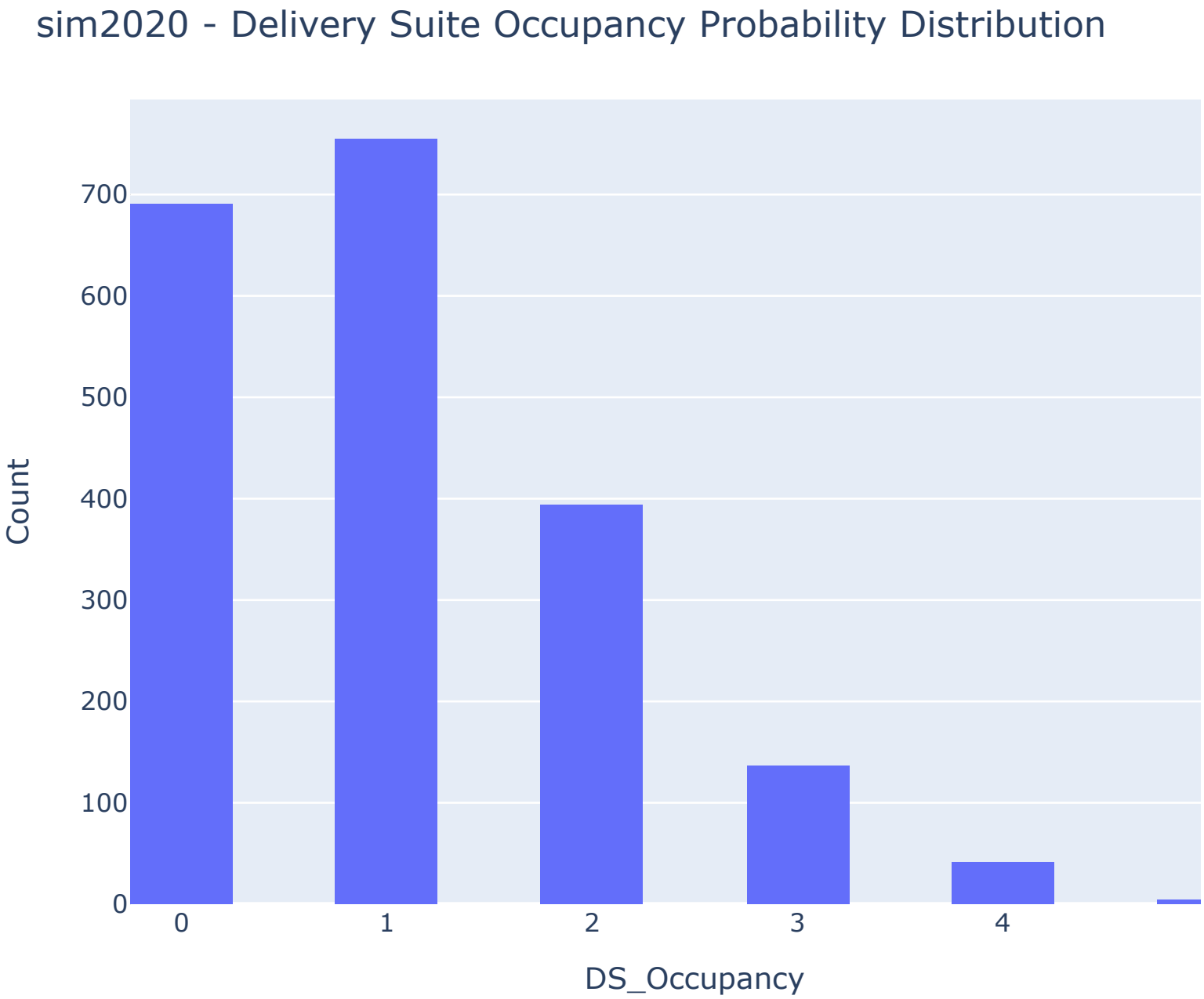
```
            print(sim_no)
        start = arrivals_data['Arrival_Time'][i]
        link = i
        patient_discharged = False
        group_categories = date_to_hierarchy(start)
        while patient_discharged == False:
            ward = simulate_patient_flow(patientflowsum_df, group_categorie
            try: end = simulate_patient_end(LOSsum_df, start, group_categor
            except:
                end = start
            if ward == 'OUT':
                patient_discharged = True

            transfer_info['Sim_No'].append(sim_no)
            transfer_info['Start'].append(start)
            transfer_info['Link'].append(link)
            transfer_info['Prev_Flow'].append(prev_flow)
            transfer_info['Ward_Code'].append(ward)
            transfer_info['End'].append(end)

            #create new starting information
            start = end
            prev_flow = '-'.join((prev_flow, ward))
            prev_ward = ward
            #patient_discharged = True

    results_df = pd.DataFrame.from_dict(transfer_info)
    return results_df

#%time run_simulation(n_sims, arrival_df, LOS_df, patientflow_df, start, f
```

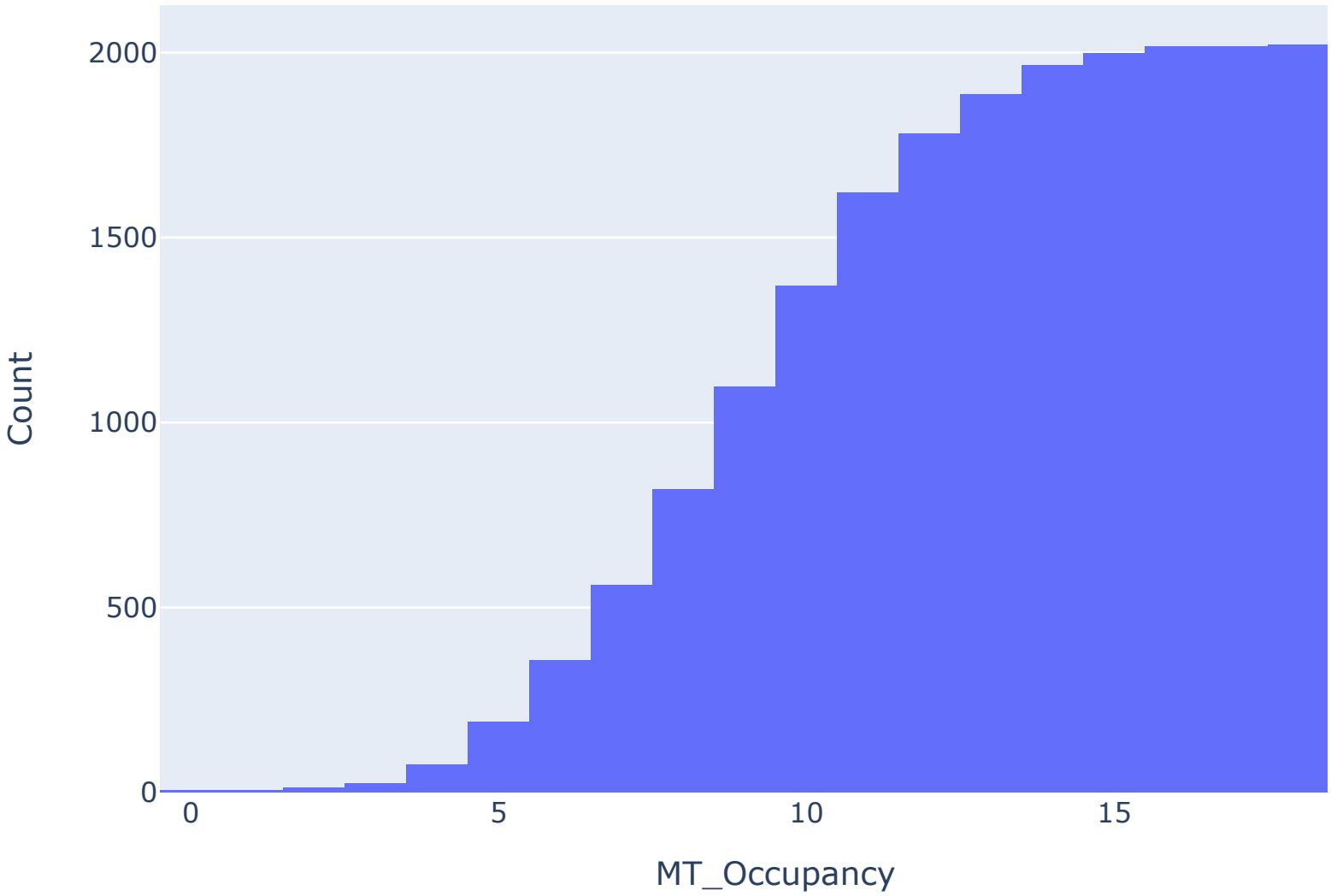
In [23]:

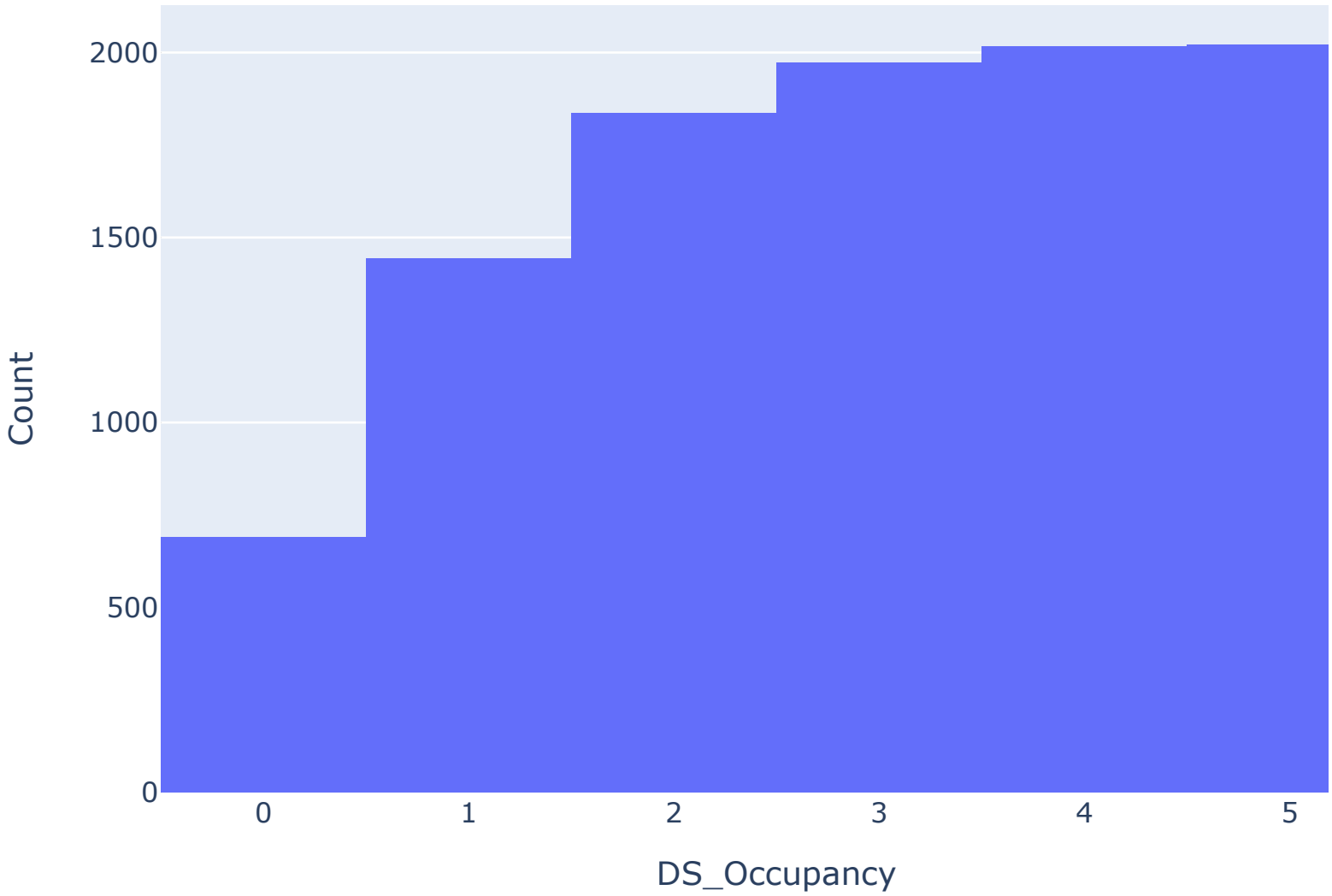
```
sim_source = {'no_sims':1,
              'arrival_df':arrivalsum_df,
              'LOS_df':LOSsum_df,
              'patientflow_df':patientflowsum_df,
              'sims': {'title':['sim2020','sim2025','sim2030'],
                       'start':['01/01/2020','01/01/2025','01/01/2030'],
                       'finish':['01/01/2021','02/01/2026','02/01/2031'],
                       'plot_info': {'name':['Maternity Occupancy Probabilit
                                             'Maternity Occupancy Cumul
                                     'x_axis':['MT_Occupancy','DS_Occupanc
                                              'MT_Occupancy','DS_Occupanc
                                    'plot_type':['Histogram','Histogram',
                                              'Cummulative Histogram','C
                                     }
                           }
              }


def all_sims_and_plots(sim_source):
    folder_loc = new_dir('plots/')
    filename = folder_loc + '/Simulation_Data_' + datetime.date.today().isc
    sims = sim_source['sims']
    prev_df = pd.DataFrame()
    no_scenarios = len(sims['title'])
    no_plots = len(sims['plot_info']['name'])
    for i in range(no_scenarios):
        sim_name = sims['title'][i]
        start = pd.Timestamp(sims['start'][i], unit='%d/%m/%Y %H:%M:%S')
        finish =  pd.Timestamp(sims['finish'][i], unit='%d/%m/%Y %H:%M:%S'
        print(sim_name)
        df = run_simulation(sim_source['no_sims'], sim_source['arrival_df'
        df['Sim_Name'] = sim_name
        df = add_patient_occupancy(df)
        for n in range(no_plots):
            plot_histogram(df, sims['plot_info']['x_axis'][n], sims['plot_i
        if prev_df.empty == False:
            df = pd.concat([df, prev_df])
        prev_df = df.copy()
    ##### ADD ALL DESCRIPTIVE COLUMNS TO SIMULATED DATA
    df = add_next_ward(df)
    df = add_hierarical_data(df)
    #df = add_events_data(df)
    df = add_analysis_info(df)
    df.to_csv(filename, index=False)
    return df

%time simrun_df = all_sims_and_plots(sim_source)
```

```
sim2020
1
0
```

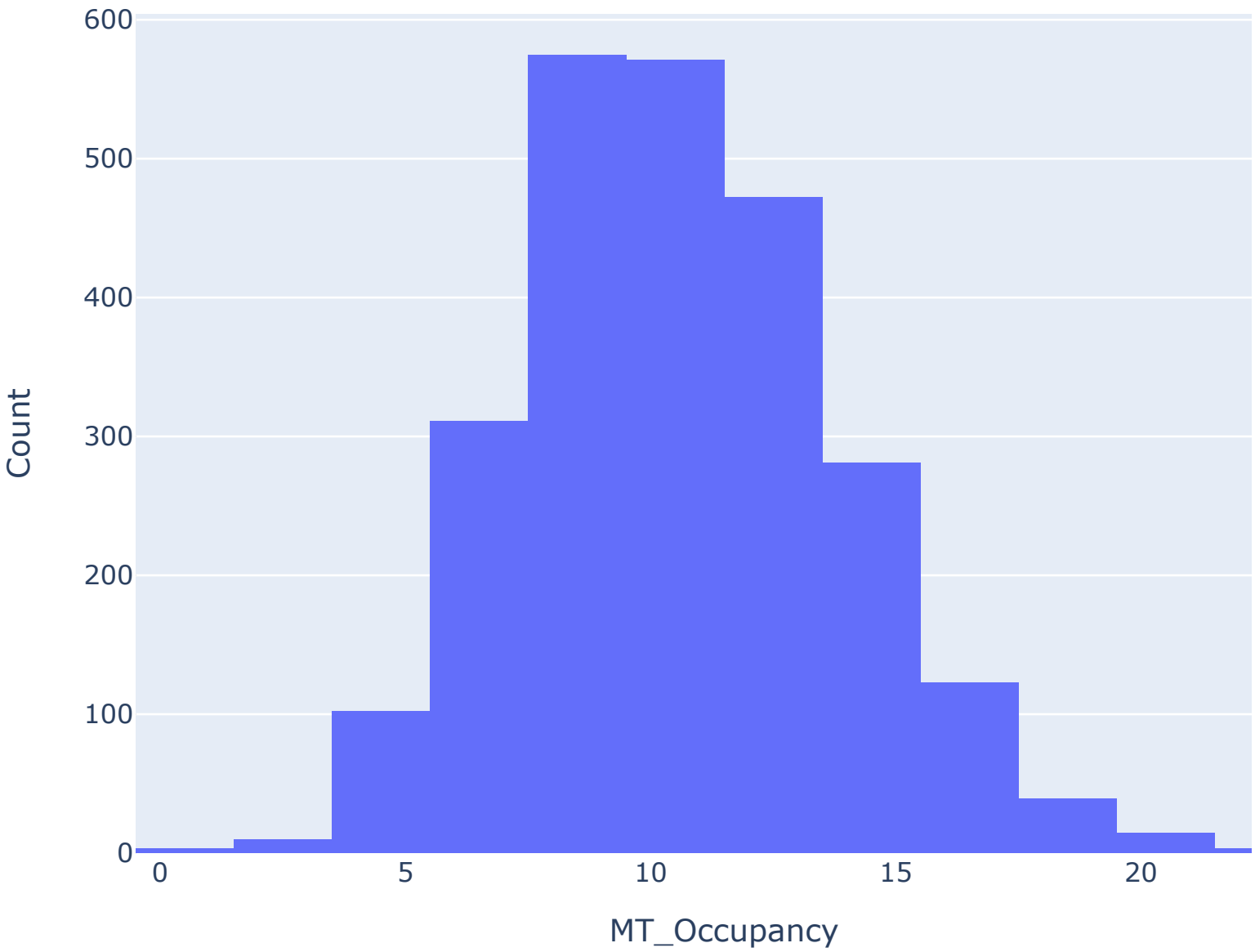

sim2020 - Maternity Occupancy Probability Distribution
Count
250
200
150
100
50
0
0
5
10
15
MT_Occupancy

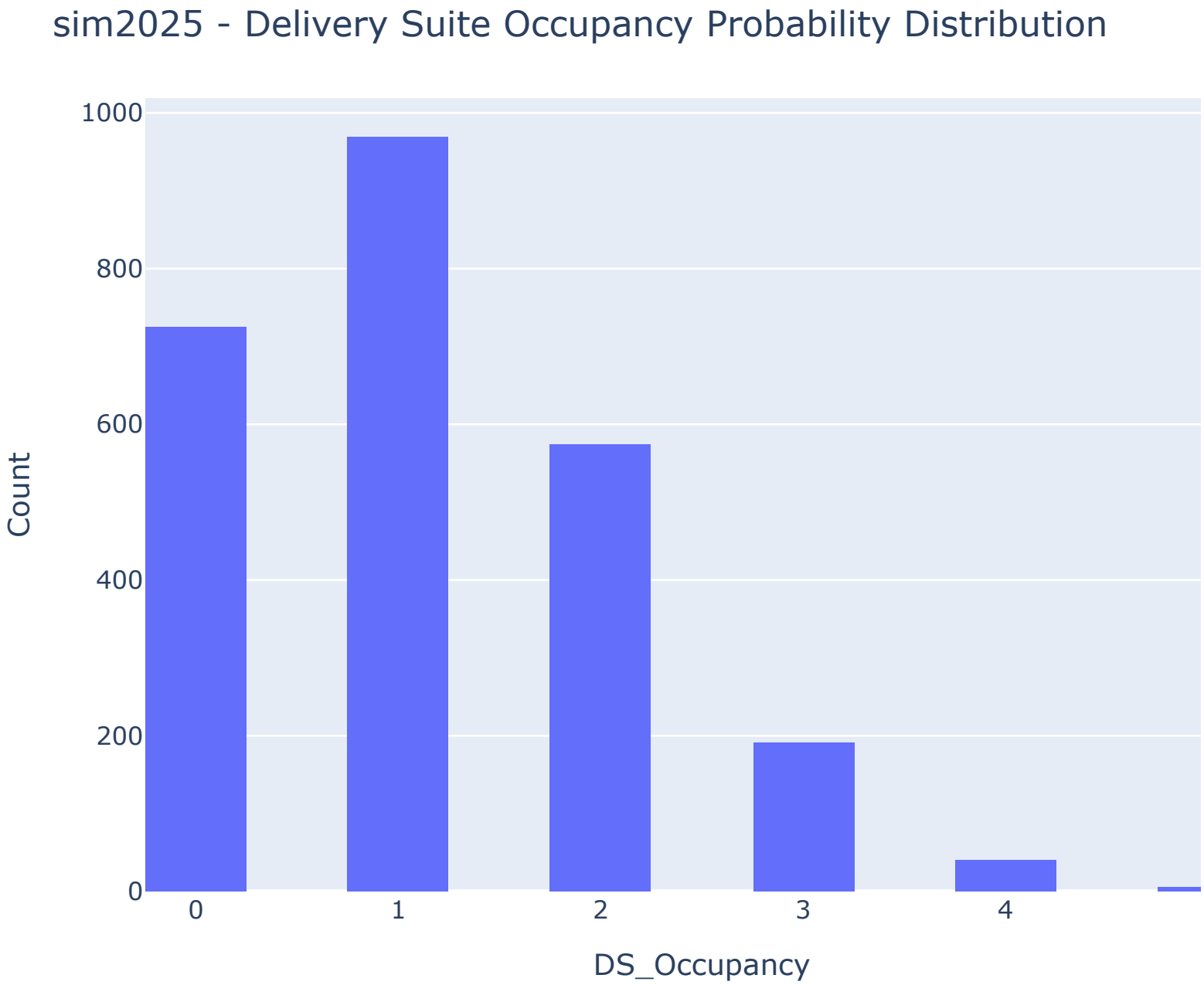

sim2020 - Delivery Suite Occupancy Probability Distribution
Count
0
100
200
300
400
500
600
700
0
1
2
3
4
DS_Occupancy

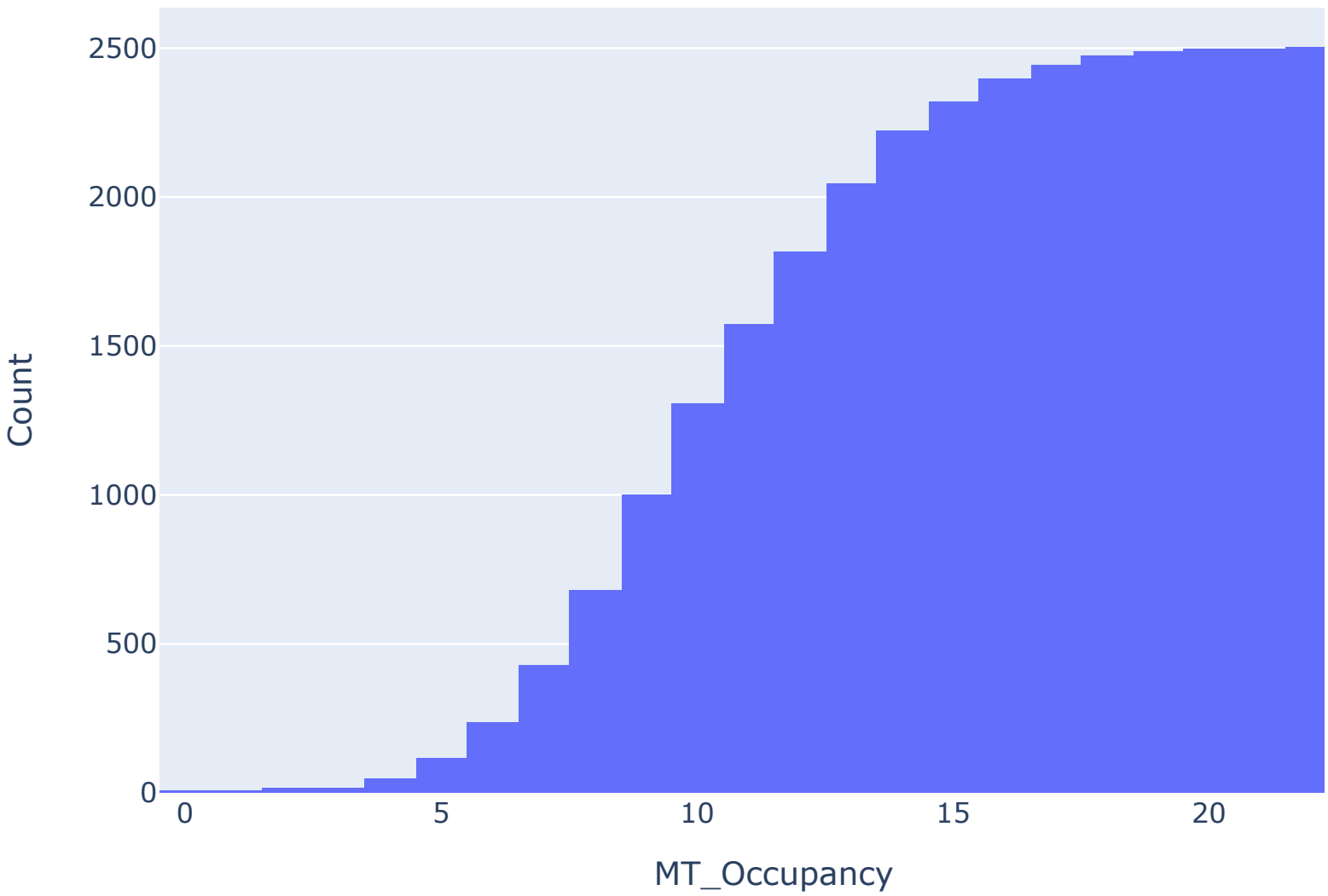

sim2020 - Maternity Occupancy Cumulative Probability
Count
2000
1500
1000
500
0
0
5
10
15
MT_Occupancy

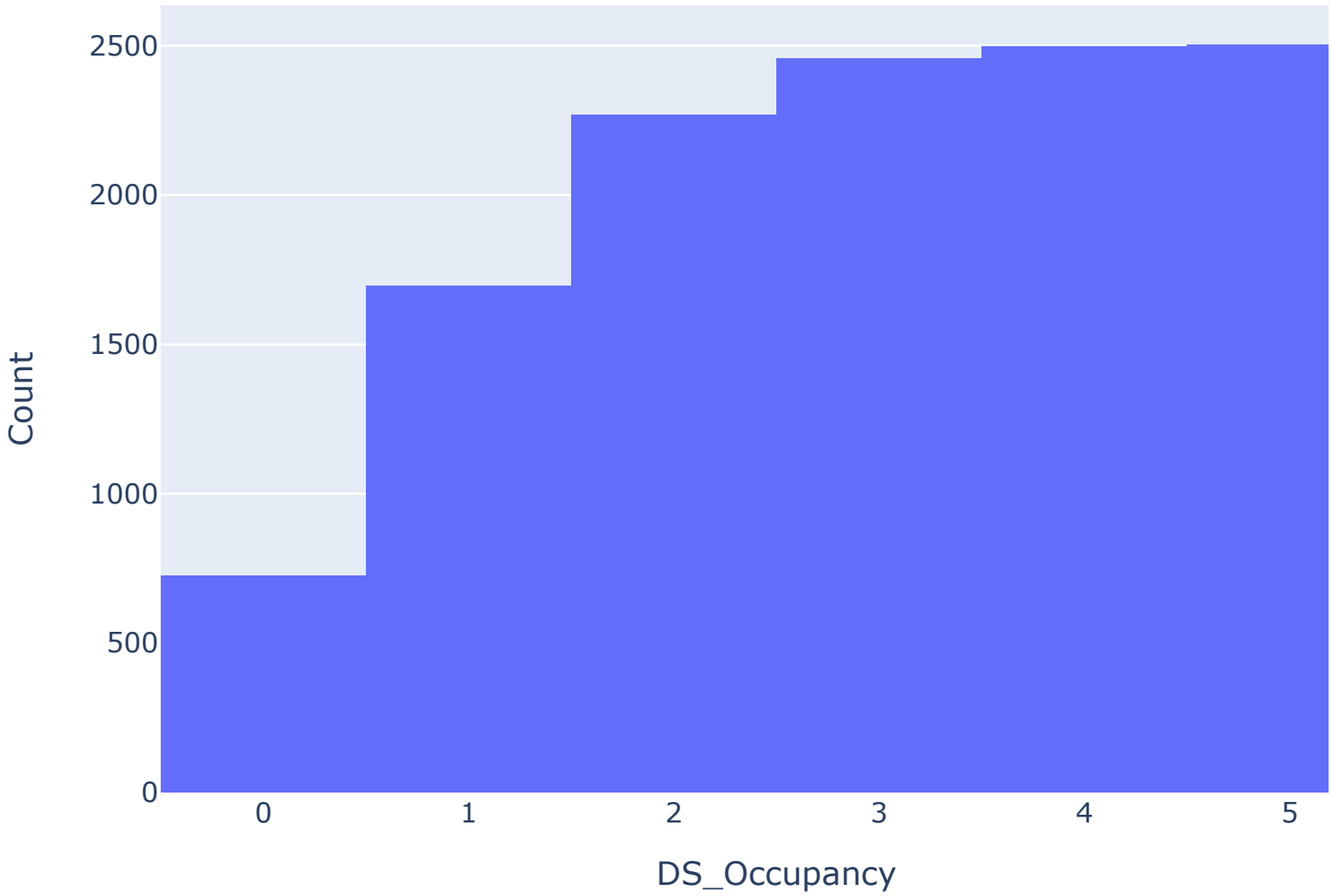

sim2020 - Delivery Suite Occupancy Cumulative Probability
Count
2000
1500
1000
500
0
0
1
2
3
4
5
DS_Occupancy

```
sim2025
1
0
```

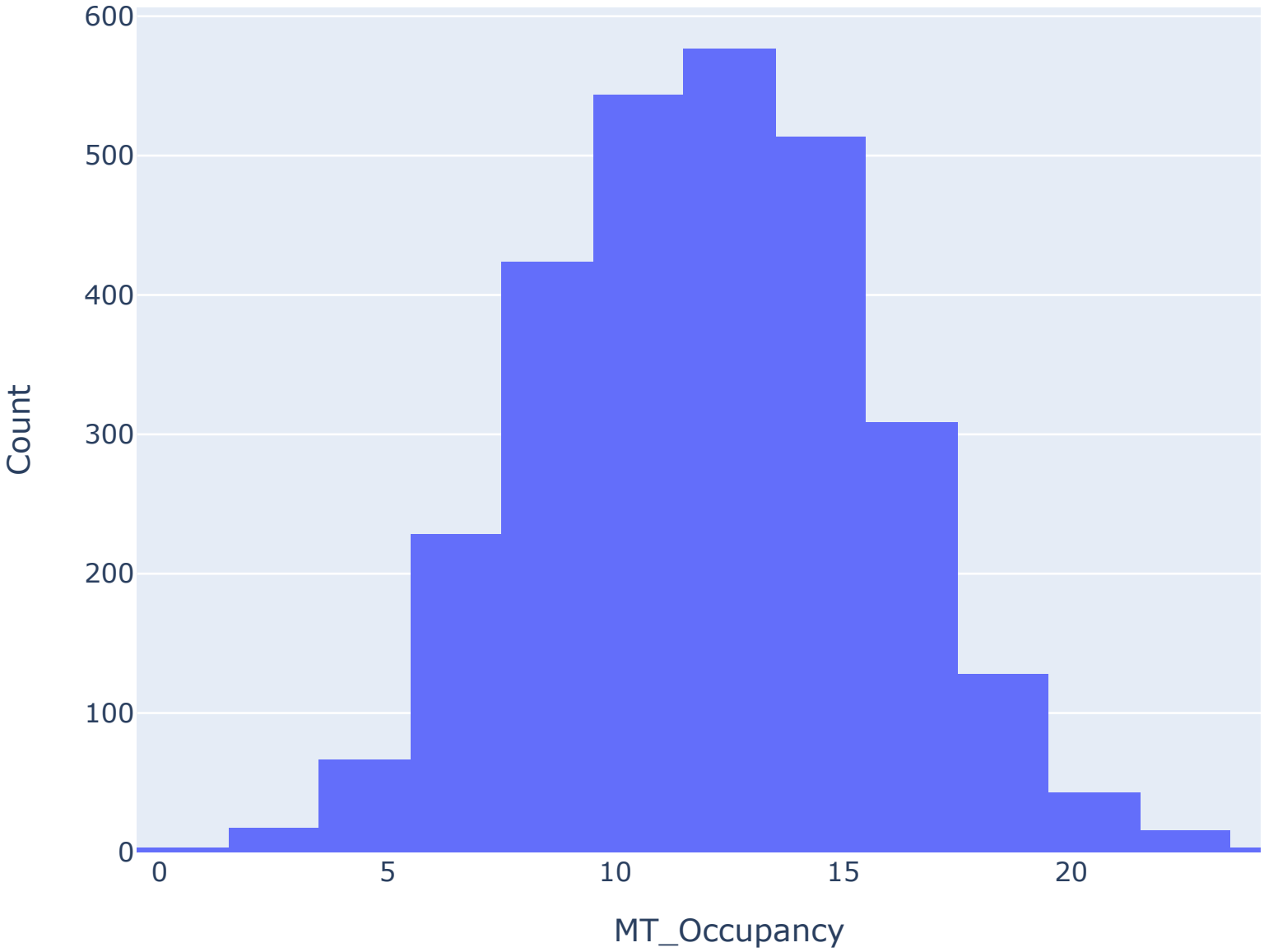

sim2025 - Maternity Occupancy Probability Distribution
Count
600
500
400
300
200
100
0
0
5
10
15
20
MT_Occupancy

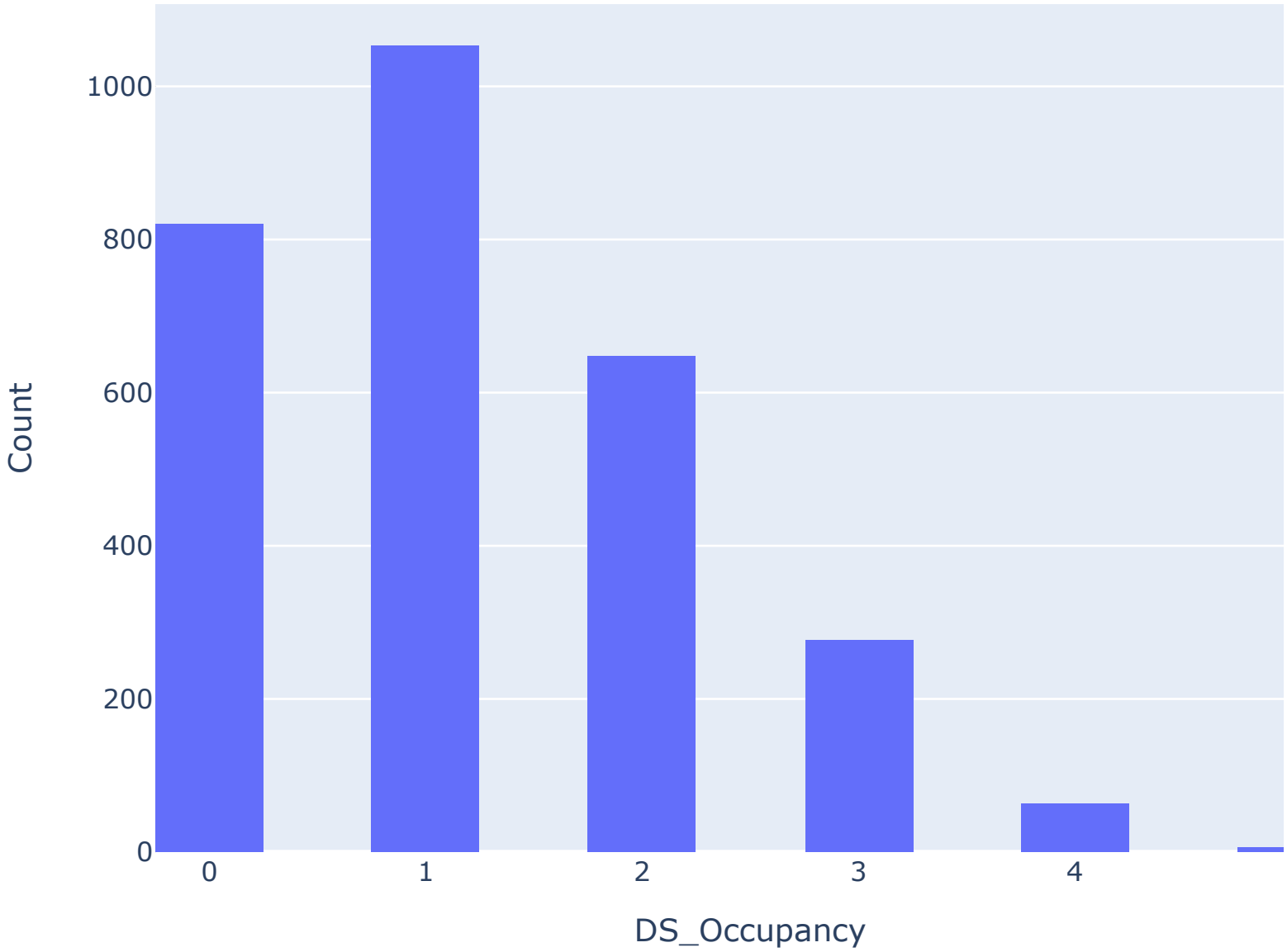

sim2025 - Delivery Suite Occupancy Probability Distribution
Count
1000
800
600
400
200
0
0
1
2
3
4
DS_Occupancy

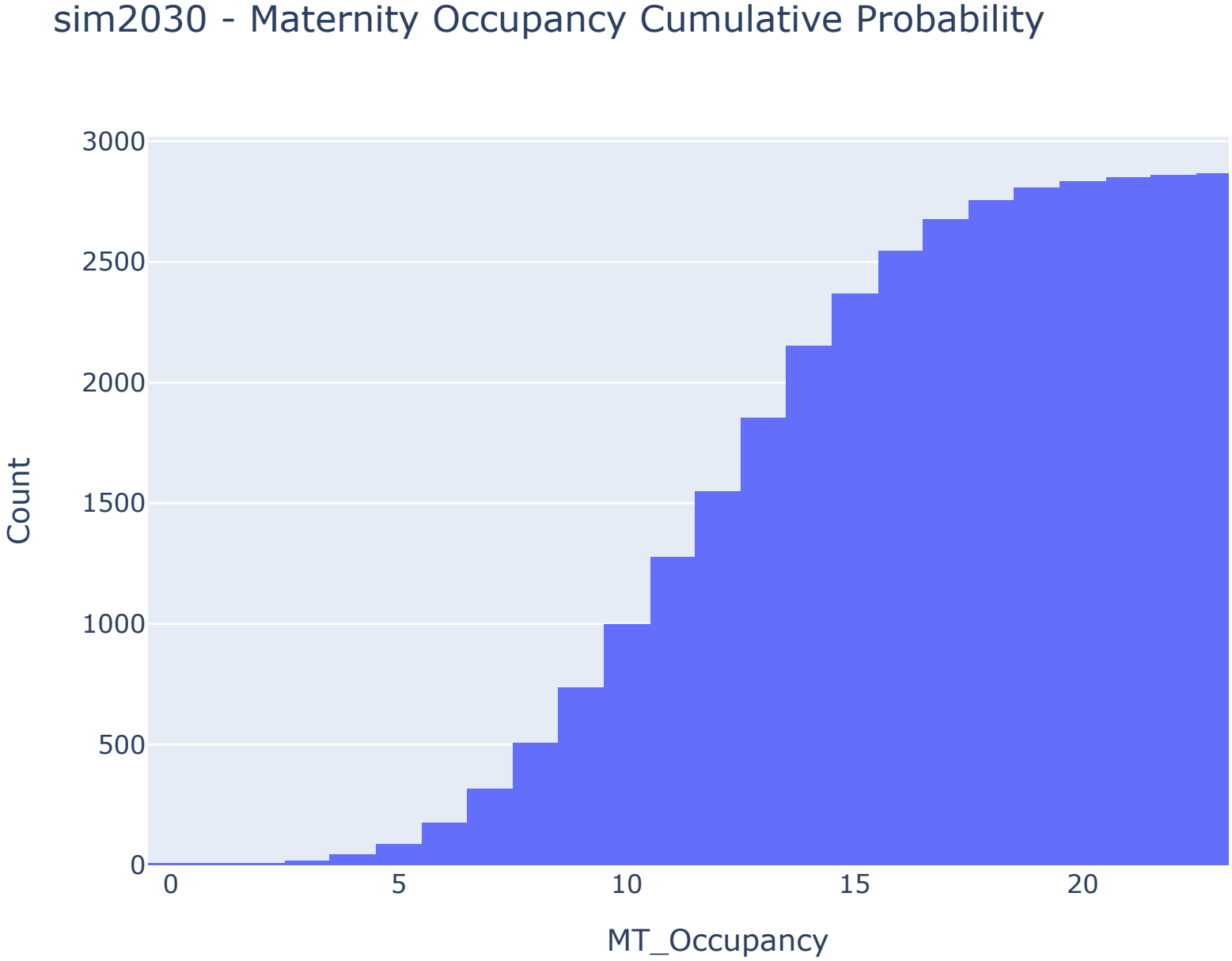

sim2025 - Maternity Occupancy Cumulative Probability
Count
2500
2000
1500
1000
500
0
0
5
10
15
20
MT_Occupancy

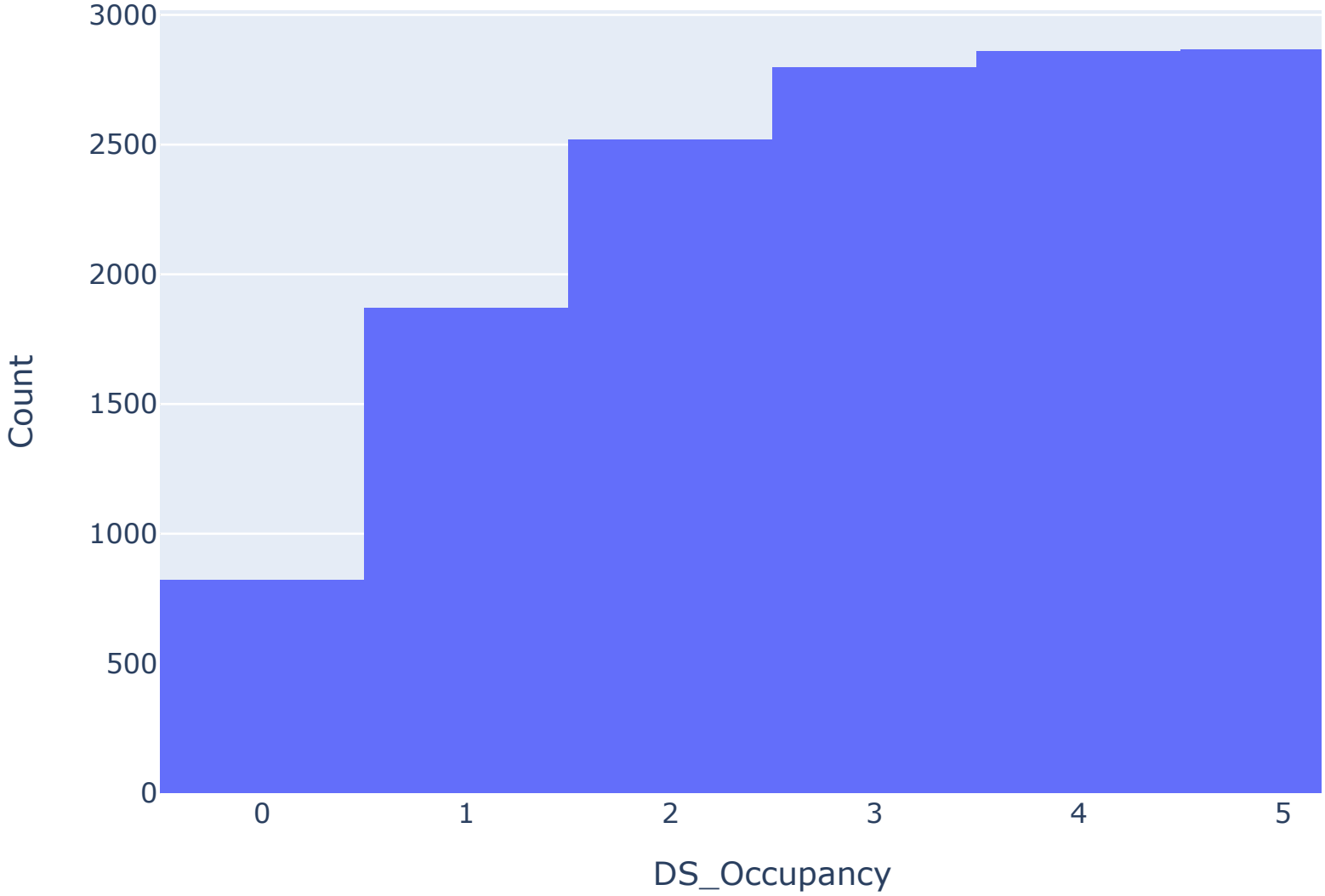

sim2025 - Delivery Suite Occupancy Cumulative Probability
Count
2500
2000
1500
1000
500
0
0
1
2
3
4
5
DS_Occupancy

```
sim2030
1
0
```


sim2030 - Maternity Occupancy Probability Distribution
Count
600
500
400
300
200
100
0
0
5
10
15
20
MT_Occupancy


sim2030 - Delivery Suite Occupancy Probability Distribution
Count
1000
800
600
400
200
0
0
1
2
3
4
DS_Occupancy


sim2030 - Maternity Occupancy Cumulative Probability
Count
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
MT_Occupancy




```
CPU times: user 51.7 s, sys: 693 ms, total: 52.4 s
Wall time: 1min 1s
```

COMBINE ALL DATASETS

In [24]:
```
df = pd.concat([simrun_df, ideal_df, orig_df])
#df.loc[(df.Sim_Name == 'ideal_hist'),'Full_Flow_Code'].unique()
#df.loc[(df.Sim_Name == 'sim2020')&(df.Full_Flow_Code == 'IN-MT-MT-OUT'),:
df.loc[df.Sim_Name == 'ideal_hist',:].describe()
```

Out[24]:

	Sim_No	MT_Occupancy	DS_Occupancy	Day	Year	Hour_of_Day
count	14315.0	14315.000000	14315.000000	14315.000000	14315.000000	14315.000000
mean	1.0	9.064198	1.059029	2.782885	2016.613273	12.368984
std	0.0	2.964369	1.023857	1.967410	2.119510	5.163953
min	1.0	0.000000	0.000000	0.000000	2013.000000	0.000000
25%	1.0	7.000000	0.000000	1.000000	2015.000000	10.000000
50%	1.0	9.000000	1.000000	3.000000	2017.000000	11.000000
75%	1.0	11.000000	2.000000	4.000000	2018.000000	16.000000
max	1.0	20.000000	5.000000	6.000000	2020.000000	23.000000

In [25]:
```
######## REVIEW DATA FROM OBSTETRICS CASES
##### CLEAN TRANSFERS DATA
df = pd.read_csv('Obs_ObstetricCases.csv')
df = df.loc[:,('Link', 'Ward','Admit','SeparationDRGGroupCode')]
obs_df = df
#df = df.loc[df.Ward == 'Maternity',]

df = pd.merge(ideal_df, obs_df, how='left', on='Link')
df.loc[(df.Ward.notnull())].groupby(['Ward_Code','Ward']).count()['Link']
```

Out[25]:
```
Ward_Code  Ward
DS         Delivery Suite          271
           Maternity              2049
           St Catherine              7
           St Clares                19
ICU        Intensive Care Unit       2
           Maternity                79
           St Clares                 1
MT         Intensive Care Unit       1
           Maternity              5714
           St Catherine             39
           St Clares                59
           St Helens                 5
OUT        Delivery Suite          271
           Intensive Care Unit       3
           Maternity              5690
           St Catherine             39
           St Clares                61
           St Helens                 5
Name: Link, dtype: int64
```

In [26]:
```
obs_df.groupby('SeparationDRGGroupCode').count()['Link']
```

Out[26]:
```
SeparationDRGGroupCode
O01    2151
O02      98
O04      62
O60    3295
O61      76
O64      86
O65      60
O66     435
Name: Link, dtype: int64
```

In [27]:
```
import plotly.express as px
fig = px.bar(annual_plot_df, x='Year', y='Int_Arrival', title='Interarrival
fig.show()
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
<ipython-input-27-301e3fc20e9f> in <module>
      1 import plotly.express as px
----> 2 fig = px.bar(annual_plot_df, x='Year', y='Int_Arrival', title='Inte
rarrival Time by Overall Interarrival mean')
      3 fig.show()

NameError: name 'annual_plot_df' is not defined
```

ARRIVALS PER YEAR

In [ ]:
```
# PREPARE DATA FOR ARRIVALS PLOT
df = ideal_df
df = df.loc[df.Year == 2013,'Start'].min()
daysin2013 = df.dayofyear
percentdaysin2013 = (365 - daysin2013) / 365
df = ideal_df
df = df.loc[df.Year == 2020,'End'].max()
daysin2020 = df.dayofyear
percentdaysin2020 = daysin2020 / 365
df = ideal_df
df = df.loc[df.Int_Arrival.notnull(),('Year','Int_Arrival')]
df = df.groupby('Year').count()
df = df.reset_index()
df = df.rename(columns={'Int_Arrival':'No_of_Patients'})
nopatients2013 = df.loc[df.Year == 2013, 'No_of_Patients']
df.loc[df.Year == 2013, 'No_of_Patients'] = int(nopatients2013 / percentday
nopatients2020 = df.loc[df.Year == 2020, 'No_of_Patients']
df.loc[df.Year == 2020, 'No_of_Patients'] = int(nopatients2020 / percentday
#Export Plot to external sheet
df.to_csv("Arrivals_per_Year.csv", index=False)
plot_arrivals_year = df
#Show plot of datat
fig = px.line(plot_arrivals_year, x='Year', y='No_of_Patients', title='Numb
fig.show()
```

IDEAL FLOW PROBABILITY

In [ ]:
```
df = ideal_df
total_patients = df.count().iloc[0]
df = df.loc[df.Prev_Flow == 'IN'].groupby(['Full_Flow_Code']).count()['Link
df = df.reset_index()
df = df.rename(columns={'Link':'No_of_Patients'})
df['Total_Patients'] = total_patients
df['Full_Flow_Code'] = df['Full_Flow_Code'].str[3:-4]
df = df.sort_values('No_of_Patients', ascending = False)
df['Percentage_Patients'] = df.No_of_Patients / df.Total_Patients
df['Cumulative_Probability'] = df.Percentage_Patients.cumsum()
df = df.drop(columns=['No_of_Patients','Total_Patients'])
ideal_patient_flow_prob_plot_df = df
df.to_csv("Ideal_Flow_Probability.csv", index=False)
#Show plot of data
fig = px.bar(ideal_patient_flow_prob_plot_df, x=df['Full_Flow_Code'], y=df
fig.add_scatter(x=df['Full_Flow_Code'], y=df['Cumulative_Probability'], nar
fig.show()
```

In [ ]:
```
ideal_patient_flow_prob_plot_df
```

BRANCHING PROBABILITIES

In [ ]:
```
####### Data Table for Pie Charts
# Split Full flow code data up
df = ideal_df.copy(deep=True)
df = df.loc[df.Prev_Flow == 'IN'].groupby('Full_Flow_Code').count()['Link'
df1 = df.Full_Flow_Code.str.split(pat="-", expand=True)
df = pd.merge(df, df1, left_index=True, right_index=True)
df = df.rename(columns={'Link':'Values'})
# format each level correctly for plats
lvl1_df = df.iloc[:]
lvl1_df['Prev_Flow'] = df[0]
lvl1_df['Ward_Code'] = df[1]
lvl2_df = df.iloc[:]
lvl2_df['Prev_Flow'] = df[0] + '-' + df[1]
lvl2_df['Ward_Code'] = df[2]
lvl3_df = df.iloc[:]
lvl3_df['Prev_Flow'] = df[0]+'-'+df[1]+'-'+df[2]
lvl3_df['Ward_Code'] = df[3]
lvl4_df = df.iloc[:]
lvl4_df['Prev_Flow'] = df[0]+'-'+df[1]+'-'+df[2]+'-'+df[3]
lvl4_df['Ward_Code'] = df[4]
lvl5_df = df.iloc[:]
lvl5_df['Prev_Flow'] = df[0]+'-'+df[1]+'-'+df[2]+'-'+df[3]+'-'+df[4]
lvl5_df['Ward_Code'] = df[5]
lvl6_df = df.iloc[:]
lvl6_df['Prev_Flow'] = df[0]+'-'+df[1]+'-'+df[2]+'-'+df[3]+'-'+df[4]+'-'+d
lvl6_df['Ward_Code'] = df[6]
#bring information back into single dataframe
df = pd.concat([lvl1_df,lvl2_df,lvl3_df,lvl4_df,lvl5_df,lvl6_df])
df = df.dropna(subset=['Ward_Code'])
df = df.drop(columns=['Full_Flow_Code',0,1,2,3,4,5,6])
pie_df = df.copy(deep = True)
pie_df.head()
```

In [ ]:
```
def flow_code_pie_chart(df, prev_flow_code):
    title = prev_flow_code
    filename = 'plots/Patient_Flow/' + title + '.png'
    df = df.loc[df.Prev_Flow == title].groupby('Ward_Code').sum()['Values']
    fig = px.pie(
        data_frame=df,
        values='Values',
        names='Ward_Code',
        color='Ward_Code',
        color_discrete_map = {'MT':'royalblue',
                              'DS':'green',
                              'ICU':'goldenrod',
                              'OUT':'salmon'},
        labels={'Ward_Code':'Next Ward'},
        title=title,
        template='presentation',
        width=800,
        height=600,
        hole=0
    )
    fig.update_traces(textinfo='percent+label')
    #fig.show()
    fig.write_image(filename)
#flow_code_pie_chart(pie_df, 'IN-DS')

def all_flow_code_pie_charts(df):
    temp_df = df.groupby('Prev_Flow').count()['Values'].reset_index()
    for entry in temp_df['Prev_Flow']:
        flow_code_pie_chart(df, entry)
```

In [ ]:
```
%time all_flow_code_pie_charts(pie_df)
```

VERIFICATION OF DATA

In [ ]:
```
df = orig_df
#df = ideal_df
```

In [ ]:
```
df.loc[df.Prev_Flow=='IN'].groupby('Ward_Code').count()['Link']
#df.groupby('Full_Flow_Code').count()['Link']
#df.count()['Link']
#df.loc[df.Prev_Flow=='IN'].groupby('Full_Flow_Code').count()['Link']
#df.groupby('Full_Flow_Code').count()['Link']
```

In [ ]:
```
#IN-DS-MT-OUT
#df.loc[(df.Full_Flow_Code=='IN-DS-MT-OUT')&(df.Prev_Flow=='IN'),('Link',"
#IN-MT-OUT
df.loc[(df.Full_Flow_Code=='IN-MT-OUT')&(df.Prev_Flow=='IN'),('Link',"Ward_
```

In [ ]:
```
arrivalsum_df.head(30)
```

In [ ]:
```
patientflowsum_df.head(50)
```

In [ ]:
```
LOSsum_df.head(50)
```

INTERPRETING RESULTS

In [ ]:
```
ideal_df.groupby('Year').describe()['Int_Arrival']
```

In [ ]:
```
####PRINTING
#jupyter nbconvert Patient_Cap_Sim.ipynb --to webpdf --allow-chromium-down
```