Root Cause Analysis_v3

August 20, 2024

1 Root Cause Analysis - PyRCA

1.1 Import all the necessary libraries

[ ]:
```
import networkx as nx
import numpy as np
import pyrca

from pyrca.analyzers.ht import HT, HTConfig
from pyrca.analyzers.epsilon_diagnosis import EpsilonDiagnosis,␣
  ↪EpsilonDiagnosisConfig
from pyrca.analyzers.bayesian import BayesianNetwork, BayesianNetworkConfig
from pyrca.analyzers.random_walk import RandomWalk, RandomWalkConfig
from pyrca.analyzers.rcd import RCD, RCDConfig

import matplotlib.pyplot as plt
import pandas as pd
import random
import os

# Some functions and libraries throw warnings
from sklearn.exceptions import ConvergenceWarning

import warnings
warnings.filterwarnings("ignore", category=RuntimeWarning)
warnings.filterwarnings("ignore", category=ConvergenceWarning)
warnings.filterwarnings("ignore", category=UserWarning)
warnings.filterwarnings("ignore", category=FutureWarning)
```

```
c:\Users\Francisco\anaconda3\envs\thesis\lib\site-packages\tqdm\auto.py:21:
TqdmWarning: IProgress not found. Please update jupyter and ipywidgets. See
https://ipywidgets.readthedocs.io/en/stable/user_install.html
  from .autonotebook import tqdm as notebook_tqdm
```

1.2 Custom Functions

1.2.1 Data and Directory Functions

```
[ ]: def draw_save(G_graph,pos,node_colors,file_name:str, inter_type:str):
         test = 'test' # no drawings
         plt.figure(figsize=(12, 10))
         plt.xlim((-12,14))
         plt.ylim((-12,8))
         plt.title(f'Causal Graph: {inter_type}', fontsize=12)
         nx.draw(G_graph, pos,with_labels=True,node_size=2000,␣
       ↪node_color=[node_colors[node] for node in G_graph.nodes()], font_size=6,␣
       ↪arrowsize=8,width=0.5)
         # plt.savefig(file_name)
         # nx.write_gml(G_graph, f'{file_name[:-4]}.gml')

     def get_file_name(var:str):
         return var[7:-4]

     def create_data_from_list(files):
         data_df = pd.DataFrame()
         for file in files:
             to_join_df = file
             data_df = pd.concat([data_df,to_join_df.loc[to_join_df.
       ↪index]],ignore_index=True)
         return data_df

     def create_train_data(files,startrow):
         data_df = pd.DataFrame()
         for file_key, file_path in files.items():
             to_join_df =  pd.read_csv(file_path, skiprows=range(1, startrow))
             data_df = pd.concat([data_df,to_join_df.loc[to_join_df.
       ↪index]],ignore_index=True)
         return data_df

     def get_from_dir(directory_path):
         # Get a list of all items (files and directories) in the specified path
         all_items = os.listdir(directory_path)
         # Iterate over each item and check if it's a directory
         for item in all_items:
             folder_path = os.path.join(directory_path, item)
             if os.path.isdir(folder_path):
                 print(f"\nProcessing folder: {item}")
                 folder_contents = os.listdir(folder_path)
                 for file in folder_contents:
                     file_path = os.path.join(folder_path, file)
                     print(f"    -> {file}")
```

```
def get_from_folders(directory_path):
    files = {}
    all_folders = os.listdir(directory_path)
    folder_counter = 0
    for folder in all_folders:
        folder_path = os.path.join(directory_path, folder)
        if os.path.isdir(folder_path):
            folder_contents = os.listdir(folder_path)
            folder_counter +=1
            file_counter = 0
            for file in folder_contents:
                file_path = os.path.join(folder_path, file)
                if file[0:4] == 'data' and file[7:12] != 'event':
                    file_counter += 1
                    files[f"{get_file_name(file)}-{folder_counter}.
 ↪{file_counter}"] = file_path
    return files, directory_path

def results_top_3(results,abnormal_set):
    result_columns = results.columns.to_list()
    result_index = results.index.to_list()

    result_data_3top = pd.DataFrame(columns=result_index, index=result_columns)

    for col in result_columns:
        for ind in result_index:
            for elem in results[col][ind]:
                if elem in abnormal_set[col.rsplit('-', 1)[0]].to_list():
                    result_data_3top[ind][col] = 1

    result_data_3top = result_data_3top.fillna(0)

    total_hit = (result_data_3top.sum('index')/len(result_columns)).to_dict()
    result_data_3top = pd.concat([result_data_3top,pd.
 ↪DataFrame(total_hit,index=['Total'])])

    return result_data_3top

def results_top_1(results,abnormal_set):
    result_columns = results.columns.to_list()
    result_index = results.index.to_list()
    result_data_1top = pd.DataFrame(columns=result_index, index=result_columns)
    for col in result_columns:
        for ind in result_index:
            try: elem = results[col][ind][0] # In case where RCD did not␣
 ↪provide any root causes
            except: continue
            if elem in abnormal_set[col.rsplit('-', 1)[0]].to_list():
                result_data_1top[ind][col] = 1

    result_data_1top = result_data_1top.fillna(0)

    total_hit = (result_data_1top.sum('index')/len(result_columns)).to_dict()
    result_data_1top = pd.concat([result_data_1top,pd.
 ↪DataFrame(total_hit,index=['Total'])])

    return result_data_1top
```

1.2.2 Algorithms

HT - Algorithms

[ ]:

```
# Function run hypothesis testing algorithm
def run_HT(folder_path: str,
           files: dict,
           startrow: int,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}
    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []
        new_colors = colors.copy()

        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'
                results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True).to_list()
```

```
        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_HT.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_HT_overlap(folder_path: str,
           files: dict,
           startrow: int,
           overlap_p:float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results_overlap'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index', columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])
    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1, startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Replace first N rows with overlap data
        data_length = abnormal_data_df.shape[0]
        overlap_n = int(np.rint(overlap_p*data_length))
        overlap_df = normal_data_df.iloc[-overlap_n:]
        abnormal_data_df = abnormal_data_df.iloc[-(data_length-overlap_n):]

        # Overlap of overlap_p timestamps
        abnormal_data_df = pd.concat([overlap_df,abnormal_data_df], ignore_index=True)

        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []
        new_colors = colors.copy()

        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'
                results[node] = model.find_root_causes(abnormal_data_df, node, True).to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])
        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_HT.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_HT_size(folder_path: str,
           files: dict,
           startrow: int,
           size_p:float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    size_n = int(np.rint(size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:size_n]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index', columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1, startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_data_df = abnormal_data_df.iloc[:size_n]
        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []
        new_colors = colors.copy()

        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'
                results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True).to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_HT.png'

        file_name_save = os.path.join(path, filename)
        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_HT_normal_size(folder_path: str,
           files: dict,
           startrow: int,
           normal_size_p:float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    normal_size_n = int(np.rint(normal_size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:normal_size_n]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []
        new_colors = colors.copy()

        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'
                results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True).to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_HT.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_HT_abnormal_size(folder_path: str,
           files: dict,
           startrow: int,
           abnormal_size_p:float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere
```

```
    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1, startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Resize abnormal data relative to one cycle time - 26.3 equals 526 timestamps
        data_length = 526
        abnormal_size_n = int(np.rint(abnormal_size_p*data_length))
        # We take the first N timestamps
        abnormal_data_df = abnormal_data_df.iloc[:abnormal_size_n]

        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []
        new_colors = colors.copy()

        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'
                results[node] = model.find_root_causes(abnormal_data_df, node, True).to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'
        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_HT.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save, file_names[file_counter])

    return results_out

def run_HT_edges_delete(folder_path: str,
           files: dict,
           startrow: int,
           edges_delete_n:int,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    edges_to_delete = random.sample(edges_list, edges_delete_n)
    edges_list_new = edges_list.copy()

    for edge in edges_to_delete:
        edges_list_new.remove(edge)

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list_new)

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['HT'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        model = HT(config=HTConfig(adj_matrix_extended_pd))
        model.train(normal_data_df)

        abnormal_nodes = []
        new_colors = colors.copy()

        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            if (abnormal_data_df[node] <100).any(): # Score instead of EoL
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'
                results[node] = model.find_root_causes(abnormal_data_df, node,␣
↪True,).to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for node in abnormal_nodes:
            rank1_root_cause.append(results[node][0]['root_cause'])
            rank2_root_cause.append(results[node][1]['root_cause'])
            rank3_root_cause.append(results[node][2]['root_cause'])

            root_cause_results.append(results[node][0]['root_cause'])
            root_cause_results.append(results[node][1]['root_cause'])
            root_cause_results.append(results[node][2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_HT.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_HT.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
↪file_names[file_counter])

    return results_out
```

ED - Algorithms

[ ]:
```
# Function run epsilon diagnosis algorithm
def run_ED(folder_path: str,
           files: dict,
           startrow: int,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_ED.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
```

```
        counter += 1
        abnormal_files[file_key] = file_path
        file_names.append(file_key+'_'+str(counter))

abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])

results_out = pd.DataFrame(index = ['ED'])

for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
    abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
    abnormal_data_df = abnormal_data_df[nodes]

    model = EpsilonDiagnosis(EpsilonDiagnosisConfig(alpha=0.
↪05,root_cause_top_k=3,bootstrap_time=200))
    abnormal_nodes = []
    new_colors = colors.copy()
    root_cause_results = []

    model.train(normal_data_df)

    for node in key_nodes:
        # Basic Anomaly Detection
        if (abnormal_data_df[node] <100).any():
            abnormal_nodes.append(node)
            new_colors[node] = 'yellow'

    results = model.find_root_causes(abnormal_data_df).to_list()

    rank1_root_cause = []
    rank2_root_cause = []
    rank3_root_cause = []

    for i in range(0,int(np.trunc(len(results)/3))):
        rank1_root_cause.append(results[i]['root_cause'])
        rank2_root_cause.append(results[i+1]['root_cause'])
        rank3_root_cause.append(results[i+2]['root_cause'])

        root_cause_results.append(results[0]['root_cause'])
        root_cause_results.append(results[1]['root_cause'])
        root_cause_results.append(results[2]['root_cause'])

    results_out[file_names[file_counter]] = [root_cause_results]
    results_file_name = f'results_{file_names[file_counter]}_ED.csv'
    results_out.to_csv(os.path.join(path, results_file_name), index=False)
```

```
        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_ED.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_ED_overlap(folder_path: str,
           files: dict,
           startrow: int,
           overlap_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results_overlap'
            filename = f'{file_key}_ED.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['ED'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Replace first N rows with overlap data
        data_length = abnormal_data_df.shape[0]
        overlap_n = int(np.rint(overlap_p*data_length))
        overlap_df = normal_data_df.iloc[-overlap_n:]
        abnormal_data_df = abnormal_data_df.iloc[-(data_length-overlap_n):]

        # Overlap of overlap_p timestamps
        abnormal_data_df = pd.concat([overlap_df,abnormal_data_df],␣
↪ignore_index=True)
```

```
        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        model = EpsilonDiagnosis(EpsilonDiagnosisConfig(alpha=0.
↪05,root_cause_top_k=3,bootstrap_time=200))
        model.train(normal_data_df)

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any():
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'

        results = model.find_root_causes(abnormal_data_df).to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_ED.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_ED.png'

        file_name_save = os.path.join(path, filename)
        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_ED_size(folder_path: str,
           files: dict,
           startrow: int,
           size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)

    interventions = {'gripper_1':'interGripper1',
                    'gripper_2':'interGripper2',
                    'max_Vel_1':'interVeloRob1',
                    'max_Vel_2':'interVeloRob2',
                    'camera_1':'interCamera1',
                    'camera_2':'interCamera2',
                    'camera_3':'interCamera3',
                    'conveyor_1':'interConveyor1',
                    'conveyor_2':'interConveyor2',
                    'conveyor_3':'interConveyor3',
                    'feeder_1':'interFeeder1',
                    'feeder_2':'interFeeder2',
                    'feeder_3':'interFeeder3',
                    'size_1':'interSize1',
                    'size_2':'interSize2',
                    'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results_overlap'
            filename = f'{file_key}_ED.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    size_n = int(np.rint(size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:size_n]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index', columns=['file_path'])
    results_out = pd.DataFrame(index = ['ED'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1, startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_data_df = abnormal_data_df.iloc[:size_n]

        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        model = EpsilonDiagnosis(EpsilonDiagnosisConfig(alpha=0.05,root_cause_top_k=3,bootstrap_time=200))
        model.train(normal_data_df)

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any():
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'

        results = model.find_root_causes(abnormal_data_df).to_list()
        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []

        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_ED.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_ED.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out
```

RW - Algorithms

[ ]:

```
# Function run random walk algorithm
def run_RW(folder_path: str,
           files: dict,
           #train_file:pd.DataFrame,
           startrow: int,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):
```

```
    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))
    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])

    results_out = pd.DataFrame(index = ['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'

        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RW.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save, file_names[file_counter])

    return results_out

def run_RW_overlap(folder_path: str,
           files: dict,
           #train_file:pd.DataFrame,
           startrow: int,
           overlap_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(), columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results_overlap'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])

    results_out = pd.DataFrame(index = ['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Replace first N rows with overlap data
        data_length = abnormal_data_df.shape[0]
        overlap_n = int(np.rint(overlap_p*data_length))
        overlap_df = normal_data_df.iloc[-overlap_n:]
        abnormal_data_df = abnormal_data_df.iloc[-(data_length-overlap_n):]

        # Overlap of overlap_p timestamps
        abnormal_data_df = pd.concat([overlap_df,abnormal_data_df],␣
↪ignore_index=True)

        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'

        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RW.png'
        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_RW_size(folder_path: str,
           files: dict,
           #train_file:pd.DataFrame,
           startrow: int,
           size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))
    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    size_n = int(np.rint(size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:size_n]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_data_df = abnormal_data_df.iloc[:size_n]

        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'

        results = model.
 ↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
 ↪to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RW.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_RW_normal_size(folder_path: str,
           files: dict,
           #train_file:pd.DataFrame,
           startrow: int,
           normal_size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(), columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    normal_size_n = int(np.rint(normal_size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:normal_size_n]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])

    results_out = pd.DataFrame(index = ['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'

        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RW.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
↪file_names[file_counter])

    return results_out

def run_RW_abnormal_size(folder_path: str,
           files: dict,
           #train_file:pd.DataFrame,
           startrow: int,
           abnormal_size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))


    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])

    results_out = pd.DataFrame(index = ['RW'])
    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Resize abnormal data relative to one cycle time - 26.3 equals 526␣
↪timestamps
        data_length = 526
        abnormal_size_n = int(np.rint(abnormal_size_p*data_length))
        # We take the first N timestamps
        abnormal_data_df = abnormal_data_df.iloc[:abnormal_size_n]

        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'

        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([normal_data_df,abnormal_data_df])).
↪to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)
        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RW.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_RW_edges_delete(folder_path: str,
           files: dict,
           #train_file:pd.DataFrame,
           startrow: int,
           edges_delete_n: int,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    edges_to_delete = random.sample(edges_list, edges_delete_n)
    edges_list_new = edges_list.copy()

    for edge in edges_to_delete:
        edges_list_new.remove(edge)

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list_new)

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
    ↪columns=['file_path'])

    results_out = pd.DataFrame(index = ['RW'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
    ↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
    ↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]
```

```
        model =␣
↪RandomWalk(RandomWalkConfig(graph=adjacency_df,root_cause_top_k=3))
        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        for node in key_nodes:
            # Basic Anomaly Detection
            if (abnormal_data_df[node] <100).any(): # from EoL to score
                abnormal_nodes.append(node)
                new_colors[node] = 'yellow'

        results = model.
↪find_root_causes(abnormal_nodes,create_data_from_list([abnormal_data_df,normal_data_df])).
↪to_list()

        rank1_root_cause = []
        rank2_root_cause = []
        rank3_root_cause = []


        for i in range(0,int(np.trunc(len(results)/3))):
            rank1_root_cause.append(results[i]['root_cause'])
            rank2_root_cause.append(results[i+1]['root_cause'])
            rank3_root_cause.append(results[i+2]['root_cause'])

            root_cause_results.append(results[0]['root_cause'])
            root_cause_results.append(results[1]['root_cause'])
            root_cause_results.append(results[2]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RW.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RW.png'

        file_name_save = os.path.join(path, filename)
        #draw_save(G_graph, pos, new_colors, file_name_save,␣
↪file_names[file_counter])

    return results_out
```

RCD - Algorithms

[ ]:

```
# Function run Root cause discovery algorithm
def run_RCD(folder_path: str,
            files: dict,
            startrow: int,
            nodes: list,
            edges_list:list,
            key_nodes: list,
            colors: dict,
            pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0
    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
            if (abnormal_data_df[node] < 100).any():
                error = True
                while error:
                    abnormal_nodes.append(node)
                    new_colors[node] = 'yellow'
                    try:
                        results[node] = model.
↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
                        error = False
                    except:
                        continue
            rank1_root_cause = []
            rank2_root_cause = []
            rank3_root_cause = []

            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RCD.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out

def run_RCD_overlap(folder_path: str,
           files: dict,
           startrow: int,
           overlap_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results_overlap'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Replace first N rows with overlap data
        data_length = abnormal_data_df.shape[0]
        overlap_n = int(np.rint(overlap_p*data_length))
        overlap_df = normal_data_df.iloc[-overlap_n:]
        abnormal_data_df = abnormal_data_df.iloc[-(data_length-overlap_n):]

        # Overlap of overlap_p timestamps
        abnormal_data_df = pd.concat([overlap_df,abnormal_data_df],␣
↪ignore_index=True)

        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
            if (abnormal_data_df[node] < 100).any():
                error = True
                while error:
                    abnormal_nodes.append(node)
                    new_colors[node] = 'yellow'
                    try:
                        results[node] = model.
↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
```

```
                        error = False
                    except:
                        continue

            rank1_root_cause = []
            rank2_root_cause = []
            rank3_root_cause = []

            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RCD.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
↪file_names[file_counter])
```

```
    return results_out

def run_RCD_size(folder_path: str,
           files: dict,
           startrow: int,
           size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    size_n = int(np.rint(size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:size_n]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_data_df = abnormal_data_df.iloc[:size_n]

        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
            if (abnormal_data_df[node] < 100).any():
                error = True
                while error:
                    abnormal_nodes.append(node)
                    new_colors[node] = 'yellow'
                    try:
                        results[node] = model.
↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
```

```
                error = False
            except:
                continue

    rank1_root_cause = []
    rank2_root_cause = []
    rank3_root_cause = []

    if len(results[node]) == 3:
        rank1_root_cause.append(results[node][0]['root_cause'])
        rank2_root_cause.append(results[node][1]['root_cause'])
        rank3_root_cause.append(results[node][2]['root_cause'])

        root_cause_results.append(results[node][0]['root_cause'])
        root_cause_results.append(results[node][1]['root_cause'])
        root_cause_results.append(results[node][2]['root_cause'])
    elif len(results[node]) == 2:
        rank1_root_cause.append(results[node][0]['root_cause'])
        rank2_root_cause.append(results[node][1]['root_cause'])

        root_cause_results.append(results[node][0]['root_cause'])
        root_cause_results.append(results[node][1]['root_cause'])

    elif len(results[node]) == 1:
        rank1_root_cause.append(results[node][0]['root_cause'])
        root_cause_results.append(results[node][0]['root_cause'])

results_out[file_names[file_counter]] = [root_cause_results]
results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
results_out.to_csv(os.path.join(path, results_file_name), index=False)

for node in rank1_root_cause:
    new_colors[node] = 'red'

for node in rank2_root_cause:
    new_colors[node] = 'crimson'

for node in rank3_root_cause:
    new_colors[node] = 'lightcoral'

filename = f'{file_names[file_counter]}_RCD.png'

file_name_save = os.path.join(path, filename)

#draw_save(G_graph, pos, new_colors, file_name_save,␣
↪file_names[file_counter])
```

```
    return results_out

def run_RCD_normal_size(folder_path: str,
           files: dict,
           startrow: int,
           normal_size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(), columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    # Resize normal data relative to one cycle time - 26.3 equals 526 timestamps
    data_length = 526
    normal_size_n = int(np.rint(normal_size_p*data_length))
    # We take the first N timestamps
    normal_data_df = normal_data_df.iloc[:normal_size_n]

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
 ↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
 ↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
 ↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
 ↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
            if (abnormal_data_df[node] < 100).any():
                error = True
                while error:
                    abnormal_nodes.append(node)
                    new_colors[node] = 'yellow'
                    try:
                        results[node] = model.
 ↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
                        error = False
                    except:
                        continue

            rank1_root_cause = []
            rank2_root_cause = []
            rank3_root_cause = []

            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RCD.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
↪file_names[file_counter])

    return results_out
```

```
def run_RCD_abnormal_size(folder_path: str,
           files: dict,
           startrow: int,
           abnormal_size_p: float,
           nodes: list,
           edges_list:list,
           key_nodes: list,
           colors: dict,
           pos: dict):

    G_graph = nx.DiGraph()
    G_graph.add_nodes_from(nodes)
    G_graph.add_edges_from(edges_list)  # Make sure `edges_list` is defined␣
 ↪somewhere

    adj_matrix_extended_pd = nx.to_pandas_adjacency(G_graph, nodes)
    adj_matrix_extended = nx.adjacency_matrix(G_graph,nodes).todense()
    adjacency_df = pd.DataFrame(adj_matrix_extended, index=G_graph.nodes(),␣
 ↪columns=G_graph.nodes())

    interventions = {'gripper_1':'interGripper1',
         'gripper_2':'interGripper2',
         'max_Vel_1':'interVeloRob1',
         'max_Vel_2':'interVeloRob2',
         'camera_1':'interCamera1',
         'camera_2':'interCamera2',
         'camera_3':'interCamera3',
         'conveyor_1':'interConveyor1',
         'conveyor_2':'interConveyor2',
         'conveyor_3':'interConveyor3',
         'feeder_1':'interFeeder1',
         'feeder_2':'interFeeder2',
         'feeder_3':'interFeeder3',
         'size_1':'interSize1',
         'size_2':'interSize2',
         'size_3':'interSize3'}

    abnormal_files = {}
    file_names = []
    counter = 0

    for file_key, file_path in files.items():
        temp_file_key = file_key.rsplit('-', 1)[0]
        if temp_file_key == 'normal':
            normal_data_df = pd.read_csv(file_path, skiprows=range(1, startrow))
            normal_data_df = normal_data_df[nodes]
            folder_name = 'Results'
            filename = f'{file_key}_HT.png'
            path = os.path.join(folder_path, folder_name)
            os.makedirs(path, exist_ok=True)
            file_name_save = os.path.join(path, filename)
            #draw_save(G_graph, pos, colors, file_name_save, file_key)

        if temp_file_key in interventions:
            counter += 1
            abnormal_files[file_key] = file_path
            file_names.append(file_key+'_'+str(counter))

    abnormal_paths_df = pd.DataFrame.from_dict(abnormal_files, orient='index',␣
↪columns=['file_path'])
    results_out = pd.DataFrame(index = ['RCD'])

    for file_counter, abnormal_file_path in enumerate(abnormal_paths_df.values.
↪flatten()):
        abnormal_data_df = pd.read_csv(abnormal_file_path, skiprows=range(1,␣
↪startrow))
        abnormal_data_df = abnormal_data_df[nodes]

        # Resize abnormal data relative to one cycle time - 26.3 equals 526␣
↪timestamps
        data_length = 526
        abnormal_size_n = int(np.rint(abnormal_size_p*data_length))
        # We take the first N timestamps
        abnormal_data_df = abnormal_data_df.iloc[:abnormal_size_n]

        abnormal_nodes = []
        new_colors = colors.copy()
        root_cause_results = []

        results = pd.DataFrame()
        for node in key_nodes:
            model = RCD(RCDConfig(bins=5,f_node=node,localized=True,k=3))␣
↪#alpha_step=0.05,start_alpha=0.001,alpha_limit=0.5
            if (abnormal_data_df[node] < 100).any():
                error = True
                while error:
                    abnormal_nodes.append(node)
                    new_colors[node] = 'yellow'
                    try:
                        results[node] = model.
↪find_root_causes(normal_data_df,abnormal_data_df).to_list()
                        error = False
                    except:
                        continue

            rank1_root_cause = []
            rank2_root_cause = []
            rank3_root_cause = []

            if len(results[node]) == 3:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])
                rank3_root_cause.append(results[node][2]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])
                root_cause_results.append(results[node][2]['root_cause'])
            elif len(results[node]) == 2:
                rank1_root_cause.append(results[node][0]['root_cause'])
                rank2_root_cause.append(results[node][1]['root_cause'])

                root_cause_results.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][1]['root_cause'])

            elif len(results[node]) == 1:
                rank1_root_cause.append(results[node][0]['root_cause'])
                root_cause_results.append(results[node][0]['root_cause'])

        results_out[file_names[file_counter]] = [root_cause_results]
        results_file_name = f'results_{file_names[file_counter]}_RCD.csv'
        results_out.to_csv(os.path.join(path, results_file_name), index=False)

        for node in rank1_root_cause:
            new_colors[node] = 'red'

        for node in rank2_root_cause:
            new_colors[node] = 'crimson'

        for node in rank3_root_cause:
            new_colors[node] = 'lightcoral'

        filename = f'{file_names[file_counter]}_RCD.png'

        file_name_save = os.path.join(path, filename)

        #draw_save(G_graph, pos, new_colors, file_name_save,␣
 ↪file_names[file_counter])

    return results_out
```

1.3 Create the Causal Graph (non-lagged)

1.3.1 Graph Parameters

```
[ ]: nodes = [
         'cam_1_X', 'cam_2_X', 'cam_3_X',
         'cam_1_Y', 'cam_2_Y', 'cam_3_Y',
         'EoL_1_X', 'EoL_2_X', 'EoL_3_X', 'EoL_4_X', 'EoL_5_X', 'EoL_6_X',
         'EoL_1_Y', 'EoL_2_Y', 'EoL_3_Y', 'EoL_4_Y', 'EoL_5_Y', 'EoL_6_Y',
         'rob_1_1', 'rob_1_2', 'rob_1_3', 'rob_1_4', 'rob_1_maxVel',
         'rob_2_1', 'rob_2_2', 'rob_2_3', 'rob_2_4', 'rob_2_maxVel',
         'rob_1_supply', 'rob_2_supply',
         'rob_1_vacuum', 'rob_2_vacuum',
         'con_1','con_2','con_3',
         'score'
     ]



     edges = [
         ('cam_1_X', 'rob_2_1'), ('cam_1_Y', 'rob_2_1'),
         ('cam_1_X', 'rob_2_2'), ('cam_1_Y', 'rob_2_2'),
         ('cam_1_X', 'rob_2_3'), ('cam_1_Y', 'rob_2_3'),
         ('cam_1_X', 'rob_2_4'), ('cam_1_Y', 'rob_2_4'),

         ('cam_2_X', 'rob_1_1'), ('cam_2_Y', 'rob_1_1'),
         ('cam_2_X', 'rob_1_2'), ('cam_2_Y', 'rob_1_2'),
         ('cam_2_X', 'rob_1_3'), ('cam_2_Y', 'rob_1_3'),
         ('cam_2_X', 'rob_1_4'), ('cam_2_Y', 'rob_1_4'),

         ('cam_3_X', 'rob_1_1'), ('cam_3_Y', 'rob_1_1'),
         ('cam_3_X', 'rob_1_2'), ('cam_3_Y', 'rob_1_2'),
         ('cam_3_X', 'rob_1_3'), ('cam_3_Y', 'rob_1_3'),
         ('cam_3_X', 'rob_1_4'), ('cam_3_Y', 'rob_1_4'),

         ('rob_1_maxVel', 'rob_1_1'), ('rob_1_maxVel', 'rob_1_2'),
         ('rob_1_maxVel', 'rob_1_3'), ('rob_1_maxVel', 'rob_1_4'),

         ('rob_2_maxVel', 'rob_2_1'), ('rob_2_maxVel', 'rob_2_2'),
         ('rob_2_maxVel', 'rob_2_3'), ('rob_2_maxVel', 'rob_2_4'),

         ('con_2', 'rob_1_1'), ('con_2', 'rob_1_2'), ('con_2', 'rob_1_3'), ('con_2',␣
       ↪'rob_1_4'),
         ('con_3', 'rob_1_1'), ('con_3', 'rob_1_2'), ('con_3', 'rob_1_3'), ('con_3',␣
       ↪'rob_1_4'),

         ('con_2', 'rob_2_1'), ('con_2', 'rob_2_2'), ('con_2', 'rob_2_3'), ('con_2',␣
       ↪'rob_2_4'),
         ('con_1', 'rob_2_1'), ('con_1', 'rob_2_2'), ('con_1', 'rob_2_3'), ('con_1',␣
       ↪'rob_2_4'),

         ('con_2', 'EoL_1_X'), ('con_2', 'EoL_1_Y'),

         ('rob_1_1', 'rob_2_1'), ('rob_1_1', 'rob_2_2'), ('rob_1_1', 'rob_2_3'),␣
       ↪('rob_1_1', 'rob_2_4'),
         ('rob_1_2', 'rob_2_1'), ('rob_1_2', 'rob_2_2'), ('rob_1_2', 'rob_2_3'),␣
       ↪('rob_1_2', 'rob_2_4'),
         ('rob_1_3', 'rob_2_1'), ('rob_1_3', 'rob_2_2'), ('rob_1_3', 'rob_2_3'),␣
       ↪('rob_1_3', 'rob_2_4'),
         ('rob_1_4', 'rob_2_1'), ('rob_1_4', 'rob_2_2'), ('rob_1_4', 'rob_2_3'),␣
       ↪('rob_1_4', 'rob_2_4'),

         ('rob_1_supply', 'rob_1_vacuum'),
         ('rob_2_supply', 'rob_2_vacuum'),


         ('rob_1_vacuum', 'rob_2_1'), ('rob_1_vacuum', 'rob_2_2'),
         ('rob_1_vacuum', 'rob_2_3'), ('rob_1_vacuum', 'rob_2_4'),

         ('rob_1_1', 'EoL_2_X'), ('rob_1_2', 'EoL_2_X'),
         ('rob_1_3', 'EoL_2_X'), ('rob_1_4', 'EoL_2_X'),
         ('rob_1_1', 'EoL_2_Y'), ('rob_1_2', 'EoL_2_Y'),
         ('rob_1_3', 'EoL_2_Y'), ('rob_1_4', 'EoL_2_Y'),

         ('rob_2_1', 'EoL_3_X'), ('rob_2_2', 'EoL_3_X'),
         ('rob_2_3', 'EoL_3_X'), ('rob_2_4', 'EoL_3_X'),
         ('rob_2_1', 'EoL_3_Y'), ('rob_2_2', 'EoL_3_Y'),
         ('rob_2_3', 'EoL_3_Y'), ('rob_2_4', 'EoL_3_Y'),

         ('rob_2_1', 'EoL_4_X'), ('rob_2_2', 'EoL_4_X'),
         ('rob_2_3', 'EoL_4_X'), ('rob_2_4', 'EoL_4_X'),
         ('rob_2_1', 'EoL_4_Y'), ('rob_2_2', 'EoL_4_Y'),
         ('rob_2_3', 'EoL_4_Y'), ('rob_2_4', 'EoL_4_Y'),

         ('rob_2_1', 'EoL_5_X'), ('rob_2_2', 'EoL_5_X'),
         ('rob_2_3', 'EoL_5_X'), ('rob_2_4', 'EoL_5_X'),
         ('rob_2_1', 'EoL_5_Y'), ('rob_2_2', 'EoL_5_Y'),
         ('rob_2_3', 'EoL_5_Y'), ('rob_2_4', 'EoL_5_Y'),

         ('rob_2_1', 'EoL_6_X'), ('rob_2_2', 'EoL_6_X'),
         ('rob_2_3', 'EoL_6_X'), ('rob_2_4', 'EoL_6_X'),
         ('rob_2_1', 'EoL_6_Y'), ('rob_2_2', 'EoL_6_Y'),
         ('rob_2_3', 'EoL_6_Y'), ('rob_2_4', 'EoL_6_Y'),

         ('rob_1_vacuum', 'EoL_2_X'), ('rob_1_vacuum', 'EoL_2_Y'),
         ('rob_2_vacuum', 'EoL_3_X'), ('rob_2_vacuum', 'EoL_3_Y'),
         ('rob_2_vacuum', 'EoL_4_X'), ('rob_2_vacuum', 'EoL_4_Y'),
         ('rob_2_vacuum', 'EoL_5_X'), ('rob_2_vacuum', 'EoL_5_Y'),
         ('rob_2_vacuum', 'EoL_6_X'), ('rob_2_vacuum', 'EoL_6_Y'),

         ('EoL_1_X','score'), ('EoL_2_X','score'), ('EoL_3_X','score'),␣
      ↪('EoL_4_X','score'), ('EoL_5_X','score'), ('EoL_6_X','score'),
         ('EoL_1_Y','score'), ('EoL_2_Y','score'), ('EoL_3_Y','score'),␣
      ↪('EoL_4_Y','score'), ('EoL_5_Y','score'), ('EoL_6_Y','score')
     ]

     print(len(edges))

     check_nodes = ['score']
```

```
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```

1.3.2 Additional Parameters

[ ]:

```
pos = {
    'cam_1_X':(8,4), 'cam_2_X':(-9,6), 'cam_3_X':(-5,6),
    'cam_1_Y':(8,2), 'cam_2_Y':(-7,6), 'cam_3_Y':(-3,6),
    'EoL_1_X':(10,-8), 'EoL_2_X':(-10,-8), 'EoL_3_X':(-6,-8), 'EoL_4_X':
 ↪(-2,-8), 'EoL_5_X':(2,-8), 'EoL_6_X':(6,-8),
    'EoL_1_Y':(12,-8), 'EoL_2_Y':(-8,-8), 'EoL_3_Y':(-4,-8), 'EoL_4_Y':(0,-8),␣
 ↪'EoL_5_Y':(4,-8), 'EoL_6_Y':(8,-8),
    'score':(0,-10),
    'rob_2_1':(-6,-4), 'rob_2_2':(-4,-4), 'rob_2_3':(-2,-4), 'rob_2_4':(-0,-4),␣
 ↪'rob_2_maxVel':(2,-4),
    'rob_1_1':(-9,1), 'rob_1_2':(-7,1), 'rob_1_3':(-5,1), 'rob_1_4':(-3,1),␣
 ↪'rob_1_maxVel':(-1,1),
    'rob_1_vacuum':(2,1), 'rob_2_vacuum':(5,-4),'rob_1_supply':(5,1),␣
 ↪'rob_2_supply':(8,-4),
    'con_1':(8,-1),'con_2':(11,6),'con_3':(3,6)
}

colors = {
    'cam_1_X':'skyblue', 'cam_2_X':'skyblue', 'cam_3_X':'skyblue',
    'cam_1_Y':'skyblue', 'cam_2_Y':'skyblue', 'cam_3_Y':'skyblue',
    'EoL_1_X':'lightgreen', 'EoL_2_X':'lightgreen', 'EoL_3_X':'lightgreen',␣
 ↪'EoL_4_X':'lightgreen', 'EoL_5_X':'lightgreen', 'EoL_6_X':'lightgreen',
    'EoL_1_Y':'lightgreen', 'EoL_2_Y':'lightgreen', 'EoL_3_Y':'lightgreen',␣
 ↪'EoL_4_Y':'lightgreen', 'EoL_5_Y':'lightgreen', 'EoL_6_Y':'lightgreen',
    'score':'lightsalmon',
    'rob_1_1':'tan', 'rob_1_2':'tan', 'rob_1_3':'tan', 'rob_1_4':'tan',␣
 ↪'rob_1_maxVel':'tan',
    'rob_2_1':'tan', 'rob_2_2':'tan', 'rob_2_3':'tan', 'rob_2_4':'tan',␣
  ↪'rob_2_maxVel':'tan',
    'rob_1_vacuum':'tan', 'rob_2_vacuum':'tan','rob_1_supply':'tan',␣
  ↪'rob_2_supply':'tan',
    'con_1':'lightgrey','con_2':'lightgrey','con_3':'lightgrey'
}
```

1.4 Show datasets in folders

[ ]:

```
# Specify the directory path
directory_path = 'G:\\My Drive\\Master Thesis\\Simulation\\Dataset'
```

[ ]:

```
files,folder_path = get_from_folders(directory_path)
```

1.5 Run RCA trough folder

A warm-up phase is considered. Each product takes roughly 26.30 seconds from the assembly entry point to the assembly end of line. There is some distance from the drop point of the items to the start and some interventions need time to become stable, thus we need to skip in total roughly 839 rows. Each 8 seconds a new product exits the assembly line.

1.5.1 Algorithm #1 - Hypothesis Testing

[ ]:

```
result_HT = run_HT_size(folder_path,files,startrow=839,size_p=2.
  ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

1.5.2 Algorithm #2 - Epsilon Diagnosis

[ ]:

```
result_ED = run_ED_size(folder_path,files,startrow=839,size_p=2.
  ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

1.5.3 Algorithm #3 - Random Walk

[ ]:

```
result_RW = run_RW_size(folder_path,files,startrow=839,size_p=2.
  ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

1.5.4 Algorithm #4: RCD

[ ]:

```
result_RCD = run_RCD_size(folder_path,files,startrow=839,size_p=2.
  ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

1.6 Data Analysis

1.6.1 Summary Algorithms

[ ]:
```
result_all = pd.DataFrame()
result_all = pd.concat([result_HT,result_ED,result_RW,result_RCD])

result_all_size_1 = result_all.filter(like='size_1')
result_all_feeder_3 = result_all.filter(like='feeder_3')
result_all_gripper_1 = result_all.filter(like='gripper_1')
result_all_max_Vel_2 = result_all.filter(like='max_Vel_2')
```

1.6.2 Intervention - Root Cause

[ ]:
```
abnormal_sets = pd.DataFrame()
abnormal_sets['size_1'] = ['cam_1_X', 'cam_1_Y']
abnormal_sets['feeder_3'] = ['cam_3_X', 'cam_3_Y']
abnormal_sets['gripper_1'] = ['rob_1_supply',None]
abnormal_sets['max_Vel_2'] = ['rob_2_maxVel',None]
```

[ ]:
```
main_dir = 'G:\My Drive\Master Thesis\Simulation\Results'
```

1.6.3 TOP 3 - Root Cause

[ ]:
```
result_data_3top = results_top_3(result_all,abnormal_sets)
result_data_3top.tail()

result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top.csv'))
```

[ ]:
```
result_data_3top_size_1 = results_top_3(result_all_size_1,abnormal_sets)
result_data_3top_size_1.tail()

result_data_3top_size_1.to_csv(os.path.join(main_dir, 'result_data_3top_size_1.
  ↪csv'))
```

[ ]:
```
result_data_3top_feeder_3 = results_top_3(result_all_feeder_3,abnormal_sets)
result_data_3top_feeder_3.tail()

result_data_3top_feeder_3.to_csv(os.path.join(main_dir,␣
  ↪'result_data_3top_feeder_3.csv'))
```

[ ]:
```
result_data_3top_gripper_1 = results_top_3(result_all_gripper_1,abnormal_sets)
result_data_3top_gripper_1.tail()

result_data_3top_gripper_1.to_csv(os.path.join(main_dir,␣
  ↪'result_data_3top_gripper_1.csv'))
```

[ ]:

```
result_data_3top_max_Vel_2 = results_top_3(result_all_max_Vel_2,abnormal_sets)
result_data_3top_max_Vel_2.tail()

result_data_3top_max_Vel_2.to_csv(os.path.join(main_dir,␣
 ↪'result_data_3top_max_Vel_2.csv'))
```

1.6.4 TOP 1 - Root Cause

[ ]:

```
result_data_1top = results_top_1(result_all,abnormal_sets)
result_data_1top.tail()

result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top.csv'))
```

[ ]:

```
result_data_1top_size_1 = results_top_1(result_all_size_1,abnormal_sets)
result_data_1top_size_1.tail()

result_data_1top_size_1.to_csv(os.path.join(main_dir, 'result_data_1top_size_1.
 ↪csv'))
```

[ ]:

```
result_data_1top_feeder_3 = results_top_1(result_all_feeder_3,abnormal_sets)
result_data_1top_feeder_3.tail()

result_data_1top_feeder_3.to_csv(os.path.join(main_dir,␣
 ↪'result_data_1top_feeder_3.csv'))
```

[ ]:

```
result_data_1top_gripper_1 = results_top_1(result_all_gripper_1,abnormal_sets)
result_data_1top_gripper_1.tail()

result_data_1top_gripper_1.to_csv(os.path.join(main_dir,␣
 ↪'result_data_1top_gripper_1.csv'))
```

[ ]:

```
result_data_1top_max_Vel_2 = results_top_1(result_all_max_Vel_2,abnormal_sets)
result_data_1top_max_Vel_2.tail()

result_data_1top_max_Vel_2.to_csv(os.path.join(main_dir,␣
 ↪'result_data_1top_max_Vel_2.csv'))
```

[ ]:

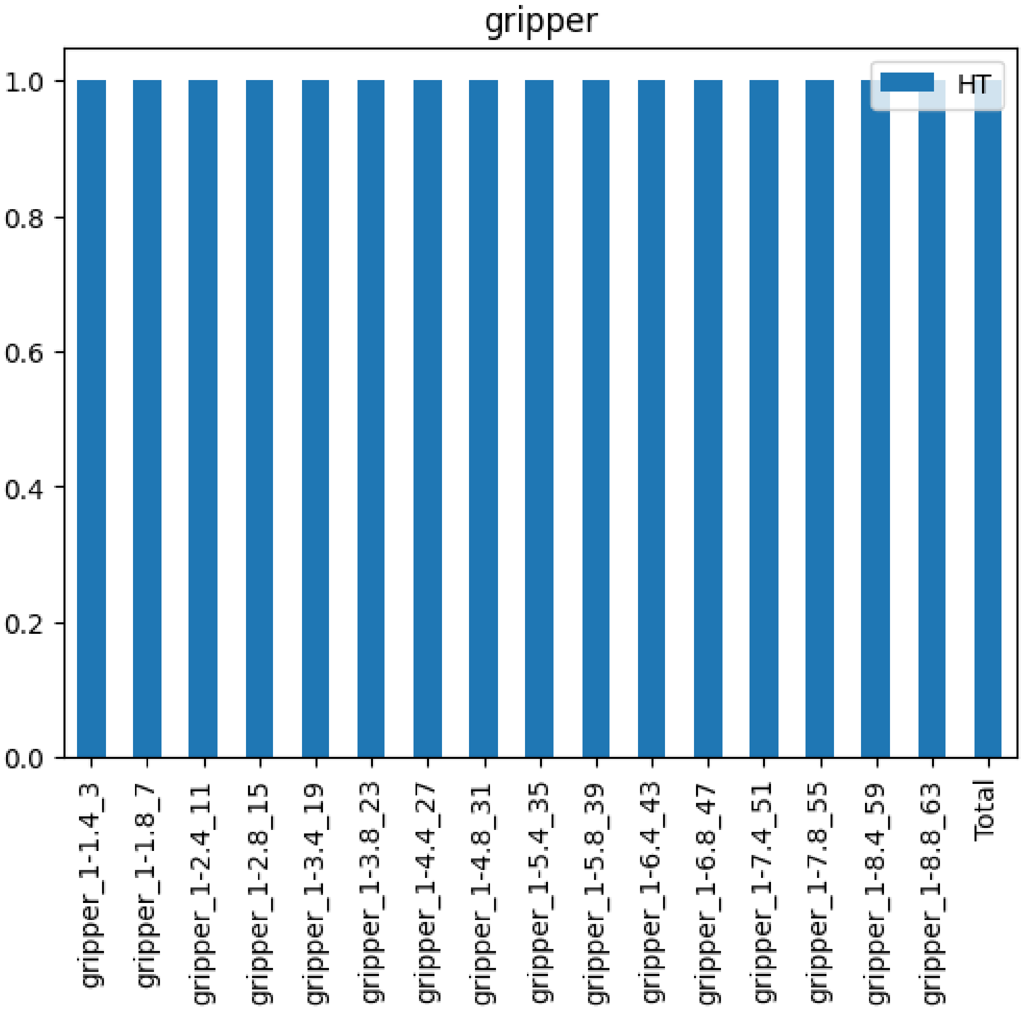
```
result_data_1top['ED']
```

```
---------------------------------------------------------------------------
ValueError                                Traceback (most recent call last)
Cell In[37], line 1
----> 1 result_data_1top['ED'].item()

File c:\Users\Francisco\anaconda3\envs\thesis\lib\site-packages\pandas\core\bas
 ↪py:418, in IndexOpsMixin.item(self)
    416 if len(self) == 1:
```

```
    417     return next(iter(self))
--> 418 raise ValueError("can only convert an array of size 1 to a Python␣
 ↪scalar")

ValueError: can only convert an array of size 1 to a Python scalar
```

```
[ ]: plot_data = pd.read_csv(os.path.join(main_dir, 'result_data_1top_size_1.csv'))
     result_data_1top_gripper_1.plot.bar(y='HT', x = 'Total', title = 'gripper')
```

```
[ ]: <Axes: title={'center': 'gripper'}>
```



1.7 Variation 1 - Overlap

1.7.1 HT -Algorithm

[ ]:
```
result_HT_overlap_1 = run_HT_overlap(folder_path,files,startrow=839,overlap_p=0.
  ↪10,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_overlap_2 = run_HT_overlap(folder_path,files,startrow=839,overlap_p=0.
  ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_overlap_3 = run_HT_overlap(folder_path,files,startrow=839,overlap_p=0.
  ↪50,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_overlap_4 = run_HT_overlap(folder_path,files,startrow=839,overlap_p=0.
  ↪75,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_overlap_5 = run_HT_overlap(folder_path,files,startrow=839,overlap_p=0.
  ↪95,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

[ ]:
```
result_overlap_HT = pd.DataFrame()
result_overlap_HT = pd.
  ↪concat([result_HT_overlap_1,result_HT_overlap_2,result_HT_overlap_3,result_HT_overlap_4,res
  ↪ignore_index=True)
result_overlap_HT['Overlap Percent'] = pd.DataFrame({'HT':
  ↪['10%','20%','50%','75%','95%']})
result_overlap_HT.set_index('Overlap Percent', inplace=True)
result_overlap_HT
```

[ ]:
```
                                                   size_1-1.2_1  \
Overlap Percent
10%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
20%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
50%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
75%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
95%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]

                                                 feeder_3-1.3_2  \
Overlap Percent
10%                      [rob_2_maxVel, rob_1_maxVel, rob_2_3]
20%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
50%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
75%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
95%                 [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]

                                                gripper_1-1.4_3  \
Overlap Percent
10%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
20%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
75%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
95%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
```

```
                                            max_Vel_2-1.5_4  \
Overlap Percent
10%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
20%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
50%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
75%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
95%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]

                                               size_1-1.6_5  \
Overlap Percent
10%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
20%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
50%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
75%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
95%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]

                                             feeder_3-1.7_6  \
Overlap Percent
10%                   [rob_2_maxVel, rob_1_maxVel, rob_2_3]
20%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
50%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
75%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
95%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]

                                            gripper_1-1.8_7  \
Overlap Percent
10%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
20%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
75%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
95%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]

                                            max_Vel_2-1.9_8  \
Overlap Percent
10%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
20%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
50%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
75%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
95%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]

                                               size_1-2.2_9  \
Overlap Percent
10%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
20%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
50%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
75%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
95%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
```

```
                                            feeder_3-2.3_10  …  \
Overlap Percent                                              …   
10%                   [rob_2_maxVel, rob_1_maxVel, rob_2_3]  …   
20%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]  …   
50%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]  …   
75%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]  …   
95%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]  …   

                                           gripper_1-7.8_55  \
Overlap Percent                                               
10%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   
20%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   
50%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   
75%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   
95%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   

                                           max_Vel_2-7.9_56  \
Overlap Percent                                               
10%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]   
20%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]   
50%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]   
75%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]   
95%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]   

                                              size_1-8.2_57  \
Overlap Percent                                               
10%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   
20%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   
50%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   
75%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   
95%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   

                                            feeder_3-8.3_58  \
Overlap Percent                                               
10%                   [rob_2_maxVel, rob_1_maxVel, rob_2_3]   
20%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   
50%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   
75%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   
95%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]   

                                           gripper_1-8.4_59  \
Overlap Percent                                               
10%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   
20%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   
50%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   
75%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]   
```

```
95%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]

                                           max_Vel_2-8.5_60  \
Overlap Percent
10%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
20%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
50%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
75%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
95%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]

                                              size_1-8.6_61  \
Overlap Percent
10%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
20%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
50%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
75%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
95%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]

                                            feeder_3-8.7_62  \
Overlap Percent
10%                   [rob_2_maxVel, rob_1_maxVel, rob_2_3]
20%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
50%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
75%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]
95%              [rob_1_maxVel, rob_2_maxVel, rob_1_vacuum]

                                           gripper_1-8.8_63  \
Overlap Percent
10%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
20%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
75%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
95%              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]

                                           max_Vel_2-8.9_64
Overlap Percent
10%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
20%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
50%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
75%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
95%              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]

[5 rows x 64 columns]
```

[ ]:

```
result_data_3top = results_top_3(result_overlap_HT,abnormal_sets)
result_data_3top.tail()
```

```
[ ]:                   10%  20%  50%  75%  95%
     size_1-8.6_61      0.0  0.0  0.0  0.0  0.0
     feeder_3-8.7_62    0.0  0.0  0.0  0.0  0.0
     gripper_1-8.8_63   1.0  1.0  1.0  1.0  1.0
     max_Vel_2-8.9_64   1.0  1.0  1.0  1.0  1.0
     Total              0.5  0.5  0.5  0.5  0.5
```

```
[ ]: result_data_1top = results_top_1(result_overlap_HT,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                   10%  20%  50%  75%  95%
     size_1-8.6_61      0.0  0.0  0.0  0.0  0.0
     feeder_3-8.7_62    0.0  0.0  0.0  0.0  0.0
     gripper_1-8.8_63   1.0  1.0  1.0  1.0  1.0
     max_Vel_2-8.9_64   1.0  1.0  1.0  1.0  1.0
     Total              0.5  0.5  0.5  0.5  0.5
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_1_HT.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_1_HT.csv'))
```

1.7.2 ED - Algorithm

```
[ ]: result_ED_overlap_1 = run_ED_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪10,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_ED_overlap_2 = run_ED_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_ED_overlap_3 = run_ED_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪50,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_ED_overlap_4 = run_ED_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪75,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_ED_overlap_5 = run_ED_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪95,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
[ ]: result_overlap_ED = pd.DataFrame()
     result_overlap_ED = pd.
      ↪concat([result_ED_overlap_1,result_ED_overlap_2,result_ED_overlap_3,result_ED_overlap_4,res
      ↪ignore_index=True)
     result_overlap_ED['Overlap Percent'] = pd.DataFrame({'ED':
      ↪['10%','20%','50%','75%','95%']})
     result_overlap_ED.set_index('Overlap Percent', inplace=True)
     result_overlap_ED
```

```
[ ]:                                      size_1-1.2_1  \
     Overlap Percent
     10%                      [rob_1_3, rob_1_2, rob_1_4]
     20%                      [EoL_2_Y, rob_1_3, rob_1_2]
     50%                          [con_3, EoL_2_Y, con_1]
```

```
75%                   [EoL_4_Y, EoL_3_Y, cam_3_Y]
95%              [cam_3_X, EoL_2_X, rob_2_vacuum]

                                   feeder_3-1.3_2  \
Overlap Percent
10%                   [cam_2_Y, cam_3_X, EoL_1_Y]
20%                     [EoL_2_X, cam_2_Y, con_1]
50%                     [cam_3_X, EoL_2_X, con_1]
75%                   [EoL_4_Y, cam_3_X, EoL_3_Y]
95%              [rob_2_vacuum, EoL_1_X, EoL_1_Y]

                                  gripper_1-1.4_3  \
Overlap Percent
10%                   [rob_1_3, rob_1_2, rob_1_4]
20%                   [EoL_1_X, rob_1_3, rob_1_2]
50%                       [con_2, EoL_2_X, con_1]
75%                   [EoL_4_Y, EoL_3_Y, cam_3_Y]
95%              [cam_3_X, rob_2_vacuum, EoL_1_X]

                             max_Vel_2-1.5_4  \
Overlap Percent
10%              [rob_1_3, rob_1_2, rob_1_4]
20%              [EoL_1_X, EoL_2_Y, rob_1_3]
50%                [EoL_2_Y, con_3, rob_1_3]
75%              [EoL_6_X, cam_3_X, EoL_5_X]
95%              [EoL_2_X, cam_3_X, EoL_3_X]

                                     size_1-1.6_5  \
Overlap Percent
10%                   [EoL_2_Y, rob_1_3, rob_1_2]
20%                   [EoL_2_Y, rob_1_3, rob_1_2]
50%                     [EoL_2_Y, con_2, EoL_2_X]
75%                   [EoL_4_Y, EoL_3_Y, EoL_6_X]
95%              [EoL_2_X, cam_3_X, rob_2_vacuum]

                                   feeder_3-1.7_6  \
Overlap Percent
10%                     [cam_3_X, con_2, EoL_3_X]
20%                     [EoL_2_X, con_2, cam_3_X]
50%                     [cam_3_X, con_2, EoL_2_X]
75%                   [EoL_4_Y, cam_3_X, EoL_3_Y]
95%              [rob_2_vacuum, EoL_1_X, EoL_1_Y]

                                  gripper_1-1.8_7  \
Overlap Percent
10%                   [rob_1_3, rob_1_2, rob_1_4]
20%                   [rob_1_3, rob_1_2, rob_1_4]
```

```
50%                       [EoL_2_X, con_3, con_1]
75%                   [EoL_4_Y, EoL_3_Y, cam_3_X]
95%              [cam_3_X, rob_2_vacuum, EoL_1_X]

                             max_Vel_2-1.9_8  \
Overlap Percent
10%              [EoL_1_X, rob_1_3, rob_1_2]
20%              [EoL_1_X, EoL_2_Y, rob_1_3]
50%                  [EoL_2_Y, con_1, con_3]
75%              [cam_3_Y, EoL_6_X, EoL_2_Y]
95%              [EoL_2_X, cam_3_X, EoL_3_X]

                                     size_1-2.2_9  \
Overlap Percent
10%                   [EoL_2_Y, rob_1_3, rob_1_2]
20%                   [EoL_2_Y, rob_1_3, rob_1_2]
50%                       [EoL_2_Y, con_2, con_1]
75%                   [EoL_4_Y, EoL_3_Y, cam_3_Y]
95%              [cam_3_X, EoL_2_X, rob_2_vacuum]

                                  feeder_3-2.3_10  …  \
Overlap Percent                                    …
10%                   [EoL_1_Y, EoL_1_X, cam_3_X]  …
20%                   [EoL_1_X, EoL_2_X, cam_3_X]  …
50%                     [cam_3_X, EoL_2_X, con_3]  …
75%                   [EoL_4_Y, cam_3_X, EoL_3_Y]  …
95%              [rob_2_vacuum, EoL_1_X, EoL_1_Y]  …

                                  gripper_1-7.8_55  \
Overlap Percent
10%                   [rob_1_3, rob_1_2, rob_1_4]
20%                   [EoL_1_X, rob_1_3, rob_1_2]
50%                       [EoL_2_X, con_3, con_2]
75%                   [EoL_4_Y, EoL_3_Y, cam_3_Y]
95%              [cam_3_X, rob_2_vacuum, EoL_1_X]

                            max_Vel_2-7.9_56  \
Overlap Percent
10%              [EoL_2_Y, rob_1_3, rob_1_2]
20%              [EoL_2_Y, rob_1_3, rob_1_2]
50%                  [EoL_2_Y, con_2, con_3]
75%              [cam_3_Y, EoL_5_X, EoL_6_X]
95%              [EoL_2_X, cam_3_X, EoL_3_X]

                                    size_1-8.2_57  \
Overlap Percent
10%                   [EoL_2_Y, rob_1_3, rob_1_2]
```

```
20%                   [EoL_2_Y, rob_1_3, rob_1_2]
50%                       [EoL_2_Y, con_3, con_1]
75%                   [EoL_4_Y, EoL_3_Y, cam_3_Y]
95%              [cam_3_X, EoL_2_X, rob_2_vacuum]

                                  feeder_3-8.3_58  \
Overlap Percent
10%                     [cam_3_X, con_3, EoL_3_X]
20%                     [EoL_2_X, cam_3_X, con_3]
50%                     [cam_3_X, EoL_2_X, con_3]
75%                   [EoL_4_Y, cam_3_X, EoL_3_Y]
95%              [rob_2_vacuum, EoL_1_X, EoL_1_Y]

                                 gripper_1-8.4_59  \
Overlap Percent
10%                   [rob_1_3, rob_1_2, rob_1_4]
20%                   [rob_1_3, rob_1_2, rob_1_4]
50%                       [EoL_2_X, con_3, con_1]
75%                   [EoL_4_Y, EoL_3_Y, cam_3_Y]
95%              [cam_3_X, rob_2_vacuum, EoL_1_X]

                                 max_Vel_2-8.5_60  \
Overlap Percent
10%                   [rob_1_3, rob_1_2, rob_1_4]
20%                   [EoL_2_Y, rob_1_3, rob_1_2]
50%                       [EoL_4_Y, con_2, con_1]
75%                   [EoL_4_Y, cam_3_X, EoL_6_X]
95%              [cam_3_X, EoL_2_X, rob_2_vacuum]

                                    size_1-8.6_61  \
Overlap Percent
10%                   [EoL_1_X, EoL_2_Y, rob_1_3]
20%                   [EoL_1_X, EoL_2_Y, rob_1_3]
50%                       [EoL_2_Y, con_1, con_3]
75%                   [EoL_4_Y, EoL_3_Y, EoL_6_X]
95%              [EoL_2_X, cam_3_X, rob_2_vacuum]

                                  feeder_3-8.7_62  \
Overlap Percent
10%                   [cam_3_X, EoL_1_Y, EoL_3_X]
20%                     [EoL_2_X, con_2, cam_3_X]
50%                     [cam_3_X, EoL_2_X, con_2]
75%                   [EoL_4_Y, cam_3_X, EoL_3_Y]
95%              [rob_2_vacuum, EoL_1_X, EoL_1_Y]

                                 gripper_1-8.8_63             max_Vel_2-8.9_64
Overlap Percent
```

```
10%                  [rob_1_3, rob_1_2, rob_1_4]  [EoL_2_Y, rob_1_3, rob_1_2]
20%                  [rob_1_3, rob_1_2, rob_1_4]  [EoL_2_Y, rob_1_3, rob_1_2]
50%                      [EoL_2_X, con_1, con_2]      [EoL_2_Y, con_2, con_1]
75%                  [EoL_4_Y, EoL_3_Y, cam_3_Y]  [cam_3_X, cam_3_Y, EoL_6_X]
95%             [cam_3_X, rob_2_vacuum, EoL_1_X]  [cam_3_X, EoL_2_X, EoL_3_X]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_overlap_ED,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                    10%       20%   50%   75%  95%
     size_1-8.6_61      0.00  0.000000  0.00  0.00  0.0
     feeder_3-8.7_62    1.00  1.000000  1.00  1.00  0.0
     gripper_1-8.8_63   0.00  0.000000  0.00  0.00  0.0
     max_Vel_2-8.9_64   0.00  0.000000  0.00  0.00  0.0
     Total              0.25  0.171875  0.25  0.25  0.0
```

```
[ ]: result_data_1top = results_top_1(result_overlap_ED,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                        10%  20%   50%  75%  95%
     size_1-8.6_61      0.000000  0.0  0.00  0.0  0.0
     feeder_3-8.7_62    1.000000  0.0  1.00  0.0  0.0
     gripper_1-8.8_63   0.000000  0.0  0.00  0.0  0.0
     max_Vel_2-8.9_64   0.000000  0.0  0.00  0.0  0.0
     Total              0.109375  0.0  0.25  0.0  0.0
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_1_ED.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_1_ED.csv'))
```

1.7.3 RW - Algorithm

```
[ ]: result_RW_overlap_1 = run_RW_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪10,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_overlap_2 = run_RW_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_overlap_3 = run_RW_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪50,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_overlap_4 = run_RW_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪75,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_overlap_5 = run_RW_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪95,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
[ ]: result_overlap_RW = pd.DataFrame()
```

```
result_overlap_RW = pd.
↪concat([result_RW_overlap_1,result_RW_overlap_2,result_RW_overlap_3,result_RW_overlap_4,res
↪ignore_index=True)
result_overlap_RW['Overlap Percent'] = pd.DataFrame({'RW':
↪['10%','20%','50%','75%','95%']})
result_overlap_RW.set_index('Overlap Percent', inplace=True)
result_overlap_RW
```

[ ]:

```
                                        size_1-1.2_1  \
Overlap Percent
10%                 [rob_2_supply, cam_1_X, cam_1_Y]
20%                        [cam_1_Y, cam_1_X, con_2]
50%                 [rob_2_supply, cam_1_Y, cam_1_X]
75%                   [rob_2_supply, cam_1_X, con_2]
95%              [rob_2_supply, rob_1_supply, con_2]

                                        feeder_3-1.3_2  \
Overlap Percent
10%              [rob_2_supply, rob_1_supply, cam_3_Y]
20%              [rob_2_supply, cam_1_Y, rob_1_supply]
50%              [rob_1_supply, rob_2_supply, cam_1_Y]
75%              [rob_1_supply, cam_1_Y, rob_2_maxVel]
95%                   [rob_2_supply, cam_3_Y, cam_3_X]

                                       gripper_1-1.4_3  \
Overlap Percent
10%              [rob_1_supply, rob_2_supply, cam_1_X]
20%              [rob_1_supply, rob_2_supply, cam_1_Y]
50%              [rob_1_supply, rob_2_supply, cam_1_Y]
75%              [rob_1_supply, rob_2_supply, cam_1_Y]
95%                [rob_1_supply, rob_2_supply, con_2]

                                            max_Vel_2-1.5_4  \
Overlap Percent
10%              [rob_2_supply, rob_2_maxVel, rob_1_supply]
20%              [rob_2_supply, rob_2_maxVel, rob_1_supply]
50%                     [rob_2_supply, rob_2_maxVel, con_2]
75%                   [rob_2_maxVel, cam_1_Y, rob_1_supply]
95%                     [rob_2_maxVel, con_2, rob_1_supply]

                                        size_1-1.6_5  \
Overlap Percent
10%                 [rob_2_supply, cam_1_Y, cam_1_X]
20%                 [cam_1_X, cam_1_Y, rob_1_supply]
50%                 [rob_2_supply, cam_1_Y, cam_1_X]
75%                        [cam_1_Y, con_2, cam_1_X]
95%              [rob_2_supply, con_2, rob_1_supply]
```

```
                                        feeder_3-1.7_6  \
Overlap Percent
10%                [rob_2_supply, con_2, rob_1_supply]
20%              [rob_2_supply, rob_1_supply, cam_1_Y]
50%              [rob_2_supply, rob_1_supply, cam_1_Y]
75%                   [rob_2_supply, cam_1_X, cam_1_Y]
95%                [rob_1_supply, con_2, rob_2_supply]

                                       gripper_1-1.8_7  \
Overlap Percent
10%              [rob_1_supply, rob_2_supply, cam_1_X]
20%              [rob_1_supply, rob_2_supply, cam_1_X]
50%                   [rob_1_supply, cam_1_Y, cam_1_X]
75%              [rob_1_supply, rob_2_supply, cam_1_Y]
95%                [rob_1_supply, rob_2_supply, con_2]

                                       max_Vel_2-1.9_8  \
Overlap Percent
10%              [rob_2_maxVel, rob_2_supply, cam_1_X]
20%              [rob_2_maxVel, rob_2_supply, cam_1_X]
50%                   [rob_2_maxVel, cam_1_X, cam_1_Y]
75%              [rob_2_supply, rob_2_maxVel, cam_1_X]
95%              [rob_2_maxVel, rob_2_supply, cam_1_X]

                                          size_1-2.2_9  \
Overlap Percent
10%                   [rob_2_supply, cam_1_X, cam_1_Y]
20%                   [cam_1_Y, rob_2_supply, cam_1_X]
50%                   [rob_2_supply, cam_1_X, cam_1_Y]
75%                     [rob_2_supply, cam_1_Y, con_2]
95%              [rob_2_supply, cam_1_Y, rob_1_supply]

                                       feeder_3-2.3_10  …  \
Overlap Percent                                         …
10%                   [rob_1_supply, cam_1_Y, cam_3_X]  …
20%              [rob_2_supply, rob_1_supply, cam_1_Y]  …
50%              [rob_2_supply, cam_1_Y, rob_1_supply]  …
75%                     [cam_1_Y, rob_2_supply, con_2]  …
95%                     [con_2, cam_3_Y, rob_2_supply]  …

                                      gripper_1-7.8_55  \
Overlap Percent
10%              [rob_1_supply, rob_2_supply, cam_1_Y]
20%              [rob_1_supply, rob_2_supply, cam_1_Y]
50%              [rob_1_supply, rob_2_supply, cam_1_Y]
75%              [rob_1_supply, rob_2_supply, cam_1_X]
```

```
95%                [rob_1_supply, con_2, rob_2_supply]

                                           max_Vel_2-7.9_56  \
Overlap Percent
10%                   [rob_2_supply, rob_2_maxVel, cam_1_X]
20%                   [rob_2_supply, rob_2_maxVel, cam_1_X]
50%                   [rob_2_maxVel, rob_2_supply, cam_1_X]
75%                     [rob_2_maxVel, rob_2_supply, con_2]
95%              [rob_2_maxVel, rob_2_supply, rob_1_supply]

                                       size_1-8.2_57  \
Overlap Percent
10%                 [rob_2_supply, cam_1_X, cam_1_Y]
20%                 [rob_2_supply, cam_1_Y, cam_1_X]
50%                 [cam_1_X, cam_1_Y, rob_2_supply]
75%                 [cam_1_Y, cam_1_X, rob_1_supply]
95%              [rob_2_supply, rob_1_supply, con_2]

                                       feeder_3-8.3_58  \
Overlap Percent
10%              [rob_2_supply, rob_1_supply, cam_1_Y]
20%              [rob_2_supply, rob_1_supply, cam_1_Y]
50%              [rob_2_supply, rob_1_supply, cam_1_Y]
75%                   [rob_1_supply, cam_1_Y, cam_3_Y]
95%                [rob_2_supply, con_2, rob_1_supply]

                                      gripper_1-8.4_59  \
Overlap Percent
10%              [rob_1_supply, rob_2_supply, cam_1_Y]
20%              [rob_1_supply, rob_2_supply, cam_1_X]
50%              [rob_1_supply, rob_2_supply, cam_1_Y]
75%              [rob_1_supply, cam_1_Y, rob_2_maxVel]
95%              [rob_1_supply, rob_2_supply, cam_3_X]

                                           max_Vel_2-8.5_60  \
Overlap Percent
10%                     [rob_2_maxVel, con_2, rob_1_supply]
20%                     [rob_2_maxVel, rob_2_supply, con_2]
50%                   [rob_2_maxVel, rob_2_supply, cam_1_Y]
75%              [rob_2_maxVel, rob_2_supply, rob_1_supply]
95%                   [rob_2_maxVel, rob_2_supply, cam_1_Y]

                                    size_1-8.6_61  \
Overlap Percent
10%              [rob_2_supply, cam_1_X, cam_1_Y]
20%              [cam_1_X, cam_1_Y, rob_2_supply]
50%              [cam_1_Y, cam_1_X, rob_2_supply]
```

```
75%                [cam_1_X, con_2, rob_1_supply]
95%                [rob_2_supply, con_2, cam_1_Y]

                                       feeder_3-8.7_62  \
Overlap Percent
10%              [rob_1_supply, rob_2_supply, cam_3_X]
20%              [rob_2_supply, rob_1_supply, cam_1_Y]
50%              [rob_2_supply, rob_1_supply, cam_1_Y]
75%                [rob_2_supply, rob_1_supply, con_2]
95%                [rob_2_supply, con_2, rob_1_supply]

                                      gripper_1-8.8_63  \
Overlap Percent
10%              [rob_1_supply, rob_2_supply, cam_1_X]
20%              [rob_1_supply, rob_2_supply, cam_1_Y]
50%                [rob_1_supply, rob_2_supply, con_2]
75%                [rob_1_supply, rob_2_supply, con_2]
95%                     [rob_1_supply, con_2, cam_1_Y]

                                           max_Vel_2-8.9_64
Overlap Percent
10%                   [rob_2_maxVel, rob_2_supply, cam_1_Y]
20%              [rob_2_maxVel, rob_2_supply, rob_1_supply]
50%                   [rob_2_maxVel, cam_1_Y, rob_1_supply]
75%                   [rob_2_maxVel, rob_2_supply, cam_1_Y]
95%                   [rob_2_maxVel, rob_2_supply, cam_1_Y]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_overlap_RW,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                     10%   20%   50%   75%     95%
     size_1-8.6_61     1.0000  1.00  1.00  1.00  1.0000
     feeder_3-8.7_62   1.0000  0.00  0.00  0.00  0.0000
     gripper_1-8.8_63  1.0000  1.00  1.00  1.00  1.0000
     max_Vel_2-8.9_64  1.0000  1.00  1.00  1.00  1.0000
     Total             0.8125  0.75  0.75  0.75  0.6875
```

```
[ ]: result_data_1top = results_top_1(result_overlap_RW,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                        10%       20%      50%       75%      95%
     size_1-8.6_61     0.000000  1.000000  1.00000  1.000000  0.00000
     feeder_3-8.7_62   0.000000  0.000000  0.00000  0.000000  0.00000
     gripper_1-8.8_63  1.000000  1.000000  1.00000  1.000000  1.00000
     max_Vel_2-8.9_64  1.000000  1.000000  1.00000  1.000000  1.00000
```

```
Total              0.484375  0.546875  0.53125  0.546875  0.46875
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_1_RW.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_1_RW.csv'))
```

1.7.4 RCD - Algorithm

```
[ ]: result_RCD_overlap_1 =␣
      ↪run_RCD_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪10,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_overlap_2 =␣
      ↪run_RCD_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_overlap_3 =␣
      ↪run_RCD_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪50,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_overlap_4 =␣
      ↪run_RCD_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪75,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_overlap_5 =␣
      ↪run_RCD_overlap(folder_path,files,startrow=839,overlap_p=0.
      ↪95,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
[ ]: result_overlap_RCD = pd.DataFrame()
     result_overlap_RCD = pd.
      ↪concat([result_RCD_overlap_1,result_RCD_overlap_2,result_RCD_overlap_3,result_RCD_overlap_4
      ↪ignore_index=True)
     result_overlap_RCD['Overlap Percent'] = pd.DataFrame({'RCD':
      ↪['10%','20%','50%','75%','95%']})
     result_overlap_RCD.set_index('Overlap Percent', inplace=True)
     result_overlap_RCD
```

```
[ ]:                                 size_1-1.2_1              feeder_3-1.3_2  \
     Overlap Percent
     10%              [EoL_3_X, cam_2_Y, EoL_1_Y]  [EoL_2_Y, EoL_1_Y, cam_2_Y]
     20%              [EoL_3_X, cam_2_Y, EoL_1_Y]  [EoL_3_X, EoL_1_Y, cam_2_Y]
     50%              [cam_1_Y, EoL_2_X, cam_2_Y]  [EoL_2_Y, EoL_1_Y, cam_1_Y]
     75%              [EoL_3_X, cam_3_Y, EoL_4_X]  [EoL_2_X, cam_2_Y, EoL_2_Y]
     95%                       [cam_3_Y, EoL_3_Y]                   [cam_3_Y]

                                       gripper_1-1.4_3  \
     Overlap Percent
     10%              [EoL_2_Y, rob_1_supply, cam_2_Y]
     20%                   [EoL_3_X, cam_2_Y, EoL_1_Y]
     50%                   [EoL_2_Y, cam_1_Y, cam_3_X]
     75%                   [EoL_2_Y, cam_2_Y, EoL_1_Y]
     95%                            [EoL_5_X, EoL_3_X]
```

```
                             max_Vel_2-1.5_4                 size_1-1.6_5  \
Overlap Percent
10%              [cam_2_Y, EoL_1_Y, EoL_2_Y]  [EoL_3_X, cam_2_Y, EoL_1_Y]
20%              [cam_2_Y, EoL_1_Y, EoL_2_Y]  [EoL_3_X, EoL_1_Y, cam_3_Y]
50%              [EoL_6_Y, EoL_2_X, cam_1_X]  [cam_1_Y, EoL_2_X, cam_2_Y]
75%                       [cam_2_Y, EoL_1_Y]  [EoL_3_X, cam_3_Y, cam_1_Y]
95%                   [rob_2_maxVel, cam_3_X]           [EoL_5_X, cam_2_Y]

                              feeder_3-1.7_6  \
Overlap Percent
10%              [EoL_3_X, cam_3_Y, cam_2_Y]
20%              [EoL_3_X, cam_3_Y, EoL_1_Y]
50%              [EoL_2_Y, EoL_1_Y, cam_1_Y]
75%              [EoL_2_X, cam_2_Y, EoL_2_Y]
95%                       [cam_3_Y, cam_3_X]

                                  gripper_1-1.8_7  \
Overlap Percent
10%              [rob_1_supply, cam_2_Y, cam_3_X]
20%                   [EoL_2_Y, EoL_1_Y, cam_3_Y]
50%                   [EoL_2_Y, EoL_1_Y, cam_1_Y]
75%                   [EoL_2_X, cam_3_Y, cam_2_Y]
95%                       [cam_3_Y, rob_1_supply]

                                  max_Vel_2-1.9_8  \
Overlap Percent
10%                   [EoL_6_Y, EoL_2_X, cam_2_Y]
20%                   [EoL_6_Y, cam_3_Y, EoL_2_Y]
50%              [rob_2_maxVel, EoL_2_X, cam_1_Y]
75%                   [EoL_6_Y, EoL_1_Y, cam_3_Y]
95%                       [EoL_6_X, rob_2_maxVel]

                                size_1-2.2_9              feeder_3-2.3_10  \
Overlap Percent
10%              [EoL_3_Y, cam_2_Y, EoL_2_Y]  [EoL_2_Y, cam_2_Y, EoL_1_Y]
20%              [EoL_4_Y, cam_2_Y, EoL_1_Y]  [EoL_3_X, cam_3_Y, cam_2_Y]
50%              [cam_1_Y, EoL_2_X, EoL_3_X]  [EoL_2_Y, EoL_1_Y, cam_1_Y]
75%              [EoL_3_X, cam_2_Y, cam_3_Y]  [EoL_2_X, cam_2_Y, EoL_2_Y]
95%                       [EoL_3_Y, EoL_3_X]                    [EoL_2_X]

                 …                  gripper_1-7.8_55  \
Overlap Percent  …
10%              …  [EoL_3_X, rob_1_supply, cam_2_Y]
20%              …       [EoL_3_X, cam_2_Y, cam_3_Y]
50%              …       [EoL_2_Y, EoL_1_Y, cam_1_X]
75%              …       [EoL_2_X, cam_2_Y, EoL_2_Y]
```

```
95%              …                          [EoL_3_X]

                                 max_Vel_2-7.9_56  \
Overlap Percent
10%                   [EoL_6_Y, EoL_2_X, cam_2_Y]
20%                   [EoL_6_X, cam_2_Y, EoL_1_Y]
50%                   [EoL_6_X, EoL_2_X, cam_2_Y]
75%              [rob_2_maxVel, EoL_1_Y, cam_2_Y]
95%              [rob_2_maxVel, cam_3_X, EoL_6_X]

                               size_1-8.2_57              feeder_3-8.3_58  \
Overlap Percent
10%              [EoL_3_X, cam_3_Y, EoL_1_Y]  [EoL_3_X, cam_1_Y, cam_1_X]
20%              [EoL_4_Y, cam_2_Y, EoL_1_Y]  [cam_3_Y, EoL_3_X, EoL_1_Y]
50%              [cam_1_X, EoL_2_X, cam_2_Y]  [cam_3_X, EoL_2_Y, cam_2_Y]
75%              [EoL_3_X, cam_3_Y, EoL_4_X]  [EoL_2_Y, EoL_1_Y, cam_2_Y]
95%              [EoL_5_X, cam_3_X, EoL_6_Y]           [EoL_2_X, EoL_3_X]

                                 gripper_1-8.4_59  \
Overlap Percent
10%                   [EoL_3_Y, EoL_1_Y, cam_2_Y]
20%                   [EoL_3_X, EoL_1_Y, cam_2_Y]
50%                   [EoL_2_Y, EoL_1_Y, cam_1_X]
75%                   [EoL_2_X, cam_2_Y, EoL_2_Y]
95%              [rob_1_supply, EoL_3_X, cam_3_X]

                            max_Vel_2-8.5_60                size_1-8.6_61  \
Overlap Percent
10%              [EoL_6_Y, EoL_2_X, cam_2_Y]  [EoL_3_Y, cam_2_Y, EoL_1_Y]
20%              [EoL_6_X, cam_2_Y, cam_3_X]  [EoL_4_X, EoL_2_X, cam_2_Y]
50%              [EoL_6_X, EoL_2_X, cam_1_X]  [cam_1_Y, EoL_2_X, cam_2_Y]
75%              [EoL_6_Y, cam_3_Y, EoL_1_Y]  [cam_1_Y, cam_3_Y, EoL_1_Y]
95%              [EoL_6_X, cam_3_X, EoL_6_Y]           [EoL_3_X, EoL_3_Y]

                             feeder_3-8.7_62             gripper_1-8.8_63  \
Overlap Percent
10%              [EoL_2_Y, cam_2_Y, EoL_1_Y]  [EoL_2_Y, cam_2_Y, EoL_1_Y]
20%              [EoL_3_X, cam_3_Y, EoL_1_Y]  [EoL_3_X, cam_2_Y, EoL_1_Y]
50%              [EoL_2_Y, EoL_1_Y, cam_1_Y]  [EoL_2_Y, cam_3_X, cam_2_Y]
75%              [EoL_2_X, cam_2_Y, EoL_2_Y]  [EoL_2_X, EoL_2_Y, EoL_1_Y]
95%                                [cam_3_Y]  [EoL_3_X, cam_3_X, EoL_2_X]

                                 max_Vel_2-8.9_64
Overlap Percent
10%                   [EoL_3_Y, EoL_2_X, cam_2_Y]
20%                   [EoL_3_Y, cam_2_Y, EoL_1_Y]
50%              [rob_2_maxVel, EoL_2_X, cam_1_Y]
```

```
75%               [rob_2_maxVel, cam_2_Y, EoL_1_Y]
95%               [rob_2_maxVel, EoL_6_X, cam_3_X]

[5 rows x 64 columns]
```

[ ]:
```
result_data_3top = results_top_3(result_overlap_RCD,abnormal_sets)
result_data_3top.tail()
```

[ ]:
```
                     10%       20%       50%       75%       95%
size_1-8.6_61      0.00000  0.000000  1.000000  1.000000  0.000000
feeder_3-8.7_62    0.00000  1.000000  0.000000  0.000000  1.000000
gripper_1-8.8_63   0.00000  0.000000  0.000000  0.000000  0.000000
max_Vel_2-8.9_64   0.00000  0.000000  1.000000  1.000000  1.000000
Total              0.28125  0.203125  0.390625  0.140625  0.515625
```

[ ]:
```
result_data_1top = results_top_1(result_overlap_RCD,abnormal_sets)
result_data_1top.tail()
```

[ ]:
```
                     10%      20%       50%       75%       95%
size_1-8.6_61      0.00000  0.00000  1.000000  1.000000  0.000000
feeder_3-8.7_62    0.00000  0.00000  0.000000  0.000000  1.000000
gripper_1-8.8_63   0.00000  0.00000  0.000000  0.000000  0.000000
max_Vel_2-8.9_64   0.00000  0.00000  1.000000  1.000000  1.000000
Total              0.15625  0.09375  0.390625  0.078125  0.296875
```

[ ]:
```
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_1_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_1_RCD.csv'))
```

1.8 Variation 2 - Normal Size

The ED-algorithm requires the same length for the normal and abnormal data set.

1.8.1 HT - Algorithm

[ ]:
```
result_HT_normal_size_1 =␣
 ↪run_HT_normal_size(folder_path,files,startrow=839,normal_size_p=2.
 ↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_normal_size_2 =␣
 ↪run_HT_normal_size(folder_path,files,startrow=839,normal_size_p=1.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_normal_size_3 =␣
 ↪run_HT_normal_size(folder_path,files,startrow=839,normal_size_p=1.
 ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_normal_size_4 =␣
 ↪run_HT_normal_size(folder_path,files,startrow=839,normal_size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
result_HT_normal_size_5 =␣
 ↪run_HT_normal_size(folder_path,files,startrow=839,normal_size_p=0.
 ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

[ ]:

```
result_normal_size_HT = pd.DataFrame()
result_normal_size_HT = pd.
 ↪concat([result_HT_normal_size_1,result_HT_normal_size_2,result_HT_normal_size_3,result_HT_n
 ↪ignore_index=True)
result_normal_size_HT['Normal Size Percent'] = pd.DataFrame({'HT':
 ↪['200%','150%','100%','50%','20%']})
result_normal_size_HT.set_index('Normal Size Percent', inplace=True)
result_normal_size_HT
```

[ ]:

```
                                         size_1-1.2_1  \
Normal Size Percent
200%                 [rob_1_maxVel, rob_1_3, rob_1_1]
150%                     [con_3, con_2, rob_1_maxVel]
100%                      [rob_1_2, rob_1_1, rob_1_3]
50%                       [rob_1_3, rob_1_1, rob_1_2]
20%                  [cam_1_X, cam_1_Y, rob_1_maxVel]

                                            feeder_3-1.3_2  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%                 [cam_3_X, rob_2_maxVel, rob_1_maxVel]
100%                      [rob_1_maxVel, rob_1_2, rob_1_1]
50%                       [cam_3_X, rob_1_maxVel, EoL_2_X]
20%                    [rob_2_maxVel, score, rob_1_maxVel]

                                                gripper_1-1.4_3  \
Normal Size Percent
200%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                  [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
20%                       [rob_1_supply, rob_1_vacuum, rob_1_3]

                                                max_Vel_2-1.5_4  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                        [rob_2_maxVel, rob_1_maxVel, con_3]
100%                      [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                       [rob_2_maxVel, rob_1_maxVel, rob_2_1]
20%                       [rob_2_maxVel, rob_1_vacuum, rob_2_1]

                                         size_1-1.6_5  \
Normal Size Percent
```

```
200%                 [rob_1_maxVel, rob_1_3, rob_1_2]
150%                     [rob_1_maxVel, con_3, con_2]
100%                 [rob_1_maxVel, rob_1_1, rob_1_2]
50%                  [rob_1_maxVel, rob_1_3, rob_1_2]
20%                  [cam_1_X, cam_1_Y, rob_1_maxVel]

                                            feeder_3-1.7_6  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%                 [cam_3_X, rob_2_maxVel, rob_1_maxVel]
100%                      [rob_1_maxVel, rob_1_2, rob_1_1]
50%                       [cam_3_X, rob_1_maxVel, EoL_2_X]
20%                         [rob_2_maxVel, cam_1_X, score]

                                                gripper_1-1.8_7  \
Normal Size Percent
200%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                  [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
20%                  [rob_1_supply, rob_1_vacuum, rob_1_maxVel]

                                                max_Vel_2-1.9_8  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                        [rob_2_maxVel, rob_1_maxVel, con_3]
100%                      [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                       [rob_2_maxVel, rob_1_maxVel, rob_2_1]
20%                       [rob_2_maxVel, rob_1_vacuum, rob_2_1]

                                         size_1-2.2_9  \
Normal Size Percent
200%                 [rob_1_maxVel, rob_1_3, rob_1_2]
150%                     [rob_1_maxVel, con_3, con_2]
100%                 [rob_1_maxVel, rob_1_1, rob_1_2]
50%                  [rob_1_maxVel, rob_1_3, rob_1_2]
20%                       [cam_1_X, cam_1_Y, rob_1_3]

                                           feeder_3-2.3_10  …  \
Normal Size Percent                                         …
200%                 [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]  …
150%                 [cam_3_X, rob_2_maxVel, rob_1_maxVel]  …
100%                      [rob_1_maxVel, rob_1_2, rob_1_1]  …
50%                       [cam_3_X, rob_1_maxVel, EoL_2_X]  …
20%                    [rob_2_maxVel, score, rob_1_maxVel]  …

                                               gripper_1-7.8_55  \
Normal Size Percent
200%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                  [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
20%                  [rob_1_supply, rob_1_vacuum, rob_1_maxVel]

                                               max_Vel_2-7.9_56  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                        [rob_2_maxVel, rob_1_maxVel, con_3]
100%                      [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                       [rob_2_maxVel, rob_1_maxVel, rob_2_1]
20%                       [rob_2_maxVel, rob_1_vacuum, rob_2_1]

                                        size_1-8.2_57  \
Normal Size Percent
200%                 [rob_1_maxVel, rob_1_3, rob_1_2]
150%                     [rob_1_maxVel, con_3, con_2]
100%                 [rob_1_maxVel, rob_1_2, rob_1_1]
50%                  [rob_1_maxVel, rob_1_3, rob_1_2]
20%                  [cam_1_X, cam_1_Y, rob_1_maxVel]

                                           feeder_3-8.3_58  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%                 [cam_3_X, rob_2_maxVel, rob_1_maxVel]
100%                      [rob_1_maxVel, rob_1_2, rob_1_1]
50%                       [cam_3_X, rob_1_maxVel, EoL_2_X]
20%                    [rob_2_maxVel, score, rob_1_maxVel]

                                               gripper_1-8.4_59  \
Normal Size Percent
200%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                       [rob_1_supply, rob_1_vacuum, rob_1_1]
20%                  [rob_1_supply, rob_1_vacuum, rob_1_maxVel]

                                               max_Vel_2-8.5_60  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                        [rob_2_maxVel, rob_1_maxVel, con_3]
100%                      [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                       [rob_2_maxVel, rob_1_maxVel, rob_2_1]
20%                       [rob_2_maxVel, rob_1_vacuum, rob_2_1]
```

```
                                        size_1-8.6_61  \
Normal Size Percent
200%                 [rob_1_maxVel, rob_1_1, rob_1_3]
150%                     [rob_1_maxVel, con_3, con_2]
100%                 [rob_1_maxVel, rob_1_2, rob_1_1]
50%                  [rob_1_maxVel, rob_1_3, rob_1_1]
20%                  [cam_1_X, cam_1_Y, rob_1_maxVel]

                                           feeder_3-8.7_62  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%                 [cam_3_X, rob_2_maxVel, rob_1_maxVel]
100%                      [rob_1_maxVel, rob_1_2, rob_1_1]
50%                       [cam_3_X, rob_1_maxVel, EoL_2_X]
20%                    [rob_2_maxVel, score, rob_1_maxVel]

                                               gripper_1-8.8_63  \
Normal Size Percent
200%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                 [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                  [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
20%                  [rob_1_supply, rob_1_vacuum, rob_1_maxVel]

                                               max_Vel_2-8.9_64
Normal Size Percent
200%                 [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                        [rob_2_maxVel, rob_1_maxVel, con_3]
100%                      [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                       [rob_2_maxVel, rob_1_maxVel, rob_2_1]
20%                       [rob_2_maxVel, rob_1_vacuum, rob_2_1]

[5 rows x 64 columns]
```

[ ]:

```
result_data_3top = results_top_3(result_normal_size_HT,abnormal_sets)
result_data_3top.tail()
```

[ ]:

```
                    200%  150%  100%   50%   20%
size_1-8.6_61     0.0000  0.00   0.0  0.00  1.00
feeder_3-8.7_62   0.0000  1.00   0.0  1.00  0.00
gripper_1-8.8_63  1.0000  1.00   1.0  1.00  1.00
max_Vel_2-8.9_64  1.0000  1.00   1.0  1.00  1.00
Total             0.5625  0.75   0.5  0.75  0.75
```

[ ]:

```
result_data_1top = results_top_1(result_normal_size_HT,abnormal_sets)
result_data_1top.tail()
```

```
[ ]:                  200%  150%  100%   50%   20%
     size_1-8.6_61      0.0  0.00   0.0  0.00  1.00
     feeder_3-8.7_62    0.0  1.00   0.0  1.00  0.00
     gripper_1-8.8_63   1.0  1.00   1.0  1.00  1.00
     max_Vel_2-8.9_64   1.0  1.00   1.0  1.00  1.00
     Total              0.5  0.75   0.5  0.75  0.75
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_2_HT.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_2_HT.csv'))
```

1.8.2 RW - Algorithm

```
[ ]: result_RW_normal_size_1 =␣
      ↪run_RW_normal_size(folder_path,files,startrow=839,normal_size_p=2.
      ↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_normal_size_2 =␣
      ↪run_RW_normal_size(folder_path,files,startrow=839,normal_size_p=1.
      ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_normal_size_3 =␣
      ↪run_RW_normal_size(folder_path,files,startrow=839,normal_size_p=1.
      ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_normal_size_4 =␣
      ↪run_RW_normal_size(folder_path,files,startrow=839,normal_size_p=0.
      ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_normal_size_5 =␣
      ↪run_RW_normal_size(folder_path,files,startrow=839,normal_size_p=0.
      ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
[ ]: result_normal_size_RW = pd.DataFrame()
     result_normal_size_RW = pd.
      ↪concat([result_RW_normal_size_1,result_RW_normal_size_2,result_RW_normal_size_3,result_RW_n
      ↪ignore_index=True)
     result_normal_size_RW['Normal Size Percent'] = pd.DataFrame({'RW':
      ↪['200%','150%','100%','50%','20%']})
     result_normal_size_RW.set_index('Normal Size Percent', inplace=True)
     result_normal_size_RW
```

```
[ ]:                                              size_1-1.2_1  \
     Normal Size Percent
     200%                   [cam_1_X, rob_2_supply, rob_1_supply]
     150%                        [cam_1_X, cam_1_Y, rob_1_supply]
     100%                        [cam_1_Y, cam_1_X, rob_2_supply]
     50%                         [cam_1_Y, cam_1_X, rob_2_supply]
     20%                         [cam_1_X, cam_1_Y, rob_1_supply]

                                                     feeder_3-1.3_2  \
     Normal Size Percent
```

```
200%                 [rob_2_supply, rob_1_supply, rob_2_maxVel]
150%                      [rob_2_supply, rob_1_supply, cam_1_Y]
100%                           [rob_2_supply, cam_3_X, cam_1_Y]
50%                            [rob_2_supply, cam_1_X, cam_1_Y]
20%                       [cam_1_X, rob_1_supply, rob_2_supply]

                                           gripper_1-1.4_3  \
Normal Size Percent
200%                 [rob_1_supply, rob_2_supply, cam_1_Y]
150%                 [rob_1_supply, rob_2_supply, cam_1_Y]
100%                 [rob_1_supply, rob_2_supply, cam_1_Y]
50%                  [rob_1_supply, rob_2_supply, cam_1_Y]
20%                       [rob_1_supply, cam_1_X, cam_1_Y]

                                                max_Vel_2-1.5_4  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_2_supply, rob_1_supply]
150%                 [rob_2_maxVel, rob_2_supply, rob_1_supply]
100%                           [rob_2_maxVel, cam_2_Y, cam_3_X]
50%                       [rob_2_maxVel, rob_1_supply, cam_1_X]
20%                            [rob_2_maxVel, cam_1_X, cam_1_Y]

                                         size_1-1.6_5  \
Normal Size Percent
200%                 [cam_1_Y, cam_1_X, rob_2_supply]
150%                 [cam_1_Y, cam_1_X, rob_2_supply]
100%                      [cam_1_Y, cam_1_X, cam_3_X]
50%                  [cam_1_X, cam_1_Y, rob_2_supply]
20%                  [cam_1_X, cam_1_Y, rob_1_supply]

                                            feeder_3-1.7_6  \
Normal Size Percent
200%                 [rob_1_supply, rob_2_supply, cam_1_X]
150%                 [rob_2_supply, cam_1_X, rob_1_supply]
100%                           [cam_3_X, cam_3_Y, cam_1_X]
50%                       [cam_1_X, rob_2_supply, cam_1_Y]
20%                              [cam_1_X, cam_1_Y, con_2]

                                           gripper_1-1.8_7  \
Normal Size Percent
200%                   [rob_1_supply, rob_2_supply, con_2]
150%                 [rob_1_supply, cam_1_X, rob_2_maxVel]
100%                 [rob_1_supply, rob_2_supply, cam_1_Y]
50%                  [rob_1_supply, rob_2_supply, cam_1_Y]
20%                       [rob_1_supply, cam_1_X, cam_1_Y]

                                                max_Vel_2-1.9_8  \
Normal Size Percent
200%                 [rob_2_maxVel, rob_2_supply, rob_1_supply]
150%                      [rob_2_maxVel, rob_2_supply, cam_1_Y]
100%                      [rob_2_maxVel, cam_3_X, rob_2_supply]
50%                       [rob_2_maxVel, rob_2_supply, cam_1_X]
20%                            [rob_2_maxVel, cam_1_X, cam_1_Y]

                                         size_1-2.2_9  \
Normal Size Percent
200%                 [cam_1_Y, cam_1_X, rob_2_supply]
150%                 [cam_1_X, cam_1_Y, rob_2_supply]
100%                 [cam_1_X, cam_1_Y, rob_2_supply]
50%                  [cam_1_Y, cam_1_X, rob_2_supply]
20%                         [cam_1_X, cam_1_Y, con_2]

                                           feeder_3-2.3_10  …  \
Normal Size Percent                                         …
200%                 [rob_1_supply, rob_2_supply, cam_1_Y]  …
150%                 [rob_1_supply, rob_2_supply, cam_1_Y]  …
100%                      [rob_2_supply, cam_3_X, cam_3_Y]  …
50%                       [cam_1_Y, rob_2_supply, cam_1_X]  …
20%                         [cam_1_X, rob_1_supply, con_2]  …

                                          gripper_1-7.8_55  \
Normal Size Percent
200%                 [rob_1_supply, rob_2_supply, cam_1_X]
150%                 [rob_1_supply, rob_2_supply, cam_1_X]
100%                 [rob_1_supply, rob_2_supply, cam_1_X]
50%                  [rob_1_supply, rob_2_supply, cam_1_X]
20%                       [rob_1_supply, cam_1_X, cam_1_Y]

                                               max_Vel_2-7.9_56  \
Normal Size Percent
200%                 [rob_1_supply, rob_2_maxVel, rob_2_supply]
150%                 [rob_2_maxVel, rob_2_supply, rob_1_supply]
100%                           [rob_2_maxVel, cam_3_X, cam_2_Y]
50%                       [rob_2_maxVel, rob_1_supply, cam_1_X]
20%                            [rob_2_maxVel, cam_1_X, cam_1_Y]

                                        size_1-8.2_57  \
Normal Size Percent
200%                 [rob_2_supply, cam_1_X, cam_1_Y]
150%                 [cam_1_X, cam_1_Y, rob_2_supply]
100%                 [cam_1_Y, cam_1_X, rob_2_supply]
50%                  [cam_1_Y, cam_1_X, rob_2_supply]
20%                         [cam_1_Y, cam_1_X, con_2]
```

```
                                           feeder_3-8.3_58  \
Normal Size Percent
200%                 [rob_1_supply, rob_2_supply, cam_1_Y]
150%                 [rob_1_supply, cam_1_Y, rob_2_maxVel]
100%                      [cam_3_X, cam_3_Y, rob_1_supply]
50%                  [rob_1_supply, cam_1_Y, rob_2_supply]
20%                       [cam_1_X, rob_1_supply, cam_1_Y]

                                          gripper_1-8.4_59  \
Normal Size Percent
200%                 [rob_1_supply, rob_2_supply, cam_1_X]
150%                 [rob_1_supply, rob_2_supply, cam_1_Y]
100%                 [rob_1_supply, rob_2_supply, cam_1_X]
50%                  [rob_1_supply, rob_2_supply, cam_1_X]
20%                       [rob_1_supply, cam_1_X, cam_1_Y]

                                               max_Vel_2-8.5_60  \
Normal Size Percent
200%                 [rob_2_supply, rob_2_maxVel, rob_1_supply]
150%                      [rob_2_maxVel, rob_2_supply, cam_1_Y]
100%                      [rob_2_supply, rob_2_maxVel, cam_3_X]
50%                       [rob_2_maxVel, cam_1_X, rob_2_supply]
20%                            [rob_2_maxVel, cam_1_X, cam_1_Y]

                                        size_1-8.6_61  \
Normal Size Percent
200%                 [cam_1_X, cam_1_Y, rob_1_supply]
150%                 [cam_1_Y, cam_1_X, rob_2_maxVel]
100%                      [cam_1_Y, cam_1_X, cam_3_X]
50%                  [cam_1_X, cam_1_Y, rob_2_supply]
20%                  [cam_1_X, cam_1_Y, rob_1_supply]

                                           feeder_3-8.7_62  \
Normal Size Percent
200%                 [rob_2_supply, rob_1_supply, cam_1_X]
150%                 [rob_2_supply, rob_1_supply, cam_1_Y]
100%                 [rob_2_supply, rob_1_supply, cam_3_Y]
50%                  [rob_2_supply, rob_1_supply, cam_1_X]
20%                       [cam_1_X, rob_1_supply, cam_1_Y]

                                          gripper_1-8.8_63  \
Normal Size Percent
200%                   [rob_1_supply, con_2, rob_2_supply]
150%                 [rob_1_supply, rob_2_maxVel, cam_1_X]
100%                 [rob_1_supply, rob_2_supply, cam_1_X]
50%                       [rob_1_supply, cam_1_X, cam_1_Y]
20%                       [rob_1_supply, cam_1_X, cam_1_Y]
```

```
                                         max_Vel_2-8.9_64
Normal Size Percent
200%                    [rob_2_maxVel, rob_1_supply, cam_1_X]
150%                         [rob_2_maxVel, cam_1_Y, cam_1_X]
100%                    [rob_2_maxVel, cam_3_X, rob_2_supply]
50%                     [rob_2_maxVel, cam_1_X, rob_1_supply]
20%                          [rob_2_maxVel, cam_1_X, cam_1_Y]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_normal_size_RW,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                     200%  150%  100%   50%   20%
     size_1-8.6_61     1.00000  1.00   1.0  1.00  1.00
     feeder_3-8.7_62   0.00000  0.00   1.0  0.00  0.00
     gripper_1-8.8_63  1.00000  1.00   1.0  1.00  1.00
     max_Vel_2-8.9_64  1.00000  1.00   1.0  1.00  1.00
     Total             0.78125  0.75   1.0  0.75  0.75
```

```
[ ]: result_data_1top = results_top_1(result_normal_size_RW,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                      200%     150%   100%   50%   20%
     size_1-8.6_61     1.000000  1.00000  1.000  1.00  1.00
     feeder_3-8.7_62   0.000000  0.00000  0.000  0.00  0.00
     gripper_1-8.8_63  1.000000  1.00000  1.000  1.00  1.00
     max_Vel_2-8.9_64  1.000000  1.00000  1.000  1.00  1.00
     Total             0.484375  0.71875  0.625  0.75  0.75
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_2_RW.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_2_RW.csv'))
```

1.8.3 RCD - Algorithm

```
[ ]: result_RCD_normal_size_1 =␣
       ↪run_RCD_normal_size(folder_path,files,startrow=839,normal_size_p=2.
       ↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_normal_size_2 =␣
       ↪run_RCD_normal_size(folder_path,files,startrow=839,normal_size_p=1.
       ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_normal_size_3 =␣
       ↪run_RCD_normal_size(folder_path,files,startrow=839,normal_size_p=1.
       ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
result_RCD_normal_size_4 =␣
 ↪run_RCD_normal_size(folder_path,files,startrow=839,normal_size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_RCD_normal_size_5 =␣
 ↪run_RCD_normal_size(folder_path,files,startrow=839,normal_size_p=0.
 ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

[ ]:

```
result_normal_size_RCD = pd.DataFrame()
result_normal_size_RCD = pd.
 ↪concat([result_RCD_normal_size_1,result_RCD_normal_size_2,result_RCD_normal_size_3,result_R
 ↪ignore_index=True)
result_normal_size_RCD['Normal Size Percent'] = pd.DataFrame({'RCD':
 ↪['200%','150%','100%','50%','20%']})
result_normal_size_RCD.set_index('Normal Size Percent', inplace=True)
result_normal_size_RCD
```

[ ]:

```
                                    size_1-1.2_1               feeder_3-1.3_2  \
Normal Size Percent
200%                          [EoL_4_X, cam_1_X]           [EoL_6_Y, EoL_2_X]
150%                 [EoL_5_X, EoL_6_Y, EoL_6_X]           [EoL_6_X, EoL_6_Y]
100%                          [EoL_6_Y, cam_1_Y]  [EoL_4_X, EoL_6_Y, EoL_2_Y]
50%                  [cam_1_Y, EoL_5_Y, EoL_6_Y]           [EoL_5_X, EoL_2_Y]
20%                  [EoL_4_X, EoL_5_Y, EoL_3_X]  [EoL_5_X, EoL_2_X, EoL_2_Y]

                                      gripper_1-1.4_3  \
Normal Size Percent
200%                               [EoL_3_Y, EoL_6_Y]
150%                 [EoL_4_X, EoL_2_Y, rob_1_supply]
100%                      [EoL_6_Y, EoL_3_X, EoL_4_Y]
50%                                [EoL_4_Y, EoL_2_Y]
20%                                [EoL_6_Y, cam_3_X]

                             max_Vel_2-1.5_4                 size_1-1.6_5  \
Normal Size Percent
200%                               [EoL_6_X]  [EoL_4_X, EoL_6_X, EoL_6_Y]
150%                          [rob_2_maxVel]           [EoL_5_X, cam_1_Y]
100%                          [rob_2_maxVel]           [EoL_4_X, EoL_4_Y]
50%                                [EoL_6_Y]           [cam_1_Y, EoL_5_X]
20%                  [EoL_6_X, rob_2_maxVel]           [EoL_3_X, EoL_5_Y]

                                  feeder_3-1.7_6              gripper_1-1.8_7  \
Normal Size Percent
200%                 [EoL_4_X, EoL_3_X, cam_3_Y]  [EoL_2_Y, EoL_4_Y, EoL_5_Y]
150%                 [EoL_6_X, EoL_4_X, cam_3_X]  [EoL_4_Y, EoL_4_X, EoL_5_Y]
100%                          [EoL_4_X, EoL_3_Y]           [EoL_2_Y, EoL_5_Y]
50%                           [EoL_4_X, EoL_2_Y]           [EoL_2_Y, EoL_5_Y]
20%                  [EoL_5_Y, EoL_4_X, EoL_3_Y]           [EoL_3_X, cam_3_X]
```

```
                             max_Vel_2-1.9_8                 size_1-2.2_9  \
Normal Size Percent
200%                               [EoL_6_Y]  [EoL_3_Y, EoL_6_Y, EoL_3_X]
150%                               [EoL_6_Y]           [EoL_6_X, EoL_6_Y]
100%                 [EoL_6_X, rob_2_maxVel]  [EoL_6_Y, EoL_6_X, EoL_4_Y]
50%                                [EoL_6_Y]           [cam_1_Y, EoL_4_X]
20%                       [EoL_6_Y, cam_3_X]  [cam_1_X, EoL_6_X, EoL_2_X]

                                 feeder_3-2.3_10  …  \
Normal Size Percent                               …
200%                          [EoL_5_Y, EoL_6_Y]  …
150%                          [cam_3_X, EoL_6_Y]  …
100%                          [EoL_3_Y, EoL_6_X]  …
50%                  [EoL_6_Y, EoL_3_X, EoL_3_Y]  …
20%                  [cam_3_X, cam_3_Y, EoL_3_X]  …

                                     gripper_1-7.8_55  \
Normal Size Percent
200%                      [EoL_2_Y, EoL_5_X, EoL_2_X]
150%                               [EoL_4_X, EoL_2_Y]
100%                 [rob_1_supply, EoL_2_Y, EoL_6_X]
50%                                [EoL_5_Y, EoL_5_X]
20%                                [EoL_1_Y, EoL_2_Y]

                                     max_Vel_2-7.9_56  \
Normal Size Percent
200%                               [EoL_6_X, EoL_6_Y]
150%                               [EoL_6_X, EoL_6_Y]
100%                          [EoL_6_Y, rob_2_maxVel]
50%                                         [EoL_6_Y]
20%                  [EoL_2_X, cam_3_X, rob_2_maxVel]

                                   size_1-8.2_57              feeder_3-8.3_58  \
Normal Size Percent
200%                          [EoL_4_X, EoL_6_X]  [EoL_3_X, EoL_5_Y, EoL_4_Y]
150%                 [cam_1_Y, EoL_4_X, EoL_5_X]  [EoL_6_Y, EoL_5_X, EoL_4_X]
100%                 [EoL_5_Y, EoL_6_Y, EoL_3_X]  [EoL_3_X, EoL_2_Y, EoL_2_X]
50%                           [EoL_5_Y, EoL_5_X]           [EoL_2_Y, EoL_3_X]
20%                           [EoL_5_X, cam_1_X]  [EoL_2_Y, EoL_5_X, EoL_2_X]

                                     gripper_1-8.4_59  \
Normal Size Percent
200%                 [rob_1_supply, EoL_4_Y, EoL_2_Y]
150%                               [EoL_3_X, EoL_5_Y]
100%                      [EoL_5_Y, EoL_4_Y, EoL_3_X]
50%                                [EoL_3_X, EoL_6_Y]
```

```
20%                                [EoL_4_Y, EoL_2_X]

                            max_Vel_2-8.5_60                size_1-8.6_61  \
Normal Size Percent
200%                               [EoL_6_X]  [cam_1_X, EoL_6_X, EoL_3_X]
150%                               [EoL_6_Y]           [EoL_6_Y, cam_1_Y]
100%                 [rob_2_maxVel, EoL_6_Y]           [EoL_5_Y, EoL_6_Y]
50%                                [EoL_6_Y]  [EoL_4_Y, cam_1_Y, EoL_3_Y]
20%                  [rob_2_maxVel, EoL_6_X]           [cam_1_Y, EoL_3_X]

                                 feeder_3-8.7_62  \
Normal Size Percent
200%                          [EoL_5_X, cam_3_Y]
150%                          [EoL_5_Y, EoL_2_X]
100%                 [EoL_2_Y, EoL_3_X, cam_3_Y]
50%                  [cam_3_X, EoL_6_Y, EoL_5_Y]
20%                           [EoL_2_X, EoL_5_X]

                                     gripper_1-8.8_63  \
Normal Size Percent
200%                      [EoL_5_X, EoL_4_Y, EoL_2_X]
150%                          [EoL_2_X, rob_1_supply]
100%                               [EoL_3_Y, EoL_4_X]
50%                  [rob_1_supply, EoL_4_X, EoL_3_Y]
20%                       [EoL_5_X, EoL_6_Y, EoL_3_Y]

                                     max_Vel_2-8.9_64
Normal Size Percent
200%                                   [rob_2_maxVel]
150%                 [EoL_6_X, rob_2_maxVel, EoL_6_Y]
100%                               [EoL_6_X, EoL_2_X]
50%                           [EoL_2_X, rob_2_maxVel]
20%                                [EoL_5_X, cam_2_Y]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_normal_size_RCD,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                       200%  150%      100%       50%       20%
     size_1-8.6_61     1.000000   1.0  0.000000  1.000000  1.000000
     feeder_3-8.7_62   1.000000   0.0  1.000000  1.000000  0.000000
     gripper_1-8.8_63  0.000000   1.0  0.000000  1.000000  0.000000
     max_Vel_2-8.9_64  1.000000   1.0  0.000000  1.000000  0.000000
     Total             0.359375   0.5  0.421875  0.296875  0.328125
```

[ ]:
```
result_data_1top = results_top_1(result_normal_size_RCD,abnormal_sets)
result_data_1top.tail()
```

[ ]:
```
                      200%      150%      100%      50%       20%
size_1-8.6_61     1.000000  0.000000  0.000000  0.00000  1.000000
feeder_3-8.7_62   0.000000  0.000000  0.000000  1.00000  0.000000
gripper_1-8.8_63  0.000000  0.000000  0.000000  1.00000  0.000000
max_Vel_2-8.9_64  1.000000  0.000000  0.000000  0.00000  0.000000
Total             0.171875  0.296875  0.171875  0.21875  0.171875
```

[ ]:
```
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_2_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_2_RCD.csv'))
```

1.9 Variation 3 - Abnormal Size

The ED-algorithm requires the same length for the normal and abnormal data set.

1.9.1 HT - Algorithm

[ ]:
```
result_HT_abnormal_size_1 =␣
 ↪run_HT_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=2.
 ↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_abnormal_size_2 =␣
 ↪run_HT_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=1.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_abnormal_size_3 =␣
 ↪run_HT_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=1.
 ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_abnormal_size_4 =␣
 ↪run_HT_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_HT_abnormal_size_5 =␣
 ↪run_HT_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=0.
 ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

[ ]:
```
result_abnormal_size_HT = pd.DataFrame()
result_abnormal_size_HT = pd.
 ↪concat([result_HT_abnormal_size_1,result_HT_abnormal_size_2,result_HT_abnormal_size_3,resul
 ↪ignore_index=True)
result_abnormal_size_HT['abnormal Size Percent'] = pd.DataFrame({'HT':
 ↪['200%','150%','100%','50%','20%']})
result_abnormal_size_HT.set_index('abnormal Size Percent', inplace=True)
result_abnormal_size_HT
```

[ ]:
```
                                              size_1-1.2_1  \
abnormal Size Percent
200%                   [rob_1_maxVel, rob_1_3, rob_1_1]
```

```
150%                   [rob_1_maxVel, rob_1_3, rob_1_1]
100%                        [rob_1_1, rob_1_3, rob_1_2]
50%                         [rob_1_1, rob_1_3, rob_1_2]
20%                         [rob_1_1, rob_1_3, rob_1_2]

                                              feeder_3-1.3_2  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
100%                        [rob_2_maxVel, EoL_4_Y, cam_3_X]
50%                              [EoL_4_Y, cam_3_X, EoL_5_Y]
20%                              [EoL_4_Y, cam_3_X, EoL_5_Y]

                                                  gripper_1-1.4_3  \
abnormal Size Percent
200%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                        [rob_1_supply, rob_1_vacuum, rob_1_1]
50%                         [rob_1_supply, rob_1_vacuum, rob_1_1]
20%                         [rob_1_supply, rob_1_vacuum, rob_1_1]

                                                  max_Vel_2-1.5_4  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
100%                        [rob_2_maxVel, rob_1_vacuum, rob_1_1]
50%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]
20%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]

                                           size_1-1.6_5  \
abnormal Size Percent
200%                   [rob_1_maxVel, rob_1_3, rob_1_2]
150%                   [rob_1_maxVel, rob_1_1, rob_1_3]
100%                        [rob_1_1, rob_1_3, rob_1_2]
50%                         [rob_1_1, rob_1_3, rob_1_2]
20%                         [rob_1_1, rob_1_3, rob_1_2]

                                              feeder_3-1.7_6  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
100%                        [rob_2_maxVel, EoL_4_Y, cam_3_X]
50%                         [rob_2_maxVel, EoL_4_Y, cam_3_X]
20%                              [EoL_4_Y, cam_3_X, EoL_5_Y]

                                                  gripper_1-1.8_7  \
abnormal Size Percent
```

```
200%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                         [rob_1_supply, rob_1_vacuum, rob_1_1]
20%                         [rob_1_supply, rob_1_vacuum, rob_1_1]

                                                  max_Vel_2-1.9_8  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
100%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
50%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]
20%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]

                                           size_1-2.2_9  \
abnormal Size Percent
200%                   [rob_1_maxVel, rob_1_3, rob_1_2]
150%                   [rob_1_maxVel, rob_1_3, rob_1_1]
100%                   [rob_1_maxVel, rob_1_1, rob_1_3]
50%                         [rob_1_1, rob_1_3, rob_1_2]
20%                         [rob_1_1, rob_1_3, rob_1_2]

                                             feeder_3-2.3_10  …  \
abnormal Size Percent                                         …
200%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]  …
150%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]  …
100%                        [rob_2_maxVel, EoL_4_Y, cam_3_X]  …
50%                              [EoL_4_Y, cam_3_X, EoL_5_Y]  …
20%                              [EoL_4_Y, cam_3_X, EoL_5_Y]  …

                                                 gripper_1-7.8_55  \
abnormal Size Percent
200%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                         [rob_1_supply, rob_1_vacuum, rob_1_1]
20%                         [rob_1_supply, rob_1_vacuum, rob_1_1]

                                                 max_Vel_2-7.9_56  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
100%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
50%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]
20%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]

                                          size_1-8.2_57  \
abnormal Size Percent
200%                   [rob_1_maxVel, rob_1_3, rob_1_2]
150%                   [rob_1_maxVel, rob_1_3, rob_1_1]
100%                        [rob_1_1, rob_1_3, rob_1_2]
50%                         [rob_1_1, rob_1_3, rob_1_2]
20%                         [rob_1_1, rob_1_3, rob_1_2]

                                             feeder_3-8.3_58  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
100%                        [rob_2_maxVel, EoL_4_Y, cam_3_X]
50%                              [EoL_4_Y, cam_3_X, EoL_5_Y]
20%                              [EoL_4_Y, cam_3_X, EoL_5_Y]

                                            gripper_1-8.4_59  \
abnormal Size Percent
200%                   [rob_1_supply, rob_1_vacuum, rob_1_1]
150%                   [rob_1_supply, rob_1_vacuum, rob_1_1]
100%                   [rob_1_supply, rob_1_vacuum, rob_1_1]
50%                    [rob_1_supply, rob_1_vacuum, rob_1_1]
20%                    [rob_1_supply, rob_1_vacuum, rob_1_1]

                                                 max_Vel_2-8.5_60  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
100%                        [rob_2_maxVel, rob_1_vacuum, rob_1_1]
50%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]
20%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]

                                          size_1-8.6_61  \
abnormal Size Percent
200%                   [rob_1_maxVel, rob_1_1, rob_1_3]
150%                   [rob_1_maxVel, rob_1_1, rob_1_3]
100%                   [rob_1_maxVel, rob_1_1, rob_1_3]
50%                         [rob_1_1, rob_1_3, rob_1_2]
20%                         [rob_1_1, rob_1_3, rob_1_2]

                                             feeder_3-8.7_62  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%                   [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
100%                        [rob_2_maxVel, EoL_4_Y, cam_3_X]
50%                              [EoL_4_Y, cam_3_X, EoL_5_Y]
20%                              [EoL_4_Y, cam_3_X, EoL_5_Y]
```

```
                                            gripper_1-8.8_63  \
abnormal Size Percent
200%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%                   [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%                         [rob_1_supply, rob_1_vacuum, rob_1_1]
20%                         [rob_1_supply, rob_1_vacuum, rob_1_1]

                                            max_Vel_2-8.9_64
abnormal Size Percent
200%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%                   [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
100%                        [rob_2_maxVel, rob_1_vacuum, rob_1_1]
50%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]
20%                         [rob_2_maxVel, rob_1_vacuum, rob_1_1]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_abnormal_size_HT,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                      200%      150%  100%   50%   20%
     size_1-8.6_61     0.000000  0.000000  0.00  0.00  0.00
     feeder_3-8.7_62   0.000000  0.000000  1.00  1.00  1.00
     gripper_1-8.8_63  1.000000  1.000000  1.00  1.00  1.00
     max_Vel_2-8.9_64  1.000000  1.000000  1.00  1.00  1.00
     Total             0.578125  0.578125  0.75  0.75  0.75
```

```
[ ]: result_data_1top = results_top_1(result_abnormal_size_HT,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                  200%  150%  100%  50%  20%
     size_1-8.6_61      0.0   0.0   0.0  0.0  0.0
     feeder_3-8.7_62    0.0   0.0   0.0  0.0  0.0
     gripper_1-8.8_63   1.0   1.0   1.0  1.0  1.0
     max_Vel_2-8.9_64   1.0   1.0   1.0  1.0  1.0
     Total              0.5   0.5   0.5  0.5  0.5
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_3_HT.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_3_HT.csv'))
```

1.9.2 RW - Algorithm

```
[ ]:
```

```
result_RW_abnormal_size_1 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=2.
 ↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_RW_abnormal_size_2 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=1.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_RW_abnormal_size_3 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=1.
 ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_RW_abnormal_size_4 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_RW_abnormal_size_5 =␣
 ↪run_RW_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=0.
 ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

[ ]:

```
result_abnormal_size_RW = pd.DataFrame()
result_abnormal_size_RW = pd.
 ↪concat([result_RW_abnormal_size_1,result_RW_abnormal_size_2,result_RW_abnormal_size_3,resul
 ↪ignore_index=True)
result_abnormal_size_RW['abnormal Size Percent'] = pd.DataFrame({'RW':
 ↪['200%','150%','100%','50%','20%']})
result_abnormal_size_RW.set_index('abnormal Size Percent', inplace=True)
result_abnormal_size_RW
```

[ ]:

```
                                                size_1-1.2_1  \
abnormal Size Percent
200%                     [rob_2_supply, rob_1_supply, con_2]
150%                     [rob_2_supply, rob_1_supply, con_2]
100%                   [rob_1_supply, cam_2_Y, rob_2_supply]
50%                      [rob_1_supply, rob_2_supply, con_2]
20%                      [rob_2_supply, con_2, rob_1_supply]

                                              feeder_3-1.3_2  \
abnormal Size Percent
200%                   [rob_2_supply, rob_1_supply, cam_3_X]
150%                   [rob_2_supply, rob_1_supply, cam_3_X]
100%                     [rob_2_supply, rob_1_supply, con_2]
50%                      [rob_2_supply, rob_1_supply, con_2]
20%                      [rob_2_supply, rob_1_supply, con_2]

                                             gripper_1-1.4_3  \
abnormal Size Percent
200%                   [rob_1_supply, rob_2_supply, cam_1_X]
150%                   [rob_1_supply, rob_2_supply, cam_1_X]
100%                   [rob_1_supply, rob_2_supply, cam_2_X]
50%                    [rob_1_supply, rob_2_supply, cam_1_X]
```

```
20%                      [rob_2_supply, rob_1_supply, con_2]

                                                  max_Vel_2-1.5_4  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_2_supply, rob_1_supply]
150%                        [rob_2_supply, rob_2_maxVel, cam_1_X]
100%                        [rob_2_supply, rob_2_maxVel, cam_2_Y]
50%                    [rob_2_maxVel, rob_1_supply, rob_2_supply]
20%                           [rob_2_maxVel, con_2, rob_1_supply]

                                                size_1-1.6_5  \
abnormal Size Percent
200%                     [rob_2_supply, rob_1_supply, con_2]
150%                   [rob_2_supply, rob_1_supply, cam_1_X]
100%                               [cam_3_X, cam_2_Y, con_2]
50%                      [rob_2_supply, rob_1_supply, con_2]
20%                      [rob_2_supply, con_2, rob_1_supply]

                                              feeder_3-1.7_6  \
abnormal Size Percent
200%                     [rob_2_supply, rob_1_supply, con_2]
150%                   [rob_2_supply, rob_1_supply, cam_1_X]
100%                     [rob_1_supply, rob_2_supply, con_2]
50%                      [rob_1_supply, rob_2_supply, con_2]
20%                      [rob_1_supply, rob_2_supply, con_2]

                                             gripper_1-1.8_7  \
abnormal Size Percent
200%                   [rob_1_supply, rob_2_supply, cam_1_X]
150%                     [rob_1_supply, rob_2_supply, con_2]
100%                   [rob_1_supply, rob_2_supply, cam_2_Y]
50%                      [rob_1_supply, rob_2_supply, con_2]
20%                      [rob_1_supply, rob_2_supply, con_2]

                                                  max_Vel_2-1.9_8  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_2_supply, rob_1_supply]
150%                        [rob_2_maxVel, rob_2_supply, cam_1_Y]
100%                        [rob_2_maxVel, rob_2_supply, cam_2_Y]
50%                    [rob_2_maxVel, rob_2_supply, rob_1_supply]
20%                           [rob_2_maxVel, rob_1_supply, con_1]

                                                size_1-2.2_9  \
abnormal Size Percent
200%                          [rob_2_supply, con_2, cam_1_X]
150%                          [rob_2_supply, cam_1_Y, con_2]
100%                        [rob_2_supply, cam_2_X, cam_1_X]
```

```
50%                    [rob_2_supply, rob_1_supply, cam_2_X]
20%                      [rob_2_supply, rob_1_supply, con_2]

                                             feeder_3-2.3_10  …  \
abnormal Size Percent                                         …
200%                     [rob_1_supply, rob_2_supply, con_2]  …
150%                     [rob_1_supply, rob_2_supply, con_2]  …
100%                   [rob_1_supply, rob_2_supply, cam_3_X]  …
50%                      [rob_2_supply, rob_1_supply, con_2]  …
20%                      [rob_1_supply, rob_2_supply, con_2]  …

                                            gripper_1-7.8_55  \
abnormal Size Percent
200%                     [rob_1_supply, rob_2_supply, con_2]
150%                   [rob_1_supply, rob_2_supply, cam_3_X]
100%                   [rob_1_supply, cam_2_Y, rob_2_supply]
50%                      [rob_1_supply, rob_2_supply, con_2]
20%                      [rob_1_supply, rob_2_supply, con_2]

                                                 max_Vel_2-7.9_56  \
abnormal Size Percent
200%                   [rob_2_supply, rob_2_maxVel, rob_1_supply]
150%                   [rob_2_supply, rob_2_maxVel, rob_1_supply]
100%                        [rob_2_maxVel, rob_2_supply, cam_2_Y]
50%                    [rob_2_maxVel, rob_1_supply, rob_2_supply]
20%                                [rob_2_maxVel, cam_1_X, con_2]

                                               size_1-8.2_57  \
abnormal Size Percent
200%                   [rob_2_supply, rob_1_supply, cam_1_X]
150%                   [rob_1_supply, rob_2_supply, cam_1_Y]
100%                   [rob_2_supply, cam_2_X, rob_1_supply]
50%                    [rob_2_supply, rob_1_supply, cam_1_Y]
20%                           [rob_1_supply, con_2, cam_1_X]

                                             feeder_3-8.3_58  \
abnormal Size Percent
200%                   [rob_1_supply, rob_2_supply, cam_1_X]
150%                   [rob_1_supply, rob_2_supply, cam_3_X]
100%                   [rob_1_supply, rob_2_supply, cam_1_X]
50%                      [rob_1_supply, rob_2_supply, con_2]
20%                      [rob_2_supply, rob_1_supply, con_2]

                                            gripper_1-8.4_59  \
abnormal Size Percent
200%                   [rob_1_supply, rob_2_supply, cam_2_X]
150%                     [rob_1_supply, rob_2_supply, con_2]
```

```
100%                   [rob_1_supply, rob_2_supply, cam_2_X]
50%                      [rob_1_supply, rob_2_supply, con_2]
20%                      [rob_2_supply, rob_1_supply, con_2]

                                                 max_Vel_2-8.5_60  \
abnormal Size Percent
200%                   [rob_2_maxVel, rob_2_supply, rob_1_supply]
150%                        [rob_2_maxVel, cam_1_Y, rob_1_supply]
100%                             [rob_2_maxVel, cam_1_Y, cam_2_X]
50%                    [rob_2_supply, rob_2_maxVel, rob_1_supply]
20%                         [rob_2_maxVel, cam_1_Y, rob_2_supply]

                                               size_1-8.6_61  \
abnormal Size Percent
200%                   [rob_2_supply, rob_1_supply, cam_1_X]
150%                     [rob_2_supply, rob_1_supply, con_2]
100%                   [rob_2_supply, cam_2_Y, rob_1_supply]
50%                    [rob_2_supply, rob_1_supply, cam_1_Y]
20%                      [con_2, rob_2_supply, rob_1_supply]

                                             feeder_3-8.7_62  \
abnormal Size Percent
200%                   [rob_1_supply, rob_2_supply, cam_3_Y]
150%                     [rob_2_supply, rob_1_supply, con_2]
100%                   [rob_1_supply, rob_2_supply, cam_3_X]
50%                    [rob_2_supply, rob_1_supply, cam_1_Y]
20%                      [rob_2_supply, rob_1_supply, con_2]

                                            gripper_1-8.8_63  \
abnormal Size Percent
200%                     [rob_1_supply, rob_2_supply, con_2]
150%                     [rob_1_supply, rob_2_supply, con_2]
100%                   [rob_1_supply, rob_2_supply, cam_2_X]
50%                      [rob_1_supply, rob_2_supply, con_2]
20%                      [rob_1_supply, rob_2_supply, con_2]

                                                 max_Vel_2-8.9_64
abnormal Size Percent
200%                   [rob_2_maxVel, rob_2_supply, rob_1_supply]
150%                        [rob_2_maxVel, rob_2_supply, cam_1_Y]
100%                        [rob_2_maxVel, rob_2_supply, cam_2_X]
50%                    [rob_2_maxVel, rob_2_supply, rob_1_supply]
20%                                [rob_2_maxVel, cam_1_Y, con_2]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_abnormal_size_RW,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                     200%      150%     100%    50%     20%
     size_1-8.6_61     1.000000  0.000000  0.00000  1.0000  0.00000
     feeder_3-8.7_62   1.000000  0.000000  1.00000  0.0000  0.00000
     gripper_1-8.8_63  1.000000  1.000000  1.00000  1.0000  1.00000
     max_Vel_2-8.9_64  1.000000  1.000000  1.00000  1.0000  1.00000
     Total             0.765625  0.703125  0.59375  0.5625  0.53125
```

```
[ ]: result_data_1top = results_top_1(result_abnormal_size_RW,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                 200%      150%      100%       50%    20%
     size_1-8.6_61      0.0  0.000000  0.000000  0.000000  0.000
     feeder_3-8.7_62    0.0  0.000000  0.000000  0.000000  0.000
     gripper_1-8.8_63   1.0  1.000000  1.000000  1.000000  1.000
     max_Vel_2-8.9_64   1.0  1.000000  1.000000  1.000000  1.000
     Total              0.5  0.453125  0.484375  0.484375  0.375
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_3_RW.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_3_RW.csv'))
```

1.9.3 RCD - Algorithm

```
[ ]: result_RCD_abnormal_size_1 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=2.
      ↪00,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_abnormal_size_2 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=1.
      ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_abnormal_size_3 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=1.
      ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_abnormal_size_4 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=0.
      ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_abnormal_size_5 =␣
      ↪run_RCD_abnormal_size(folder_path,files,startrow=839,abnormal_size_p=0.
      ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
[ ]: result_abnormal_size_RCD = pd.DataFrame()
     result_abnormal_size_RCD = pd.
      ↪concat([result_RCD_abnormal_size_1,result_RCD_abnormal_size_2,result_RCD_abnormal_size_3,re
      ↪ignore_index=True)
     result_abnormal_size_RCD['abnormal Size Percent'] = pd.DataFrame({'RCD':
      ↪['200%','150%','100%','50%','20%']})
```

```python
result_abnormal_size_RCD.set_index('abnormal Size Percent', inplace=True)
result_abnormal_size_RCD
```

[ ]:

```
                                      size_1-1.2_1  \
abnormal Size Percent
200%                   [EoL_6_X, EoL_3_X, EoL_6_Y]
150%                            [EoL_5_Y, cam_1_X]
100%                            [EoL_4_X, EoL_4_Y]
50%                    [cam_1_Y, EoL_3_X, cam_1_X]
20%                             [EoL_5_X, cam_1_Y]

                                    feeder_3-1.3_2  \
abnormal Size Percent
200%                            [EoL_3_X, EoL_4_Y]
150%                   [EoL_3_X, EoL_6_Y, cam_3_Y]
100%                   [EoL_2_Y, EoL_4_X, EoL_6_Y]
50%                    [EoL_3_X, EoL_5_Y, EoL_3_Y]
20%                             [EoL_3_Y, EoL_4_X]

                                   gripper_1-1.4_3  \
abnormal Size Percent
200%                            [EoL_6_Y, EoL_4_X]
150%                            [EoL_3_X, EoL_3_Y]
100%                   [EoL_3_X, EoL_5_X, EoL_5_Y]
50%                             [EoL_3_X, EoL_5_Y]
20%                             [cam_3_Y, EoL_5_Y]

                                   max_Vel_2-1.5_4  \
abnormal Size Percent
200%                       [rob_2_maxVel, EoL_6_Y]
150%                                     [EoL_6_Y]
100%                       [EoL_6_X, rob_2_maxVel]
50%                                      [EoL_6_X]
20%                    [EoL_6_Y, EoL_6_X, EoL_5_Y]

                                      size_1-1.6_5  \
abnormal Size Percent
200%                                     [EoL_3_X]
150%                   [EoL_6_Y, EoL_4_X, cam_1_Y]
100%                            [EoL_6_X, EoL_5_X]
50%                    [EoL_4_Y, EoL_3_Y, EoL_4_X]
20%                             [EoL_6_X, EoL_3_Y]

                                    feeder_3-1.7_6  \
abnormal Size Percent
200%                            [cam_3_X, EoL_5_X]
150%                   [EoL_2_X, EoL_3_Y, EoL_3_X]
```

```
100%                            [EoL_5_X, EoL_5_Y]
50%                             [EoL_6_X, EoL_6_Y]
20%                             [EoL_6_X, EoL_2_X]

                                   gripper_1-1.8_7          max_Vel_2-1.9_8  \
abnormal Size Percent                                                        
200%                            [EoL_6_X, EoL_3_Y]  [EoL_6_Y, rob_2_maxVel]   
150%                   [EoL_5_Y, EoL_3_Y, EoL_4_Y]                [EoL_6_X]   
100%                            [EoL_3_Y, EoL_4_X]                [EoL_6_X]   
50%                             [EoL_2_X, EoL_6_Y]  [EoL_6_Y, rob_2_maxVel]   
20%                    [EoL_4_X, EoL_3_X, EoL_4_Y]       [EoL_3_Y, EoL_6_Y]   

                                      size_1-2.2_9  \
abnormal Size Percent                               
200%                   [cam_1_X, EoL_5_Y, EoL_6_X]   
150%                            [EoL_4_Y, EoL_3_Y]   
100%                   [EoL_3_Y, cam_1_Y, cam_1_X]   
50%                             [EoL_5_Y, EoL_3_Y]   
20%                             [EoL_2_Y, EoL_4_X]   

                                   feeder_3-2.3_10  …  \
abnormal Size Percent                               …   
200%                   [EoL_6_Y, EoL_2_X, EoL_6_X]  …   
150%                            [EoL_5_Y, cam_3_X]  …   
100%                            [cam_3_X, EoL_4_Y]  …   
50%                    [EoL_6_Y, EoL_3_X, EoL_2_Y]  …   
20%                             [EoL_3_X, EoL_3_Y]  …   

                                  gripper_1-7.8_55  \
abnormal Size Percent                               
200%                   [EoL_5_X, EoL_2_X, EoL_4_Y]   
150%                            [EoL_3_Y, EoL_5_Y]   
100%                   [EoL_2_X, EoL_6_X, EoL_5_X]   
50%                                      [EoL_5_X]   
20%                             [EoL_5_Y, EoL_2_Y]   

                                  max_Vel_2-7.9_56  \
abnormal Size Percent                               
200%                                [rob_2_maxVel]   
150%                       [EoL_6_Y, rob_2_maxVel]   
100%                            [EoL_6_Y, EoL_6_X]   
50%                        [rob_2_maxVel, EoL_6_Y]   
20%                    [EoL_4_Y, EoL_6_X, EoL_6_Y]   

                                     size_1-8.2_57  \
abnormal Size Percent                               
200%                   [EoL_3_X, EoL_4_X, cam_1_X]   
```

```
150%                            [EoL_3_Y, EoL_6_Y]
100%                            [EoL_5_Y, cam_1_Y]
50%                    [EoL_3_X, EoL_4_X, EoL_3_Y]
20%                             [cam_1_Y, EoL_4_Y]

                                   feeder_3-8.3_58  \
abnormal Size Percent
200%                                     [EoL_6_X]
150%                            [EoL_5_X, cam_3_X]
100%                            [EoL_6_X, cam_3_Y]
50%                    [EoL_5_Y, EoL_6_Y, EoL_2_X]
20%                    [EoL_4_Y, EoL_5_Y, EoL_2_X]

                                  gripper_1-8.4_59         max_Vel_2-8.5_60  \
abnormal Size Percent
200%                   [EoL_3_X, EoL_5_Y, EoL_6_Y]                [EoL_6_X]
150%                   [EoL_4_X, EoL_2_Y, EoL_6_X]  [rob_2_maxVel, EoL_6_X]
100%                            [EoL_4_X, EoL_4_Y]           [rob_2_maxVel]
50%                    [EoL_6_X, EoL_5_X, EoL_3_Y]       [cam_2_X, EoL_6_Y]
20%                             [EoL_2_Y, EoL_4_Y]  [rob_2_maxVel, EoL_6_X]

                                     size_1-8.6_61  \
abnormal Size Percent
200%                            [EoL_5_X, EoL_4_X]
150%                   [cam_1_Y, EoL_6_Y, EoL_5_X]
100%                            [EoL_3_Y, cam_1_Y]
50%                             [EoL_3_Y, EoL_6_Y]
20%                             [cam_1_X, EoL_3_X]

                                   feeder_3-8.7_62  \
abnormal Size Percent
200%                            [EoL_4_X, EoL_5_Y]
150%                   [cam_3_X, EoL_4_Y, EoL_2_X]
100%                   [EoL_6_Y, EoL_3_X, EoL_5_X]
50%                    [EoL_5_Y, cam_3_Y, EoL_2_X]
20%                             [EoL_5_Y, EoL_2_Y]

                                       gripper_1-8.8_63  \
abnormal Size Percent
200%                                 [EoL_3_Y, EoL_3_X]
150%                                 [EoL_4_X, EoL_3_X]
100%                                 [EoL_4_X, EoL_6_X]
50%                    [EoL_3_X, EoL_2_X, rob_1_supply]
20%                                  [EoL_3_X, EoL_6_Y]

                                  max_Vel_2-8.9_64
abnormal Size Percent
```

```
200%                          [EoL_6_Y, rob_2_maxVel]
150%                               [EoL_6_Y, EoL_6_X]
100%                                   [rob_2_maxVel]
50%                                [EoL_6_Y, EoL_6_X]
20%                       [EoL_6_Y, EoL_6_X, cam_2_X]

[5 rows x 64 columns]
```

[ ]:

```
result_data_3top = results_top_3(result_abnormal_size_RCD,abnormal_sets)
result_data_3top.tail()
```

[ ]:

```
                     200%      150%      100%    50%      20%
size_1-8.6_61     0.000000  1.000000  1.000000  0.000  1.00000
feeder_3-8.7_62   0.000000  1.000000  0.000000  1.000  0.00000
gripper_1-8.8_63  0.000000  0.000000  0.000000  1.000  0.00000
max_Vel_2-8.9_64  1.000000  0.000000  1.000000  0.000  0.00000
Total             0.453125  0.453125  0.453125  0.375  0.28125
```

[ ]:

```
result_data_1top = results_top_1(result_abnormal_size_RCD,abnormal_sets)
result_data_1top.tail()
```

[ ]:

```
                     200%      150%     100%       50%     20%
size_1-8.6_61     0.000000  1.000000  0.00000  0.000000  1.0000
feeder_3-8.7_62   0.000000  1.000000  0.00000  0.000000  0.0000
gripper_1-8.8_63  0.000000  0.000000  0.00000  0.000000  0.0000
max_Vel_2-8.9_64  0.000000  0.000000  1.00000  0.000000  0.0000
Total             0.265625  0.171875  0.15625  0.203125  0.1875
```

[ ]:

```
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_3_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_3_RCD.csv'))
```

1.10 Variation 4 - Causal Graph, adjacency matrix

Only the HT- and RW-Algorithm use an adjacency matrix for training of each model.

1.10.1 HT - Algorithm

[ ]:

```
result_HT_edges_1 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=839,edges_delete_n=20,nodes=nodes,edges_list
result_HT_edges_2 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=839,edges_delete_n=40,nodes=nodes,edges_list
result_HT_edges_3 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=839,edges_delete_n=60,nodes=nodes,edges_list
result_HT_edges_4 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=839,edges_delete_n=80,nodes=nodes,edges_list
result_HT_edges_5 =␣
 ↪run_HT_edges_delete(folder_path,files,startrow=839,edges_delete_n=100,nodes=nodes,edges_lis
```

[ ]:

```
result_edges_HT = pd.DataFrame()
result_edges_HT = pd.
 ↪concat([result_HT_edges_1,result_HT_edges_2,result_HT_edges_3,result_HT_edges_4,result_HT_e
 ↪ignore_index=True)
result_edges_HT['Edges Missing'] = pd.DataFrame({'HT':
 ↪['20','40','60','80','100']})
result_edges_HT.set_index('Edges Missing', inplace=True)
result_edges_HT
```

[ ]:

```
                                        size_1-1.2_1  \
Edges Missing
20              [rob_1_maxVel, rob_1_3, rob_1_1]
40              [rob_1_maxVel, rob_1_3, rob_1_1]
60              [rob_1_maxVel, rob_1_3, rob_1_1]
80              [EoL_4_Y, rob_1_maxVel, rob_1_1]
100                  [rob_1_1, EoL_4_Y, rob_1_4]

                                           feeder_3-1.3_2  \
Edges Missing
20              [rob_2_maxVel, cam_3_X, rob_1_maxVel]
40              [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
60              [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
80                   [EoL_4_Y, rob_1_maxVel, EoL_5_X]
100                         [EoL_2_Y, cam_3_Y, score]

                                               gripper_1-1.4_3  \
Edges Missing
20              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
40              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
60              [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
80                   [rob_1_supply, EoL_4_Y, rob_1_maxVel]
100                       [rob_1_supply, rob_1_1, rob_1_4]

                                               max_Vel_2-1.5_4  \
Edges Missing
20              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
40                   [rob_2_maxVel, rob_1_maxVel, rob_1_1]
60              [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
80                        [rob_2_maxVel, rob_1_1, EoL_6_X]
100                       [rob_2_maxVel, rob_1_1, EoL_6_X]

                                        size_1-1.6_5  \
Edges Missing
20              [rob_1_maxVel, rob_1_3, rob_1_2]
40              [rob_1_maxVel, rob_1_3, rob_1_2]
60              [rob_1_maxVel, rob_1_3, rob_1_2]
80              [EoL_4_Y, rob_1_maxVel, rob_1_1]
```

```
100                 [rob_1_1, EoL_4_Y, rob_1_4]

                                      feeder_3-1.7_6  \
Edges Missing
20             [rob_2_maxVel, cam_3_X, rob_1_maxVel]
40             [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
60             [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
80                  [EoL_4_Y, rob_1_maxVel, EoL_5_X]
100                        [EoL_2_Y, cam_3_Y, score]

                                          gripper_1-1.8_7  \
Edges Missing
20             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
40             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
60             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
80                  [rob_1_supply, EoL_4_Y, rob_1_maxVel]
100                      [rob_1_supply, rob_1_1, rob_1_4]

                                          max_Vel_2-1.9_8  \
Edges Missing
20                  [rob_2_maxVel, rob_1_maxVel, rob_1_3]
40                  [rob_2_maxVel, rob_1_maxVel, rob_1_3]
60             [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
80                       [rob_2_maxVel, rob_1_1, EoL_6_X]
100                      [rob_2_maxVel, rob_1_1, EoL_6_X]

                                   size_1-2.2_9  \
Edges Missing
20             [rob_1_maxVel, rob_1_3, rob_1_2]
40             [rob_1_maxVel, rob_1_3, rob_1_2]
60             [rob_1_maxVel, rob_1_3, rob_1_2]
80             [EoL_4_Y, rob_1_maxVel, rob_1_1]
100                 [rob_1_1, EoL_4_Y, rob_1_4]

                                     feeder_3-2.3_10  …  \
Edges Missing                                         …
20             [rob_2_maxVel, cam_3_X, rob_1_maxVel]  …
40             [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]  …
60             [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]  …
80                  [EoL_4_Y, rob_1_maxVel, EoL_5_X]  …
100                        [EoL_2_Y, cam_3_Y, score]  …

                                         gripper_1-7.8_55  \
Edges Missing
20             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
40             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
60             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
```

```
80                  [rob_1_supply, EoL_4_Y, rob_1_maxVel]
100                      [rob_1_supply, rob_1_1, rob_1_4]

                                         max_Vel_2-7.9_56  \
Edges Missing
20                  [rob_2_maxVel, rob_1_maxVel, rob_1_1]
40                  [rob_2_maxVel, rob_1_maxVel, rob_1_1]
60             [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
80                       [rob_2_maxVel, rob_1_1, EoL_6_X]
100                      [rob_2_maxVel, rob_1_1, EoL_6_X]

                                  size_1-8.2_57  \
Edges Missing
20             [rob_1_maxVel, rob_1_3, rob_1_2]
40             [rob_1_maxVel, rob_1_3, rob_1_2]
60             [rob_1_maxVel, rob_1_3, rob_1_2]
80             [EoL_4_Y, rob_1_maxVel, rob_1_1]
100                 [rob_1_1, EoL_4_Y, rob_1_4]

                                     feeder_3-8.3_58  \
Edges Missing
20             [rob_2_maxVel, cam_3_X, rob_1_maxVel]
40             [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
60             [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
80                  [EoL_4_Y, rob_1_maxVel, EoL_5_X]
100                        [EoL_2_Y, cam_3_Y, score]

                                         gripper_1-8.4_59  \
Edges Missing
20             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
40             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
60             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
80                  [rob_1_supply, EoL_4_Y, rob_1_maxVel]
100                      [rob_1_supply, rob_1_1, rob_1_4]

                                         max_Vel_2-8.5_60  \
Edges Missing
20             [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
40                  [rob_2_maxVel, rob_1_maxVel, rob_1_3]
60             [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
80                       [rob_2_maxVel, rob_1_1, EoL_6_X]
100                      [rob_2_maxVel, rob_1_1, EoL_6_X]

                                  size_1-8.6_61  \
Edges Missing
20             [rob_1_maxVel, rob_1_1, rob_1_3]
40             [rob_1_maxVel, rob_1_1, rob_1_3]
```

```
60             [rob_1_maxVel, rob_1_1, rob_1_3]
80             [EoL_4_Y, rob_1_maxVel, rob_1_1]
100                 [rob_1_1, EoL_4_Y, rob_1_4]

                                     feeder_3-8.7_62  \
Edges Missing
20             [rob_2_maxVel, cam_3_X, rob_1_maxVel]
40             [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
60             [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
80                  [EoL_4_Y, rob_1_maxVel, EoL_5_X]
100                        [EoL_2_Y, cam_3_Y, score]

                                         gripper_1-8.8_63  \
Edges Missing
20             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
40             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
60             [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
80                  [rob_1_supply, EoL_4_Y, rob_1_maxVel]
100                      [rob_1_supply, rob_1_1, rob_1_4]

                                         max_Vel_2-8.9_64
Edges Missing
20                  [rob_2_maxVel, rob_1_maxVel, rob_1_3]
40                  [rob_2_maxVel, rob_1_maxVel, rob_1_3]
60             [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
80                       [rob_2_maxVel, rob_1_1, EoL_6_X]
100                      [rob_2_maxVel, rob_1_1, EoL_6_X]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_edges_HT,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                   20      40   60   80       100
     size_1-8.6_61     0.00  0.0000  0.0  0.0  0.000000
     feeder_3-8.7_62   1.00  0.0000  0.0  0.0  1.000000
     gripper_1-8.8_63  1.00  1.0000  1.0  1.0  1.000000
     max_Vel_2-8.9_64  1.00  1.0000  1.0  1.0  1.000000
     Total             0.75  0.5625  0.5  0.5  0.734375
```

```
[ ]: result_data_1top = results_top_1(result_edges_HT,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                        20   40   60   80       100
     size_1-8.6_61     0.00000  0.0  0.0  0.0  0.000000
     feeder_3-8.7_62   0.00000  0.0  0.0  0.0  0.000000
     gripper_1-8.8_63  1.00000  1.0  1.0  1.0  1.000000
```

```
max_Vel_2-8.9_64  1.00000  1.0  1.0  1.0  1.000000
Total             0.59375  0.5  0.5  0.5  0.484375
```

[ ]:
```
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_4_HT.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_4_HT.csv'))
```

1.10.2 RW - Algorithm

[ ]:
```
result_RW_edges_1 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=839,edges_delete_n=20,nodes=nodes,edges_list
result_RW_edges_2 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=839,edges_delete_n=40,nodes=nodes,edges_list
result_RW_edges_3 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=839,edges_delete_n=60,nodes=nodes,edges_list
result_RW_edges_4 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=839,edges_delete_n=80,nodes=nodes,edges_list
result_RW_edges_5 =␣
 ↪run_RW_edges_delete(folder_path,files,startrow=839,edges_delete_n=100,nodes=nodes,edges_lis
```

[ ]:
```
result_edges_RW = pd.DataFrame()
result_edges_RW = pd.
 ↪concat([result_RW_edges_1,result_RW_edges_2,result_RW_edges_3,result_RW_edges_4,result_RW_e
 ↪ignore_index=True)
result_edges_RW['Edges Missing'] = pd.DataFrame({'RW':
 ↪['20','40','60','80','100']})
result_edges_RW.set_index('Edges Missing', inplace=True)
result_edges_RW
```

[ ]:
```
                                   size_1-1.2_1  \
Edges Missing
20                 [rob_2_supply, con_2, cam_1_X]
40               [rob_2_supply, cam_1_X, cam_2_X]
60                      [con_2, cam_1_Y, cam_1_X]
80               [rob_2_vacuum, EoL_1_X, cam_1_X]
100                   [EoL_5_X, EoL_1_X, cam_1_X]

                                      feeder_3-1.3_2  \
Edges Missing
20             [rob_1_vacuum, rob_2_supply, cam_1_X]
40             [rob_1_vacuum, rob_2_supply, cam_1_X]
60                       [cam_1_X, cam_2_X, cam_3_X]
80             [rob_2_vacuum, rob_1_vacuum, EoL_1_X]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                     gripper_1-1.4_3  \
Edges Missing
20             [rob_1_vacuum, rob_2_supply, cam_1_X]
```

```
40             [rob_1_vacuum, rob_2_supply, cam_1_X]
60                         [cam_1_Y, con_2, cam_1_X]
80             [rob_2_vacuum, rob_1_vacuum, cam_1_X]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                     max_Vel_2-1.5_4  \
Edges Missing
20             [rob_2_maxVel, rob_2_supply, cam_1_X]
40             [rob_2_supply, rob_2_maxVel, cam_1_X]
60                    [rob_2_maxVel, con_2, cam_1_Y]
80             [EoL_1_X, rob_2_vacuum, rob_2_maxVel]
100                      [EoL_1_X, EoL_5_X, cam_1_X]

                                   size_1-1.6_5  \
Edges Missing
20               [rob_2_supply, con_2, cam_1_X]
40             [rob_2_supply, cam_1_X, cam_2_X]
60                    [con_2, cam_1_Y, cam_1_X]
80             [rob_2_vacuum, EoL_1_X, cam_1_X]
100                 [EoL_5_X, EoL_1_X, cam_1_X]

                                      feeder_3-1.7_6  \
Edges Missing
20               [rob_1_vacuum, rob_2_supply, con_2]
40             [rob_1_vacuum, rob_2_supply, cam_1_X]
60                         [con_2, cam_1_X, cam_2_X]
80             [rob_2_vacuum, rob_1_vacuum, EoL_1_X]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                     gripper_1-1.8_7  \
Edges Missing
20               [rob_1_vacuum, rob_2_supply, con_2]
40             [rob_1_vacuum, rob_2_supply, cam_1_X]
60                         [con_2, cam_1_X, cam_2_X]
80             [rob_2_vacuum, rob_1_vacuum, EoL_1_X]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                     max_Vel_2-1.9_8  \
Edges Missing
20             [rob_2_maxVel, cam_1_X, rob_2_supply]
40             [rob_2_maxVel, cam_1_X, rob_2_supply]
60                      [rob_2_maxVel, con_1, con_2]
80             [EoL_1_X, rob_2_vacuum, rob_2_maxVel]
100                      [EoL_1_X, EoL_5_X, cam_1_X]

                                   size_1-2.2_9  \
Edges Missing
```

```
20               [rob_2_supply, con_2, cam_1_X]
40             [rob_2_supply, cam_1_X, cam_2_X]
60                    [cam_1_Y, con_2, cam_1_X]
80             [rob_2_vacuum, EoL_1_X, cam_1_X]
100                 [EoL_5_X, EoL_1_X, cam_1_X]

                                     feeder_3-2.3_10  …  \
Edges Missing                                         …
20               [rob_1_vacuum, rob_2_supply, con_2]  …
40             [rob_1_vacuum, rob_2_supply, cam_3_Y]  …
60                         [con_2, cam_1_Y, cam_1_X]  …
80             [rob_2_vacuum, rob_1_vacuum, EoL_1_X]  …
100                      [EoL_5_X, EoL_1_X, cam_1_X]  …

                                    gripper_1-7.8_55  \
Edges Missing
20             [rob_1_vacuum, rob_2_supply, cam_1_X]
40             [rob_1_vacuum, rob_2_supply, cam_1_X]
60                       [cam_1_X, cam_2_X, cam_3_X]
80             [rob_2_vacuum, rob_1_vacuum, EoL_1_X]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                    max_Vel_2-7.9_56  \
Edges Missing
20               [rob_2_supply, rob_2_maxVel, con_2]
40             [rob_2_supply, rob_2_maxVel, cam_1_X]
60                    [rob_2_maxVel, cam_1_Y, con_2]
80             [EoL_1_X, rob_2_vacuum, rob_2_maxVel]
100                      [EoL_1_X, EoL_5_X, cam_1_X]

                                  size_1-8.2_57  \
Edges Missing
20             [rob_2_supply, cam_1_X, cam_1_Y]
40             [rob_2_supply, cam_1_X, cam_1_Y]
60                    [con_2, cam_1_Y, cam_1_X]
80             [rob_2_vacuum, EoL_1_X, cam_1_X]
100                 [EoL_5_X, EoL_1_X, cam_1_X]

                                     feeder_3-8.3_58  \
Edges Missing
20             [rob_1_vacuum, rob_2_supply, cam_3_Y]
40             [rob_1_vacuum, rob_2_supply, cam_1_Y]
60                         [con_2, cam_1_X, cam_2_X]
80             [rob_2_vacuum, rob_1_vacuum, EoL_1_X]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                    gripper_1-8.4_59  \
Edges Missing
20               [rob_1_vacuum, rob_2_supply, con_2]
40             [rob_1_vacuum, rob_2_supply, cam_1_Y]
60                    [con_2, rob_2_vacuum, cam_1_X]
80             [rob_2_vacuum, rob_1_vacuum, EoL_1_X]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                    max_Vel_2-8.5_60  \
Edges Missing
20             [rob_2_maxVel, rob_2_supply, cam_1_Y]
40             [rob_2_supply, rob_2_maxVel, cam_1_Y]
60                    [rob_2_maxVel, cam_1_Y, con_2]
80             [rob_2_vacuum, EoL_1_X, rob_2_maxVel]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                  size_1-8.6_61  \
Edges Missing
20               [rob_2_supply, con_2, cam_1_Y]
40             [rob_2_supply, cam_1_X, cam_1_Y]
60               [con_2, rob_2_maxVel, cam_1_X]
80             [rob_2_vacuum, EoL_1_X, cam_1_X]
100                 [EoL_5_X, EoL_1_X, cam_1_X]

                                     feeder_3-8.7_62  \
Edges Missing
20             [rob_1_vacuum, rob_2_supply, cam_2_Y]
40             [rob_1_vacuum, rob_2_supply, cam_3_Y]
60                    [rob_2_vacuum, con_2, cam_1_X]
80             [rob_2_vacuum, rob_1_vacuum, EoL_1_X]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                    gripper_1-8.8_63  \
Edges Missing
20               [rob_1_vacuum, rob_2_supply, con_2]
40             [rob_1_vacuum, rob_2_supply, cam_1_X]
60                         [con_2, cam_1_Y, cam_1_X]
80             [rob_2_vacuum, EoL_1_X, rob_1_vacuum]
100                      [EoL_5_X, EoL_1_X, cam_1_X]

                                    max_Vel_2-8.9_64
Edges Missing
20             [rob_2_maxVel, rob_2_supply, cam_1_Y]
40             [rob_2_supply, rob_2_maxVel, cam_1_Y]
60                    [rob_2_maxVel, cam_1_Y, con_2]
80             [rob_2_vacuum, EoL_1_X, rob_2_maxVel]
100                      [EoL_5_X, EoL_1_X, cam_1_X]
```

```
[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_edges_RW,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                       20        40        60   80   100
     size_1-8.6_61     1.00000  1.00000  1.00000  1.0  1.00
     feeder_3-8.7_62   0.00000  1.00000  0.00000  0.0  0.00
     gripper_1-8.8_63  0.00000  0.00000  0.00000  0.0  0.00
     max_Vel_2-8.9_64  1.00000  1.00000  1.00000  1.0  0.00
     Total             0.59375  0.59375  0.53125  0.5  0.25
```

```
[ ]: result_data_1top = results_top_1(result_edges_RW,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                      20       40    60   80  100
     size_1-8.6_61     0.0000  0.00000  0.00  0.0  0.0
     feeder_3-8.7_62   0.0000  0.00000  0.00  0.0  0.0
     gripper_1-8.8_63  0.0000  0.00000  0.00  0.0  0.0
     max_Vel_2-8.9_64  1.0000  0.00000  1.00  0.0  0.0
     Total             0.1875  0.09375  0.25  0.0  0.0
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_4_RW.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_4_RW.csv'))
```

1.11 Variation 5 - Size

1.11.1 HT -Algorithm

```
[ ]: result_HT_size_1 =␣
       ↪run_HT_size(folder_path,files,startrow=839,size_p=2,nodes=nodes,edges_list=edges,key_nodes=
     result_HT_size_2 = run_HT_size(folder_path,files,startrow=839,size_p=1.
       ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_HT_size_3 = run_HT_size(folder_path,files,startrow=839,size_p=1.
       ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_HT_size_4 = run_HT_size(folder_path,files,startrow=839,size_p=0.
       ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_HT_size_5 = run_HT_size(folder_path,files,startrow=839,size_p=0.
       ↪2,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
[ ]: result_size_HT = pd.DataFrame()
     result_size_HT = pd.
       ↪concat([result_HT_size_1,result_HT_size_2,result_HT_size_3,result_HT_size_4,result_HT_size_
       ↪ignore_index=True)
     result_size_HT['Data Size'] = pd.DataFrame({'HT':
       ↪['200%','150%','100%','50%','20%']})
     result_size_HT.set_index('Data Size', inplace=True)
```

```
result_size_HT
```

[ ]:

```
                               size_1-1.2_1  \
Data Size
200%       [rob_1_maxVel, rob_1_3, rob_1_1]
150%           [con_3, con_2, rob_1_maxVel]
100%            [rob_1_1, rob_1_2, rob_1_3]
50%             [rob_1_1, rob_1_3, rob_1_2]
20%             [cam_1_X, cam_1_Y, rob_1_1]

                                  feeder_3-1.3_2  \
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%       [cam_3_X, rob_2_maxVel, rob_1_maxVel]
100%                 [rob_1_2, rob_1_1, rob_1_4]
50%             [cam_3_X, EoL_2_X, rob_2_maxVel]
20%          [score, rob_2_maxVel, rob_1_maxVel]

                                      gripper_1-1.4_3  \
Data Size
200%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%            [rob_1_supply, rob_1_vacuum, rob_1_1]
50%             [rob_1_supply, rob_1_vacuum, rob_1_3]
20%             [rob_1_supply, rob_1_vacuum, rob_1_3]

                                      max_Vel_2-1.5_4  \
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%              [rob_2_maxVel, rob_1_maxVel, con_3]
100%            [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                  [rob_2_maxVel, rob_2_1, rob_1_3]
20%                  [rob_2_maxVel, rob_2_1, rob_2_2]

                               size_1-1.6_5  \
Data Size
200%       [rob_1_maxVel, rob_1_3, rob_1_2]
150%           [rob_1_maxVel, con_3, con_2]
100%            [rob_1_1, rob_1_2, rob_1_3]
50%             [rob_1_3, rob_1_1, rob_1_2]
20%             [cam_1_X, cam_1_Y, rob_1_1]

                                  feeder_3-1.7_6  \
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%       [cam_3_X, rob_2_maxVel, rob_1_maxVel]
100%                 [rob_1_2, rob_1_1, rob_1_4]
```

```
50%             [cam_3_X, EoL_2_X, rob_2_maxVel]
20%          [score, rob_2_maxVel, rob_1_maxVel]

                                      gripper_1-1.8_7  \
Data Size
200%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%             [rob_1_supply, rob_1_vacuum, rob_1_3]
20%             [rob_1_supply, rob_1_vacuum, rob_1_1]

                                      max_Vel_2-1.9_8  \
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%              [rob_2_maxVel, rob_1_maxVel, con_3]
100%            [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                  [rob_2_maxVel, rob_2_1, rob_1_3]
20%             [rob_2_maxVel, rob_1_vacuum, rob_2_1]

                               size_1-2.2_9  \
Data Size
200%       [rob_1_maxVel, rob_1_3, rob_1_2]
150%           [rob_1_maxVel, con_3, con_2]
100%       [rob_1_maxVel, rob_1_1, rob_1_2]
50%             [rob_1_3, rob_1_1, rob_1_2]
20%             [cam_1_X, cam_1_Y, rob_1_3]

                                 feeder_3-2.3_10  …  \
Data Size                                         …
200%       [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]  …
150%       [cam_3_X, rob_2_maxVel, rob_1_maxVel]  …
100%                 [rob_1_2, rob_1_1, rob_1_4]  …
50%             [cam_3_X, EoL_2_X, rob_2_maxVel]  …
20%          [score, rob_2_maxVel, rob_1_maxVel]  …

                                     gripper_1-7.8_55  \
Data Size
200%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%             [rob_1_supply, rob_1_vacuum, rob_1_3]
20%             [rob_1_supply, rob_1_vacuum, rob_1_1]

                                     max_Vel_2-7.9_56  \
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%              [rob_2_maxVel, rob_1_maxVel, con_3]
```

```
100%            [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                  [rob_2_maxVel, rob_2_1, rob_1_3]
20%                  [rob_2_maxVel, rob_2_1, rob_2_2]

                              size_1-8.2_57  \
Data Size
200%       [rob_1_maxVel, rob_1_3, rob_1_2]
150%           [rob_1_maxVel, con_3, con_2]
100%            [rob_1_2, rob_1_1, rob_1_3]
50%             [rob_1_1, rob_1_3, rob_1_2]
20%             [cam_1_X, cam_1_Y, rob_1_3]

                                 feeder_3-8.3_58  \
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
150%       [cam_3_X, rob_2_maxVel, rob_1_maxVel]
100%                 [rob_1_2, rob_1_1, rob_1_4]
50%             [cam_3_X, EoL_2_X, rob_2_maxVel]
20%          [score, rob_2_maxVel, rob_1_maxVel]

                                gripper_1-8.4_59  \
Data Size
200%       [rob_1_supply, rob_1_vacuum, rob_1_1]
150%         [rob_1_supply, rob_1_vacuum, con_3]
100%       [rob_1_supply, rob_1_vacuum, rob_1_1]
50%        [rob_1_supply, rob_1_vacuum, rob_1_1]
20%        [rob_1_supply, rob_1_vacuum, rob_1_3]

                                     max_Vel_2-8.5_60  \
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%              [rob_2_maxVel, rob_1_maxVel, con_3]
100%            [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                  [rob_2_maxVel, rob_2_1, rob_1_3]
20%                  [rob_2_maxVel, rob_2_1, rob_2_2]

                              size_1-8.6_61  \
Data Size
200%       [rob_1_maxVel, rob_1_1, rob_1_3]
150%           [rob_1_maxVel, con_3, con_2]
100%       [rob_1_maxVel, rob_1_1, rob_1_3]
50%             [rob_1_3, rob_1_1, rob_1_2]
20%             [cam_1_X, cam_1_Y, rob_1_3]

                                 feeder_3-8.7_62  \
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, EoL_4_Y]
```

```
150%       [cam_3_X, rob_2_maxVel, rob_1_maxVel]
100%                 [rob_1_2, rob_1_1, rob_1_4]
50%             [cam_3_X, EoL_2_X, rob_2_maxVel]
20%           [score, rob_2_maxVel, rob_1_maxVel]

                                     gripper_1-8.8_63  \
Data Size
200%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
150%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
100%       [rob_1_supply, rob_1_vacuum, rob_1_maxVel]
50%             [rob_1_supply, rob_1_vacuum, rob_1_1]
20%             [rob_1_supply, rob_1_vacuum, rob_1_1]

                                     max_Vel_2-8.9_64
Data Size
200%       [rob_2_maxVel, rob_1_maxVel, rob_1_vacuum]
150%              [rob_2_maxVel, rob_1_maxVel, con_3]
100%            [rob_2_maxVel, rob_1_vacuum, rob_2_1]
50%                  [rob_2_maxVel, rob_2_1, rob_1_1]
20%                  [rob_2_maxVel, rob_2_1, rob_2_2]

[5 rows x 64 columns]
```

[ ]:

```
result_data_3top = results_top_3(result_size_HT,abnormal_sets)
result_data_3top.tail()
```

[ ]:

```
                      200%  150%  100%   50%   20%
size_1-8.6_61     0.000000  0.00   0.0  0.00  1.00
feeder_3-8.7_62   0.000000  1.00   0.0  1.00  0.00
gripper_1-8.8_63  1.000000  1.00   1.0  1.00  1.00
max_Vel_2-8.9_64  1.000000  1.00   1.0  1.00  1.00
Total             0.578125  0.75   0.5  0.75  0.75
```

[ ]:

```
result_data_1top = results_top_1(result_size_HT,abnormal_sets)
result_data_1top.tail()
```

[ ]:

```
                  200%  150%  100%   50%   20%
size_1-8.6_61      0.0  0.00   0.0  0.00  1.00
feeder_3-8.7_62    0.0  1.00   0.0  1.00  0.00
gripper_1-8.8_63   1.0  1.00   1.0  1.00  1.00
max_Vel_2-8.9_64   1.0  1.00   1.0  1.00  1.00
Total              0.5  0.75   0.5  0.75  0.75
```

[ ]:

```
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_5_HT.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_5_HT.csv'))
```

1.11.2 ED - Algorithm

[ ]:

```
result_ED_size_1 =␣
 ↪run_ED_size(folder_path,files,startrow=839,size_p=2,nodes=nodes,edges_list=edges,key_nodes=
result_ED_size_2 = run_ED_size(folder_path,files,startrow=839,size_p=1.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_ED_size_3 = run_ED_size(folder_path,files,startrow=839,size_p=1.
 ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_ED_size_4 = run_ED_size(folder_path,files,startrow=839,size_p=0.
 ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
result_ED_size_5 = run_ED_size(folder_path,files,startrow=839,size_p=0.
 ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

[ ]:

```
result_size_ED = pd.DataFrame()
result_size_ED = pd.
 ↪concat([result_ED_size_1,result_ED_size_2,result_ED_size_3,result_ED_size_4,result_ED_size_
 ↪ignore_index=True)
result_size_ED['Data Size'] = pd.DataFrame({'ED':
 ↪['200%','150%','100%','50%','20%']})
result_size_ED.set_index('Data Size', inplace=True)
result_size_ED
```

[ ]:

```
                               size_1-1.2_1                  feeder_3-1.3_2  \
Data Size
200%       [rob_1_vacuum, rob_1_4, rob_1_3]       [cam_2_Y, EoL_1_Y, con_1]
150%       [rob_1_vacuum, rob_1_4, rob_1_3]       [cam_2_Y, EoL_1_Y, con_1]
100%       [EoL_1_X, rob_1_vacuum, rob_1_4]       [cam_2_Y, EoL_1_Y, con_2]
50%             [cam_3_Y, EoL_1_Y, cam_2_Y]       [EoL_1_Y, cam_2_Y, con_1]
20%        [rob_1_vacuum, rob_1_4, rob_1_3]  [cam_1_Y, con_1, rob_1_maxVel]

                       gripper_1-1.4_3                   max_Vel_2-1.5_4  \
Data Size
200%       [rob_1_4, rob_1_3, rob_1_2]  [rob_1_vacuum, rob_1_4, rob_1_3]
150%       [rob_1_4, rob_1_3, rob_1_2]  [cam_3_Y, rob_1_vacuum, rob_1_4]
100%       [rob_1_4, rob_1_3, rob_1_2]  [cam_3_Y, rob_1_vacuum, rob_1_4]
50%        [EoL_1_Y, cam_2_Y, cam_3_X]       [EoL_3_X, EoL_4_X, EoL_5_X]
20%        [rob_1_2, rob_1_4, rob_1_3]  [rob_1_vacuum, rob_1_4, rob_1_3]

                               size_1-1.6_5               feeder_3-1.7_6  \
Data Size
200%       [rob_1_vacuum, rob_1_4, rob_1_3]      [EoL_1_Y, con_2, con_3]
150%       [cam_3_Y, rob_1_vacuum, rob_1_4]  [EoL_1_Y, cam_1_Y, cam_2_Y]
100%            [cam_3_Y, rob_1_4, rob_1_3]  [EoL_1_Y, cam_2_Y, cam_1_Y]
50%             [cam_3_Y, EoL_1_Y, cam_2_Y]  [EoL_1_Y, cam_2_Y, cam_1_Y]
20%             [rob_1_2, rob_1_4, rob_1_3]    [cam_1_Y, cam_1_X, con_2]

                       gripper_1-1.8_7                   max_Vel_2-1.9_8  \
Data Size
200%       [cam_3_Y, rob_1_4, rob_1_3]  [EoL_1_X, rob_1_vacuum, rob_1_4]
150%       [cam_3_Y, rob_1_4, rob_1_3]  [EoL_1_X, rob_1_vacuum, rob_1_4]
100%       [cam_3_Y, rob_1_4, rob_1_3]       [EoL_1_X, rob_1_4, rob_1_3]
50%        [cam_3_Y, cam_2_Y, cam_3_X]       [cam_3_Y, EoL_3_X, EoL_4_X]
20%        [rob_1_4, rob_1_3, rob_1_2]       [rob_1_2, rob_1_4, rob_1_3]

                               size_1-2.2_9              feeder_3-2.3_10  …  \
Data Size                                                                 …
200%       [cam_3_Y, rob_1_vacuum, rob_1_4]    [EoL_1_Y, EoL_1_X, con_2]  …
150%       [cam_3_Y, rob_1_vacuum, rob_1_4]    [EoL_1_Y, EoL_1_X, con_2]  …
100%            [cam_3_Y, cam_3_X, rob_1_4]  [EoL_1_Y, cam_2_Y, EoL_1_X]  …
50%             [cam_3_Y, EoL_1_Y, cam_2_Y]    [cam_2_Y, EoL_1_Y, con_2]  …
20%             [rob_1_2, rob_1_4, rob_1_3]      [con_2, con_3, cam_1_Y]  …

                      gripper_1-7.8_55                  max_Vel_2-7.9_56  \
Data Size
200%       [cam_3_Y, rob_1_4, rob_1_3]  [rob_1_vacuum, rob_1_4, rob_1_3]
150%       [cam_3_Y, rob_1_4, rob_1_3]  [rob_1_vacuum, rob_1_4, rob_1_3]
100%       [cam_3_Y, rob_1_4, rob_1_3]  [cam_3_Y, rob_1_vacuum, rob_1_4]
50%        [cam_3_Y, cam_2_Y, cam_3_X]       [EoL_2_X, EoL_3_X, EoL_4_X]
20%        [rob_1_4, rob_1_3, rob_1_2]  [rob_1_vacuum, rob_1_4, rob_1_3]

                              size_1-8.2_57                   feeder_3-8.3_58  \
Data Size
200%       [cam_3_Y, rob_1_vacuum, rob_1_4]         [EoL_1_Y, con_3, cam_2_Y]
150%       [cam_3_Y, rob_1_vacuum, rob_1_4]           [EoL_1_Y, con_3, con_1]
100%       [cam_3_Y, rob_1_vacuum, rob_1_4]           [EoL_1_Y, con_3, con_2]
50%             [cam_3_Y, EoL_1_Y, EoL_2_X]  [cam_2_Y, EoL_1_Y, rob_1_supply]
20%        [rob_1_vacuum, rob_1_4, rob_1_3]             [con_2, con_3, con_1]

                      gripper_1-8.4_59                  max_Vel_2-8.5_60  \
Data Size
200%       [rob_1_4, rob_1_3, rob_1_2]  [rob_1_vacuum, rob_1_4, rob_1_3]
150%       [rob_1_4, rob_1_3, rob_1_2]  [rob_1_vacuum, rob_1_4, rob_1_3]
100%       [cam_3_Y, rob_1_4, rob_1_3]  [rob_1_vacuum, rob_1_4, rob_1_3]
50%        [cam_3_Y, EoL_1_Y, cam_2_Y]       [EoL_3_X, EoL_5_X, EoL_3_Y]
20%        [rob_1_4, rob_1_3, rob_1_2]  [rob_1_vacuum, rob_1_4, rob_1_3]

                              size_1-8.6_61            feeder_3-8.7_62  \
Data Size
200%       [EoL_1_X, rob_1_vacuum, rob_1_4]  [EoL_1_Y, con_2, cam_2_Y]
150%       [EoL_1_X, cam_3_Y, rob_1_vacuum]  [EoL_1_Y, cam_2_Y, con_2]
100%       [cam_3_Y, EoL_1_X, rob_1_vacuum]  [EoL_1_Y, cam_2_Y, con_2]
50%             [cam_3_Y, cam_2_Y, EoL_1_Y]  [EoL_1_Y, cam_2_Y, con_2]
20%             [rob_1_2, rob_1_3, rob_1_4]    [con_2, cam_1_Y, con_1]
```

```
                      gripper_1-8.8_63                  max_Vel_2-8.9_64
Data Size
200%       [rob_1_4, rob_1_3, rob_1_2]  [cam_3_Y, rob_1_vacuum, rob_1_4]
150%       [rob_1_4, rob_1_3, rob_1_2]  [EoL_3_Y, cam_3_Y, rob_1_vacuum]
100%       [cam_3_Y, EoL_1_X, rob_1_4]  [cam_3_Y, EoL_3_Y, rob_1_vacuum]
50%        [cam_3_Y, EoL_1_Y, cam_2_Y]       [EoL_2_X, EoL_3_X, EoL_3_Y]
20%        [rob_1_2, rob_1_3, rob_1_1]       [rob_1_3, rob_1_2, rob_1_1]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_size_ED,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                   200%  150%  100%  50%  20%
     size_1-8.6_61      0.0   0.0   0.0  0.0  0.0
     feeder_3-8.7_62    0.0   0.0   0.0  0.0  0.0
     gripper_1-8.8_63   0.0   0.0   0.0  0.0  0.0
     max_Vel_2-8.9_64   0.0   0.0   0.0  0.0  0.0
     Total              0.0   0.0   0.0  0.0  0.0
```

```
[ ]: result_data_1top = results_top_1(result_size_ED,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                   200%  150%  100%  50%  20%
     size_1-8.6_61      0.0   0.0   0.0  0.0  0.0
     feeder_3-8.7_62    0.0   0.0   0.0  0.0  0.0
     gripper_1-8.8_63   0.0   0.0   0.0  0.0  0.0
     max_Vel_2-8.9_64   0.0   0.0   0.0  0.0  0.0
     Total              0.0   0.0   0.0  0.0  0.0
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_5_ED.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_5_ED.csv'))
```

1.11.3 RW - Algorithm

```
[ ]: result_RW_size_1 =␣
       ↪run_RW_size(folder_path,files,startrow=839,size_p=2,nodes=nodes,edges_list=edges,key_nodes=
     result_RW_size_2 = run_RW_size(folder_path,files,startrow=839,size_p=1.
       ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_size_3 = run_RW_size(folder_path,files,startrow=839,size_p=1.
       ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_size_4 = run_RW_size(folder_path,files,startrow=839,size_p=0.
       ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RW_size_5 = run_RW_size(folder_path,files,startrow=839,size_p=0.
       ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

[ ]:
```
result_size_RW = pd.DataFrame()
result_size_RW = pd.
 ↪concat([result_RW_size_1,result_RW_size_2,result_RW_size_3,result_RW_size_4,result_RW_size_
 ↪ignore_index=True)
result_size_RW['Data Size'] = pd.DataFrame({'RW':
 ↪['200%','150%','100%','50%','20%']})
result_size_RW.set_index('Data Size', inplace=True)
result_size_RW
```

[ ]:
```
                                     size_1-1.2_1  \
Data Size
200%         [rob_2_supply, cam_1_Y, cam_1_X]
150%                [cam_1_Y, cam_1_X, con_2]
100%         [cam_1_Y, cam_1_X, rob_2_supply]
50%          [cam_1_X, cam_1_Y, rob_2_supply]
20%          [cam_1_X, cam_1_Y, rob_2_supply]

                                        feeder_3-1.3_2  \
Data Size
200%         [rob_2_supply, rob_1_supply, cam_1_Y]
150%         [rob_2_supply, rob_1_supply, cam_1_Y]
100%         [rob_2_supply, rob_1_supply, cam_3_Y]
50%          [rob_2_supply, rob_1_supply, cam_1_Y]
20%          [rob_2_supply, rob_1_supply, cam_1_X]

                                       gripper_1-1.4_3  \
Data Size
200%         [rob_1_supply, rob_2_supply, cam_1_Y]
150%         [rob_1_supply, rob_2_supply, cam_1_Y]
100%         [rob_1_supply, rob_2_supply, cam_1_Y]
50%          [rob_1_supply, rob_2_supply, cam_1_Y]
20%          [rob_1_supply, rob_2_supply, cam_1_X]

                                       max_Vel_2-1.5_4  \
Data Size
200%         [rob_2_maxVel, rob_2_supply, cam_1_X]
150%         [rob_2_maxVel, rob_2_supply, cam_1_X]
100%         [rob_2_maxVel, rob_2_supply, cam_1_X]
50%               [rob_2_maxVel, cam_1_X, cam_1_Y]
20%               [rob_2_maxVel, cam_1_X, cam_1_Y]

                                     size_1-1.6_5  \
Data Size
200%         [rob_2_supply, cam_1_X, cam_1_Y]
150%         [cam_1_X, cam_1_Y, rob_2_supply]
100%         [rob_2_supply, cam_1_X, cam_1_Y]
50%          [cam_1_Y, cam_1_X, rob_2_supply]
```

```
20%        [cam_1_Y, cam_1_X, rob_2_supply]

                                  feeder_3-1.7_6  \
Data Size
200%       [rob_1_supply, rob_2_supply, cam_3_X]
150%       [rob_1_supply, rob_2_supply, cam_1_X]
100%            [rob_1_supply, cam_3_X, cam_1_X]
50%        [rob_1_supply, cam_1_X, rob_2_supply]
20%        [cam_1_X, rob_1_supply, rob_2_supply]

                                      gripper_1-1.8_7  \
Data Size
200%            [rob_1_supply, rob_2_supply, cam_1_Y]
150%                 [rob_1_supply, cam_1_X, cam_1_Y]
100%            [rob_1_supply, rob_2_maxVel, cam_1_X]
50%        [rob_1_supply, rob_2_supply, rob_2_maxVel]
20%             [rob_1_supply, rob_2_supply, cam_1_X]

                                 max_Vel_2-1.9_8  \
Data Size
200%       [rob_2_maxVel, rob_2_supply, cam_1_X]
150%       [rob_2_maxVel, cam_1_Y, rob_2_supply]
100%            [rob_2_maxVel, cam_1_X, cam_1_Y]
50%             [rob_2_maxVel, cam_1_X, cam_1_Y]
20%             [rob_2_maxVel, cam_1_X, cam_1_Y]

                               size_1-2.2_9  \
Data Size
200%       [rob_2_supply, cam_1_X, cam_1_Y]
150%       [cam_1_X, cam_1_Y, rob_2_supply]
100%       [cam_1_Y, cam_1_X, rob_2_supply]
50%        [cam_1_Y, cam_1_X, rob_2_supply]
20%        [cam_1_Y, cam_1_X, rob_2_supply]

                                 feeder_3-2.3_10  …  \
Data Size                                         …
200%            [rob_1_supply, cam_1_Y, cam_1_X]  …
150%       [rob_1_supply, cam_1_Y, rob_2_supply]  …
100%       [rob_1_supply, cam_1_Y, rob_2_supply]  …
50%             [rob_1_supply, cam_1_X, cam_1_Y]  …
20%             [cam_1_X, rob_1_supply, cam_1_Y]  …

                                gripper_1-7.8_55  \
Data Size
200%       [rob_1_supply, rob_2_supply, cam_1_Y]
150%       [rob_1_supply, rob_2_supply, cam_1_Y]
100%       [rob_1_supply, rob_2_supply, cam_1_X]
```

```
50%        [rob_1_supply, cam_1_X, rob_2_supply]
20%        [rob_1_supply, cam_1_X, rob_2_supply]

                                max_Vel_2-7.9_56  \
Data Size
200%       [rob_2_maxVel, rob_2_supply, cam_1_X]
150%       [rob_2_maxVel, rob_2_supply, cam_1_X]
100%       [rob_2_maxVel, rob_2_supply, cam_1_X]
50%             [rob_2_maxVel, cam_1_X, cam_1_Y]
20%        [rob_2_maxVel, cam_1_Y, rob_2_supply]

                              size_1-8.2_57  \
Data Size
200%       [rob_2_supply, cam_1_Y, cam_1_X]
150%       [cam_1_X, cam_1_Y, rob_2_supply]
100%       [rob_2_supply, cam_1_Y, cam_1_X]
50%        [cam_1_X, cam_1_Y, rob_2_supply]
20%        [cam_1_Y, cam_1_X, rob_2_maxVel]

                                 feeder_3-8.3_58  \
Data Size
200%       [rob_1_supply, cam_1_Y, rob_2_supply]
150%       [rob_1_supply, cam_1_Y, rob_2_maxVel]
100%       [rob_1_supply, rob_2_supply, cam_3_Y]
50%        [rob_1_supply, cam_1_Y, rob_2_supply]
20%        [rob_2_supply, rob_1_supply, cam_1_X]

                                gripper_1-8.4_59  \
Data Size
200%       [rob_1_supply, rob_2_supply, cam_1_X]
150%       [rob_1_supply, rob_2_supply, cam_1_Y]
100%       [rob_1_supply, rob_2_supply, cam_1_X]
50%        [rob_1_supply, rob_2_supply, cam_1_Y]
20%        [rob_2_supply, rob_1_supply, cam_1_X]

                                max_Vel_2-8.5_60  \
Data Size
200%       [rob_2_maxVel, rob_2_supply, cam_1_Y]
150%            [rob_2_maxVel, cam_1_Y, cam_1_X]
100%       [rob_2_maxVel, rob_2_supply, cam_1_X]
50%        [rob_2_maxVel, rob_2_supply, cam_1_Y]
20%        [rob_2_maxVel, cam_1_X, rob_2_supply]

                              size_1-8.6_61  \
Data Size
200%       [rob_2_supply, cam_1_Y, cam_1_X]
150%       [cam_1_Y, cam_1_X, rob_2_supply]
```

```
100%              [cam_1_X, cam_1_Y, con_2]
50%        [cam_1_X, cam_1_Y, rob_2_supply]
20%        [cam_1_X, cam_1_Y, rob_2_supply]

                                 feeder_3-8.7_62  \
Data Size
200%       [rob_1_supply, rob_2_supply, cam_1_X]
150%       [rob_2_supply, rob_1_supply, cam_1_Y]
100%       [rob_2_supply, rob_1_supply, cam_3_X]
50%        [rob_2_supply, rob_1_supply, cam_1_Y]
20%        [rob_2_supply, cam_1_X, rob_1_supply]

                                gripper_1-8.8_63  \
Data Size
200%         [rob_1_supply, rob_2_supply, con_2]
150%       [rob_1_supply, cam_1_X, rob_2_supply]
100%       [rob_1_supply, rob_2_supply, cam_1_X]
50%        [rob_1_supply, cam_1_Y, rob_2_supply]
20%        [rob_1_supply, rob_2_supply, cam_1_X]

                                max_Vel_2-8.9_64
Data Size
200%       [rob_2_maxVel, rob_2_supply, cam_1_Y]
150%       [rob_2_maxVel, cam_1_X, rob_2_supply]
100%       [rob_2_maxVel, cam_1_X, rob_2_supply]
50%             [rob_2_maxVel, cam_1_X, cam_1_Y]
20%        [rob_2_maxVel, cam_1_X, rob_2_supply]

[5 rows x 64 columns]
```

```
[ ]: result_data_3top = results_top_3(result_size_RW,abnormal_sets)
     result_data_3top.tail()
```

```
[ ]:                      200%  150%     100%   50%   20%
     size_1-8.6_61     1.00000  1.00  1.00000  1.00  1.00
     feeder_3-8.7_62   0.00000  0.00  1.00000  0.00  0.00
     gripper_1-8.8_63  1.00000  1.00  1.00000  1.00  1.00
     max_Vel_2-8.9_64  1.00000  1.00  1.00000  1.00  1.00
     Total             0.78125  0.75  0.96875  0.75  0.75
```

```
[ ]: result_data_1top = results_top_1(result_size_RW,abnormal_sets)
     result_data_1top.tail()
```

```
[ ]:                      200%     150%    100%   50%       20%
     size_1-8.6_61     0.00000  1.00000  1.0000  1.00  1.000000
     feeder_3-8.7_62   0.00000  0.00000  0.0000  0.00  0.000000
     gripper_1-8.8_63  1.00000  1.00000  1.0000  1.00  1.000000
```

```
max_Vel_2-8.9_64  1.00000  1.00000  1.0000  1.00  1.000000
Total             0.53125  0.71875  0.6875  0.75  0.671875
```

```
[ ]: result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_5_RW.csv'))
     result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_5_RW.csv'))
```

1.11.4 RCD - Algorithm

```
[ ]: result_RCD_size_1 =␣
       ↪run_RCD_size(folder_path,files,startrow=839,size_p=2,nodes=nodes,edges_list=edges,key_nodes
     result_RCD_size_2 = run_RCD_size(folder_path,files,startrow=839,size_p=1.
       ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_size_3 = run_RCD_size(folder_path,files,startrow=839,size_p=1.
       ↪0,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_size_4 = run_RCD_size(folder_path,files,startrow=839,size_p=0.
       ↪5,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
     result_RCD_size_5 = run_RCD_size(folder_path,files,startrow=839,size_p=0.
       ↪20,nodes=nodes,edges_list=edges,key_nodes=check_nodes,colors=colors,pos=pos)
```

```
[ ]: result_size_RCD = pd.DataFrame()
     result_size_RCD = pd.
       ↪concat([result_RCD_size_1,result_RCD_size_2,result_RCD_size_3,result_RCD_size_4,result_RCD_
       ↪ignore_index=True)
     result_size_RCD['Data Size'] = pd.DataFrame({'RCD':
       ↪['200%','150%','100%','50%','20%']})
     result_size_RCD.set_index('Data Size', inplace=True)
     result_size_RCD
```

```
[ ]:                          size_1-1.2_1               feeder_3-1.3_2  \
     Data Size
     200%                 [EoL_3_Y, cam_1_Y]  [EoL_5_Y, EoL_6_X, cam_3_X]
     150%                 [EoL_4_X, cam_1_Y]  [EoL_6_Y, EoL_2_X, EoL_5_Y]
     100%        [cam_1_X, EoL_6_X, EoL_3_X]           [EoL_4_Y, EoL_5_X]
     50%                  [EoL_5_X, EoL_6_Y]           [EoL_4_X, EoL_6_Y]
     20%                  [EoL_1_X, EoL_1_Y]           [cam_2_Y, EoL_2_Y]

                                  gripper_1-1.4_3     max_Vel_2-1.5_4  \
     Data Size
     200%                      [EoL_4_X, EoL_2_X]           [EoL_6_X]
     150%                 [rob_1_supply, EoL_5_Y]  [EoL_6_Y, EoL_6_X]
     100%        [rob_1_supply, EoL_3_X, EoL_4_X]      [rob_2_maxVel]
     50%                       [EoL_5_X, EoL_4_X]  [EoL_2_Y, EoL_6_X]
     20%                  [EoL_5_X, rob_1_supply]  [EoL_2_Y, EoL_5_X]

                                size_1-1.6_5      feeder_3-1.7_6  \
     Data Size
     200%                 [cam_1_Y, EoL_3_Y]  [EoL_6_Y, EoL_6_X]
```

```
150%       [EoL_3_Y, cam_1_Y, cam_1_X]  [EoL_5_X, EoL_6_X]
100%                [EoL_6_X, EoL_5_Y]  [cam_3_Y, EoL_5_Y]
50%                 [EoL_3_Y, EoL_2_Y]  [EoL_4_X, EoL_6_X]
20%                 [cam_3_X, cam_1_X]  [EoL_4_Y, EoL_2_X]

                       gripper_1-1.8_7                   max_Vel_2-1.9_8  \
Data Size
200%       [EoL_2_Y, EoL_3_Y, EoL_6_Y]                         [EoL_6_Y]
150%           [rob_1_supply, EoL_3_X]           [rob_2_maxVel, EoL_6_X]
100%                [EoL_5_X, EoL_6_X]                         [EoL_4_Y]
50%                 [EoL_4_X, EoL_3_Y]       [EoL_2_X, EoL_6_Y, EoL_4_Y]
20%                 [cam_3_X, EoL_3_Y]  [EoL_4_Y, EoL_5_X, rob_2_maxVel]

                          size_1-2.2_9              feeder_3-2.3_10  …  \
Data Size                                                            …
200%       [EoL_6_Y, EoL_3_Y, EoL_4_X]  [EoL_6_Y, EoL_3_Y, EoL_4_X]  …
150%                [EoL_3_Y, EoL_6_X]           [EoL_2_X, EoL_5_X]  …
100%                [EoL_6_Y, EoL_5_Y]  [EoL_2_X, cam_3_Y, EoL_6_Y]  …
50%        [EoL_4_X, EoL_5_Y, cam_1_X]  [EoL_6_X, EoL_1_Y, EoL_3_Y]  …
20%                 [EoL_6_X, EoL_2_Y]           [EoL_3_X, cam_3_X]  …

                           gripper_1-7.8_55    max_Vel_2-7.9_56  \
Data Size
200%       [rob_1_supply, EoL_2_Y, EoL_3_Y]  [EoL_6_X, EoL_6_Y]
150%            [EoL_4_X, EoL_5_Y, EoL_5_X]           [EoL_6_Y]
100%                     [EoL_4_X, EoL_2_X]      [rob_2_maxVel]
50%                      [EoL_6_X, EoL_5_X]  [EoL_6_X, EoL_2_X]
20%                      [cam_3_X, EoL_1_Y]  [EoL_5_X, cam_3_X]

                         size_1-8.2_57              feeder_3-8.3_58  \
Data Size
200%       [cam_1_X, EoL_3_Y, EoL_5_X]  [EoL_2_Y, EoL_5_X, EoL_3_X]
150%       [EoL_5_Y, EoL_6_X, EoL_4_Y]           [EoL_4_X, EoL_6_X]
100%                [cam_1_Y, EoL_5_X]  [EoL_2_Y, EoL_5_Y, EoL_6_X]
50%                 [EoL_6_Y, EoL_3_X]  [EoL_2_X, cam_3_X, EoL_6_X]
20%                 [EoL_3_Y, EoL_3_X]  [cam_3_X, EoL_6_Y, EoL_3_X]

             gripper_1-8.4_59             max_Vel_2-8.5_60  \
Data Size
200%       [EoL_3_X, EoL_2_X]                    [EoL_6_X]
150%       [EoL_6_X, EoL_6_Y]                    [EoL_6_X]
100%       [EoL_5_X, EoL_4_Y]           [EoL_6_Y, EoL_6_X]
50%        [EoL_4_Y, EoL_6_X]  [EoL_6_Y, EoL_6_X, cam_2_X]
20%        [EoL_3_Y, EoL_4_X]           [EoL_3_Y, EoL_6_Y]

                         size_1-8.6_61              feeder_3-8.7_62  \
Data Size
```

```
200%       [EoL_6_Y, EoL_4_Y, cam_1_Y]  [cam_3_X, EoL_3_X, EoL_5_X]
150%                [EoL_6_Y, EoL_5_Y]           [EoL_5_X, EoL_2_Y]
100%       [cam_1_X, EoL_4_Y, EoL_4_X]  [EoL_6_Y, EoL_4_X, EoL_6_X]
50%                 [cam_1_X, EoL_5_Y]           [EoL_3_X, EoL_5_X]
20%                 [cam_1_Y, EoL_4_Y]           [cam_3_X, EoL_3_X]

             gripper_1-8.8_63                  max_Vel_2-8.9_64
Data Size
200%       [EoL_5_Y, EoL_5_X]           [rob_2_maxVel, EoL_6_Y]
150%       [EoL_5_Y, EoL_3_Y]  [EoL_6_Y, rob_2_maxVel, EoL_6_X]
100%       [EoL_2_X, EoL_6_Y]                         [EoL_6_Y]
50%        [EoL_2_Y, EoL_2_X]           [EoL_2_X, rob_2_maxVel]
20%        [EoL_5_X, EoL_5_Y]                [EoL_2_Y, cam_2_Y]

[5 rows x 64 columns]
```

[ ]:

```
result_data_3top = results_top_3(result_size_RCD,abnormal_sets)
result_data_3top.tail()
```

[ ]:

```
                   200%      150%     100%     50%       20%
size_1-8.6_61     1.000  0.000000  1.00000  1.0000  1.000000
feeder_3-8.7_62   1.000  0.000000  0.00000  0.0000  1.000000
gripper_1-8.8_63  0.000  0.000000  0.00000  0.0000  0.000000
max_Vel_2-8.9_64  1.000  1.000000  0.00000  1.0000  0.000000
Total             0.375  0.390625  0.40625  0.3125  0.234375
```

[ ]:

```
result_data_1top = results_top_1(result_size_RCD,abnormal_sets)
result_data_1top.tail()
```

[ ]:

```
                    200%     150%      100%     50%       20%
size_1-8.6_61     0.0000  0.00000  1.000000  1.0000  1.000000
feeder_3-8.7_62   1.0000  0.00000  0.000000  0.0000  1.000000
gripper_1-8.8_63  0.0000  0.00000  0.000000  0.0000  0.000000
max_Vel_2-8.9_64  1.0000  0.00000  0.000000  0.0000  0.000000
Total             0.1875  0.28125  0.234375  0.1875  0.078125
```

[ ]:

```
result_data_3top.to_csv(os.path.join(main_dir, 'result_data_3top_5_RCD.csv'))
result_data_1top.to_csv(os.path.join(main_dir, 'result_data_1top_5_RCD.csv'))
```